2015 Annual Report

IEA Technology Collaboration Program on High Temperature Superconductivity

iea Energy Technology Network

SUPERCONDUCTIVTY International Energy Agency

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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.

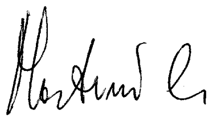
The Technology Collaborative Program on High Temperature Superconductivity (HTS TCP) is working to identify and evaluate the potential applications and benefits of superconductivity and the technical, economic and regulatory barriers to be overcome for achieving these benefits. Through its nine contracting parties and two sponsors, the HTS TCP developed a Roadmap document which outlines the state-of-the-art of where the HTS industry is at now and what steps it should take to realize widespread adoption of superconducting based devices. The Roadmap outlines R&D challenges and needs in the short, mid and long term.

The HTS TCP coordinated several information sharing and stakeholder engagement events which were successful in developing public and private sector partnerships. One example was a special session at the International Symposium on Superconductivity that enabled the "young generation" of scientists and engineers interested in superconductivity to submit abstracts and present on their work.

The committee was recently granted another five year extension from the IEA to conduct activities to help reach its goals. 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



GRID MODERNIZATION DRIVERS

The International Energy Agency's (IEA) World Energy Outlook 2014 states the energy system is under stress and there is a continued rise in global greenhouse-gas emissions in many of the world's fast-growing economies.[i] Global energy demand will increase by 37% by 2040 and carbon dioxide (CO_2) emissions grow by one-fifth (20%). Electricity is the fastest-growing final form of energy, yet the power sector contributes more than any other to the reduction in the share of fossil fuels in the global energy mix. It is forecast that 7200 GW of capacity is needed to meet increasing electricity demand. Many power plants are due to retire by 2040 (around 40% of the current fleet). The strong growth of renewables raises their share in global power generation to one-third by 2040 because of its low carbon emissions.

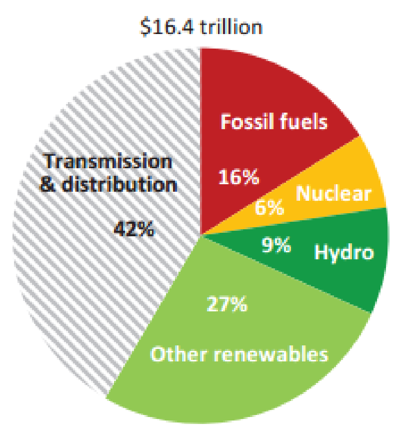
These profound changes affecting the electric power sector offer an unprecedented opportunity to transform the future grid. Increasing needs for flexibility, reliability, and resilience in the transmission and distribution (T&D) system require technologies and techniques not conceived of when much of the current infrastructure was deployed. During this period of transition, the deployment of new technologies will play a critical role in shaping the future grid.

Key Drivers of Change

- Changing mix of electricity supply to low carbon solutions
- Customer participation in electricity markets
- Expectations for greater reliability and resilience
- Integration of digital devices for managing power

Flexible grid system operations and demand response can enable renewables and reduce the need for new bulk-power-level infrastructure. End-use efficiency, smart grid technologies, demand response, storage, distributed generation, and high capacity cables can reduce the expected costs of new transmission equipment investment and contribute to enhanced resiliency and reduced pollution, as well as provide operational flexibility for grid operators. Innovative technologies have significant value for the electricity system. New technologies and data applications are enabling new services and customer choices. These hold the promise of improving consumer experience, promoting innovation, and increasing revenues beyond the sale of electric kilowatt-hours.

For the global power sector, the International Energy Agency estimates that $16.4 trillion of investment will be made; transmission and distribution (T&D) is expected to account for $7 trillion under their New Policies Scenario from 2014-2035 (in 2012 US$).[ii] (See figure at right). The Edison Electric Institute estimated that the total infrastructure investment in the United States will be between $1.5 trillion and $2.0 trillion; T&D is expected to account for about $900 billion by 2030.[iii]



High temperature superconducting based devices have the potential to play a critical role in helping to transform the global T&D grid.

Challenges Remain

Almost thirty years of research, development and demonstration (RD&D) have brought new equipment incorporating high temperature superconductivity (HTS) to the threshold of greatly improving electricity transmission and distribution. 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:

- **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 should be conducted.
- **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 proves undiminished product-performance HTS components life time 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.

