ANNUAL REPORT 2018

IEA Technology Collaboration Program on High Temperature Superconductivity

Superconductivity
INTERNATIONAL ENERGY AGENCY

iea
Energy Technology Network

Table of Contents

THE STATE OF HTS IN 2018 AND BEYOND

There has been a transition in the last several years such that high temperature superconductivity (HTS) projects are being considered as permanent infrastructure options to solve real-world electric grid problems. Moreover, in the long-term HTS has the potential to be considered for advanced transportation applications such as electric ships, aircraft, and rail. Almost thirty years of research and development has brought new equipment incorporating HTS to the threshold of greatly improving key sectors of the world's economy. However, there is still significant effort needed.

The International Energy Agency's Technology Collaborative Program on High Temperature Superconductivity (HTS TCP) is working to identify and evaluate the potential applications and benefits of superconductivity, as well as the current technical and also non-technical barriers that currently stand in the way. The Program is also considering ways to raise awareness of HTS's technology transfer possibilities outside the area of electric power applications. Through its nine contracting parties and one sponsor, 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. We are actively approaching new members to join our TCP and add technical, market and policy experience to our executive committee. We are also looking forward to the future as the last several years have brought several commercial projects into the utility planning pipeline for permanent grid solutions.

HTS TCP Executive Committee Chairman

Luciano Martini

Introduction to Applied Research on Grid Solutions

Superconductivity is a particular property of matter that enables the conduction of electric current with practically zero resistance at cryogenic temperatures. The values of these temperatures depend on specific materials, so each superconductor is characterized by a material-specific 'critical temperature' below which it offers no resistance to the passage of current.

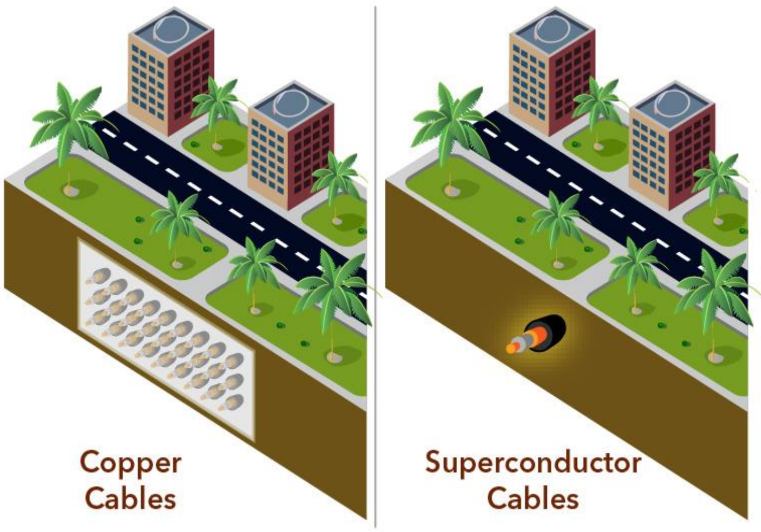
Work is underway to evaluate the possibility to replace large conventional wind generators with HTS-based devices. Image courtesy of EcoSwing.

Devices based on superconductivity have been available in certain niche markets for decades. In particular, superconducting magnets are used in many applications that require powerful electromagnets, like high-energy-physics particle accelerators and magnetic resonance and imaging (MRI) machines. Superconductivity has been employed or proposed for use in a variety of applications and sectors, including the energy, transportation, industrial, medical and defense sectors. High temperature superconducting (HTS) wire is the key enabler that makes devices for the electric power system more efficient and resilient than conventional solutions.

HTS Benefits

HTS wire, also referred to as tape, can be used to replace copper in today's equipment, enabling more compact, lighter, safer, and more efficient power equipment. Some examples are listed here.

Cables – Because HTS cables transport current with essentially no or very low electrical resistance, they can transmit up to ten times more power than conventional copper cables at far lower voltages and with much less material. This makes HTS cables ideally suited for installation in cramped urban spaces, especially because that they can be installed underground and do not produce magnetic fields or heat – the surface of a HTS cable has exactly the same temperature as its surroundings.



