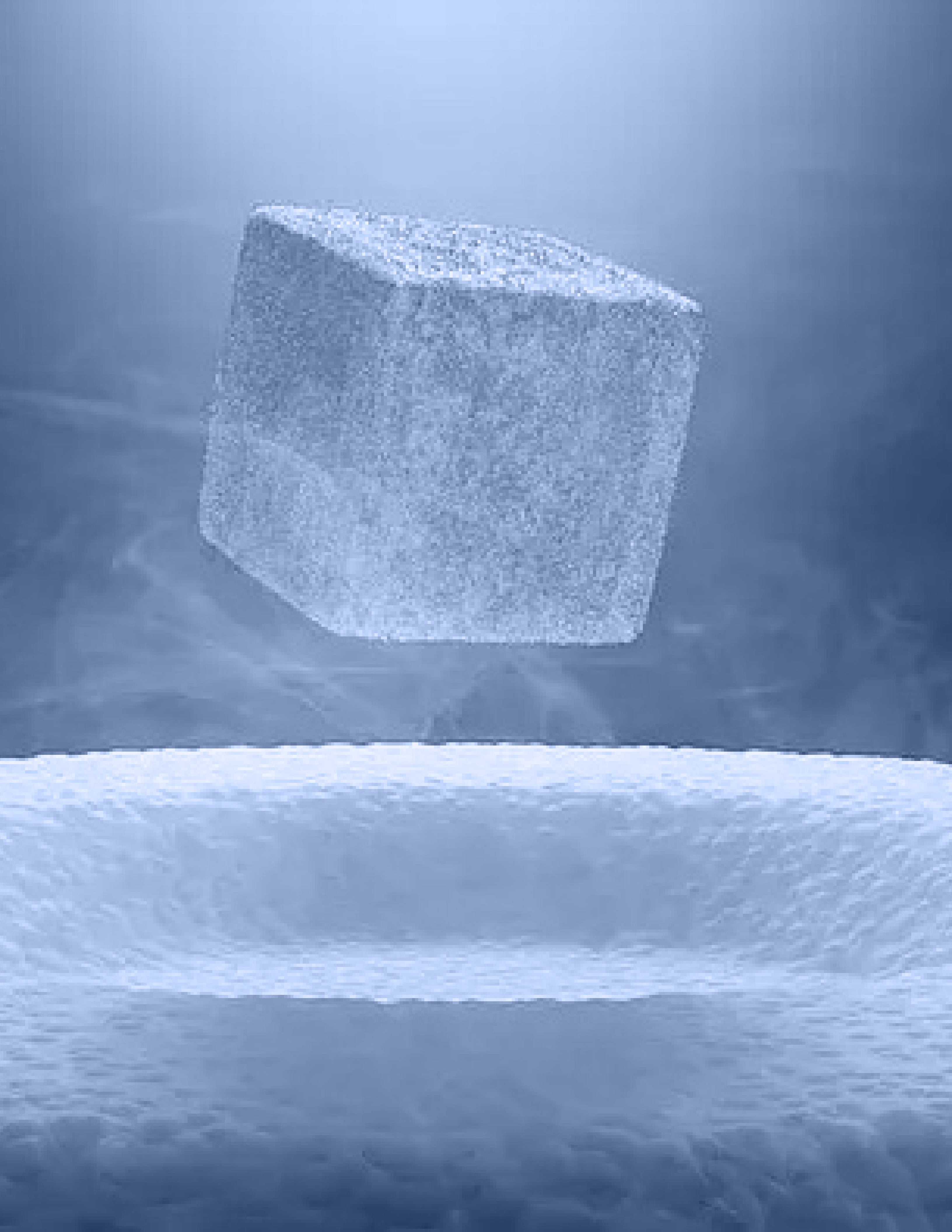
Superconductivity
INTERNATIONAL ENERGY AGENCY

ANNUAL REPORT 2022

IEA Technology Collaboration Programme on High-Temperature Superconductivity



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Message from the Chair

The International Energy Agency's Technology Collaboration Programme on High-Temperature Superconductivity (IEA HTS TCP) has settled into a positive cadence of meetings and activities in the post-COVID era. Our hybrid work environment has allowed more efficient and beneficial collaboration among our members and leadership. I am very pleased with several activities that we undertook this year to help disseminate information about HTS.

I am honored to serve as the Chair and appreciate the contributions of our vice chair, Laura Serri, and other members of our Presidium, including Giuliano Angeli and our task managers from Energetics. In addition to the TCP's leadership, I am also very honored to have broad expertise and support from our national experts. Without them, the TCP would not be as successful as it is now.

The TCP accomplished several important projects this year. At the biennial Applied Superconductivity Conference (ASC) 2022, which is the largest HTS conference in the world, the TCP gave an oral presentation on the findings of our recently published *HTS Readiness Map for Energy Delivery Systems* report. This allowed many HTS stakeholders to learn more about our TCP and the activities we have underway. The TCP also completed a study on the capacity of high-temperature superconducting wire to become a market-disruptive technology. This paper describes how manufacturing scale-up for HTS wire used in magnetic coils of fusion reactors can have benefits that apply to other applications. The premise is that high volume production of HTS wire will result in reduced cost, which can make it more economical for projects.