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 Montreal, Canada (27 to 29 May 2015) which was hosted by Hydro Quebec. At the Montreal meeting, the hosts invited representatives from regional organizations to introduce their activities and lead ExCo members in a tour of the Hydro Quebec facilities. This interaction enabled the ExCo to stay abreast of current activities, as well as to publicize the potential for HTS in electric power systems.

A planning meeting was held in Lyon, France in September 2015 to discuss ongoing ExCo business such as the IEA request for extending the Technology Collaborative Program until 2021 and the HTS roadmap document.

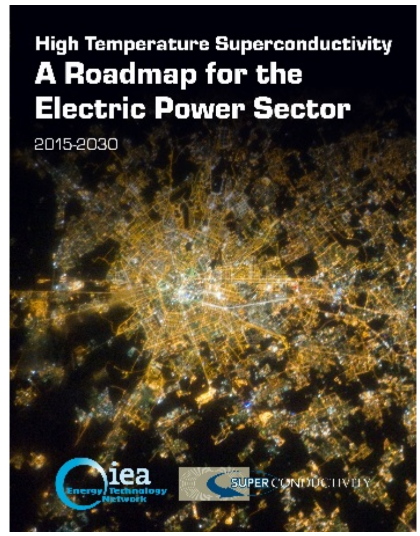
The ExCo also held a webinar meeting in December 2015 and periodic conference calls with the chair, vice-chair and operating agents. Highlights of ExCo activities for this Annual Report period include:

- Developed an HTS Roadmap for the Electric Power Sector, 2015-2030. This document reports on the state-of-the-art of where the HTS industry is at now and what steps it should take to realize widespread adoption of superconducting based devices. More information summarized below.
- Underwent the process to request a 5 year extension from IEA; the implementing agreement extension was approved for the period of 29 February 2016 to 28 February 2021.
- Contributed to a series of volumes on new applications of superconductors in World Scientific Publishing. This is important for communicating superconducting based activities to the broader scientific community.
- Made significant contributions at a major superconductivity conference in Lyon, France. More information summarized below.
- Completed a summary document highlighting its activities for the IEA Energy Technology Initiatives publication.
- Presented at the International Symposium on Superconductivity to give an update on the roadmap and other ExCo activities.
- Held a special session at the International Symposium on Superconductivity on 17 November 2015 for the "young generation" of scientists and engineers interested in superconductivity. English, Chinese and Japanese participants joined and submitted abstracts. They presented on their research topics related to the superconductivity and energy use. More information about this session is summarized below.
- Updated the website with new write-ups on successful HTS based projects. Laid the groundwork to redesign the website with more technical information and also high level policy maker information.
- Developed a summary spreadsheet of HTS projects around the world in North America, the EU, Japan, Korea, China and Russia.
- Received an invited oral presentation slot at a major superconductivity conference (Applied Superconductivity Conference) in September 2016 in the United States.
- 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 HTS ExCo is working jointly with ISGAN to develop a case study on the Essen Cable project in Germany. The ExCo has also reached out to 4E to provide information on superconducting based machines.

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.

HTS Roadmap for the Electric Power Sector



This Roadmap paints a picture of where the HTS industry is at present and what steps it should take to promote widespread adoption of superconducting based devices. It outlines research & development (R&D) challenges and needs in the short, mid and long term that can be tracked using metrics. The intent of the document is not to make predictions about the future nor identify specific organizations to tackle certain problems. The analysis conducted was based on the best data available at the time and this is intended to be the first release document that will be updated in approximately two years.

While superconducting applications span a broad range of sectors in the world's economy, the scope of this roadmap focuses on:

- HTS **wire** development
- **Cryogenic** cooling systems
- **Cables** for higher current density, reduced right of way, and improved efficiency in electricity transmission and distribution
- **Fault current limiters** that act like grid surge protectors and operate with significantly lower losses than conventional technology
- **Superconducting magnetic energy storage** for high density stored power, that can be delivered instantaneously
- **Transformers**, which have much smaller size and weight of conventional devices, and do not use mineral oil as the cooling medium
- **Generators** more compact and efficient as compared to conventional rotating machines to be also applied in off shore wind power applications

The executive summary of the roadmap can be found at http://superconductivityiea.rse-web.it.

EUCAS 2015

The European Conference on Applied Superconductivity (EUCAS) 2015 was held in 6th - 10th September in Lyon, France. There were 1137 participants in total attending the conference, which comprised 1060 presentations and 33 corporate showcase exhibitions.