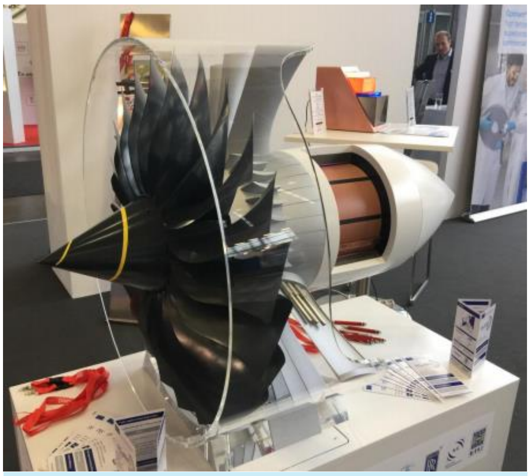
One 13-kV, 69 MVA three-phase HTS cable can replace as many as 27 single-phase, conventional XLPE copper cables.

Fault current limiters – Many of the world's utilities must cope with increasing fault (short-circuit) currents. HTS tapes offer a unique approach to fault current limiters for both distribution and transmission networks and can work both in AC and DC conditions.

Aircraft – The use of lightweight HTS could lead to eco-friendly, exceptionally quiet, and highly energy-efficient electric planes. Beneficial application of HTS technology is expected in the fields of power generation, power distribution, and forming and propulsion. In addition, auxiliary devices might be replaced by electric HTS-based solutions.

Generators – Incorporating superconducting tapes into electrical generators and equipment has the potential to increase system efficiency, reliability and safety.

Wind energy – HTS tapes have the potential to enable smaller, lighter, and more efficient wind turbine generators than would be possible with conventional materials by eliminating the need for a gearbox. This could lead to cheaper electricity.



An advanced superconducting motor demonstrator that enables higher performance and lower emissions in aircraft propulsion. Image courtesy of ASuMED.

Status

High temperature superconductivity has progressed significantly 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 commercial stage for electricity, even though HTS technology has not reached complete maturity in all its potential applications. Studies about HTS architecture and production processes, for example, are still in progress. However, important results have already been obtained and, at present, HTS technology would bring great benefits to transmission and distribution cables, fault current limiters, transformers, generators, and energy storage systems.

Remaining Challenges

Over the past few decades, a significant effort has been made worldwide on research, development, and field demonstration of applied HTS devices for the power sector. As a result of these activities, several HTS-based devices, specifically cables and SFCLs, are reaching market maturity. Laboratory-scale tests have transitioned to large-scale, HTS-based projects that serve utility customers. The transition of HTS applications to widespread market maturity faces several challenges. Examples include:

- **Process control**. There are still manufacturing problems regarding the optimal architecture and production processes for specific applications. For example, it is still difficult to grow the HTS to achieve higher critical current values, as well as choosing the correct buffer layers, without introducing excessive residual or thermal stresses for long lengths.
- **Long term reliability.** End users are generally unfamiliar with the materials used in HTS devices and cryogenic systems. Data that prove undiminished product performance of HTS components over 30 to 40 years are not available yet.
- **Business risk.** Uncertainty exists for total cost of ownership, maintenance, cost and availability of spare parts from suppliers in a relatively nascent market.
- **Economics.** The cost of HTS-enabled devices are still significantly higher than conventional, copper-based counterparts because the sophisticated production processes, current low yields, and limited throughput of HTS tape manufacturing processes have kept costs high – there are still no observed effects from economies of scale.

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 of promoting the development of HTS technology in view of common interests. Particularly, the HTS TCP:

- Collaborates with electric utilities, governments, professional engineering organizations 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 ExCo members' 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 for input and to peer review draft reports. These activities help ensure consistency in the reporting and evaluate progress in the different considered fields.
- 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 supports students, young engineers, and scientists who are learning 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 2018 Activities

Highlights of ExCo activities for this Annual Report period include:

- During the Applied Superconductivity Conference 2018, the sector's largest conference held every other year in the U.S., the TCP facilitated a special session on HTS applications with more than 100 attendees. During ASC 2018, Tabea Arndt (HTS TCP German representative) gave a plenary talk on the potential impact of HTS power applications to more than 1000 attendees.
- The TCP submitted a paper to IEEE Transactions on HTS applications for Resilient Electric Systems.
- The TCP started to draft a white paper on HTS for Resilient Electric Systems. Resilient electric systems are of growing interest to electric utilities as they work to manage increasingly damaging weather events.
- Publishing the quarterly 'HTS News' newsletter.
- Updating the website and comprehensive interactive map of HTS projects from around the world.
- Presentation at the Cryogenics and Superconductivity Society of Japan (CSSJ) Spring Meeting (in Tokyo) to give an update on the IEA HTS Roadmap activity and other ExCo activities.
- Continued to foster relationships with other IEA TCPs' implementing agreements, such as the International Smart Grid Action Network (ISGAN) and the Energy Efficient End-use Equipment (4E). The TCP helped lay the groundwork for the first Joint Workshop for the TCPs in EUWP – Electricity.

