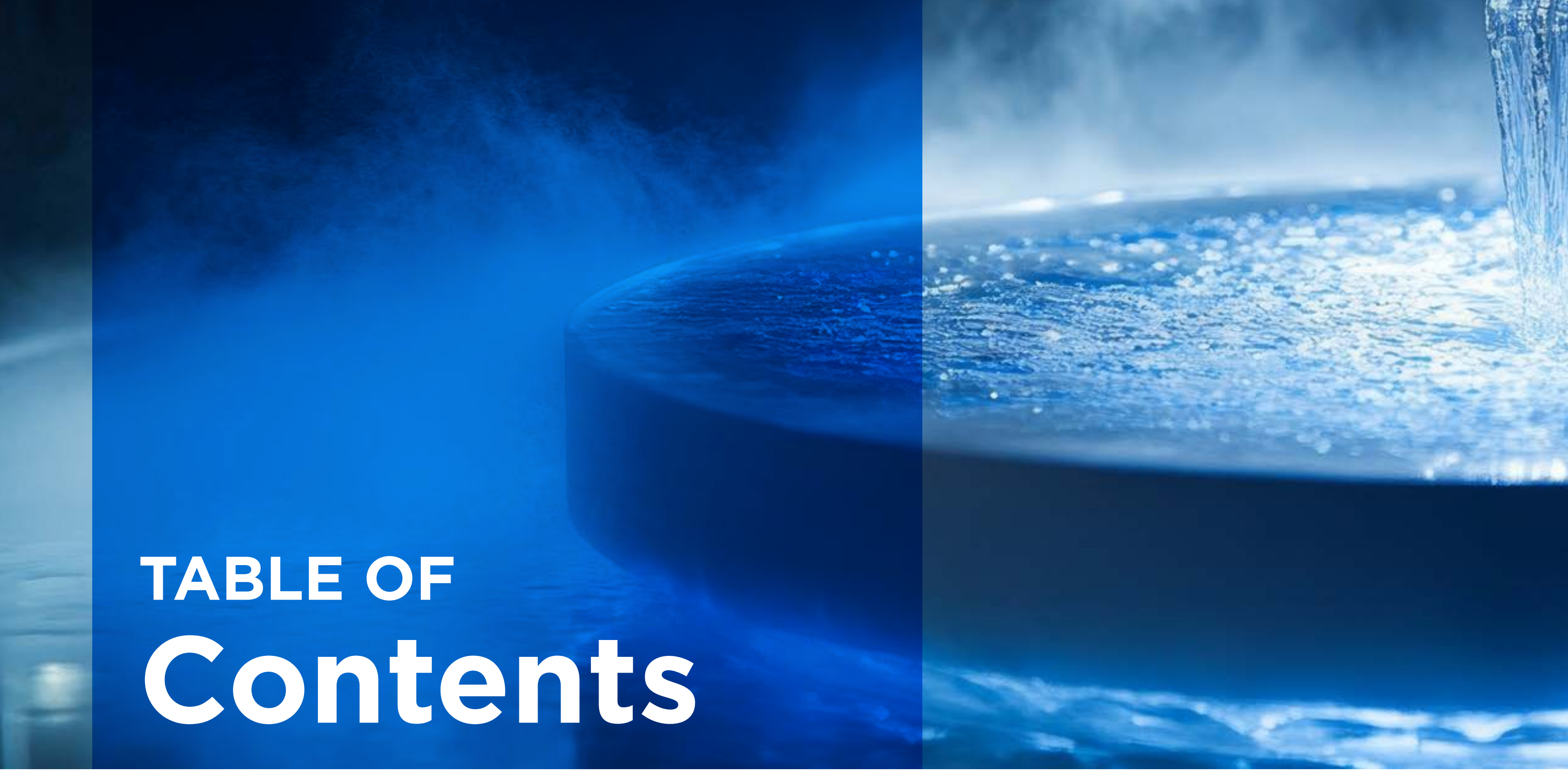
Superconductivity
INTERNATIONAL ENERGY AGENCY

# 2024 ANNUAL REPORT

IEA Technology Collaboration Programme on High-Temperature Superconductivity

Technology Collaboration Programme by iea



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# Acronyms and Abbreviations

| | |
|---|---|
| 2G | Second Generation |
| AC | Alternating Current |
| AMSC | American Superconductor Corporation |
| ARPA-E | Advanced Research Projects Agency–Energy |
| ASC | Applied Superconductivity Conference |
| CERN | European Organization for Nuclear Research |
| CIGRE | International Council on Large Electric Systems |
| CC | Coated Conductors |
| DC | Direct Current |
| EGSAL | Energy Grids Simulation and Analysis Laboratory |
| ENEA | Italian National Agency for New Technologies, Energy, and Sustainable Economic Development |
| EUCAS | European Conference on Applied Superconductivity |
| ExCo | Executive Committee |