I am also pleased that the TCP started to lay the groundwork for two new projects, which are planned for completion in 2023. These include a report on *HTS Applications for Electric Grid Resilience*, which details how HTS applications can help improve the resilience of electric delivery systems worldwide. Another report is a new *HTS Readiness Map for Industrial Applications*. This report will highlight how HTS is emerging as a potential opportunity to improve the efficiency of manufacturing processes and other industrial uses. This paper will require significant contributions from experts outside of the TCP's membership, which could help the TCP establish many new relationships with new stakeholders.

One of the challenges for our TCP is adding new country representatives. This issue is something that the TCP discusses at our ExCo meetings and will continue to do so in the future. In 2022, the TCP did add a new sponsor, Nexans, which is a global company in the cable and optical fiber industry headquartered in Paris, France.

We look forward to additional technical and market advancements and leveraging the broad expertise of the TCP into the coming year.

HTS TCP Interim Chair

Hiroyuki Ohsaki

Introduction to Applied Research

The energy transition to renewable energy sources is expected to have a significant impact on the global economy, politics, and environment. It will require changes in the way energy is produced, distributed, and consumed, as well as changes in the infrastructure, regulations, and policies that support the energy system. The energy transition is a complex and multifaceted process that involves multiple stakeholders, including governments, businesses, investors, consumers, and communities. It requires a coordinated effort and a long-term vision to ensure a smooth and sustainable transition to a low-carbon energy system that meets the needs of all.

Superconductivity, and high-temperature superconductivity in particular, is one of those technologies that can be part of the energy transition. Superconductivity is a phenomenon that causes certain materials, at low temperatures, to lose essentially all resistance to the flow of electricity. The lack of resistance enables a range of innovative technology applications. The temperature at which resistance ceases is referred to as the "transition temperature", or critical temperature (Tc). Tc is usually measured in Kelvin (K)—0 K being absolute zero. HTS gets its name originally because it has a higher transition temperature (77 K, which can be achieved when using liquid nitrogen) than low temperature superconductivity (LTS) (around 4.2 K, which can be achieved using liquid helium). Several examples of well-recognized types of superconducting wire include:

- BSCCO, known as first generation (1G) HTS wire (Bismuth - Strontium - Calcium - Copper – Oxide)
- REBCO, known as second generation (2G) HTS wire (REBCO stands for "Rare earth - Barium - Copper Oxide" for the superconducting compound; REBCO is also referred to as YBCO since Yttrium (Y) is the element most often used in 2G wire)
- MgB2 (Magnesium diboride)
- Nb3Sn (Niobium-Tin) and Nb-Ti (Niobium-Titanium) alloys

Another critical component of a superconductive device is the cryogenic (refrigeration) system for achieving operating temperatures. Low temperature superconductors operate at the "low" liquid helium temperature of (4 K or -296°C). High temperature superconducting (HTS) materials operate at the "high" temperature of liquid nitrogen (77 K or -196°C). Because liquid nitrogen (LN) is relatively ubiquitous and cheaper than liquid helium, HTS technologies offer greater potential to develop cost-effective solutions for the electric power sector.

Since the discovery of HTS in 1986, research and development have brought new equipment enabled by high-temperature superconductivity to the threshold of electricity transmission and distribution applications. Superconductor-based devices provide improvements over conventional electric grid technologies, but they also offer unique alternatives to system challenges that cannot be addressed otherwise. Laboratory-scale tests have transitioned to large-scale HTS based projects that serve utility customers. HTS projects are now part of permanent infrastructure installations to solve real-world electric grid problems.

Applications of superconductivity have been available in certain niche markets for decades. Superconducting magnets in particular are well-established 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.

The Benefit of High-Temperature Superconductivity

The primary focus of the International Energy Agency's Technology Collaborative Program on High-Temperature Superconductivity (HTS TCP) is electric transmission and distribution systems, but it also monitors advancements made in the areas of energy storage, wind energy, all electric aircraft and motors, and fusion technology.

- **Electric Transmission and Distribution Systems** – Load growth in urban and suburban regions requires utility companies to make long-range plans for increasing the capacity of the AC circuits that serve that load. It is well known that HTS cables can carry much larger levels of power than conventional cables for the same underground cross-section and right-of-way (ROW). Alternatively, an HTS cable can provide the same level power, but at a much lower voltage. In some cases, both features may be realized in a single project. In addition, many of the world's utilities are coping with increasing fault (short-circuit) currents, possibly requiring new substation circuit breakers. An HTS fault current limiter (FCL) can help manage increasing fault currents more cost- effectively and reduce losses by at least 50% in solid-state FCLs and at least 90% in fault-current-limiting reactors.
- **Energy Storage** – Energy storage can increase the penetration of renewable resources and improve power quality. Superconducting Magnetic Energy Storage (SMES) has several advantages over other storage technologies, including rapid response times, nearly infinite charge/discharge cycles without degradation, and very high round trip efficiency.
- **Wind Energy** – HTS-based wind turbines have the potential to generate the same amount of power with roughly half the size and weight of conventional designs, needing less rare earth metals and making installation easier.
- **Motors** – Electric motors account for almost two-thirds of all electric energy consumption in the United States and other developed countries. Superconducting motors have the potential to reduce losses by 50% and can be less than half the size and weight of conventional designs, which can improve the propulsion and maneuverability of transportation vehicles.
- **All-Electric Aircraft** – The use of lightweight HTS could lead to ecofriendly, 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.

