END-OF-TERM REPORT 2010 - 2016

International Energy Agency
Implementing Agreement for a Co-operative Programme for Assessing the Impacts of **High-Temperature Superconductivity** on the Electric Power Sector

SUPERCONDUCTIVITY
International Energy Agency

End of Term Report 2010 - 2016

Foreword

This document is the End of Term Report for the Implementing Agreement for a Co-operative Programme for Assessing the Impacts of High-Temperature Superconductivity on the Electric Power Sector (HTS IA). Its purpose is to highlight HTS IA activities and achievements over the last five years from 2010 - 2015.

It should be considered in association with the HTS IA Strategic Plan report. This End of Term was prepared by Brian Marchionini (HTS IA Operating Agent) with contributions from, and under the direction of, the HTS IA Executive Committee and it was unanimously accepted by them on 9 July 2015.

9 July 2015

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Summary

This Implementing Agreement brings together institutions located in nine nations who are all leaders in the effort to develop innovative electric power equipment that incorporates high temperature superconductors. The focus is on equipment for the power sector, comprising electric utilities and their large energy consuming customers, as well as large stand-alone producers and consumers of electric energy. The implementing agreement's purpose is to assess the state of efforts to advance superconductivity to devices that will significantly improve the generation, transmission, distribution and end use of electric power.

Over the last term of the implementing agreement (IA), there have been a number of successes.

- From the thought leadership of IA members, several large scale project successes were realized across the world
  - World's first direct current HTS cable energized in a real grid in Jeju Korea
  - HTS cable successfully completing a one-year test in Tokyo, Japan's grid
  - World's first limiting of a short circuit by a HTS fault current limiter (FCL) in Milan, Italy
  - HTS cable and FCL proved to be a cost effective solution compared to the conventional technology in Essen, Germany
  - World's longest HTS cable planned in Chicago, Illinois that will enable a resilient grid
- Development of a Roadmap document for the future use of high temperature superconductors by the power sector
- Planned, executed and documented at least two executive committee meetings per year to encourage information dissemination among HTS stakeholders
- Maintained membership of at least nine countries and two sponsors
- Started a major project on editing and contributing to seven books for the World Scientific Series on Modern Applications of Superconductivity
- Successful planning and execution of a young researcher award completion for high temperature superconductivity
- Developed technical documents and publications for a wide variety of audiences aimed at raising awareness of HTS devices for electric grid applications

1. Introduction

Following the IEA CERT's recommendation, the IEA Governing Board renewed the mandate for the IEA's *Implementing Agreement for a Co-operative Programme for Assessing the Impacts of High-Temperature Superconductivity on the Electric Power Sector* for the period 1 October 2005 to 30 September 2010, which was further extended to 28 February 2016. The 2010-2016 End-of-Term Report for the High-Temperature Superconductivity Implementing Agreement (HTS IA) provides an overview of the work that has been performed and completed over this five-year term.

1.1 Mission

The IA's mission consists of creating a common platform for the sharing and exchange of information and experiences concerned with the latest achievements in superconductivity technology applications worldwide. In particular, this IA's mission is to evaluate the status of and assess the prospects for future use of high-temperature superconductivity (HTS) by the electric power sector within the developed and developing world, and to disseminate these results to decision makers in governments, the private sector and the research and development (R&D) community within the member countries.

The mission has been, and will remain important because many nations wish to improve efficiency, flexibility and reliability of their electrical systems (generation, transmission, distribution and end-use). This wish expresses both the present generation's desire for goods and services and the same generation's concern for future technological progress — in particular, concern over how to reduce environmental impacts while increasing the availability of economical electrical power. HTS demonstration projects that have already been accomplished and are now under way in Asia, Europe and North America continue to substantiate early expectations that the use of HTS technology can significantly increase the power sector's ability to meet these demands.

During the past term, this IA's evaluations and assessments have reflected the concerns that animate the electric power sector and the concerns of the R&D community that makes innovation possible. Those concerns include cost, technical feasibility, reliability, energy efficiency, environmental compatibility, and increased productivity.

1.2 Objectives

The overall objective of the IEA's *Implementing Agreement for a Co-operative Programme for Assessing the Impacts of High-Temperature Superconductivity on the Electric Power Sector* is to support producers, transmission and distribution system operators and consumers of electric power, by providing expert and unbiased views of the significance of the work now under way to bring improved HTS technology to the electric power sector. The objective is made feasible by co-operation and information sharing among the HTS IA participants. This co-operation also makes the cost of achieving the objective something that many nations can afford. The implementing agreement activity covers fundamental topics such as HTS materials, cryogenic systems, and HTS based electric grid devices such as:

- **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 IA has only 1 Annex whose specific objectives are as follows:

- To support HTS technology transfer to the power sector, including large industrial consumers and other end-users, by creating and disseminating reliable, intelligible information.
- To contribute to the development of the technology by indicating technical areas that need further attention in order to serve potential future end-users and by indicating important goals and evaluating technology, to encourage the steps (technical and institutional) needed for future commercialization of HTS devices.
- To facilitate the creation of research collaborations and information sharing among international experts in multi-disciplinary fields to address the complex problems of developing innovative devices based on HTS technology.
- To support development of reliable, energy-efficient, cost-effective electric power technologies incorporating high-temperature superconductors, with emphasis upon technologies that result in improved efficiency and reduced emissions.
- To enhance the appreciation of the opportunities made available by HTS in the electric sector and the challenges to their realization by both policy makers and the general public.

