Superconductivity
INTERNATIONAL ENERGY AGENCY

iea Energy Technology Network

ANNUAL REPORT 2017

IEA Technology Collaboration Program on High Temperature Superconductivity

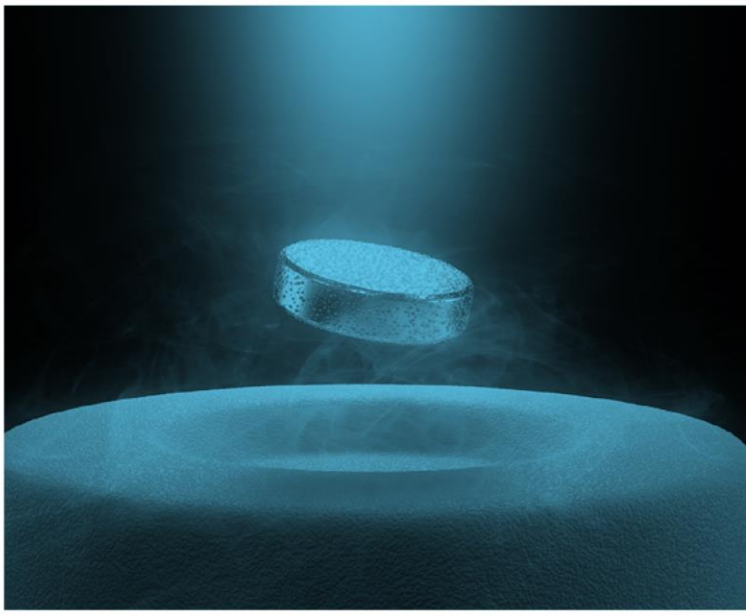


TABLE OF CONTENTS

MESSAGE FROM THE CHAIR

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

The International Energy Agency's Technology Collaborative Program on High Temperature Superconductivity (HTS TCP) is working to identify and evaluate the potential applications and benefits of superconductivity, as well as the technical, economical and regulatory barriers that currently stand in the way. Through its nine contracting parties and one sponsor, the HTS TCP is developing technical communications documents to provide information that will help a range of stakeholders.

The HTS TCP coordinated several information-sharing and stakeholder engagement events, which were successful in developing public and private sector partnerships. Our Executive Committee is looking forward to working with stakeholders to help enable HTS-based devices to be energized on the electric power grid. We are actively engaging new countries to join our TCP and add technical, market and policy experience to our executive committee. We are also looking forward to 2018 when we'll work to show how HTS solutions align with IEA goals.

HTS TCP Chairman

Luciano Martini

INTRODUCTION TO APPLIED RESEARCH ON GRID SOLUTIONS

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

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

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

HTS Benefits

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

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

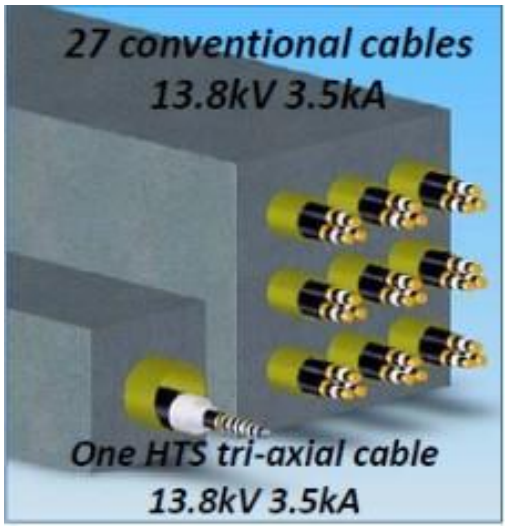
- **Cables –** Because HTS cables transport current with essentially no or very low electrical resistance, they can transmit up to ten times more power than conventional copper ones can at far lower voltages and with much less material. This makes HTS cables ideally suited for installation in cramped urban spaces, especially because that they can be installed underground and do not produce magnetic fields or heat.
- **Fault current limiters –** Many of the world's utilities must cope with increasing fault (short-circuit) currents. HTS tapes offer a unique approach to fault current limiters for both distribution and transmission networks and can work both in AC and DC conditions.
- **Wind energy –** HTS tapes have the potential to enable smaller and lighter wind turbine generators than would be possible with conventional materials by eliminating the need for a gearbox. This could lead to lower-cost electricity.
- **Aircraft –** The use of lightweight HTS could lead to eco-friendly, exceptionally quiet, and highly energy- efficient electric planes. Beneficial application of HTS technology is expected in the fields of power generation, power distribution & forming and propulsion. In addition auxiliary devices might be replaced by electric HTS based solutions.
- **Generators –** Incorporating superconducting tapes into electrical generators and equipment has the potential to increase system efficiency, reliability and safety.

