ANNUAL REPORT 2016

IEA Technology Collaboration Program on High Temperature Superconductivity

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MESSAGE FROM THE CHAIR

Almost thirty years of research and development have brought new equipment incorporating high temperature superconductivity (HTS) to the threshold of greatly improving electricity transmission and distribution. Laboratory scale tests have transitioned to large scale HTS based projects that serve utility customers. HTS project are being considered as permanent infrastructure to solve real world electric grid problems. The production of HTS wire has increased to more than 15 companies. But there is still work to do.

The Technology Collaborative Program on High Temperature Superconductivity (HTS TCP) is working to identify and evaluate the potential applications and benefits of superconductivity and the technical, economical and regulatory barriers to be overcome for achieving these benefits. Through its nine contracting parties and two sponsors, the HTS TCP is developing technical communications documents to provide information that will help a range of stakeholders.

The HTS TCP coordinated several information sharing and stakeholder engagement events, which were successful in developing public and private sector partnerships. One example was leading the development of a special session at the largest superconductivity conference in North America.

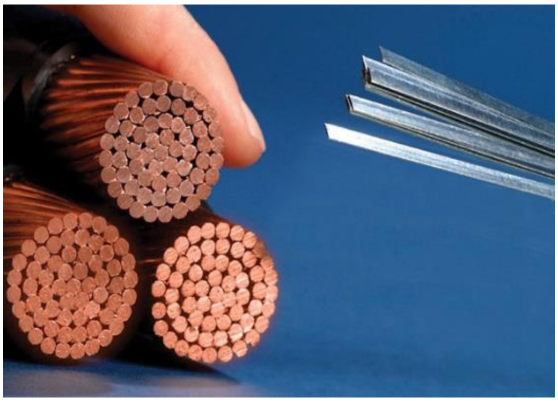
Our active and engaged Executive Committee is looking forward to working with stakeholders to help enable HTS based devices to be energized on the electric power grid.

HTS TCP Chairman

Luciano Martini

BASIC RESEARCH TO GRID SOLUTIONS

Superconductivity is a phenomenon that causes certain materials, at extremely low temperatures, to lose all resistance to the flow of electricity. The lack of resistance enables a range of innovative technology applications.



The ultra thin wires carry the equivalent power as the large diameter copper wires. Courtesy of AMSC.

Devices based on superconductivity have been available in certain niche markets for decades. In particular, superconducting magnets are used in many applications requiring powerful electromagnets, such as in magnetic resonance imaging (MRI) machines. Superconductivity has broad applications, including the energy, transportation, industry, medical, and defense sectors.

High temperature superconducting (HTS) wire is the key enabler of making devices for the electric power system that are more efficient and resilient than conventional solutions.

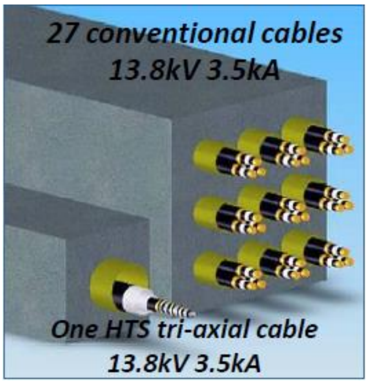
HTS Benefits

HTS wire can be used to replace copper in today's equipment, enabling smaller, lighter, safer, more efficient, future power equipment. For example:

Planning is underway to replace conventional wind generator with HTS based device. Courtesy of EcoSwing.

- **Wind energy:** Superconducting wire has the potential to enable smaller and lighter wind turbine generators than would be possible with conventional materials, essentially eliminating the need for a gearbox. Superconductors offer the prospect of less expensive electricity by enabling powerful but much lighter generators for wind turbine applications.
- **Aircraft:** Superconducting machines have the potential to be an enabling technology for all-electric aircraft development. Using lightweight superconductors, electric planes could be eco-friendly, exceptionally quiet, and highly energy efficient and could dramatically cut down on maintenance costs through the elimination of engine hydraulics.
- **Fault current limiters:** Many of the world's utilities must cope with increasing fault (short-circuit) currents. HTS offers a unique approach to "fault current limiters" for both distribution and transmission networks.

- **Cables:** Because high-temperature superconducting cables transport current with essentially no or very low electrical resistance, they can transmit up to ten times more power than conventional copper cables (or can carry equivalent power at much lower voltages). In addition these cables require reduced space in urban environments since they may be installed underground and they do not produce a magnetic field or heat.
- **Generators:** Incorporating superconducting wire into electrical generators and equipment has the potential to increase system efficiency, reliability and safety.