Summary of Past and Future ExCo meetings	
Milan, Italy	January/February 2017
Kawasaki, Japan	July 2017
Geneva, Switzerland	September 2017
Houston, Texas, USA	April 2018
Seattle, Washington, USA	October 2018
Lausanne, Switzerland	April 2019
Glasgow, Scotland	September 2019

Examples of Engagement

Several examples of how the executive committee has helped fulfill its mission include:

- developing an HTS roadmap for the electric power sector
- playing a key role in a major superconductivity conference
- hosting a conference to engage the young generation of researchers
- developing an interactive web-based map with significant HTS projects for the electric grid

More information is available below.

Applied Superconductivity Conference 2018

During the Applied Superconductivity Conference (ASC) in Seattle, Washington, USA, the HTS TCP facilitated a special session on HTS applications for resilient electric systems. Resilient electric systems are of growing interest to electric utilities as they try and manage increasingly damaging weather events. More than 100 attendees were in attendance to hear speakers that represented HTS power application and cryogenic manufacturers. These speakers gave examples of how HTS can help to harden electric grids. The TCP also used an interactive tool during the session so participants could ask questions through an online app and also respond to several polling questions. This format made the session more interactive and kept the audience engaged. The feedback after this session was very positive.

TCP Operating Agent Brian Marchionini facilitates a discussion between panelists and the audience during the Special Session at ASC 2018.

In addition, Tabea Arndt gave a plenary talk on the use of HTS power applications to more than 1000 attendees. This further highlighted the ability of HTS to help modernize the electric grid while also improving the energy usage in other end-use sectors of the economy such as transportation and industrial systems.

Houston ExCo Meeting

The first IEA-HTS Executive Committee meeting of Fiscal Year 2018 was held in Houston, Texas, USA from 9–11 April 2018 and hosted by the Texas Center for Superconductivity at the University of Houston (TcSUH). Attendees included ExCo representatives from Italy, Germany, Switzerland, Japan, South Korea and the United States; with French observers connected remotely. It also featured a series of presentations from US manufacturers of wire and HTS applications. These presenters provided technical updates to the meeting participants. Presenters included representatives from very active industry players as HyperTech, AMSC, MetOx, the University of Houston, and SuperPower. The ExCo meeting also featured a tour of TcSUH. This allowed ExCo members to learn about TcSUH's wire development activities, as well as their partnership with industry.

ExCo members and guests at the University of Houston.

HTS-TCP Newsletter

This year, a quarterly newsletter was published on the HTS TCP website. Different issues have been circulated among ExCo members. These newsletters are intended to disseminate HTS activities and news around the world in a timely way.

World Projects at a Glance

The ExCo maintains a web-based spreadsheet that catalogs HTS-based projects around the world. Data are collected by region: North America, the European Union, Japan, Korea, China and Russia. The database is updated as needed with data such as current and voltage ratings, current status, partners, budget and references. This resource can be accessed at the TCP's website.

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 wires and primarily coated conductor tapes. The text below highlights several project examples that have made recent progress.

KOREAN CABLE PROJECTS

Two Korean HTS cable projects are underway at the Korean Electric Power Corporation (KEPCO). KEPCO is installing a 1-km 22.9 kV, 50 MVA cable near Seoul that makes use of a 7.5-kW turbo-Brayton refrigeration system. This cable will connect two substations and be a permanent component of KEPCO's electric grid. KEPCO held a ribbon-cutting ceremony in September 2016 and the installation will be complete and fully operational by January 2019. An additional 3-km HTS cable project will differ from KEPCO's 1-km commercial cable by using a coaxial type cable structure. The project aims to provide important data on the economics of long-length HTS cables.