| | |
|---|---|
| HTS | High-Temperature Superconductivity |
| HVDC | High Voltage Direct Current |
| IEA | International Energy Agency |
| IEC TC 90 | International Electrotechnical Commission Technical Commission 90 |
| INL | Idaho National Laboratory |
| IRIS | Research Infrastructure on Applied Superconductivity |
| ISGAN | International Smart Grid Action Network |
| $J_c$ | Critical Current |
| KEPCO | Korea Electric Power Corporation |
| KEPRI | Korea Electric Power Corporation Research Institute |
| KIT | Karlsruhe Institute of Technology |
| LTS | Low Temperature Superconductivity |
| MRI | Magnetic Resonance Imaging |
| NEDO | New Energy and Industrial Technology Development Organization |
| R&D | Research and Development |
| REBCO | Rare-Earth Barium Copper Oxide |
| REWP | Renewable Energy Working Party |
| RSE S.p.A | Ricerca sul Sistema Energetico |
| RTRI | Railway Technical Research Institute |
| SCARLET | Superconducting CAbles foR sustainabLe Energy Transition |
| ScGA | Superconductivity Global Alliance |
| SCMAGLEV | SuperConducting MAGnetic LEVitation |
| SFCL | Superconducting Fault Current Limiter |
| SMES | Superconducting Magnetic Energy Storage |
| SST | Shanghai Superconductor Technology Co., Ltd. |
| TCP | Technology Collaboration Programme |
| TRL | Technology Readiness Level |
| U.S. DOE | United States Department of Energy |

# MESSAGE FROM
# The Chair

In 2024, I had the honor of continuing to Chair the International Energy Agency (IEA) Technology Collaboration Programme (TCP) on High-Temperature Superconductivity (HTS). Membership with the group's Executive Committee (ExCo) has offered me a unique and unbiased view of the latest developments in HTS applications across America, Asia, and Europe. While the main core of the HTS TCP is traditionally focused on energy applications of HTS in power grids like superconducting fault current limiters and HTS cables, the TCP also established significant connections this year to numerous industries involved in developing HTS magnets for fusion. This is an emerging and promising sector that can act as a crucial leverage point to accelerate the cost reduction and commercialization of HTS applications for power grids.

The TCP's work consists of promoting the advantages of HTS technologies at all possible levels, and to do so, several approaches have been pursued. In 2024, one of the most important approaches consisted of organizing both management and technical meetings. The HTS TCP has actively responded to the increasing interest in hydrogen as an energy vector by joining the IEA Hydrogen Coordination Group. HTS cables, in fact, are recognized as one of the most promising applications that could transport electrical and chemical energy at the same time, as hydrogen can be pumped inside cryostats to refrigerate HTS tapes to their critical temperatures where they transition into superconductors.