Status

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

HTS applications in the electric power sector are moving from the pre-commercial to commercial stage for electricity, even though HTS technology has not reached complete maturity in all its potential applications. Studies about HTS architecture and production processes, for example, are still in progress. However, important results have already been obtained and, at present, HTS technology would bring great benefits to:

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



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

Challenges Remain

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

- **Process control**. There are still manufacturing problems regarding the optimal architecture and production processes for the specific application. For example, it is still difficult to grow the HTS to achieve higher critical current values, as well as choosing the correct buffer layers, without introducing excessive residual or thermal stresses for long lengths.
- **Long term reliability.** End users are generally unfamiliar with the materials used in HTS devices and cryogenic systems. Data that prove undiminished product-performance of HTS components over 30 to 40 years are not available yet.
- **Business risk.** Uncertainty exists for total cost of ownership, maintenance, cost and availability of spare parts from suppliers in a relatively nascent market.
- **Economics.** The cost of HTS-enabled devices are still significantly higher than conventional, copper-based counterparts because the sophisticated production processes, current low yields, and limited throughput of HTS tape manufacturing processes have kept costs high. However, it is not possible yet to simply compare the cost of an HTS-based device with a conventional one because of the unique, ancillary benefits that HTS devices unleash. Therefore, a *system* cost analysis, including ancillary equipment (for example, refrigeration equipment) should be undertaken to provide to provide a fair comparison.

Purpose and Scope

The International Energy Agency's Technology Collaborative Program on High Temperature Superconductivity (HTS TCP) brings together key stakeholders to address the challenges of promoting the development of HTS technology in view of common interests. Particularly, the HTS TCP:

- Turns to the electric utilities, the governments, the professional engineering and the RD&D communities to confirm and communicate the potential benefits of HTS technology.
- Sponsors workshops, co-authors books and journal articles, exchanges information, introduces ExCo members' research facilities to other participants and guides the assessments.
- Develops position papers and strategic documents such as roadmaps and technical reports. Participants also ask experts from their countries to provide for input and to peer-review draft reports. These activities help ensure consistency in the reporting and evaluate progress in the different considered fields.
- Provides expertise that can inform the evaluations and assessments performed by ExCo members.
- Interacts with other related IEA TCPs to leverage synergies and opportunities.
- Disseminates work at international meetings and workshops and support 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 2017 ACTIVITIES

Highlights of ExCo activities for this Annual Report period include:

ExCo members and guests at the reception hosted by NEDO.

- Presentation of a poster at major superconductivity conference called the European Conference on Applied Superconductivity – better known as EUCAS – to highlight the HTS TCP and also standardization efforts. This work was accepted as an IEEE publication and will be published in 2018.
- The International Symposium on Superconductivity (ISS) 2016 took place in Tokyo, and several ExCo members made presentation, including Dr. Tabea Arndt (Invited talk of EU activities) and Dr. Yutaka Yamada (Italian SFCL and HTS wires).
- Publishing quarterly newsletters with HTS news
- Updating the website and comprehensive interactive map from HTS projects around the world.
- Presentation at Cryogenics and Superconductivity Society of Japan (CSSJ) 2016, Spring Meeting (in Tokyo) to give an update on the IEA HTS Roadmap activity and other ExCo activities.
- Continuation of fostering relationships with other IEA TCPs' implementing agreements, such as International Smart Grid Action Network (ISGAN) and Energy Efficient End-use Equipment (4E). The TCP helped lay the groundwork for the first Joint Workshop for the TCPs in the EUWP – Electricity.