- **Fusion** – HTS-based fusion energy significantly improve magnetic fields so they are considerably smaller than conventional, low temperature superconducting magnets. These advancements could lower costs, empower smaller organizations, and create faster schedules compared to larger tokomaks.

Remaining Challenges

Over the past few decades, significant efforts have been made worldwide on the research, development, and field demonstration of applied HTS devices in the power sector. As a result of these activities, several HTS-based devices, specifically HTS cables and FCLs, are being energized in utility grids as permanent solutions to electricity delivery challenges. However, other applications are still lagging in deployment into commercial installations. The transition of HTS applications to widespread market maturity faces several general challenges.

Improved 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. Furthermore, if raw material cost of conventional materials increase it could provide advantages for HTS based solutions.

Other HTS applications are a means to reduce costs by increasing manufacturing volume. Some studies of wire cost versus production volume suggest that the 20,000 km requirement for a commercial fusion reactor could yield wire prices that would make HTS transmission cables economically viable. This may be a "chicken and egg" situation, with fusion needing a viable transmission cable market and vice-versa, with neither ultimately happening. Other niche markets like rotating machines, mobility applications, and FCLs could expand HTS.

Improved 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.

Proven 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 component lifetime over 30 to 40 years.

Reduced Business Risk

Uncertainty for total cost of ownership and cost and availability of parts from suppliers in a relatively nascent market.

Factory Testing

Underground conventional cable is shipped from the manufacturing plant on large reels. The capacity of a shipping reel is limited to between 0.5 and 1 km, typically, depending on cable design and transportation methods. Factory acceptance testing for voltage integrity of solid electrical insulation is necessary for 100% of all reels shipped to the project site. Otherwise, a reel with potential insulation defects may produce failure in the field when first energized. Location of the failed section, removal, reinstallation, and recommissioning is a costly and time-consuming process.

Projects involving more than a few reels of untested cable have a statistically high probability of encountering a faulty reel due to the inherent variability in any manufacturing process. Acceptance testing is therefore a standardized step in the manufacture of conventional cable. On one hand, at present, there is no means to do the same for an HTS cable because the insulation of present day HTS cables requires wetting paper tapes with a liquid cryogen. Factory testing would require immersing an entire shipping reel in the liquid cryogen – a clear impracticality. On the other hand, the HTS cable electrical insulation is the combination of lapped material, for instance polypropylene laminated paper (PPLP), and liquid nitrogen. Impregnation with liquid nitrogen will be performed on site after cable installation. The likelihood of an insulation defect is lower than in the case of a conventional cable with a solid dielectric insulation.

Cryogenic and Vacuum Systems

There is a need for optimized and field-proven cryogenic systems for HTS cable installations that are essentially “invisible” to the end-user. Cryogenic refrigeration is a well-established industry for many applications, but in medium-sized systems, in the range of few dozen kW@70K of cold power, there are not available systems designed specifically for HTS cables. Whereas for larger size systems, in the range of several 100 kW@70 K of cold power, cryocoolers for LNG industry (reliquefication of methane onboard) are perfectly suitable. Economic studies suggest that the efficiencies of commercially available refrigerators are inadequate for medium-size utility applications.

Available refrigerator sizes also are not optimal. Space limitations within the substation for refrigeration equipment, particularly in the dense urban locations most attractive for this application, may require innovative approaches, yet to be determined if not compensated by space savings thanks to the compactness of HTS cable systems compared to conventional technologies (less transformers, less terminations). These situations can lead to uncertainties regarding system design and performance below a certain size. Operational characteristics and maintenance procedures are progressing towards unmanned systems with remote controlled systems and maintenance periodicity of 2 to 5 years.

Additionally, there is little or no precedent for mechanical equipment installed inside utility substations besides chilling units for power electronics, nor for the presence of non-utility maintenance personnel that would be required to place the cooling station in areas where no electrical habilitation is required (possible thanks to cryogenic transfer lines). Electric utilities are generally very conservative and risk-averse, preferring equipment that is well-proven for the application and operations that are entirely under their control. Thus, achieving a higher TRL requires cryogenic systems that have been optimized and fully tested, such as cryocoolers for the LNG industry. Operation and maintenance practices that are consistent with current electric utility industry standards are also needed. Significant progress has been made in that direction through the publication in 2019 of IEC standards for AC superconducting cable from 6 to 500kV.