2. Strategic Direction

The HTS IA promoted the development of superconducting technology by evaluating the status of and assessing the prospects for future use of HTS by the electric power sector within the developed and developing world. This was done by drawing on the expertise of the Executive Committee (ExCo) members, including relevant government officers and their representatives, and their colleagues in the IA's nine member countries, which are in Asia, Europe and North America. In addition, the IA drew upon the interest and expertise in at least three countries that are not members of this IA.

HTS technology is of interest to a range of stakeholders because it has the potential to enable electrical equipment that can provide more compact equipment, with less weight and with more safety and less environmental impact than is now possible. The table below depicts some of the target audiences and their interest in HTS technology. These audiences, or stakeholders, have different needs and therefore the IA needs to craft a different message for them.

End users (Utilities)	• Utilities are conservative when installing new technologies and are interested in low cost, reliable technologies that can be integrated into their electric grid. • Utilities are not concerned about the superconducting material itself but rather the entire system as it is integrated in the grid. These devices can provide more compact power delivery and reduced losses for electricity transmission when compared to conventional technologies

Equipment manufacturers	• Equipment manufacturers are concerned about the HTS wire as it is a key component of the devices they are developing. • Different applications may require a different type of HTS wire
Wire manufacturers	• Are striving for lower cost and higher performance wire for a range of applications
Government Officials (e.g. policy makers)	• These stakeholders are concerned about how these novel devices will result in lower greenhouse gas emissions, reduced electricity costs for customers, and even economic growth from job creation in this high tech industry

The HTS IA has supported the EUWP's mission by providing inputs, including reports of the IA's activities and policy messages.

The HTS IA's strategy has three complementary aspects:

1. With regard to the topics of interest, the IA's strategy is to *focus on pre-competitive issues.*

2. With regard to method, the IA's strategy is to *involve all of its participants*. Each is obliged to and does facilitate contacts with relevant persons and institutions in their home countries, provide relevant information, introduce relevant work, identify peer reviewers, furnish the perspective of likely decision-makers and to disseminate results of the IA's work. The focus on pre-competitive topics of mutual interest makes possible the cooperation that has been achieved. By focussing on cooperation and participation, *information that might be withheld in other venues is brought forth and shared in this one*.

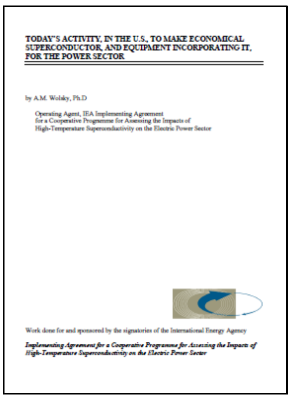
3. The third aspect is *pro-active outreach* to all leading participants in the development of HTS for ultimate use in the power sector. The IA engages them *whether or not they are located in IA member countries*. These leading participants, usually either for-profit firms or research institutes, are asked for their perspective, based upon their own HTS and their broader business experience. They may also be asked to peer-review the IA's draft reports.

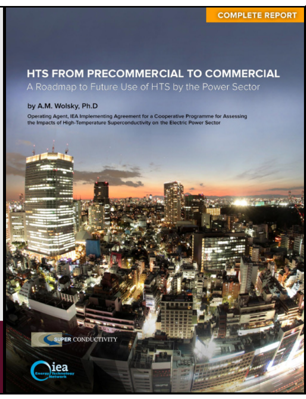
3. Scope

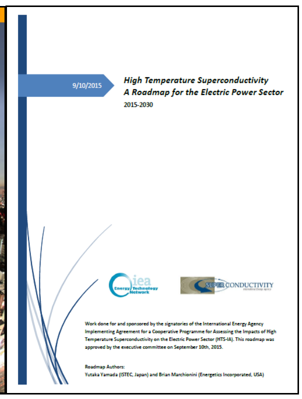
During the 2010-2016 term, the HTS IA developed, exchanged, and disseminated information and perspectives from all the world's active groups. The IA has involved experts from the private sector, public utilities, research institutes and government agencies in its efforts. The information and perspectives developed and communicated bore upon the full range of issues, from R&D on the relevant materials to the commercial considerations of parties trying to develop equipment for future adoption and to utilities who would be end-users. Some of this information and perspective was recorded in detailed and comprehensive, peer-reviewed technical reports.
Other information, typically reports by members of their own countries' activities and results, is distributed to all the participants in this IA. Other, more subtle, assessments result

from face-to-face discussion among IA members and experts and officials at facility visits and public meetings. The table below depicts examples of reports that were developed in this term. There are annual reports for each of the years in this term except for 2010. The operating agent was not asked by the ExCo to develop a report in this year; however, there were reports compiled for the subsequent years. The 2015-2016 annual report is in development. Also, noteworthy is that because of a change in the reporting period, the Annual Report from 1 March 2014 to 28 February 2015 actually includes data back to the end of the previous Annual Report.