One HTS cable has the same power throughput as 27 conventional copper cables. Courtesy of Oak Ridge National Laboratory.

Status

High temperature superconductivity has come a long way since its discovery in 1986. The technology has progressed from basic materials research, to laboratory testing, and, in the past decade, to demonstrations of full-size equipment.

HTS applications in the electric power sector are moving from the pre-commercial to the commercial stage for electricity transmission. Examples of electric grid applications that could benefit greatly from high temperature superconductivity include:

- Transmission and distribution cables
- Fault current limiters
- Transformers
- Generators
- Energy storage

Challenges Remain

Over the past few decades, a significant effort has been spent worldwide on research, development, and field demonstration of applied HTS devices for the power sector. As a result of these activities, several applied HTS devices, specifically cables and SFCLs, are reaching market maturity. Lab scale tests have transitioned to large scale HTS based projects that serve utility customers. In addition, further development of HTS has the potential to reduce the cost of wind powered electricity generation. However, the transition of HTS applications to widespread market maturity faces several challenges. Examples include:

- **Process control**. There is a general lack of manufacturing knowledge in producing HTS wires with nanometer-sized precipitates or phases uniformly distributed over kilometer lengths.
- **Long term reliability.** End users are generally unfamiliar with the materials used in HTS devices and cryogenic systems. Data are not available that prove undiminished product-performance HTS components lifetime over 30 to 40 years.
- **Business risk.** Uncertainty for total cost of ownership and cost and availability of parts from suppliers in a relatively nascent market.
- **Economics.** The cost associated with manufacturing HTS wire due to sophisticated processes, low yields and limited throughput of the manufacturing processes makes it several times more expensive than copper wire. However, it is not reasonable to simply compare the cost of an HTS based device to a conventional one. Because of the unique attributes of HTS devices, a *system* cost analysis including ancillary equipment (for example, refrigeration equipment), should be conducted.

Purpose and Scope

The International Energy Agency's Technology Collaborative Program on High Temperature Superconductivity (HTS TCP) brings together key stakeholders to address the challenges and related common interests. The HTS TCP:

- Conducts outreach toward the electric utilities, governments, the professional engineering community, and the RD&D community to confirm and communicate the potential benefits of HTS technology.
- Sponsors workshops, co-authors books and journal articles, exchanges information, introduces their research facilities to other participants and guides the assessments.
- Develops position papers and strategic documents such as roadmaps and technical reports. Participants also ask experts from their countries to provide input and to peer-review draft reports; these activities help ensure consistency in the reporting and evaluating of progress in the various fields under consideration.
- Provides expertise that can inform the evaluations and assessments performed by ExCo members.
- Interacts with other related IEA TCPs to leverage synergies and opportunities.
- Disseminates work at international meetings and workshops and educate students, young engineers, and scientists about HTS applications in the power sector.
- Addresses and clarifies perceived risks and hurdles to introduce a disruptive technology into the conservative electric power industry.

SUMMARY OF ACTIVITIES

The ExCo held a meeting in Munich, Germany (May 2016), which was hosted by Siemens. The hosts invited representatives from regional organizations to introduce their activities and lead ExCo members in a tour of a superconducting FCL (SFCL) site in Augsburg near Munich. This device is operating in a real grid and demonstrating the capabilities of SFCLs.

ExCo members of HTS-TCP in front of superconducting FCL facility in Augsburg, Germany.

A shortened ExCo meeting was held in Denver, Colorado in the United States in September 2016 to discuss ongoing business such as the status of the website redesign, new member engagement, and project updates from the United States.

Highlights of ExCo activities for this Annual Report period include:

- Orchestrated a special session at the 2016 Applied Superconductivity Conference. This special session was attended by more than 100 experts in the superconductivity field; these participants learned about our TCP and the latest advancements in HTS applications for the electric power sector.
- Made significant contributions at a major superconductivity conference, ISS 2016 in Tokyo, through several presentations from ExCo members: Dr. Tabea Arndt (Invited talk of EU activities) and Dr. Yutaka Yamada (Italian SFCL and HTS wires).
- Completely redesigned the website and developed a comprehensive interactive map from HTS projects around the world.
- Presented at Cryogenics and Superconductivity Society of Japan (CSSJ) 2016, Spring Meeting (in Tokyo) to give an update on the IEA HTS Roadmap activity and other ExCo activities.
- Facilitated Japanese domestic IEA-TCP meetings held in June 2016, December 2016, and Feb. 2017 for dissemination of TCP activity and discussion for HTS application and regulation.
- Received a 5 year extension from IEA for the period of 29 February 2016 to 28 February 2021.
- Completed a summary document highlighting its activities for the IEA Energy Technology Initiatives publication.
- Continued to foster relationships with other IEA implementing agreements, such as International Smart Grid Action Network (ISGAN) and Energy Efficient End-use Equipment (4E). The TCP helped to lay the groundwork for the first Joint Workshop for the TCPs in the EUWP – Electricity.

Summary of Past and Future Events

ExCo meetings	
Munich, Germany	May 2016
Denver, United States	September 2016
Milan, Italy	January/February 2017
Tokyo, Japan	July 2017
Geneva, Switzerland	September 2017
Special Events	
Applied Superconductivity Conference – special session, Denver, USA	September 2016
International Superconductivity Symposium, Tokyo, Japan	December 2016

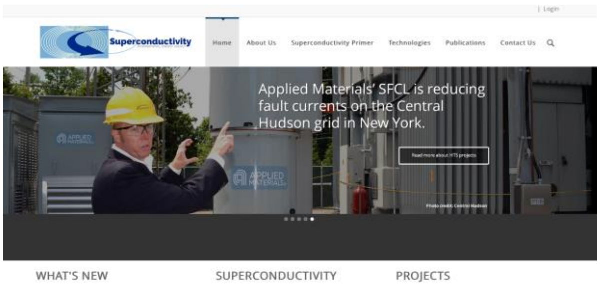
EXAMPLES OF ENGAGEMENT

Several examples of how the executive committee has helped to fulfill its mission include developing a HTS roadmap document for the electric power sector, playing a large role in a major superconductivity conference, hosting a conference to engage the young generation of researchers, and developing a spreadsheet with significant HTS projects for the electric grid. More information is available below.

Examples of how the executive committee has helped to promote the benefits of HTS are shown below in our involvement and developing a roadmap in ASC 2016, and in ISS 2016, publishing a new HTS-TCP letter, “HTS News and Trend”, and shaping-up the HTS-TCP website, “World at a Glance” (a comprehensive interactive tool for mapping ongoing HTS National Projects World Wide).

Revamped IEA HTS TCP Website

In 2016, the HTS TCP completely revitalized its website. This includes a new look and additional content to provide information to an array of stakeholders. The site will continue to be updated with project data, publications, and case studies. The resources available on the site will help utilities and other end users as well as policy-makers access information on the benefits and current applications of HTS technologies and how they operate on the electric grid.



The front page of the new IEA HTS TCP website.

HTS TCP Leads a Session at the Applied Superconductivity Conference

The Applied Superconductivity Conference (ASC) was held at the Colorado Convention Center in Denver from September 5–10, 2016. More than 2,000 researchers attended and presented their recent results and activity. On the first day of the conference, the IEA HTS TCP convened a special session to discuss “What Will Drive Market Maturity for HTS Applications in the Electric Grid”. Approximately 150 participants attended this session, which started with an overview of the IEA HTS TCP and a summary of the Roadmap for the Electric Power Sector, 2015-2030. A panel discussion by distinguished experts in the applications and materials areas followed.

Audience at the special session.

Survey of Chinese HTS Activities

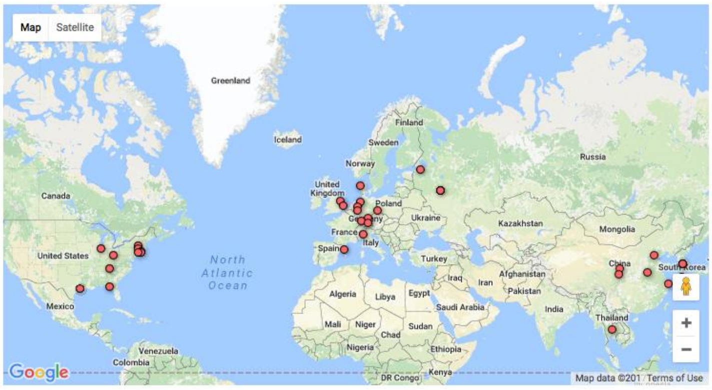
Chinese HTS R&D is growing. The efficiency of electric power use is a big issue in China due to the increasing growth of electric power consumption, and governmental funding in electric power efficiency amounted to more than 100M USD over the past 5 years. To survey the present status of HTS R&D, one of the HTS TCP OAs, Yamada, visited Shanghai and Xian in late December 2016. He found that, similar to efforts in the US, EU, and Japan, three coated conductor companies in the Shanghai area and other wire companies are actively developing their HTS technology. Furthermore, more than 15 companies and institutes are trying to conduct feasibility studies for HTS applications.