Cable Splices

Cable splices between installed sections are a necessary fact for all underground cable systems. Cable splices are by far the weakest link in the cable system and are prone to failure if not properly constructed. Splicing must occur in the field, whether in permanent underground vaults or in temporary field facilities for later direct burial. Splicing is as much an art as it is a science. It requires clean conditions and a high degree of training. HTS cable splices have greater complexity which requires a longer repair time in case of failure. Indeed, splicing HTS cables involves integrating the vacuum cryostat in the splice joint. Several HTS cable systems in existence have demonstrated the feasibility of cable splices at both medium and high voltage. The methods for achieving highly reliable splices in the field can take advantage of increasing the part of prefabricated components and reducing the on-site assembly.

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 and use of HTS technology in view of common interests. Particularly, the HTS TCP:

Bending parts of tri-axial superconducting cable, *Courtesy NEDO*

- Collaborates with electric utilities, governments, professional engineering organization 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 Executive Committee (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, which helps ensure consistency in reporting and evaluating progress across various scientific and engineering 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 2022 Activities

Activities

While the pandemic changed the format of the TCPs ExCo meetings, it did not change the frequency. Two Executive Committee meetings were held:

- ExCo meeting (via webinar) was held in June 2022
- ExCo meeting (via webinar) was held in December 2022

The 2021-2026 work plan focuses on two main areas: analysis of cross-cutting issues and communications and outreach with increased industry and government collaboration. The HTS Technology Collaborative Program (TCP) works to identify and assess the potential applications and benefits of superconductivity, as well as what technical, economic, and regulatory barriers must be overcome to achieve them. In the 2021-2026 period, the HTS TCP is focusing on activities that could accelerate the market adoption of superconducting applications. The rationale for this is that the technology readiness level of several HTS applications have reached a point where it is technically capable to be included in electric system operation, for instance.

The HTS TCP's activities in 2022 demonstrated to key stakeholders that existing HTS technologies are technically and economically viable in several electric power and other related application areas. To achieve this, the HTS TCP works with its contracting parties to develop technical communications documents that provide information for a range of stakeholders and share critical updates with the wider industry at technical conferences.

Oral Presentation and Industry Status Research Conducted at the 2022 Applied Superconductivity Conference (October 2022)

At the biennial Applied Superconductivity Conference (ASC) 2022, the first in-person gathering of the largest HTS conference in the world since the COVID-19 pandemic began, the TCP gave an oral presentation to about 75 attendees on the findings of the HTS Readiness Map for Energy Delivery Systems report, first published in 2021 and summarized in a manuscript for the ASC 2022 Special Issue of the IEEE Transactions on Applied Superconductivity, the conference proceedings of the 2022 Applied Superconductivity Conference.

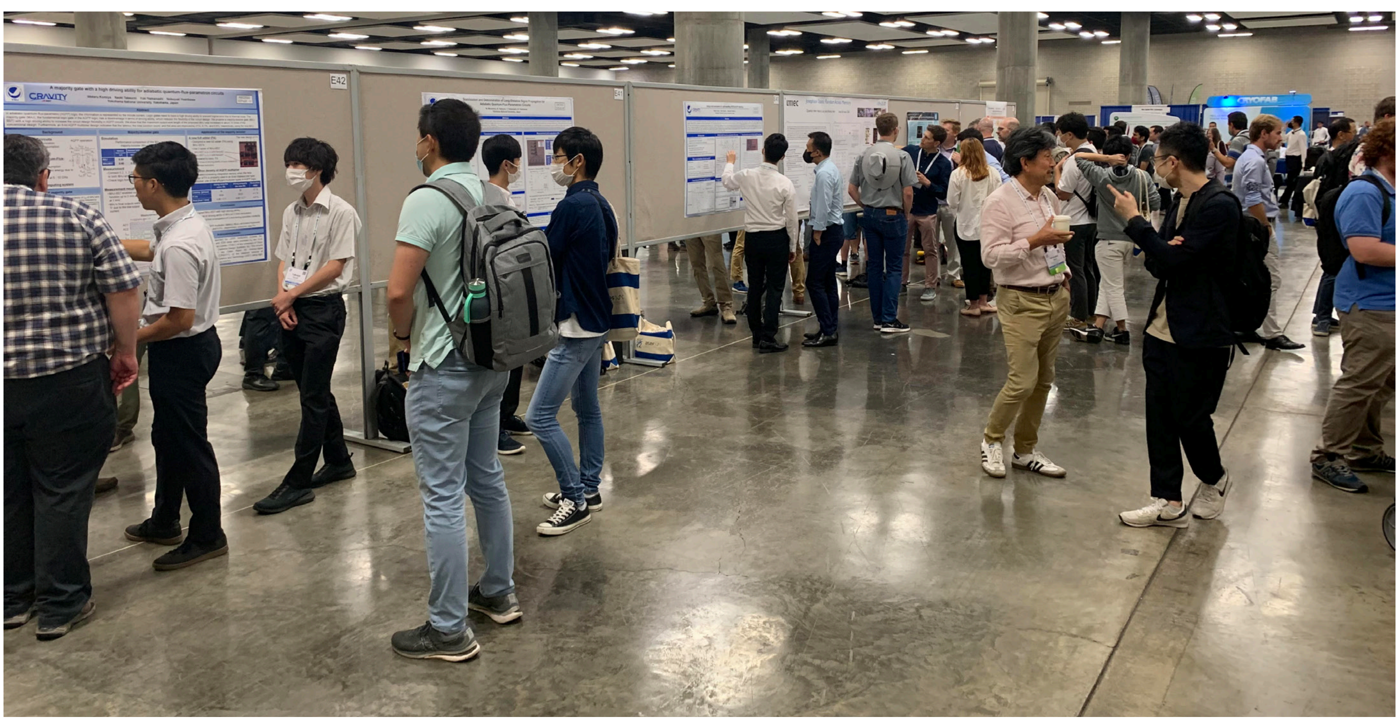
The TCP collaborated with outside experts to define and analyze the Technology Readiness Levels (TRL) of various energy delivery applications for HTS. These TRL levels reflect the present degree of technological development for the main transmission, substation, and distribution HTS applications in the energy delivery sector. The report, HTS Readiness Map for Energy Delivery Systems, also estimates the pathway and timeline from these TRL levels to reach commercialization (if commercialization has not yet been achieved). This awareness is essential for the electric power system that supplies our residential, commercial, and industrial sectors, which is transitioning rapidly into a safer, more efficient, and cleaner power supply where the capability of HTS-enabled solutions could significantly ease the transmission challenges of the rapidly rising demand for electric power.