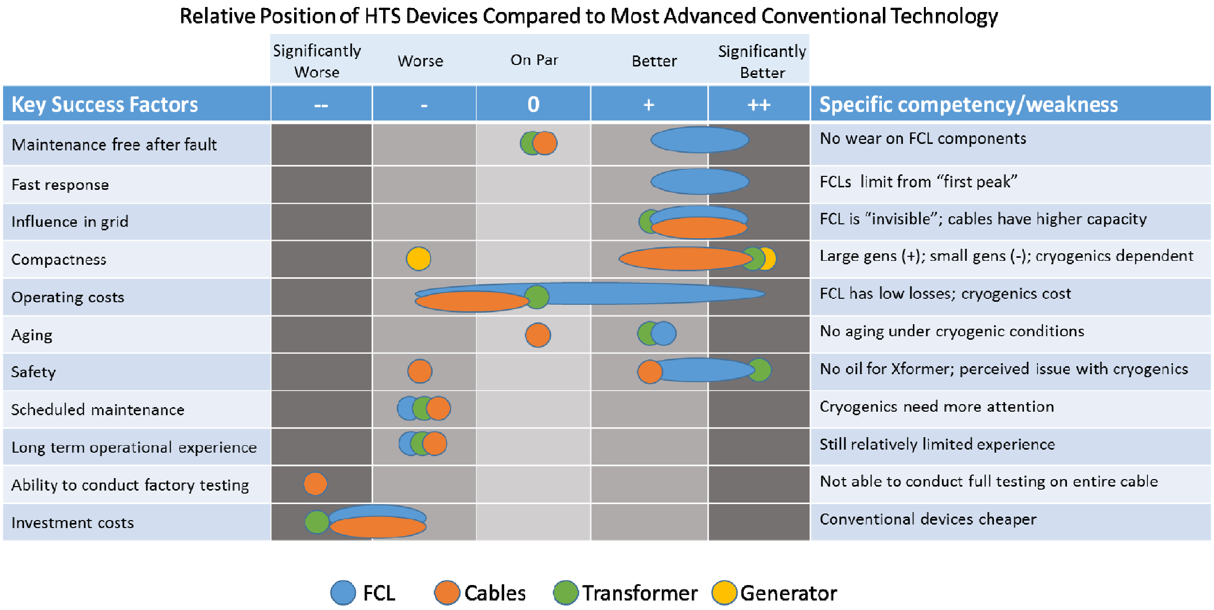
Title	Document Type	Author	Year
Fault Current Limiters: Some Recent Developments	Report Presentation	A. Wolsky	2011
Today's activity, in the U.S., to make economical superconductor, and equipment incorporating it, for the power sector	Report	A. Wolsky	2012
High Temperature Superconductivity: meeting Global Electricity Demand	Fact Sheet	A. Wolsky	2012
HTS IA Annual Report 1 October 2011 to 30 Sept 2012	Annual Report	A. Wolsky	2012
HTS IA Annual Report 1 October 2012 to 30 Sept 2013	Annual Report	A. Wolsky	2013
HTS from Pre-commercial to Commercial	Report	A. Wolsky	2013
HTS from Pre-commercial to Commercial	Executive Summary	A. Wolsky	2013
IEA Energy Technology Initiatives: Helping Secure the Energy Future	Fact Sheet	B. Marchionini, S. Watanabe, Y. Yamada	2014
HTS IA Annual Report 1 March 2014 to 28 February 2015 (*) (*) Modified FY as requested by IEA	Annual Report	B. Marchionini, S. Watanabe, Y. Yamada	2015
High Temperature Superconductivity: A Roadmap for the Electric Power Sector 2015-2030	Roadmap	B. Marchionini, S. Watanabe, Y. Yamada	2015
HTS IA Annual Report 1 March 2015 to 28 February 2016	Annual Report	B. Marchionini, S. Watanabe, Y. Yamada	2015 (in draft)





One specific example of these reports is the 2015 HTS applications Roadmap document. The roadmap document discusses the journey the technology has made from basic science discovery to the development of large scale demonstration projects operating in the grid. The roadmap covers the challenges facing the HTS industry such as cost of wire and cryogenic systems, reliability and maintenance of cryogenic systems, and developing products for the conservative electric utility industry. An example of the data from the roadmap can be found in the graphic below. Based on data collected from industry stakeholders, it shows relative position of HTS based devices compared to the most advanced conventional technologies. HTS devices general perform better on many key success factors, but additional R&D is needed in some areas. For instance, small HTS wind turbine generators may fare slightly worse in compactness than conventional generators, but large wind generators fare significantly better because of the economies of scale with the cryogenics equipment.