The HTS TCP was well represented in the electric power applications sessions of this major bi-annual conference. Examples of our involvement include:

- ExCo members participated in a special session, on “large scale-industries and utilities” dedicated to cables and fault current limiters being developed in Europe.
- Presentation on the AmpaCity cable and fault current limiter project in Essen Germany.
- Presentation from wire manufacturer Columbus in Italy on MgB_2 wires for electric power applications. Columbus supplies a large volume of long wires for a variety of applications such as wind turbines, cables and MRI devices.

Introductory talk of Dr. Martini (RSE).

2015 International Symposium on Superconductivity

Encouraging the next generation of scientists and engineers to become interested in superconductivity is critical. Students and young professionals have the potential to develop new and innovative ideas to help the technology proceed along the pathway to commercialization. To this end, the HTS TCP hosted a competition to nurture young researchers in this topic area.

On 17 November 2015 a Special Session at the International Symposium on Superconductivity was held in Tokyo, Japan entitled *Superconducting Applications and Future Energy Perspective*. Eight candidates presented their research and perspectives for helping to advance the state of the art in superconductivity for energy applications. Three of these presenters were selected for the Young Generation Award.

Recipients of Young Generation Award with their certificates (Drs. Wu, Kumagai, and Ainslie in the center) and Mr. Watanabe (right) and Dr. Martini (left).

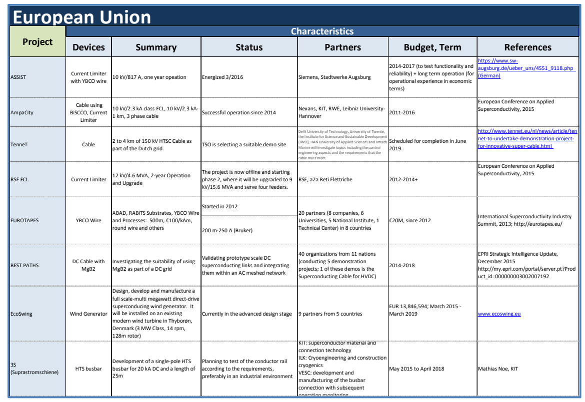
The three Young Generation Award winners were:

- Dr. Wu of Northwest Institute for Non-ferrous Metal Research who presented the development of MgB_2 and Bi2212 wires and lithium-battery materials.
- Dr. Kumagai from the University of Tokyo presented on how HTS cables are being utilized for train railways.
- Dr. Ainslie from the University of Cambridge presented on how the study of bulk superconductors can be useful for motors and power generators.

World Projects at a Glance

The ExCo developed an Excel based spreadsheet that catalogs HTS based projects around the world. Data is separated into the following regions: 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.

Examples of significant HTS based projects can be found in the next section.



European Union

Project	Characteristics					
	Devices	Summary	Status	Partners	Budget, Term	References
ASSIST	Current Limiter with YBCO wire	10 kV/817 A, one year opeation	Energized 3/2016	Siemens, Stadtwerke Augsburg	2014-2017 (to test functionality and reliability) + long term operation (for operational experience in economic terms)	https://www.sw-augsburg.de/ueber_uns/4551_9118.php (German)
AmpaCity	Cable using BiSCCO, Current Limiter	10 kV/2.3 kA class FCL, 10 kV/2.3 kA-1 km, 3 phase cable	Successful operation since 2014	Nexans, KIT, RWE, Leibniz University-Hannover	2011-2016	European Conference on Applied Superconductivity, 2015
TenneT	Cable	2 to 4 km of 150 kV HTSC Cable as part of the Dutch grid.	TSO is selecting a suitable demo site	Delft University of Technology, University of Twente, the Institute for Science and Sustainable Development (IWO), HAN University of Applied Sciences and Imtech Marine will investigate topics including the control engineering aspects and the requirements that the cable must meet.	Scheduled for completion in June 2019.	http://www.tennet.eu/nl/news/article/tennet-to-undertake-demonstration-project-for-innovative-super-cable.html
RSE FCL	Current Limiter	12 kV/4.6 MVA, 2-year Operation and Upgrade	The project is now offline and starting phase 2, where it will be upgraded to 9 kV/15.6 MVA and serve four feeders.	RSE, a2a Reti Elettriche	2012-2014+	European Conference on Applied Superconductivity, 2015
EUROTAPES	YBCO Wire	ABAD, RABiTS Substrates, YBCO Wire and Processes: 500m, €100/kAm, round wire and others	Started in 2012 200 m-250 A (Bruker)	20 partners (8 companies, 6 Universities, 5 National Institute, 1 Technical Center) in 8 countries	€20M, since 2012	International Superconductivity Industry Summit, 2013; http://eurotapes.eu/
BEST PATHS	DC Cable with MgB2	Investigating the suitability of using MgB2 as part of a DC grid	Validating prototype scale DC superconducting links and integrating them within an AC meshed network	40 organizations from 11 nations (conducting 5 demonstration projects; 1 of these demos is the Superconducting Cable for HVDC)	2014-2018	EPRI Strategic Intelligence Update, December 2015 http://my.epri.com/portal/server.pt?Product_id=000000003002007192
EcoSwing	Wind Generator	Design, develop and manufacture a full scale-multi megawatt direct-drive superconducing wind generator. It will be installed on an existing modern wind turbine in Thyborøn, Denmark (3 MW Class, 14 rpm, 128m rotor)	Currently in the advanced design stage	9 partners from 5 countries	EUR 13,846,594; March 2015 - March 2019	www.ecoswing.eu
3S (Suprastromschiene)	HTS busbar	Development of a single-pole HTS busbar for 20 kA DC and a length of 25m	Planning to test of the conductor rail according to the requirements, preferably in an industrial environment	KIT: superconductor material and connection technology ILK: Cryoengineering and construction cryogenics VESC: development and manufacturing of the busbar connection with subsequent operation monitoring	May 2015 to April 2018	Mathias Noe, KIT