In the presentation, the TCP used an interactive tool to poll the audience on how long they suspect it will take for the fusion industry's demand for HTS wire to lower manufacturing costs, which are critical to the HTS industry's growth. This format made the session more interactive and kept the audience engaged and candid.

TCP members also collected information on HTS developments around the world for many application areas, learning that all-electric and hydrogen-powered aircraft, fusion, and quantum computing applications have grown significantly, while sessions on superconducting materials and HTS power systems were fewer than in years past.

Publication of Report: HTS Wire Enabling Market Disruption paper (February 2023)

The TCP completed a study on the capacity of high temperature superconducting wire to emerge as a market-disruptive technology – one that enables entirely new market developments in various economic sectors. The paper discusses how 2G HTS (REBCO) wire has been gamechanger for magnetic fusion, where tokamaks have been able to significantly improve their magnetic fields with HTS magnets that are considerably smaller than conventional, low temperature superconducting magnets. These advancements could lower costs, empower smaller organizations, and create faster schedules compared to larger tokamaks like International Thermonuclear Experimental Reactor (ITER). Analysis conducted by the TCP concluded that a tokamak with HTS magnets is conservatively estimated to be one-sixteenth the size of one using LTS.



Project Updates

Around the world, projects are demonstrating the technical feasibility of electric power equipment incorporating HTS tapes. The text below highlights several project examples from IEA HTS TCP Member Countries.

ITALY

National "Ricerca di Sistema" (RdS) Projects

At the beginning of 2022, a new three-year project (*Project 2.2 – Evolution, planning, programming and operation of electricity networks*) started. The goal of first task is the investigation of insulated/non-insulated superconducting winding based on 2G tapes in AC and DC. In the superconductivity lab of Ricerca sul Sistema Energetico – RSE S.p.A. (Milano), a new support for layer-wound HTS coils was designed, realized and tested in few pieces in collaboration with University of Bologna.

In the second task, still run in collaboration with University of Bologna, a dedicated software called OSCaR (*Optimization tool for Superconducting Cable Research*) was developed. OSCaR aimed at multiple cost indexes and cable design parameters and an application of this code is concerned with DC MgB_2 cables.

"National Plan for Recovery and Resiliency" (PNRR) Projects

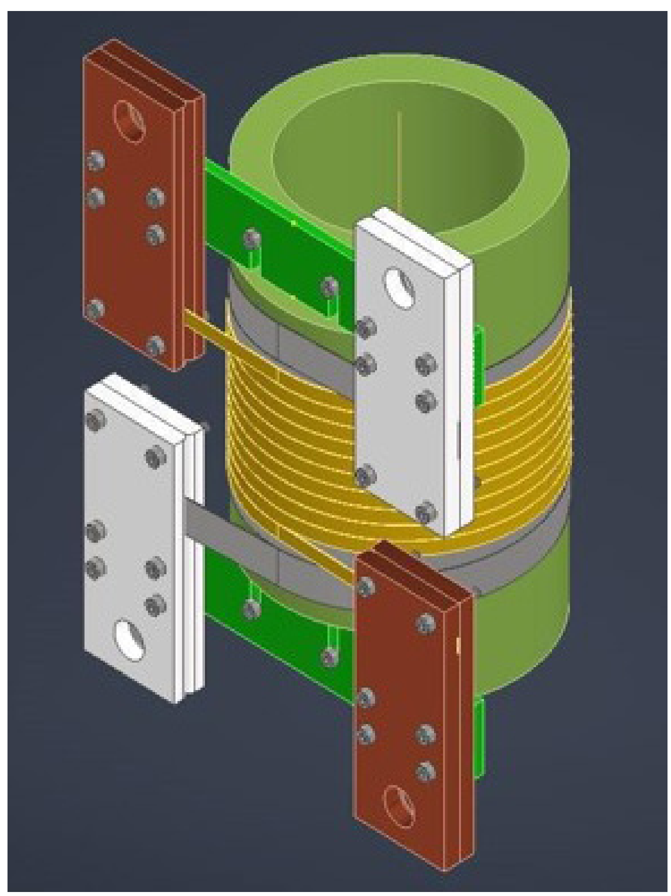
In the frame of NextGenerationEU a number of PNRR projects (2022-2025) were launched in Italy.