The implementing agreement's web site contains a restricted area for members only as well as a publicly available section for dissemination purposes.[1]

Distribution of written materials is not the only way information is exchanged. The HTS IA has devoted substantial effort to create opportunities for members and the larger community, including students, potential end-users and policy makers, to talk with each other at formal meetings and while visiting each other's laboratories and test facilities.

Several workshops were organized in order to pave the way for fruitful information exchange and knowledge transfer among industrial subjects, universities and research institutes. Representatives from many important manufacturers, as Nexans, Siemens, AMSC, Sumitomo, Furukawa, Fujikura, Taiyo Nippon Sanso, Mayekawa actively contributed to these workshops. The results are summarized in the following table (Table A).

[1] http://superconductivityiea.rse-web.it

Table A. Meetings Held by or Attended by IA to Exchange Information and Educate Policy Makers and Students, 2010-2016		
Meeting	**Venues**	**Participants**
Symposia	Young Generation of Superconductivity Award at ISS2014 Conference, Japan, November 2014	>50
Workshops	• "Special workshop on recent achievements on HTS conductors and refrigeration systems in the US" (Santa Fe, 17 May 2011) • "Special workshop on German HTS activities" (Heidelberg, Germany, 11 May 2012) • "Recent status of Japanese HTS technology" (Makuhari (JP), November 29-30, 2012) • "Special workshop on Swiss activities on Superconductivity", (Lausanne, 23 May 2013) • "Energy Technology 2020+: Contributions by superconductivity" (Paris, 21-22 October 2013) • "HTS Applications in the Power Sector" (JeJu Island, Korea, 4 December 2014)	20 - 50 participants for each event
Conferences	• EUCAS 2011, 10th European Conference on Applied Superconductivity, The Hague, The Netherlands, September 2011. • Applied Superconductivity Conference, Portland, Oregon, United States, August 2012 • EUCAS 2013, 11th European Conference on Applied Superconductivity, Genoa, Italy, September 2013. • Applied Superconductivity Conference, Charlotte, North Carolina, United States, August 2014 • EUCAS 2015, 12th European Conference on Applied Superconductivity, Lyon, France, September 2015	7 ExCo + Alternates 12 10 15 15 (expected)
Networks	• ESAS - European Society for Applied Superconductivity • ISTEC - International Superconductivity Technology Center • CONECTUS - Consortium of European Companies Determined To Use Superconductivity • CCAS - Coalition for the Commercial Application of Superconductors • ISIS – International Superconductivity Industry Summit (network and yearly conferences) • CIGRE - International Council on Large Electric Systems • IEC - International Electrotechnical Commission, Technical Committee on Superconductivity International Standards	
Scientific Exchanges	• Dr. Hara of TEPCO on Yokohama Cable project • Dr. Shiohara of ISTEC on M-PAC project • Dr. Ahmed, SCE on Electric utility perspective on HTS	90% of membership

Table A. Meetings Held by or Attended by IA to Exchange Information and Educate Policy Makers and Students, 2010-2016		
Meeting	**Venues**	**Participants**
	power applications • Dr. Bottura of CERN on the Status of LHC Upgrade” • Dr. Ballarino of CERN on the LINK project • Dr. Moon of SuNAM for HTS YBCO wire commercialization • Dr. Larbalestier of HFML for HTS magnet progress	
Facility Visits	• Los Alamos National Lab (LANL) STC Tour , Cable and Magnet Lab Tour (2011, USA) • Bruker LTS and HTS conductors production plant (2011, Germany) • Fuji Electric (2012, Japan) • SFCL installation at a Milan substation (2014, Italy) • Jeju HTS DC cable test site (2014, South Korea) • Hydro power plant at Hydro-Quebec (2015, Canada)	80% of membership
Executive Committee Meetings	• Stockholm, Sweden, May 2010 • Zurich, Switzerland, October 2010 • Santa Fe, New Mexico, United States, May 2011 • Hanau & Alzenau Germany, November 2011 • Heidelberg, Germany, May 2012 • Tokyo, Japan, November 2012 • Lausanne, Switzerland, May 2013 • Paris France, October 2013 • Washington, DC, United States, February 2014 • Milan, Italy, June 2014 • Jeju Province, Korea, December 2014 • Montreal Canada, May 2015 • Lyon, France, September 2015 (planned)	90% of membership

Most important, the IA develops information regarding future, rather than simply recording past accomplishments. During this term, the IA completed an initial roadmap for HTS electric power applications in 2013. This roadmap identified tasks that should be accomplished to achieve commercialization of the HTS technology in the electric power section for applications such as power cables. An updated roadmap out to 2030 which covers all relevant HTS applications as well as enabling technologies as refrigeration is expected to be completed by December 2015. The resulting document is meant to inform senior RD&D managers in the public and private sectors and policy makers about the current status, challenges and needs for more widespread deployment of HTS based electric power devices.