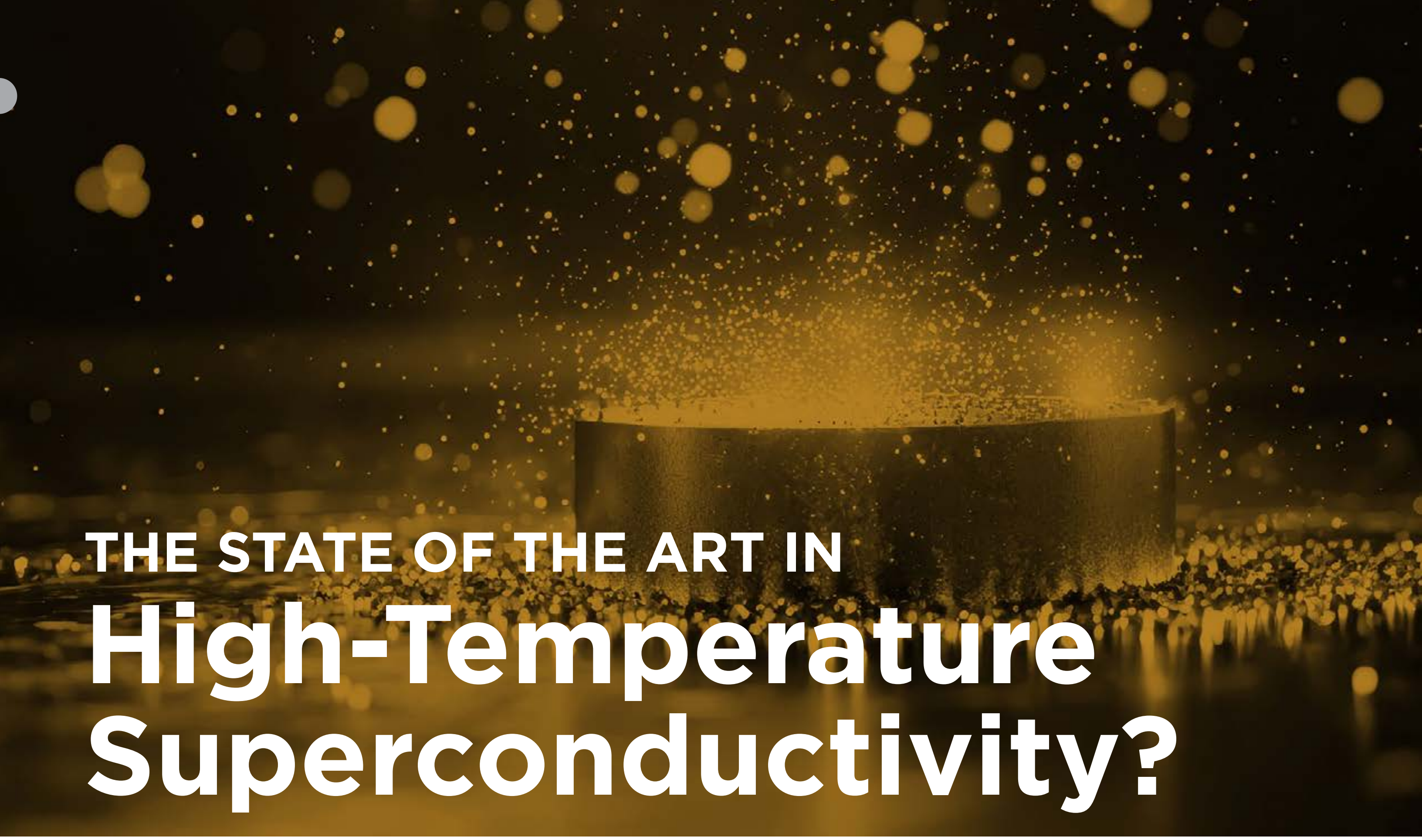
On the publications side, the HTS TCP published *High-Temperature Superconductivity for Resilient Electric Grids*. This document illustrates how electric grid applications utilizing HTS have or plan to contribute to enhancing grid resilience. In the current landscape, a global energy transition is coinciding with a geopolitical crisis, so the resilience of the electric grid is paramount to ensuring stable and sustainable power, for safeguarding national security, and for facilitating the integration of a diverse set of renewable energy sources.

During the Fall ExCo 2024 meeting, the TCP unanimously agreed to begin IEA's Request of Extension process to extend the TCP's work for another five years after its current five-year period concludes at the end of February 2026. Throughout 2025, a new five-year Strategic Plan (2026-31) will be prepared and submitted to IEA. This will give the TCP a valuable opportunity to reflect on the state of HTS grid applications, assess the TCP's role and effectiveness, and identify areas for improving future outcomes.

Finally, I would like to thank the Vice-Chair Hiroyuki Ohsaki, the Task Managers, the leadership team, all members of this TCP for their constant and fundamental support, and our observers for their deep interest and contribution to the TCP's scholarship and activities.

HTS TCP Chair

**Laura Serri**

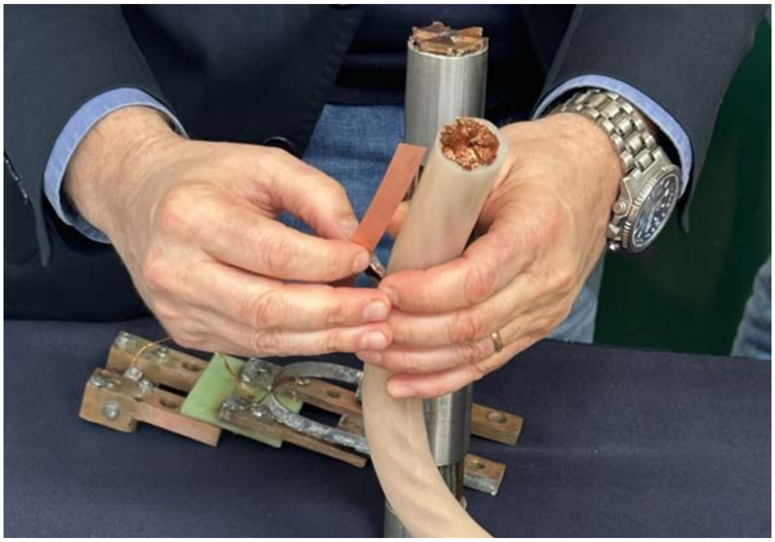


# THE STATE OF THE ART IN High-Temperature Superconductivity?

## Science and History of Superconductivity

All materials exhibit some degree of resistance to the flow of electricity and release heat as a result. Even universally recognized conductors like copper wires resist electricity to some extent. After a century of scientific discovery, though, a growing set of materials have been found to lose their electrical resistance entirely at very low temperatures. These materials, known as “superconductors,” conduct electricity with perfect efficiency, capable of transmitting up to two hundred times more electrical current than copper wires of equal size.