In the project "Technologies for the production, distribution and final use of hydrogen" (*PNRR H2*) one innovative task is focused on the simulation and techno-economic analysis of systems based on the HTS cables cooled by liquid hydrogen for the combined transport of hydrogen and electricity.

The Project "Innovative Research Infrastructure on applied Superconductivity (*IRIS*) uses different applications of superconductivity with a total budget of 60 M€ and it is coordinated by INFN (*Italian National Institute for Nuclear Physics*). Most of the funding is dedicated at developing an innovative distributed research infrastructure including six different poles from North to South Italy. In addition, two demonstrators are foreseen: one energy saving HTS magnet for sustainable accelerators and 1 GW green MgB2 superconducting line.

European Project Scarlet

The European Project Scarlet (www.scarlet-project.eu - 2022-2027) is coordinated by SINTEF (Norway). The main goal is developing and manufacturing superconducting DC cable systems at the gigawatt level (nitrogen, helium and hydrogen cooled), bringing them to the last qualification step before commercialization in the vision of connecting distributed renewables. Italy plays a significant role in the consortium including three partners: RINA, RSE, University of Bologna.



FRANCE

The Super Rail project will install two superconducting DC cables near Montparnasse station in Paris. This is the first time that cables of this type will be integrated into a rail network and is set to be the first permanent installation in France on any network. These power cables will help secure the network at a time when rail traffic is constantly growing in mega-cities. Nexans and its partners won the project from Bpifrance (French Public Investment Bank) under the “Investissements d’Avenir” (Investments for the Future) initiative coordinated by SNCF Réseau. Partners of the project include SWM, NKT, Linde, THEVA, University of Applied Sciences South Westphalia, and KIT.

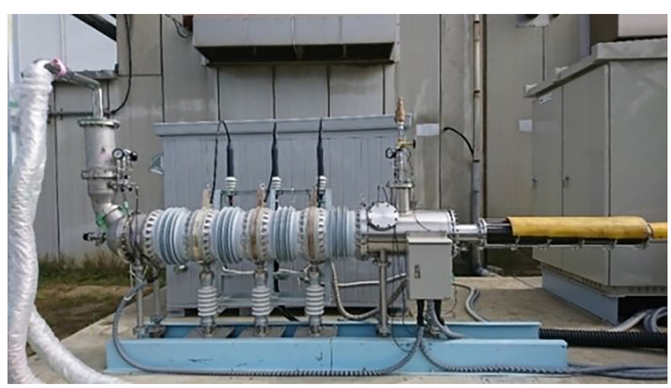
GERMANY

The SuperLink project is a superconducting power cable that is planned for installation in the center of Munich, Germany. The 12 km underground power link is expected to be the longest superconducting power cable solution in the world. The SuperLink design has a power rating of 500 MW and a voltage level of 110 kV, which is slated for installation between two substations those are the main Menzing substation in the west of the city and the load center MunichSouth using existing ducts to keep the construction work at a minimum.

JAPAN

The New Energy and Industrial Technology Development Organization (NEDO), SWCC Showa Cable Systems Co., Ltd. (SWCC), and BASF Japan Ltd. (BASF) have completed the world’s first demonstration test of a tri-axial superconducting cable system installed in a commercial chemical plant. The project was completed at BASF Japan’s Totsuka site (Totsuka Ward, Yokohama City) from November 2020to September 2021. The testing proved the system is capable of supplying power reliably for about one year.

A condition of this test was that it was necessary to use Terminal of tri-axial superconducting cable, Courtesy NEDO the plant’s existing facilities, so the cable was installed on an existing rack, which is located about 5 meters above the ground. Therefore, it was necessary to bend the cable 90 degrees (bending radius 1.5 meters) at four locations. The cable’s flexibility allowed it to be installed without any problems. Although the flow path of liquid nitrogen becomes narrower at bends with a compact cable, it can flow over long distances (approximately 400 meters round trip) in the system without any problems, confirming that it can be used for complex plant layouts.