IA Funding

This is a cost-shared agreement among the member countries. The total annual budget over the 2010-2016 term was 200 thousand to 230 thousand USD. This funding was primarily used to support the operating agent expenses. Members are also expected to contribute inkind by hosting ExCo meetings, arranging facility visits, symposia and conferences, and encouraging technical experts and industry leaders to offer their views on issues of importance to the group.

The countries represented by the IA-HTS have different strategies to provide funding to HTS R&D activities towards HTS applications in the power sector. For example, Japan and Korea have a very comprehensive national program composed by several specific projects covering all value chain from HTS wires to HTS main applications, including dedicated efforts on enabling technologies as cryogenics (refrigerators) and electrical insulation. The United States sponsored similar types of projects involving different stakeholders such as HTS wire manufacturers, HTS application developers, electric utilities, and cryogenic companies.

Other IA-HTS countries usually support strategic projects on specific HTS applications and in particular HTS cables and fault current limiters (FCL). In Europe, R&D funding from the European Commission Framework Program VII (FP7) have been made available in the past 5 years to support HTS material development and very ambitious HTS projects on cables, FCL and wind turbines for off-shore applications.

The highest funding levels for HTS R&D have been from the United States, Japan and Korea relative to the rest of the world. However, a significant amount of resources have been allocated by other countries such as Germany and Italy.

IA Membership

Bruker HTS GmbH in 2010 and Columbus Superconductor in 2011 joined the IA as sponsors. During the past term, the United Kingdom, Sweden and Norway left the IA. Existing contracting parties include governments, utilities, manufacturers, and R&D centres (see Table B).

Table B. Participants in the HTS Implementing Agreement, 2010–2016		
Country	**Organisation(s)**	**Organisation Type**
CANADA	Hydro-Quebec	Industry
FINLAND	Tampere University of Technology TEKES National Technology Agency	University Government
GERMANY	Karlsruhe Institute of Technology Siemens	Publicly Funded Research Centre Industry (Corporate Technology Research)
ISRAEL	Ministry of National Infrastructure Tel Aviv University	Government University
ITALY	Ricerca sul Sistema Energetico S.p.A	Research Centre
JAPAN	New Energy and Industrial Technology Development Organization Yokohama National University University of Tokyo (from 2013)	Government University (Advisor) University (Advisor)
REPUBLIC OF KOREA	Korean Electric Power Institute Korea Polytechnic University	Industry University
SWITZERLAND	Swiss Federal Office of Energy Ecole Polytechnique Fédérale de Lausanne	Government Academia
UNITED STATES	U.S. Department of Energy	Government

IA Contribution to Technology Network of IEA

The HTS IA maintains close collegial relations with the International Smart Grid Action Network and in particular with Annex 5—Smart Grid International Research Facility Network and Annex 6—Power Transmission and Distribution Systems. The IA also developed a revised one pager for the IEA Energy Technology Initiatives document and completed the two page reporting template for the Working Party on Energy End-Use Technologies.

In addition, the IA has also supported the IEA Secretariat by providing information on HTS based wind turbines.

Reflecting the common interest of its members and the goal of mutual interaction, this IA has a single annex.

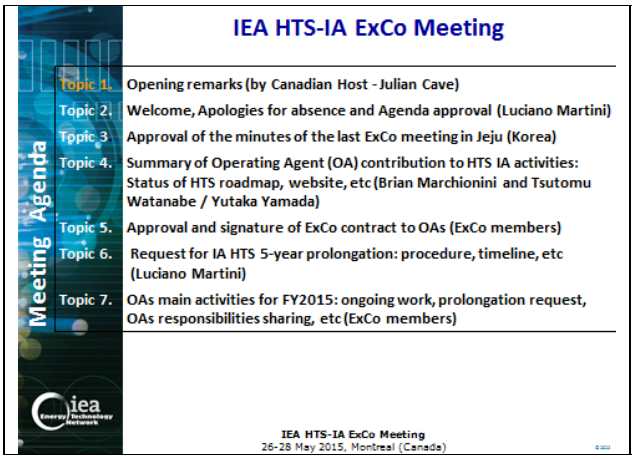
4. Contractual and Management Requirements

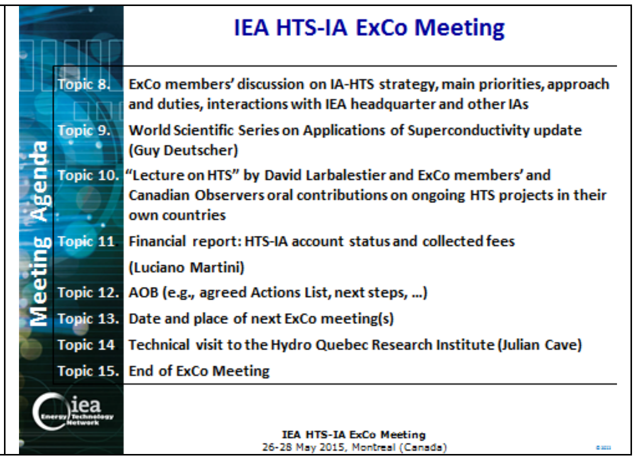
IA ExCo Meetings

The ExCo regularly meets twice a year, usually in the spring and the fall. Date and time of ExCo meetings are usually agreed about 1 year in advance and the draft agenda of the meeting is circulated 2-3 months prior to the meeting asking to ExCo members for specific topics to be eventually proposed and added.