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.

Siemens SCFL in Germany's Stadwerke Grid

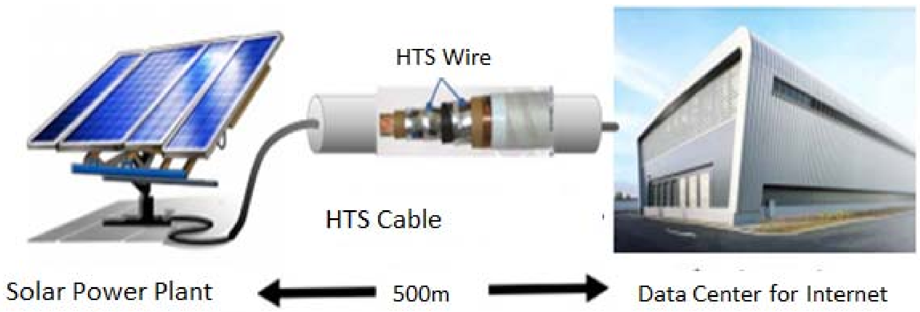
A superconducting fault current limiter with a rated current of 817 amperes will secure the connection between Stadtwerke Augsburg's grid and an industrial company. When in operation in early 2016, an energy load with a maximum feed-in power of 15 megawatts will be fed from the company's grid into the Stadwerke's grid. Without appropriate measures, this load would exceed the permissible short-circuit level. During the field test, a short-circuit limiting reactor, which will be used as a backup solution, will be bypassed by a superconducting fault current limiter.

AmpaCity Cable and Fault Current Limiter in Essen, Germany

A 1 km-long, 10 kV three-layer coaxial cable is currently in operation in the Essen grid. A fault current limiter (shown in the photo on right) was also installed and thus eliminated the need of four substations positioned downstream. The project focuses on the practical realization of superconducting cables and will identify any issues that arise during the two-year long operation. In-grid continuous loading trials began last summer. German electric utility RWE together with Siemens, Nexans, and Karlsruhe Institute of Technology are all working on this project. Demonstrations such as AmpaCity have the potential to change future public opinions for using HTS and liquid nitrogen systems. RWE is strengthening public relations on the HTS facility and its impact on the community in Essen. More than 100 press releases are available via TV, magazines, and newspapers. These efforts will result in the acceptance of HTS system in the society.

HTS DC Cable for Data Center in Hokkaido, Japan

In August 2015, the consortium named Ishikari Superconducting DC Power Transmission System (Chiyoda Chemical Engineering Plant, SEI, Chubu university, Sakura Internet) announced a successful transmission of 500m long HTS DC cable with a large current of 1.5kA (corresponding to about 300,000 households) and 100MVA in Ishikari city of Hokkaido, Japan. Furthermore, they started the DC current transmission from a solar power plant to a data center in Ishikari. There are no DC-AC conversions in the line and it is expected to be a highly efficient use of the power. A schematic of the system can be found below.