Superconductivity is a phenomenon of quantum mechanics that explains this advantage. Every superconducting material has a specific, “critical” temperature below which it begins to superconduct electricity. Below this temperature, electrons lock into pairs (called “Cooper pairs”), allowing them to move through superconducting materials (or superconductors) in a coordinated, frictionless way with zero resistance. Superconductors also expel magnetic fields through another phenomenon known as the Meissner effect that locks objects into their quantum state and suspends them midair.



A thin HTS tape (left) transmits the same amount of power as the thick copper wire (right)

A handful of technologies, like particle accelerators and magnetic resonance imaging (MRIs), managed to harness superconductivity in the 20th century, but many potential applications remained unattainable, considering that superconductivity had only ever been observed at a few degrees above Absolute Zero–a temperature far too low to achieve practicably. In the late 1980s, though, scientists discovered an even narrower class of materials that exhibited superconductivity at temperatures above the boiling point of nitrogen (~77 Kelvin or -196°C), giving birth to “high-temperature” superconductivity (HTS) and an even broader array of potential applications.

## How HTS Can Supercharge the Energy Transition

By many measures, the superconductivity field has reached a historic inflection point similar to the arrival of Nb-Ti in the 1980s that helped the industry establish its first product: MRIs. Superconductivity is beginning to power many technologies in commercial settings at the frontiers of science and the energy transition, including grid components like cables, fault current limiters, and wind turbines. Other applications include industrial induction heaters, MAGLEV trains, electric airplanes, fusion reactors, quantum computers, data centers, and liquid hydrogen storage and distribution. While the benefits of resistance-free electricity are clear–especially for an energy system ill-equipped to match the blistering pace of electrification and climate change–only the most intrepid and pioneering utilities have adopted HTS technology, despite a variety of unique energy services only superconducting technologies can provide. Other industries, though, have moved more swiftly to capitalize on HTS’s advantages.

The fusion industry has purchased such large volumes of HTS tapes that the HTS manufacturing sector’s fortunes have been largely reversed, with falling costs and manufacturing forecasts calling for cheaper-than-copper HTS tape by as soon as 2027. The space sector has also embraced superconductivity with the Hēki mission preparing to demonstrate a flux-pumped HTS magnet aboard the International Space Station in 2025, marking the first such test in orbit.

These examples reflect a broader trend toward integrating superconducting technologies into mission-critical systems, supported by advances in cryogenics, materials science, and AI-driven design. The superconductivity industry is now focused on scaling production, standardizing components, and reducing costs to enable widespread adoption across energy, aerospace, and computing sectors.

### Grid Transmission and Distribution Cables

Load growth in urban and suburban regions requires utility companies to make long-range plans for increasing the capacity of alternating current (AC) circuits that serve that load. HTS cables can carry three to ten times more power than conventional cables with 90% less resistive line losses for the same cross-section and right-of-way. HTS cables can provide the same level power, but at a much lower voltage, which allows utilities to avoid building new high-voltage substations or upgrading insulation systems.

This advantage is especially useful in dense urban areas, where it is exceptionally challenging and even impossible at times to expand rights-of-ways or build new transformer stations. Close to 25 grid-connected superconducting transmission projects have been built in the last three decades around the world, but historically, the cost and complexity of superconducting transmission systems have limited their application to projects where the density of transmission capacity is extraordinary, making HTS the only choice. But as the perceived risks and costs of HTS cables fall, their use may become widespread as the clear benefits of HTS cables outweigh their costs–particularly on a system-level basis.

Pictured is a prototype of the SuperLink cable that was installed and commissioned at the Menzing substation in Munich, Germany in October 2024 for testing. Its performance will shape the final design of the SuperLink cable, which at 12-15 kilometers in length, will become the longest HTS cable in the world. Credit © NKT

## Superconducting Fault Current Limiters

As the diversity of grid-connected assets like distributed generation, renewables, electric vehicles, and data centers increases with the pace of electrification, many utilities are also facing rising fault (short-circuit) currents, which can exceed the interrupting ratings of existing circuit breakers and force utilities to consider adding new substation protection schemes and fault current limiting technologies. Superconducting fault current limiters (SFCLs) can help manage fault currents more cost- effectively by automatically and instantaneously limiting fault currents without affecting normal operations. Compared to solid-state or reactor-based designs, SFCLs can operate with substantially lower steady-state losses, offer passive self-recovery, and reduce system stress and equipment costs associated with fault events. Dozens of SFCLs have been built around the world, and as fault current increase with the pace of electrification and the grid integration challenges that presents, their demand is expected to grow substantially.