Typically, eight out of the nine member countries participate in any given meeting plus the sponsors' representatives; several contracting parties are often represented by two or even three members at each ExCo meeting. At the beginning of each ExCo meeting the agenda is approved and then the minutes of the previous meeting are presented and finally approved. The host country typically invites presenters from industry or academia to give updates on related topics in an open session. All material presented at the meeting (agenda, documents and presentations) is uploaded on the restricted area of the HTS IA web site. Meeting minutes summarizing the discussion outcomes are circulated to all participants within 3-4 weeks for comments; a consolidated version is then circulated, which is finally approved at the following ExCo meeting.

Other management issues that are usually discussed during the ExCo meetings include: a summary of OA activity in the past months, financial report and account status, IA-HTS strategy, main priorities, and interactions with IEA headquarter and other IAs. Election of Chairman and vice-Chairman is included once a year at each autumn ExCo meeting. In the following the typical agenda from the last ExCo meeting held in Montreal on May 26-28 is reported.





IA Annual Reports

These reports are developed by the operating agents of the IA.

IEA Framework and IA Legal Text

The ExCo conducts its business in accordance with the text of the Implementing Agreement, last-revised in 2015. For the first time in the IA history, the ExCo also developed a contract with the operating agents. In 2014, two new operating agents were unanimously selected by the ExCo to work collaboratively in support of IA activities. Before this time, the ExCo was served by one operating agent. By having two operating agents it enables the ExCo to leverage the technical communications expertise from Energetics Incorporated in the United Stated and the extensive technical knowledge from the International Superconductivity Technology Center (ISTEC) in Japan. This unique combination of skill sets was a successful alternative to completing IA activities.

On the rare occasions when the ExCo has been in doubt (e.g., when inviting entities to become either new Contracting Parties or Sponsors), the IA has sought, received, and followed the guidance of the Secretariat's Legal Office.

5. Contribution to Technology Evolution/Progress

This IA does not itself conduct joint laboratory research or field demonstration projects, though most of the ExCo's members do so. The HTS IA develops, exchanges and disseminates information and perspective to permit its members to see the overall significance of what has been done and identify what remains to be done. This is meant to be helpful to RD&D managers, decision makers and policy makers.

The HTS IA is fully committed to contribute to a series of volumes by World Scientific Publishing on Modern Applications of superconductivity by Dr. Guy Deutscher Editor of the Series. Several volumes are close to completion (as "Nano-scale structured HTS Superconductors", "Intermediate Superconductors for Applications: MgB2", "SMES Applications", and "Superconducting Fault Current Limiters") and other four volumes have been officially approved and launched. This is important for communicating superconducting based activities to the broader scientific community.

A different measure of the IA's contribution is afforded by invitations received during the past term from other organisations whose interests touch the power sector and superconductivity. They are detailed below:

- The International Superconductivity Summit invited members of the IA ExCo to serve as reviewers during its awards competition for the "young generation of HTS researcher" event.

- Keynote presentation and plenary presentations at the Applied Superconductivity Conference 2014 (United States).

- The IEEE Council of Superconductivity (CSC) Europe Committee and the ESAS (European Society for Applied Superconductivity) invited the IA to become involved in the recently begun "European Superconductivity News Forum."

- CIGRE's WG D1.38 has involved several members of the IA's ExCo and its OA in WG15's efforts to summarise and disseminate information about HTS.

6. Contribution to Technology Deployment/Market Facilitation

During the past term, pre-commercial but nearly full-scale HTS cables have been demonstrated in many parts of the world. Also, pre-commercial but full-scale HTS motors have been built and tested. Similarly, Fault Current Limiters were built and field tested. In short, HTS technology has progressed to the development and demonstration phase; it is not yet ready for full-scale market deployment.

Now, dialogue and partnership between the private sector and the public sector are crucial to future deployment of HTS-based technology in the power sector. The HTS IA involves both. From the thought leadership of IA members, several project successes were realized across the world during the 2010–2016 term:

- The world's first direct current HTS cable was energized in a real grid in Jeju Korea.
- A HTS cable successfully completed a one-year test in Tokyo, Japan's grid.
- The world's first limiting of a grid three-phase short circuit by a HTS fault current limiter was demonstrated in Milan, Italy.
- A HTS cable and FCL proved to be a cost effective solution compared to the conventional technology in Essen, Germany.
- The world's longest HTS cable was planned in Chicago, Illinois, which will enable a resilient grid.