HTS-TCP Newsletter

This year, the quarterly publication “HTS-News and Trends” was founded and published on the website. Three issues have been circulated among ExCo members. These newsletters are intended to disseminate timely HTS activity around the world.

World Projects at a Glance

The ExCo developed a web-based spreadsheet that catalogs HTS based projects around the world. Data is separated by region: North America, the European Union, Japan, Korea, China and Russia. The database is updated on an as needed basis with data such as current and voltage ratings, current status, partners, budget, and references.



Interactive tool for learning more about HTS projects around the world.

PROJECT UPDATES

Around the world, projects are demonstrating the technical feasibility of equipment incorporating HTS. The text below highlights several project examples that have made recent progress.

Korean Cable Projects

Two Korean HTS cable activities are underway by the Korean Electric Power Corporation (KEPCO): a 1 km cable and a 2 km HTS Cable. KEPCO is installing a 1 km cable near Seoul that will carry 22.9 kV, 50 MVA and utilize a 7.5-kW turbo-brayton refrigeration system. This cable will be a permanent part of KEPCO’s electric grid to connect two substations. KEPCO held a ribbon cutting ceremony in September 2016 and plans to complete the installation by October 2017.

The 2 km HTS cable project will differ from KEPCO’s 1 km commercial cable project both in length and cable structure (co-axial type). The project is aimed at providing important data on the economics of long length HTS cables. This will be the longest HTS cable demonstration in the world as the longest HTS cable demonstration up to this point has been 1 km.[1]

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[1] 2016 ISS presentation by M. Park, “Korean Commercial Cable and New 2km Project” (December 2016). https://www.tia-nano.jp/ascot/iss2016/program/program.html. paku@changwon.ac.kr

FASTGRID

FASTGRID is 12-partner project launching a smart DC Fault Current Limiter (FCL) for 1kA-50kV HVDC Cables. EU countries are expected to increasingly develop HVDC grids, but such systems need high-performance FCLs in order to limit short-circuit currents associated to faults. In this framework, the European project FASTGRID was launched in January 2017 and will last until June 2020. In particular, the FASTGRID consortium partners will closely collaborate to develop advanced 2G YBCO tapes for DC SFCL applications. The main outcome will consist of a demonstration DC SFCL prototype made out of an innovative HTS conductor to be validated by laboratory testing against dielectric and short-circuit stresses.

Ultra-Supertape

The Ultra-Supertape project was launched in December 2015 to further development from the Eurotapes project, which has shown promising results for industrialization of coated conductors. The Ultra-Supertape project is focused on high and ultra-high field conductors using various kinds of chemical synthesis methods such as Chemical Solution Deposition. This project will resu[2]lt in a faster and lower-cost coated conductor with respect to those that have been produced before.

Japanese HTS AC Cable

A new Japanese HTS cable project started under NEDO. The main targets are as follows:

- safety evaluation test methods
- guidelines for quick recovery from accidents and failures
- highly efficient cooling systems coefficient of performance > 0.11
- Maintenance period: 40,000 hours

Next Generation Electric Machines Program by U.S. Department of Energy

The U.S. Department of Energy announced nearly $25 million for 13 projects aimed at advancing technologies for energy-efficient electric motors through applied research and development. $15M of the total amount was given to four research teams in the superconducting field. The Office of Energy Efficiency and Renewable Energy's (EERE) Next Generation Electric Machines projects will address the limitations of traditional materials and designs used in electric motor components by cost-effectively enhancing their efficiency, improving their performance, and reducing weight. This effort will support innovative approaches that will significantly improve the technology in industrial electric motors, which use approximately 70 percent of the electricity consumed by U.S. manufacturers and nearly a quarter of all electricity consumed nationally.

Advanced Superconductor Manufacturing Institute (ASMI) in the United States

The goal of ASMI is to build an industry-based consortium to speed full commercialization of high-temperature superconductors. ASMI has broad support from small, medium and large companies in the United States, as well as universities, and national laboratories. ASMI is seeking federal funding from US agencies to be part of the National Network of Manufacturing Innovation, which helps to cost share public and private resources to advance manufacturing techniques. ASMI is holding workshops to develop cost-shared projects and also to develop a long term sustainability model.