In June 2024, Nexans and SNCF Réseau announced plans to connect an SFCL (pictured) to the French railway system, making it the first installation of an SFCL in a rail network anywhere in the world. The SFCL will improve the network's reliability and safety by absorbing surges, short-circuits, and other power supply disruptions that would otherwise force SNCF Réseau to interrupt rail operations for repairs. Credit © NKT

## Energy Storage

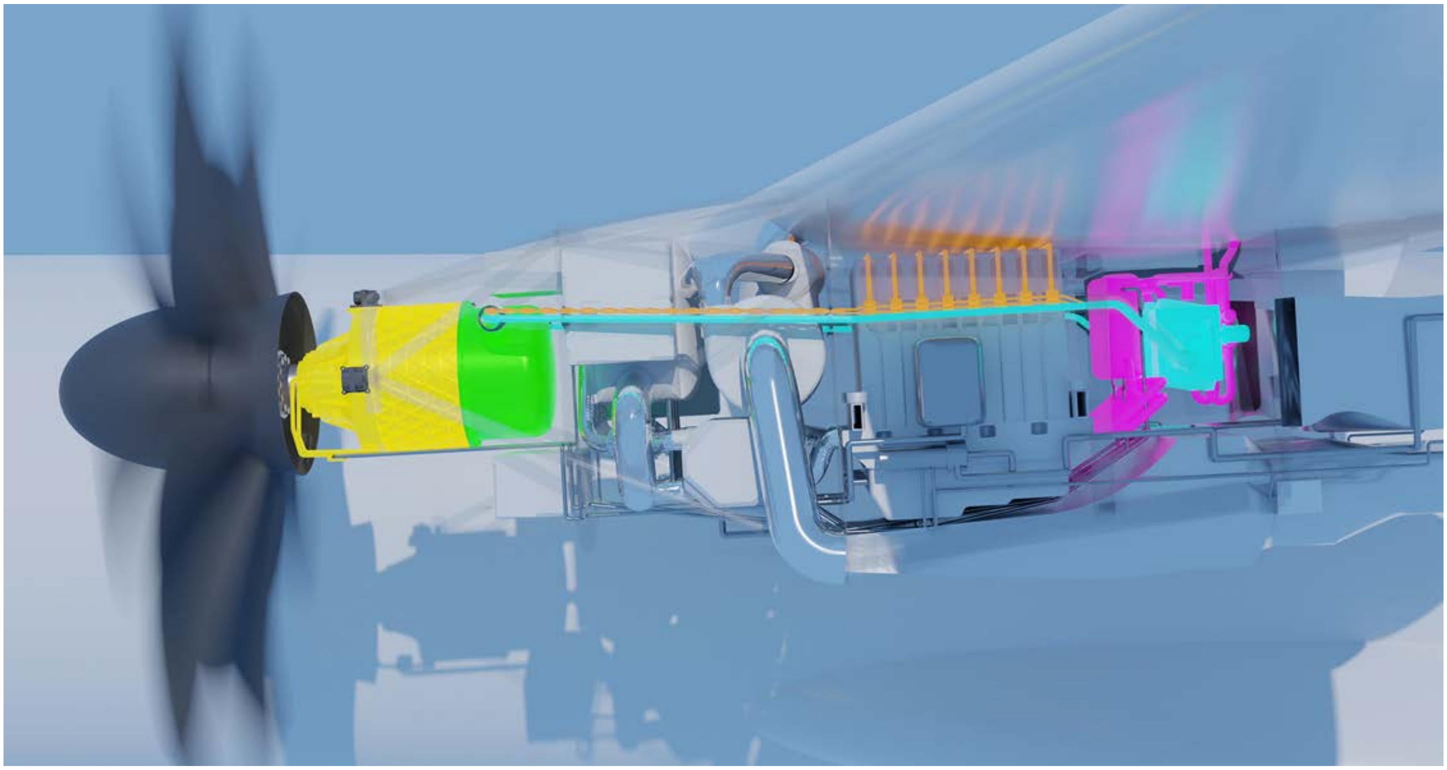
Energy storage can increase the penetration of renewable resources and improve power quality. Superconducting Magnetic Energy Storage (SMES) has several advantages over other storage technologies, including rapid response times that are perfectly suited for maintaining power quality and stability, minimal degradation over many charge cycles (as magnetic fields do not degrade, unlike chemical batteries), and very high round trip efficiencies. However, due to high costs, cryogenic requirements, and limited energy capacity, SMES is currently best suited for short-duration, high-power applications rather than bulk energy storage.

## 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, which enables easier installations. Since HTS machines use superconducting field windings instead of permanent magnets, they can also reduce or even eliminate the need for rare earth elements, making HTS-powered wind turbines even more environmentally and geopolitically sustainable.