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

EXAMPLES OF ENGAGEMENT

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

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

More information is available below.

IEA Joint TCP Workshop

On January 31, 2017, a workshop was jointly organized by four Technology Collaboration Programs (TCPs) of the IEA, namely: HTS (High Temperature Superconductivity), ISGAN (International Smart Grids Action Network), DSM (Demand Side Management) and 4E (Energy Efficiency of Electrical equipment). The workshop focused on the energy efficiency for the entire electricity lifecycle, from its generation, transmission, and distribution to its end-uses.

The goal of the workshop was to discuss the challenges and opportunities for an efficient and sustainable electricity system by addressing the different frameworks of relevance for various policy actors, including technology and innovation support, regulation, and standardization. Recent and future developments were discussed and expertise was shared to help develop a greater understanding of policies and practices in the field of energy efficient systems. The workshop leveraged the experience of different TCPs through keynotes speeches, oral presentations and round table discussions.

Kawasaki ExCo Meeting

The first IEA-HTS Executive Committee (ExCo) meeting of Fiscal Year 2017 was held in Kawasaki, Japan from 4–5 July 2017 and hosted by New Energy and Industrial Technology Development Organization (NEDO). Attendees, including ExCo representatives from Italy, Switzerland, the United States, France as an observer, Japan and several Japanese superconductivity companies and institutes, joined the meeting and presented activities on HTS tape and industry applications.

The meeting began with updates on HTS activity from representatives of China, France, Germany, Italy, Japan, Korea, Switzerland, and the United States. Several groups in Japan

Figure 1- Exco Meeting at Kawasaki, Presentation of HTS cable by Jean-Maxime Saugrain (Nexans)

then introduced their recent work, including a Japanese national HTS project by the New Energy and Industrial Technology Development Organization (NEDO), an HTS MRI using YBCO tape by Mitsubishi electric company, a railway HTS cable system by Railway Technical Research Institute (RTRI), an HTS power cable by Tokyo Electric Power Company (TEPCO) and Sumitomo Electric Co., Ltd. (SEI), and refrigerators for a cable system by Taiyo Nissan and Mayekawa Corporations.

The meeting also included a discussion on HTS cable systems entitled, "What do we need for HTS cable commercialization?" Attendees, including an HTS cable leader from Nexans (Figure 1) that is conducting the Ampacity project in Essen Germany, discussed and exchanged opinions about the future issues to bring HTS to industrialization. Members from the Tokyo Embassy joined the session and showed interest in the main goal of HTS applications: high technology for future energy. On the last day, the delegates visited the RIKEN NMR facility in Yokohama. This facility is developing an HTS NMR magnet over 1 GHz while operating conventional NMR systems for the study of biological chemistry, physiology and medicine.

European Conference on Applied Superconductivity 2017

The European Conference on Applied Superconductivity (EUCAS) 2017 was held 17-24 September 2017 at the International Conference Centre of Geneva (CICG), which was hosted by CERN in collaboration with the University of Geneva and EPFL-SPC. More than 1,130 participants from around the world attended the meeting, including 17 plenary talk presenters and special guests, 177 oral presentations, and more than 800 poster presentations. The IEA HTS TCP presented its recent activity and standardization aspects during a poster session to increase the visibility of the TCP.