[2] 2016 ISS presentation by Dr. Tabea Arndt, "R&D in Electric Power Devices based on Superconducting Technology in Europe" (December 2016) https://www.tia-nano.jp/ascot/iss2016/program/program.html
2016 ISS presentation by Professor Xavier Obradors, "Progress in the Development of Nanostructured Coated Conductors in Europe" (December 2016) https://www.tia-nano.jp/ascot/iss2016/program/program.html

WORKING ARRANGEMENT

There are currently two operating agents (OAs) supporting the HTS TCP, one based in the United States and one in Japan. They are managed by the ExCo whose duties are specified in a contract with the OAs and include provision of technical and administrative services as required for the organization. The HTS TCP operation is supported by a combination of cost sharing, task sharing, and knowledge sharing. ExCo members cover their travel expenses to attend ExCo meetings and bear all the costs incurred in conducting task activities, such as report writing and travel to meetings and workshops.

The ExCo Chairman, vice-chairman and operating agents prepare an annual work plan and associated annual budget for the calendar year, which are submitted for approval by the ExCo. The expenses associated with the operation of the HTS IA Secretariat and annual work plan, including the operating agent's time and travel and other joint costs of the ExCo are met from a Common Fund to which all HTS TCP members contribute. There are no changes foreseen in the working arrangement or current fee structure. The HTS TCP is financially secure with the Common Fund, having had surplus for the past several years.

Membership in the ExCo remained the same since the previous annual report. However, the ExCo is making a concerted effort to increase membership. With the new roadmap, the ExCo will reach out to targeted countries to join the HTS TCP.

Future Activities

Several activities that could be undertaken in the next year include:

- Develop communications and outreach materials for non-technical audiences on the benefits of HTS applications.
- Develop a technical fact sheet on HTS cables and Fault Current Limiters that is geared towards electric utilities.
- Develop a document based on real world examples of the economics of HTS.
- Develop a document that investigates the system behavior of HTS applications.
- Develop technology readiness level diagrams for HTS power applications.
- Develop one special edition white paper on a specific topic such as safety, warranties, and standards with HTS applications; outline how superconductivity can play a role in a low carbon society.
- Expand network of the TCP by engaging new entities conducting research and developing in HTS.
- Organize workshops to help gain visibility with other TCPs.

Target experts in the cryogenics area to add technical resources.

CONTACT INFORMATION FOR EXCO DELEGATES/ALTERNATES, SPONSORS AND OPERATING AGENTS

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About the International Energy Agency

The IEA is an autonomous organization which works to ensure reliable, affordable and clean energy for its 29 member countries and beyond. The IEA has four main areas of focus: energy security, economic development, environmental awareness and engagement worldwide.

Founded in 1974, the IEA was initially designed to help countries co-ordinate a collective response to major disruptions in the supply of oil such as the crisis of 1973-1974. While this remains a key aspect of its work, the IEA has evolved and expanded. It is at the heart of global dialogue on energy, providing authoritative statistics and analysis.

As an autonomous organization, the IEA examines the full spectrum of energy issues and advocates policies that will enhance the reliability, affordability and sustainability of energy in its 29 member countries and beyond.

The four main areas of IEA focus are:

- **Energy security**: Promoting diversity, efficiency and flexibility within all energy sectors;
- **Economic development**: Ensuring the stable supply of energy to IEA member countries and promoting free markets to foster economic growth and eliminate energy poverty;
- **Environmental awareness**: Enhancing international knowledge of options for tackling climate change; and
- **Engagement worldwide**: Working closely with non-member countries, especially major producers and consumers, to find solutions to shared energy and environmental concerns.

Energy Technology Initiatives

The IEA energy technology network is an ever-expanding, co-operative group of more than 6,000 experts that support and encourage global technology collaboration. At the core of the IEA energy technology network are a number of independent, multilateral energy technology initiatives – the IEA Technology Collaboration Programmes (TCPs).

Through these TCPs, of which there are currently more than forty including 4E, experts from governments, industries, businesses, and international and non-governmental organizations from both IEA member and non-member countries unite to address common technology challenges and share the results of their work. Each TCP has a unique scope and range of activities.

Further information is available at: http://www.iea.org/tcp