## Motors

Electric motors consume roughly half of all electricity and nearly two-thirds of industrial electricity use in the United States and other developed economies. HTS motors can significantly reduce electrical losses by up to 50%, while achieving less than half the size and weight of comparable conventional machines. These characteristics make HTS motors particularly attractive for large-scale transportation applications, where higher torque density and reduced mass can enhance propulsion efficiency and maneuverability.



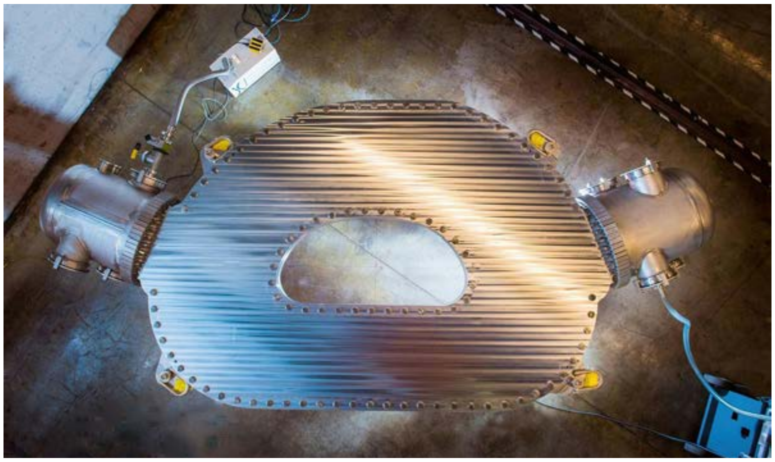
In May 2024, Airbus UpNext launched Cryoprop (pictured), a 2-megawatt superconducting electric propulsion system to demonstrate the maturation of superconducting technologies for use in electric propulsion systems of a future hydrogen-powered aircraft. Credit © AirbusUpNext

## Aircraft

The use of lightweight HTS wires could lead to ecofriendly, exceptionally quiet, and highly energy-efficient electric planes. HTS wires are being explored for electric and hybrid-electric aircraft propulsion systems, mainly because they drastically reduce motor and generator weight, enable high power densities for distributed propulsion, and can lower noise levels by enabling smaller, slower-turning electric fans.

## Fusion

Superconductivity has become a cornerstone of fusion energy development. HTS-based fusion systems, equipped with HTS magnets that can exceed 20 Tesla, enable much stronger magnetic fields than those achievable with conventional low-temperature superconductors (LTS). HTS has allowed engineers to design much more compact and efficient tokamaks 16 times smaller than conventional ones powered by LTS magnets. This dramatic reduction in system size and complexity is considering an industry "game-changer" that has lowered development costs, accelerated construction timelines, and allowed smaller organizations to participate in a fusion race that, until now,



Commonwealth Fusion Systems show their Toroidal Field Model Coil prototype, tested successfully in 2021 and detailed in peer-reviewed papers in 2024. Credit © CFS has only been feasible for well-resourced governments and multinational cooperatives like the International Thermonuclear Experimental Reactor to enter. Today, there are over 50 fusion companies around the world thanks to the economic and technological advantages of HTS. (For a more in-depth analysis, read our feature on fusion in our 2023 publication *HTS Wire Enabling Market Disruption*).

## Remaining Challenges

Over the past few decades, significant global efforts have focused on the research, development, and demonstration of applied HTS devices for power applications. As a result, and as previously described, several HTS-based systems like power cables and fault current limiters have been deployed in utility grids as permanent solutions to electricity delivery challenges. But other grid applications of HTS, like transformers and rotating machines, remain in earlier stages of market adoption. And overall, only a limited number of the most intrepid and pioneering utilities in the world have installed HTS-enabled grid components to date.

Some of the grand challenges HTS technologies must overcome to enjoy wider deployment in electric grids around the world include improving the economics of HTS systems; the properties and manufacture of HTS tape; the safety, reliability, and interoperability of integrated systems of HTS components, and the workforce. A concerted effort from policymakers, utilities, and industry stakeholders is necessary to overcome the following challenges.

### HTS Wire and Cryogenic Costs

HTS applications have been limited for decades by extremely high material costs, preventing them from replacing copper and iron in electric infrastructure. As of 2024, HTS tape remains significantly more expensive than conventional copper wire, though recent industrial-scale production has lowered prices considerably. Rising demand from the fusion industry is pushing manufacturers to produce multi-ton annual outputs, leading to higher throughput, improved yields, and rapid cost declines.