However, more work remains to get HTS based devices to penetrate the market. To date, virtually all projects have been demonstration projects using government funding assistance. One of the major challenges for HTS devices integration in the grid is that electric utilities are very conservative in their choice of grid technologies. They typically require low cost, highly reliable equipment that has a proven track record serving customers. Other challenges are related to the technology itself such as cost of HTS wire and cryogenic systems and reliability and maintenance of cryogenic systems.

During this term, half of the Contracting Parties have come from industry. They include both utilities and equipment suppliers, as shown below:

Utilities and their R&D divisions

- IREQ of Hydro-Quebec (Canada)
- The Korean Electric Power Research Institute of KEPCO (Republic of Korea)
- RSE Spa (Italy)

Equipment suppliers

- Siemens (Germany)

HTS conductor manufacturer (Sponsors)

- Bruker HTS GmbH
- Columbus Superconductor

During the past term, the HTS IA's interactions with industry included two-way information exchange, peer-review and the sharing of perspectives. There have been a number of experts, besides ExCo members, who graciously gave their attention and expertise to the IA during the past term.

7. Policy Relevance

There are two primary mechanisms or channels by which the HTS IA has made its results known to policy makers. The first is by providing unbiased technical expertise and interacting with policy makers in member countries. The second is by contributing to documents in the public domain, such as articles, briefs, newsletters, and other publications, and by amassing data and making some available in publications and via the website.

The first approach is direct and consequential, as suggested by the following connections:

- Government officials from Japan and the U.S. participate in the ExCo.
- One of the German delegates advises the responsible persons in its government.
- The Italian representative is supporting the Ministry of Economic Development.
- Korea is represented by its electric power company, which has a vigorous HTS RD&D program that is among the world's leaders.

The IA's ExCo, OA, and others have actively followed the second approach, as well.
For instance in 2014 and 2015, the New Energy and Industrial Technology Development Organization (NEDO) (and Japanese IEA members) held Japanese domestic committee meetings with companies, universities and national research instituted to inform them of IEA activity for activating HTS industrialization progress.)

On its own initiative, the HTS IA prepared a briefing 2 page document, *High-Temperature Superconductors: Meeting Global Electricity Demands*,[2] for its members' use and was distributed to both government officials and the private sector by members of the ExCo in accordance with their national circumstances. The document draws attention to the following central facts:

- Electricity now enables many services, including: communication, record keeping, computation, accounting, and information retrieval, as well as recreation. In particular, the internet, mobile phones, and personal computers would not be everywhere desired without affordable and reliable electricity.
- Improved electrical equipment is desired to reduce the environmental impact of new demand.
- HTS can enable more powerful compact off shore wind turbines; fault current limiters; cleaner, safer, more compact transformers; and much smaller, higher-power cables to bring power into densely populated areas.

Additionally, a document entitled Empowering Variable Renewables, Options for Flexible Electricity Systems was posted on the IA's web site.

Throughout the past term, the HTS IA routinely made all of its documents available to its Desk Officers for their reference and use. Moreover, the OA had regular interactions with David Elzinga (IA's Desk Officer), Carrie Pottinger (Programme Manager Technology R&D Networks), and Hugo Chandler (Renewable Energy Division).

[2] http://superconductivityiea.rse-web.it/document/fact_sheet_Electric_Power_HTS_IEA_11-08-12_8.5x11.pdf

8. Contribution to Environmental Protection

During the past term, the HTS IA repeatedly documented little-emphasized environmental benefits from the future deployment of HTS power equipment. These benefits would occur both in generation and in transmission and distribution.

With respect to generation, the salient benefit is to make off shore wind turbines more economic and thus reduce the cost of the most widely available variable renewable. Today's materials and designs limit wind turbines to roughly 6 MW; more power would entail too much weight on the supporting tower. These towers are particularly expensive to construct and maintain when located off-shore. In general, off-shore locations can offer the most wind power. Because HTS promises to enable much smaller and lighter electrical generators, it also promises to lower the cost of off shore wind power. Lowering the cost of off shore wind energy will contribute to reducing the world's dependence on fossil fuels and improve the environment.

With respect to energy storage, the IA enabled many of its members to learn about work on superconducting magnetic energy storage (SMES) under way in Japan and the U.S. and work in the U.S. on flywheel energy storage using HTS technologies.

With respect to transmission and distribution, the IA has drawn attention to two benefits of HTS technology: improved environmental footprint and safety.

As HTS high-temperature superconducting cables transport current with essentially no electrical resistance they can transmit up to 10 times more power than conventional copper cables (or can carry equivalent power at much lower voltages). In addition HTS cables and other devices require reduced space in urban environments and they do not produce a magnetic field or heat.

Additionally, superconducting fault current limiters help to improve safety and reliability of power systems while helping to integrate variable and distributed generation sources.