Terminal of tri-axial superconducting cable, *Courtesy NEDO*

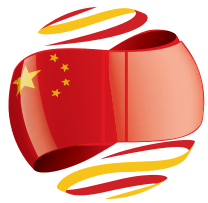
KOREA

The KEPCO sponsored Shingal Heungdeok triple-core HTS power cable project was energized in July 2019 and has been operating as expected. The success of this project has spawned an additional project. The MunSan Project is planned to have two HTScables that are each 1km long and operational at 23kV, 60MVA. This triaxial power cable will connect the Munsan and Seonyu substations. One of the benefits of using the HTS cable is that it uses a small23kV switching station instead of a larger 154kV substation, which is important for the urban area where the project is planned. The cable is planned to be energized in 2025.

UNITED STATES

Since August 2021, the Resilient Electric Grid (REG) system has been a permanent asset of the Chicago Illinois's electric grid designed to improve reliability and resiliency while reducing disruption to public infrastructure. The REG system enables 200 times more power than that of normal copper wire – to be transferred from one point to another without electrical resistance loss. At the same time, the wire is uniquely able to self-heal and protect the system against dramatic changes in current flow, a protection not possible with conventional technologies. The partners are AMSC and the Commonwealth Edison Company (ComEd).

ComEd has contemplated a project to extend the Chicago REG project to connect additional, existing substations in Chicago's central business district. If pursued, the second project would be larger in scope than the first and provide greater reliability, resiliency and load-serving capabilities during outages or other grid disruptions.



CHINA

While not a member of the HTS TCP, China has several projects that are being monitored. Shanghai Electric Cable Research Institute energized a 35kV 2.2kA HTS cable project in Shanghai. It is a 3 in 1 type cable that is 1.2km long. The cable used approximately 170 km of REBCO wire with cooper lamination with an average piece length of 150m. The project was energized in 2021 and connects two 220 kV transformer stations in the commercial business district. The project partners include Shanghai Superconducting Technology Co., Ltd, Shanghai Electric Cable Research Institute and the State Grid Corporation of China.

A 500-meter tri-axial cable for the Shenzhen Ping An Financial Center was developed and energized with 110 km of tape with an average piece length of 150m. The manufacturing of the HTS wire was completed in 3 months. The project partners are Guangdong Electric Power Design, Bejing Jiaotong University, Zhongtian Technology Group, Shenzhen Power Supply Bereau, and CSIC Pride Cryogenic Technology Co. Ltd

Working Arrangement

In 2022, one Task Manager based in the United States supported the HTS TCP. Task managers 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 have historically covered 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. This will continue when the ExCo starts holding in person meetings again.

The ExCo Chairman, vice-chairman, and task managers 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 ExCo and the annual work plan, including the task manager'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 changed in 2022. The TCP added a new sponsor, Nexans, which is a global company in the cable and optical fiber industry headquartered in Paris, France. ASG Superconductors also renewed its TCP sponsorship. The TCP maintains six active Contracting Parties and two sponsors. Maintaining these parties and expanding membership is paramount to the success of the TCP. The TCP plans to pursue new member countries in 2023 as HTS activity expands around the world.

The TCP has a strong policy relevance within each of its member countries. It provides unbiased technical expertise to policy makers and contributes to documents in the public domain by gathering data for publication. For instance, the HTS TCP maintains this relevance through various channels such as:

- Government officials from Japan and 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

Alignment with IEA Mission

The HTS TCP's strategy is aligned with key components of the IEA mission. These include energy efficiency, energy security, system integration of renewables and engaging stakeholders around the world.

- Energy Efficiency – Contributes to several applications with improved efficiency over conventional systems in electricity grids, industry, and transportation. Examples include components for AC and DC grids such as cables, transformers, energy storage systems, busbars, but also induction heaters and in future transportation applications for all-electric aircraft, high-speed train, and electric ships.
- Energy Security – Supports energy security focusing on HTS-based technologies

- primarily fault current limiters and superconducting magnetic energy storage systems (SMES), that can help to enhance grid reliability and resilience.

- System Integration of Renewables – Provides research, analysis and information related to the use of HTS components - such as high-capacity power cables, fault current limiters, high-efficiency generators for offshore wind turbines, energy storage, and innovative transformers–able to facilitate increased renewable generation integration in electric grids.
- Engagement Worldwide – Actively engages groups of stakeholders, such as electric utilities, governments, the professional engineering community and the RD&D community, worldwide.
- Connects with other IEA TCPs such as the International Smart Grid Action Network and Wind TCP.