In 2017, second-generation (2G) rare-earth barium copper oxide (REBCO) HTS tapes cost around $300-500 per kiloampere-meter (kA-m). Five years later, the same tape cost $100-150/kA-m, five to eight times cheaper than a decade prior, thanks to large-volume orders for fusion tokamak magnets. Despite these cost decreases, $100-150/kA-m is still three to four times higher than the price of copper[1], which means that HTS cables, for instance, remains 5 to 10 times more expensive than conventional DC cables.

Many industry experts agree that the cost of HTS wire must fall to at least $50/kA-m for broad adoption in the power sector and even further to $25-50/kA-m for widespread commercial adoption. However, prices must fall even further to approximately $10/kA-m to be cost-competitive with copper, a price some industry forecasters believe the fusion industry–with over 50 companies worldwide–could render by as soon as 2027. However, some manufacturers report that REBCO prices are approaching cost of materials, making further cost improvements more challenging to attain in the near future.

Costs of HTS-based devices, though, should never be compared directly to conventional ones because of the unique attributes and services HTS devices provide. System cost analyses should be undertaken, instead, such as a levelized cost of energy, a critical metric for the power sector. For example, one member of the HTS TCP reported that the cost of their cryogenic system for an HTS research and development (R&D) project was more expensive than the HTS wire (MgB2), becoming the biggest part of their project's cost stack for the first time in their careers. Additionally, the raw material costs of conventional materials, like copper, have been increasing, which makes HTS-based solutions more cost competitive, as well.

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1 Wang, Kai et al. Advances in second-generation high-temperature superconducting tapes and their applications in high-field magnets. Soft Sci 2022;2:12. https://dx.doi.org/10.20517/ss.2022.10

At recent superconductivity conferences, the message on costs were clear: cost reductions may continue without any interventions, but to accelerate the pace of HTS price declines, serious investments at the national level to fund public-private partnerships will be necessary.

## HTS Wire Quality

The consistency, mechanical strength, and stability of REBCO wire are all remaining technical challenges that must be improved to enhance the quality of HTS wire. In terms of consistency, local defects in HTS tape can cause inconsistencies in the tape's critical current ($J_C$), which is the maximum electrical current a superconductor can carry without losing its zero-resistance state and transitioning into a normal, resistive state. Currently, the manufacturing industry is aiming to reach kilometer-scale consistency and per-tape $J_C$ reproducibility within a few percent by employing reel-to-reel in-line $J_C$ mapping, machine-learning anomaly detection, closed-loop process control for deposition, and tighter raw-material control.

Additionally, REBCO wire is a laminated stack of a substrate, buffers, the superconducting layer, and a stabilizer, which can delaminate under extreme Lorentz forces in high-field magnets (such as those in fusion tokamaks) and in other conditions. Better buffer and substrate interfaces that reduce voids, tougher lamination methods, optimizer stabilizer layers, and higher tolerances under repeated bending, tensile, and thermal validation cycles are necessary to improve the quality of HTS tape.

IEA HTS TCP Chairwoman Laura Serri examines an HTS tape during a technical tour of KIT's superconductivity lab at the Fall 2024 ExCo meeting in Karlsruhe, Germany

The pliability of REBCO tape is still quite limited compared to copper wire, for instance, which means that making reliable, low-resistance splices or joints necessary for long cables and magnet winding is challenging. Some joining methods degrade the tape's critical current or have poor thermal and electrical stability. More robust and reproducible joining processes with predictable contact resistance and no critical current degradations after thermal cycles or coil heat treatments are needed.

Finally, any of these deficiencies can trigger a quench–a sudden, rapid loss of the tape's superconducting state and transition back to its normal, resistive state. A minor wire movement due to Lorentz forces, a manufacturing defect, a temporary loss of coolant, or some other localized thermal or magnetic disturbance will heat a tiny section of the wire above its critical temperature and release a large amount of stored energy as heat, damaging the superconducting device if not properly managed. To mitigate these risks, sophisticated quench detection and protection systems are mandatory for most superconducting systems. These systems detect the onset of a quench by monitoring voltage spikes and trigger protection mechanisms. In REBCO tape, though, quench propagation is slow and voltage signals are weak, making quench detection one of the largest remaining technical barriers HTS faces.

## Limited Supply of HTS Wire

Currently, manufacturers are struggling to meet global demand for HTS wire. The fusion sector's demand for gigawatt-scale orders to build compact tokamak fusion reactors has forced the industry to increase production by a factor of ten in only a few years. Today, REBCO tapes are produced in 500-to-1,000-meter lengths across the globe, but a single fusion reactor generally requires 10 to 30 kilometers (km) of HTS tape. With approximately 50 fusion companies now scattered across the globe, manufacturing backlogs are nearly certain without greater production volumes of HTS tape as the demand from this industry alone moves from hundreds of kilometers of tape per year to thousands. The industry is responding, though, as newcomers Shanghai Superconductor expects to produce 3,000 km of HTS tape by 2026, and Suprema, a new Italian tape manufacturer, has plans to scale to 300 km per year of manufacturing throughput.