Transformers are also crucial component of the electricity system. The electrical coils of today's transformers are immersed in a large tank of oil for cooling. Unfortunately, the oil sometimes leaks from the tanks, and can result in contaminated groundwater, an environmental hazard. Since the oil is flammable, utilities' implement safety measures to avoid fires. When they do occur, transformer fires can be very violent and endanger people and destroy property. These safety issues can be mitigated by HTS transformers since they use inert liquid nitrogen as a coolant instead of oil.

9. Contribution to Information Dissemination

During the past term, all reports, presentations and any other documents were distributed to each member of the ExCo by email and by posting them on the members section of the website, at the close of each ExCo meeting. The documents can be easily accessed by ExCo members and be downloaded at any time.

As a matter of routine, each ExCo member is responsible for distributing the material within his or her own country.

- In Canada, J. Cave advises others, particularly those at Hydro-Quebec, of progress in HTS and the opportunities for adopting future equipment.
- In Germany, T. Arndt serves as reviewer for and advises Germany's Federal Ministry of Economics and Technology on matters related to superconductivity and electric power, and M. Noe is a liaison to industry and academic stakeholders through his position at KIT.
- In Israel, G. Deutscher and/or his alternate report directly to Israel's Chief Scientist who is located in Israel's Ministry of National Infrastructure.
- In Italy, L. Martini distributes this IA's findings to the Members of the Italian power sector and the HTS research community. Moreover, Dr. Martini is secretary of the Italian Electrotechnical Committee TC90 "Superconductivity".
- In Japan, S. Kinoshita transfer the IA's information directly to the relevant part of Japan's government, NEDO and H. Ohsaki is a liaison to industry and academic stakeholders through his position at the University of Tokyo.
- In Korea, Sidole Hwang informs organizations in Korea of this IA's activity and he directly informs and advises Korea Electric Power Research Institute.
- In Switzerland, R. Brüniger, maintains a website by which all IA results are made available to the Swiss superconductivity community. Brüniger is the Swiss government's contact with IAs and conveys its results to policy makers.
- Finally in the US, D. Haught is the liaison for the US Department of Energy.

Because this is a cost-shared agreement, the default distribution is limited to institutions in member countries. Copies of the detailed comprehensive reports are also sent to experts who have made technical contributions, usually private sector or research institution representatives.

The HTS IA continues to keep its web site (http://superconductivityiea.rse-web.it) complete and up-to-date. An important feature of the web site is its comprehensive collection of links by which the user can access all of the principal institutions involved in HTS power technologies. Another feature of the web site is that it highlights a significant accomplishment with a link to access additional information.

10. Outreach to IEA Non-Member Countries

Since inception, the HTS IA has reached out to countries that are not members of IEA (non-member countries). During the past term, the HTS IA has vigorously and effectively reached out to non-member countries. One example includes Russia's Federal Agency of Science and Innovation. The HTS IA's experience is that much effort was required to surmount the institutional impediments to joining an IEA Implementing Agreement.

Institutions in several non-member countries have been willing and valuable, albeit unofficial, contributors to the IA. For instance, China and Russia have cooperated with the IA. These groups provide information, peer reviews and alerts to their national plans. Naturally, the ExCo would prefer that these countries join and support the agreement, but various institutional and financial impediments remain to be surmounted.

11. Added Value

The mission of HTS IA is to evaluate the status and assess the prospects for future use of HTS by the electric power sector around the world and communicate the results to R&D managers and the decision makers who influence budgets and policies. By having institutions in many nations proceed jointly and collaborate toward common goals, duplication may be avoided and substantial funds can be saved. For those situations in which a nation desires its own internal assessment, the IA's work provides an independent check on local considerations, in the same way as the IEA Secretariat's *World Energy Outlook* provides an independent check on projections, if any, offered by national organisations.

The HTS IA focuses on the significance of what is transpiring in industry and the challenges that remain for more widespread deployment of HTS in the electric power sector. No other group is dedicated to this IA's goal. Other venues concern themselves either with technical accomplishments within a sub-specialty or with promoting the sales of HTS equipment. While both of these activities are important, they do not satisfy the desire for R&D managers in government and the private sector to comprehend the big picture for HTS technologies in the electric sector. Indeed, if any single entity were to try to assess the world-wide HTS situation, the cost would be many times the cost of this IA and the assessment would have to involve the members of the ExCo.

The unique nature of the HTS IA is made possible by the member nations' various representatives. These representatives include ministries (Japan's NEDO and the U.S. Department of Energy), multidisciplinary research centres and universities (Finland's Tech University of Tampere, Germany's KIT, Israel's Tel Aviv Univ., Japan's Yokohama National University and Switzerland's University of Geneva), equipment suppliers (Germany's Siemens) and the research arms of electric utilities (Canada's Hydro-Quebec, Italy's RSE, and Korea's KEPRI). Each is nationally recognised within its own country, and each brings a perspective to energy technology development that enriches the others.