Future Activities

Several activities that are planned for 2023 include:

- The TCP is planning to hold a joint meeting with the IEA Wind TCP to explore the viability of applying HTS technologies in wind turbines in 2023, such as superconducting motors that could boost performance. The TCPs plan to explore ways to partner and learn from one another in this meeting.
- The TCP will hold a virtual Spring Executive Committee meeting in April. The current plans are to invite a guest speaker from an emerging HTS application area (e.g. industrial sectors, fusion) from the industry or one of the TCPs with which the IEA HTS TCP is coordinating.
- Several TCP members are planning Europe's largest superconductivity conference, the 16th European Conference on Applied Superconductivity (EUCAS), and numerous members are planning to attend its proceedings. The TCP is crafting an abstract to present a new paper on the role of HTS in grid resilience at EUCAS, as well.
- The TCP will hold its first in-person Executive Committee meeting since the pandemic began in September 2023 in Geneva, Switzerland. This three-day meeting will include technical presentations on HTS projects from all members countries, a potential site visit to CERN, guest presentations from other TCPs or industries and potential workshops alongside regular TCP business.
- The group is developing a report on *HTS Applications for Electric Grid Resilience*, which details how HTS applications can help improve the resilience of electric delivery systems worldwide. The importance of improving the resilience of energy systems worldwide was evident in a recent EUWP meeting, which inspired the TCP to develop a new publication that will identify existing threats to energy reliability and describe where HTS is a well-suited to mitigate those risks and thereby enhance resilience.

- The TCP is also developing another readiness map, the *HTS Readiness Map for Industrial Applications*. State-of-the-art manufacturing processes and other industrial uses are beginning to emerge as natural opportunities to apply HTS technology. As a result, the TCP is embarking on an ambitious project to identify and analyze these potential applications and create a new technical readiness map to characterize each application area's technological maturity. This paper will require significant contributions from experts outside of the TCP's membership, which could help the TCP establish many new relationships with researchers, companies, and other experts to further support the deployment of HTS technologies beyond its traditional uses. This would boost the manufacture of core enabling technologies like HTS wire and cryogenics.

Contact Information for ExCo Delegates / Alternates, Sponsors, and Task Managers

Country	Nomination	Name and Organization	Contact Info
Executive Committee			
Canada	Delegate	**Dr. Frédéric Sirois** *Polytechnique Montréal*	f.sirois@polymtl.ca
Germany	Delegate	**Prof. Mathias Noe** *Karlsruhe Institute of Technology*	mathias.noe@kit.edu
	Alternate	**Dr. Tabea Arndt** *Karlsruhe Institute of Technology*	tabea.arndt@kit.edu
	Alternate	**Prof. Bernhard Holzapfel** *Karlsruhe Institute of Technology*	bernhard.holzapfel@kit.edu
Italy	Vice Chair	**Laura Serri** *Ricerca sul Sistema Energetico – RSE S.p.A.*	laura.serri@res-web.it
	Delegate	**Angeli Giuliano** *Ricerca sul Sistema Energetico – RSE S.p.A.*	giuliano.angeli@rse-web.it
Japan	Chair (Interim)	**Prof. Hiroyuki Ohsaki** *The University of Tokyo*	ohsaki@k.u-tokyo.ac.jp
	Delegate	**Yurugi Yoshiko** New Energy and Industrial Technology Development Organization (*NEDO)*	Yurugiysk@nedo.go.jp
	Alternate	**Mr. Susumu Kinoshita** New Energy and Industrial Technology Development Organization (*NEDO)*	kinoshitassm@nedo.go.jp
Republic of Korea	Delegate	**Dr. Hyung Suk Yang** *KEPCO*	h.yang@kepco.co.kr
	Alternate	**Jee Je-yull** *KEPCO*	jeyull.lee@kepco.co.kr
Switzerland	Delegate	**Carmine Senatore** *Swiss Federal Office of Energy*	carmine.senatore@unige.ch
	Delegate	**Michael Moser** *Swiss Federal Office of Energy*	michael.moser@bfe.admin.ch
	Alternate	**Roland Brüniger** *Swiss Federal Office of Energy*	roland.brueniger@brueniger.swiss
United States of America	Delegate	**Merrill Smith** *US Department of Energy*	Merrill.smith@hq.doe.gov
Sponsors and Task Managers			
France	Sponsor	**Jean Maxime Saugrain** *Nexans*	Jean_Maxime.Saugrain@nexans.com
Italy	Sponsor	**Christian-Eric Bruzek** *ASG Superconductors*	bruzek.christian-eric@as-g.it
United States of America	Task Manager	**Brian Marchionini** *Energetics*	bmarchionini@energetics.com
United States of America	Deputy Task Manager	**Don Mosteller** *Energetics*	dmosteller@energetics.com

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.

The Technology Collaboration Programme

The Technology Collaboration Programme supports the work of independent, international groups of experts that enable governments and industries from around the world to lead programs and projects on a wide range of energy technologies and related issues. The experts in these collaborations work to advance the research, development, and commercialization of energy technologies. The scope and strategy of each collaboration is in keeping with the IEA Shared Goals of energy security, environmental protection, and economic growth, as well as engagement worldwide.

The breadth of the analytical expertise in the Technology Collaboration Programme is a unique asset to the global transition to a cleaner energy future. These collaborations involve over 6 000 experts worldwide who represent nearly 300 public and private organizations located in 55 countries.

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 several 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 nonmember 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***

International Energy Agency
9 rue de la Fédération
75739 Paris Cedex 15
France