In the "Progress in HTS Conductor Industry" session, HTS wire companies presented an update of their products. As demonstrated in the session, many companies are now constantly producing a large amount of HTS conductors, including YBCO tape-coated conductors. This is a key factor for HTS applications like electric power devices, NMR, MRI, high energy physics accelerators, and fusion devices. According to one of the HTS experts, the supply of coated conductors will soon reach 3,000 km/year.

In the "Industry Session," some of the superconducting company CEOs introduced an effort to industrialize superconducting technologies. Leaders of major projects presented on R&D and Lessons Learned. Throughout the conference, researchers showed HTS applications and demonstrations, and the lessons of this session were meant to provide guidance to researchers who manage R&D projects.

A shortened HTS ExCo meeting was held in conjunction with EUCAS to discuss ongoing business such as the status of new member engagement and project updates. The IEA Desk Officer participated via web-conference and delivered a presentation on the clean energy goals of IEA. CERN also participated as an observer in the meeting.

European Cryogenics Day 2017 and the Second International Workshop on Cooling Systems for High-temperature Superconductor Applications

The European Cryogenics Day 2017 and the Second International Workshop on Cooling Systems for High-temperature Superconductor Applications took place in Karlsruhe, Germany on September 13-15 at the KIT campus. The events were attended by 132 participants from 19 countries organizations.

The European Cryogenics Day featured topics on Cryogenics in Astrophysics, Particle Physics and Computing, Transportation, Air Separation and Power Applications. Two presentations were given by IEA HTS Executive Committee members, including one from Hiroyuki Ohsaki of University of Toyko as a review and update on MAGLEV and another from Mathias Noe (KIT, Germany) about cooling requirements for superconducting power cables.

The International Conference on Cooling Systems for HTS applications covered topics such as power applications, novel machinery, and small scale applications. The conference also held a poster session covering new activities in

cryogenics and the conference's host, KIT, led a technical tour of the Karlsruhe Tritium Neutrino Experiment - KATRIN. More information about the poster session conference can be found at https://www.ecd-iwchts2017.kit.edu/56.php.

Chinese Applied Superconductivity Conference at Tianjin University

The Chinese Applied Superconductivity Conference was held at Tianjin University in Tianjin, China on 20-24 August 2017. This conference is held biennially and covers both HTS tapes and their applications in the electric grid, similarly to ASC and EUCAS. There were 620 attendees (Figure 2) with 12 plenary talks, 144 oral presentations, and 212 poster presentations. There were 14 companies in the technology exhibition including the Futon Group, Western Superconducting Technologies Co. Ltd., Sumitomo Electric Industries Ltd., and Shanghai Superconductor Technology Co. Ltd.

Figure 2 - Participants at the 2017 Chinese Applied Superconductivity Conference at Tianjin University.

China has invested around $100 million USD into HTS over a 5-year period. The following items were highlighted at this conference:

1. **HTS tapes, especially YBCO.** There are now 3 companies working in this area in Shanghai district.
2. **Superconducting Fault Current Limiters**. There are several projects in high voltage FCL using YBCO and Bi tapes.
3. **Cables.** Futong Group, which mainly works in the optical fibers sector, is now testing an HTS power cable (100m, 33kV-1kA) in their Tianjin factory branch.

A small meeting for HTS cable was held during the conference, attended by participants from different bodies, such as HTS CC tape producers, refrigerator companies, and an electric power company.

HTS-TCP Newsletter

This year, the quarterly publication "HTS-News and Trends" published on the website. Different issues have been circulated among ExCo members. These newsletters are intended to timely disseminate HTS activities and news around the world.

World Projects at a Glance

In 2017, the ExCo modified a web-based spreadsheet that catalogs HTS based projects around the world. Data are collected by region: North America, the European Union, Japan, Korea, China and Russia. The database is updated as needed with data such as current and voltage ratings, current status, partners, budget, and references.