Siemens 10kV Superconducting Fault Current Limiter (Courtesy of Dr. Franz Meyer of BINE Informationsdienst)

CHINESE HTS PROJECTS

Three electric power applications projects are ongoing in China. In Shanghai, China Southern Power Grid is developing a kilometer-class AC HTS cable, which will carry 2kA at 10kV. China State Grid is also considering an R&D km-class 35kV/2kA DC HTS cable. At Nanao, in Guangdong province, China Southern Power Grid started a 35kV/2kA SFCL project in 2017. This area has many wind power generators, and an SFCL is considered to be effective in connecting the electric power distribution with switch gear.

JAPANESE CABLE PROJECT

In 2016 NEDO started an HTS project to promote commercialization of high-temperature superconductivity technology. One of the main development items was the development of HTS power transmission cables, and its targets were as follows:

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

The development was successfully completed at the end of FY 2018. The project includes another development item for a superconducting power feeding system of DC railway application with an emphasis on the development of cooling technique. It will continue until FY 2020.

In 2018 the development of low-cost co-axial three-phase HTS cables for in-plant use was launched as a four-year project coordinated by NEDO.

European Project

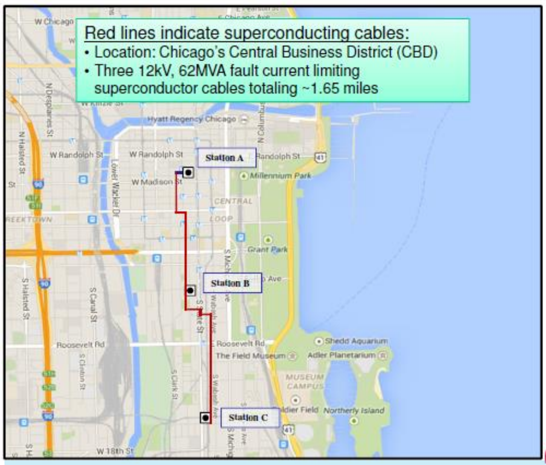
FASTGRID is a 12-partner European project that is focusing on the development of advanced coated conductor tapes suitable for a smart DC FCL for a 1kA-50kV HVDC prototype. The FASTGRID consortium partners will closely collaborate to develop advanced YBCO tapes for DC superconducting (SFCL) applications. The main outcome will consist of a demonstration DC SFCL prototype made out of an innovative HTS conductor to be validated by laboratory tests against dielectric and short-circuit stresses. European Union countries are expected to increasingly develop high-voltage direct current grids, but such systems need high-performance FCLs in order to limit short-circuit currents associated with faults. In this framework, the European project FASTGRID was launched in January 2017 and will last until June 2020.

Ultra-Supertape

The Ultra-Supertape project was launched in December 2015 as a further development of the Eurotapes Project, which showed promising results for industrialization of HTS-coated conductors. The Ultra-Supertape project is focused on high and ultra-high field conductors that use various kinds of chemical synthesis methods, such as chemical solution deposition. This project will result in a faster and lower-cost, HTS-coated conductor.

US HTS Cable in Chicago

An HTS cable has received final approval in the United States in the Commonwealth Edison electric utility service territory. The cable will tie two substations together for increased resilience during fault currents. Project funding is provided by the Department of Homeland Security and Commonwealth Edison.



The Chicago cable project plans to connect three substations. Image Courtesy of AMSC and ComEd.

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

The U.S. Department of Energy is in the third year of funding $25 million for 13 projects aimed at developing new technologies for energy-efficient electric motors through applied research and development. $15 million USD 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 their weight. This effort will support innovative approaches that will significantly improve the technology in industrial electric motors, which use approximately 70% of the electricity consumed by U.S. manufacturers and nearly a quarter of all electricity consumed nationally. The three HTS wire development recipients include STI, AMSC, and the Texas Center for Superconductivity at the University of Houston. More information about other EERE projects can be found at https://www.energy.gov/eere/amo/next-generation-electric-machines-project-descriptions.

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 support services. The HTS TCP operation is supported by a combination of cost-, task-, 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 ExCo and the 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. No changes to either the working arrangement or current structure fee are anticipated. In FY 2017 the fee structure had been modified based on the GDP of the member countries. The HTS TCP Common Fund is financially secure, and has had a surplus for the past several years.