HTS DC, AC Cable Test in Jeju, Korea

Korea Electric Power Corporation (KEPCO), LS Cable & System, and AMSC announced that a HVDC HTS cable was energized on Jeju Island in late 2014. The 500 meter, 80kV DC cable by AMSC's Amperium® HTS wire were successfully tested in KEPCO's electricity grid. KEPCO is planning to make a 1km and 154kV AC cable at the same site.

DC Cable for Train Operation in the Izu district, Japan

The Railway Technical Research Institute in Japan announced in April, 2015 that they succeeded in transporting a current of 2000A for a real train operation in a Tokyo suburb area (photo on the left shows the HTS cable). This system was tested in 2014 in their laboratory railway center, which has a train running with 310m long transmission cable. They expect more efficient power use in a train system such as reduction of power loss or substation using HTS DC train cable.

Advanced Superconductor Manufacturing Institute (ASMI) in the United States

The University of Houston announced plans for ASMI in May, when it received a $500,000 planning grant from the National Institute of Standards and Technology. The goal of the institute is to build an industry-based consortium to speed full commercialization of high-temperature superconductors. ASMI is holding workshops to develop cost-shared projects and also to develop a long term sustainability model.

Resilient Electric Grid Project in the United States

AMSC selected Nexans to design, fabricate and qualify, a medium voltage, HTS cable for AMSC as part of the company's Resilient Electric Grid project in Chicago, Illinois. Utilizing AMSC's Amperium® HTS wire, Nexans will design and fabricate the HTS power cable, including the power cable terminations and a cable splice, for qualification and performance evaluation as part of AMSC's REG program with The Department of Homeland Security. The planned HTS power cable tests are required by electric utilities and will be performed at Nexans' test facility in Hannover, Germany, which is specially equipped to perform tests on superconducting systems for power grids. The qualification of the HTS power cable will represent an important step toward the construction phase of AMSC's REG program in Chicago.

National Programs

Japan

The Japanese Agency for Medical Research and Development is funding HTS Coil for Medical Applications, such as MRI and a Heavy Iron Accelerator, in 2013 and ended in 2015. The next large national project is being planned by NEDO for highly reliable power cables, train cables, highly stable HTS coil for MRI and highly productive methods for HTS wires.

Korea

While Korea's national program, Dream of Advanced Power Applications of Superconductivity (DAPAS), has concluded, work to advance applications to the power sector continues. Korea just completed a successful demonstration of an HTS DC cable and work is underway on a transmission voltage AC cable.

United States

While US funding responsibilities were reorganized in 2010, work continues with US wire manufacturers such as SuperPower, AMSC, STI, MetOx, Oxford Instruments, and HyperTech. Examples of other organizations continuing HTS research include the Department of Homeland Security, New York State Energy Research and Development Authority, the Advanced Magnet Laboratory, Texas Center for Superconductivity at the University of Houston, and Florida State University. The Department of Energy's Advanced Manufacturing Office has a funding opportunity for superconducting wire manufacturing.

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 IA members contribute. There are no changes foreseen in the working arrangement or current fee structure. The HTS IA 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:

- Revamp the website to include broader information on HTS technologies, benefits, and publications.
- Develop a document based on real world examples of the economics of HTS.
- Develop a comprehensive overview of HTS based applications for the power sector.
- Develop quarterly newsletter on HTS project updates.
- Develop a document that investigates the system behavior of HTS applications.
- Update roadmap on an as needed basis.
- 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.
- Organize workshops to help gain visibility with other TCPs.
- Target experts in the cryogenics area to add technical resources.

Contact Information for ExCo Delegates, 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 members 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) (formally known as Implementing Agreements).

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

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

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[i] IEA "World Energy Outlook 2014". http://www.worldenergyoutlook.org/publications/weo-2014/

[ii] "Cumulative global power sector investment by type and selected region in the New Policies Scenario, 2014-2035" from IEA, "World Energy Investment Outlook – Special Report", OECD/IEA, 2014. https://www.iea.org/publications/freepublications/publication/WEIO2014.pdf

[iii] Edison Electric Institute. "Transforming America's Power Industry: The Investment Challenge 2010-2030." November 2008. http://www.eei.org/ourissues/finance/Documents/Transforming_Americas_Power_Industry_Exec_Summary.pdf.