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

PROJECT UPDATES

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

KOREAN CABLE PROJECTS

Two Korean HTS cable projects are underway by the Korean Electric Power Corporation (KEPCO). KEPCO is installing a 1-km 22.9 kV, 50 MVA cable near Seoul that makes use of a 7.5-kW turbo-Brayton refrigeration system. This cable will be a permanent component of KEPCO's electric grid to connect two substations. KEPCO held a ribbon cutting ceremony in September 2016 and completed the installation in October 2017.

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

EUROPEAN PROJECT FASTGRID

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

ULTRA-SUPERTAPE

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

JAPANESE HTS AC CABLE

A new Japanese HTS cable project coordinated by NEDO was initiated. The main targets are as follows:

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

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

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

The U.S. Department of Energy announced nearly $25 million USD for 13 projects aimed at developing new technologies for energy-efficient electric motors through applied research and development. $15 million USD of the total amount was given to four research teams in the superconducting field. The Office of Energy Efficiency and Renewable Energy's (EERE) Next Generation Electric Machines projects supported by the Program will address the limitations of traditional materials and designs used in electric motor components by cost-effectively enhancing their efficiency, improving their performance, and reducing their weight. This effort will support innovative approaches that will significantly improve the technology in industrial electric motors, which uses approximately 70% of the electricity consumed by U.S. manufacturers and nearly a quarter of all electricity consumed nationally. More information about other EERE projects can be found at https://www.energy.gov/eere/amo/next-generation-electric-machines-project-descriptions.

Advanced Superconductor manufacturing Institute (ASMI) in the United States

The goal of ASMI is to build an industry-based consortium to accelerate the full commercialization of high-temperature superconductors. ASMI has broad support from small, medium and large U.S. companies, universities, and the U.S. Department of Energy's National Laboratories. ASMI is seeking federal funding from U.S. agencies to join the National Network of Manufacturing Innovation, which leverages public-private partnerships and cost-sharing arrangements to advance manufacturing techniques. ASMI is holding workshops to develop cost-shared projects and also to develop a long-term sustainability model for HTS manufacturing.

China Projects

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

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. The HTS TCP operation is supported by a combination of cost-, task-, and knowledge sharing. ExCo members cover their travel expenses to attend ExCo meetings and bear all the costs incurred in conducting task activities, such as report writing and travel to meetings and workshops.

The ExCo Chairman, vice-chairman and operating agents prepare an annual work plan and associated annual budget for the calendar year, which are submitted for approval by the ExCo. The expenses associated with the operation of the HTS IA ExCo and the annual work plan, including the operating agent's time and travel and other joint costs of the ExCo, are met from a Common Fund to which all HTS TCP members contribute. There are neither changes foreseen in the working arrangement nor current structure fee. However, in FY 2017 the fee structure was modified based on the GDP of the member countries. The HTS TCP is financially secure with the Common Fund, having had surplus for the past several years.

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

FUTURE ACTIVITIES

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

- Activities that will help to close the gap between R&D and commercialization. This will entail working with utilities so they can better understand the benefits of the technology applications.
- Developing communications and outreach materials for non-technical audiences on the benefits of HTS applications.
- Developing a technical fact sheet on HTS cables and Fault Current Limiters that is geared towards electric utilities.
- Developing technology readiness level diagrams for HTS power applications.
- Developing one special edition white paper on a specific topic such as safety, warranties, and standards about HTS applications; outline how superconductivity can play a role in a low carbon society.
- Expanding the network of the TCP by engaging new entities conducting research and development in HTS.
- Organizing workshops to help gain visibility with other TCPs.
- Organizing a Special Session at ASC 2018
- Incorporating new members seamlessly, like France and CERN
- Organizing at least 2 ExCo meetings in 2018
- Involving new OA from Japan fully
- Keeping ExCo members informed about HTS TCP activity
- Organizing monthly Presidium calls

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About the International Energy Agency

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

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

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

The four main areas of IEA focus are:

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

Energy Technology Initiatives

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

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

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