Membership in the ExCo remained the same since the previous annual report, but the ExCo is making a concerted effort to increase membership.

Future Activities

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

- Foster interaction with electric utilities on the benefits of HTS applications.
- Activities that will help to close the gap between R&D and commercialization. This will entail working with utilities so they can better understand the benefits of the technology applications.
- Developing communications and outreach materials for non-technical audiences on the benefits of HTS applications.
- Developing a technical fact sheet on HTS cables and fault current limiters that is geared towards electric utilities.
- Developing technology readiness level diagrams for HTS power applications.
- Developing one special edition white paper on a specific topic such as safety, warranties, and standards about HTS applications; outline how superconductivity can play a role in a low carbon society.
- Expanding the TCP network by engaging new entities that are conducting HTS research and development.
- Organizing workshops to help gain visibility with other TCPs.
- Organizing a Special Session at ASC 2020.
- Recruiting new members.
- Organizing at least 2 ExCo meetings in 2019.
- Keeping ExCo members informed about HTS TCP activities and ensuring participation from the TCP in IEA End-Use Working Party meetings.
- Organizing monthly “Presidium” calls with the Chair, Vice-Chair and operating agents.

Contact Information for ExCo Delegates/Alternates, Sponsors and Operating Agents

Country	Nomination	Name and Organization	Contact Info
Executive Committee			
Canada	**Delegate**	**Dr. Julian Cave** Hydro Quebec	Cave.Julian@IREQ.ca
Finland	**Delegate** **Alternate**	**Dr. Risto Mikkonen** Tampere University of Technology **Dr. Antti Stenvall** Tampere University of Technology	Risto.Mikkonen@tut.fi Antti.Stenvall@tut.fi
Germany	**Delegate** **Delegate** **Alternate**	**Dr. Tabea Arndt** Siemens AG **Prof. Mathias Noe** Karlsruhe Institute of Technology **Prof. Bernhard Holzapfel** Karlsruhe Institute of Technology	Tabea.Arndt@siemens.com mathias.noe@kit.edu bernhard.holzapfel@kit.edu
Israel	**Delegate**	**Prof. Guy Deutscher** Tel-Aviv University	guyde@post.tau.ac.il
Italy	**Delegate** **Alternate**	**Dr. Luciano Martini (Chairman)** Ricerca sul Sistema Energetico – RSE S.p.A. **Dr. Michele de Nigris** Ricerca sul Sistema Energetico – RSE S.p.A.	Luciano.Martini@rse-web.it michele.deNigris@rse-web.it
Japan	**Delegate** **Alternate** **Alternate**	**Mr. Shinichi Ishii** NEDO **Prof. Hiroyuki Ohsaki (Vice-Chairman)** The University of Tokyo **Mr. Susumu Kinoshita** NEDO	ishiisni@nedo.go.jp ohsaki@k.u-tokyo.ac.jp kinoshitassm@nedo.go.jp
Republic of Korea	**Delegate** **Alternate**	**Dr. Sang Chul Han** KEPCO **Dr. Gye-Won Hong** Korea Polytechnic University	sangchulhan@kepco.co.kr gwhong@kpu.ac.kr
Switzerland	**Delegate** **Alternate** **Alternate**	**Mr. Michael Moser** Swiss Federal Office of Energy **Dr. Bertrand Dutoit** Ecole Polytechnique Fédérale de Lausanne **Mr. Roland Brüniger** Swiss Federal Office of Energy	michael.moser@bfe.admin.ch bertrand.dutoit@epfl.ch roland.brueniger@r-brueniger-ag.ch
United States	**Delegate** **Alternate**	**Ms. Debbie Haught** U.S. Department of Energy **Dr. Dominic Lee** Oak Ridge National Laboratory	debbie.haught@hq.doe.gov leedf@ornl.gov
Sponsors			
Italy	- -	**Dr. Giovanni Grasso** Columbus Superconductors S.R.L. **Mr. Matteo Tropeano** Columbus Superconductors S.R.L.	grasso.gianni@clbs.it tropeano.matteo@clbs.it
Operating Agents			
United States	-	**Brian Marchionini** **Donald Mosteller** Energetics Incorporated	bmarchionini@energetics.com dmosteller@energetics.com
Japan	-	**Ataru Ichinose** CRIEPI	ai@criepi.denken.or.jp

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 coordinate 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