Pictured is an HTS coated conductor (CC) manufacturing line at KIT Campus North based on Bruker's manufacturing techniques for long CC and wide tapes.

### *System Integration*

The superconductivity industry and its target market, electric utilities, usually perceive the readiness of various HTS technologies differently. Historically, the HTS industry is more optimistic than electric utilities, who are generally more pessimistic about the technology's reliability. However, a consensus is emerging between the two about how to address this. Utilities and industry representatives both agree that an integrated product combining multiple HTS components into a single, turnkey product is what end-users need–and that larger, system-level demonstrations of multiple HTS components are the way to get there.

Utilities and other market segments are beginning to recognize that a subset of superconducting technologies like superconducting cables and fault current limiters have reached high technology readiness levels (TRLs), but that the industry needs to derisk its technology further by field validating the interoperability and reliability of HTS components–not only with one another, but with existing systems. Some technologists envision a larger paradigm shift: a future wherein HTS solutions are so commonplace that conventional grids, not HTS components, will be forced to retrofit or completely replace their infrastructure to optimize the benefits of HTS in novel, integrated grid design architectures.

While that future may someday come, most industry representatives believe such a future is not imminent, and that publicly funded public-private partnerships are necessary next steps the industry must take to advance HTS. Endeavors of this scale have remained too capitally intensive, complex, and risky for private companies to conduct alone, but many point to the success of "technology ecosystems" or "innovation hubs" that the HTS industry could emulate, which self-organize once established in discrete locations. Such settings would allow for long-duration tests of HTS component lifetimes (which some suggest should reach 100 years or more), which would help utilities understand maintenance cycles and operating costs in addition to the system's overall reliability. Data are not available that proves undiminished product-performance HTS component lifetime over 30 to 40 years.


Members of the IEA HTS TCP tour of KIT's Energy Grids Simulation and Analysis Laboratory (EGSAL) at KIT Campus North.

## Workforce Development

End users like utilities remain unfamiliar with the materials used in HTS devices and cryogenic systems, which reinforces their apprehension over swapping conventional technologies with relatively novel ones. Currently, the HTS industry is overwhelmingly dominated by highly specialized professionals with PhDs working in academic or national laboratories. Even within this core demographic, university superconductivity programs–which themselves are scarce–must compete for talent with other intriguing sectors like quantum computing and semiconductor manufacturing. Expanded education pathways beyond PhDs into apprenticeships, technical degrees, and cross-disciplinary programs in material science, engineering, cryogenics, systems, and manufacturing would help the HTS industry establish the workforce it needs to construct and maintain HTS infrastructure well into the future.

# Purpose and Scope of the IEA HTS TCP

The IEA HTS TCP works to identify and assess the potential applications and benefits of superconductivity in the power grid, as well as what technical, economic, and regulatory barriers must be overcome to achieve them. It also monitors applications of HTS in other sectors where successful deployments have created spillover effects that benefit the technology's power sector prospects.

The TCP's membership consists of government, academic, and industry representatives who collectively plan and pursue activities that identify, assess, and communicate the readiness and benefits of HTS. Some of these activities include:

- Collaborating with electric utilities, governments, professional engineering organizations, and the R&D community to confirm and communicate the potential benefits of HTS technology
- Sponsoring workshops, co-authoring books and journal articles, exchanging information, introducing ExCo members' research facilities to other participants, and guiding the assessments
- Developing position papers and strategic documents, such as roadmaps and technical reports, with input and review from technical experts in TCP member countries, which ensure consistent reporting and progress evaluation across various scientific and engineering fields
- Collaborating with other related IEA TCPs to leverage synergies and opportunities
- Disseminating work at international meetings and workshops, and supporting students, young engineers, and scientists who are learning about HTS applications in the power sector
- Addressing and clarifying real and perceived risks and hurdles to introduce a disruptive technology into the conservative electric power industry

TCP members also directly contribute to the advancement of HTS through basic and applied research projects in their professional roles while also advising the largest private commercial deployments of HTS in their home countries. Members advise their energy and economic development ministers, as well as standards-making bodies, on country-level research, development, demonstration, and deployment strategies, technological progress, and the development of HTS-supportive policies.

SUMMARY OF

# TCP Activities in 2024

The HTS TCP's activities in 2024 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 worked with its contracting parties to develop technical communication documents that provide information for a range of stakeholders and share critical updates.

## Spring 2024 ExCo Meeting – Virtual Meeting, 4 April 2024

The IEA HTS TCP held its Spring 2024 ExCo meeting virtually after meeting in person in Geneva, Switzerland the previous fall and before travelling to Karlsruhe, Germany later in 2024. Representatives from Italy, Japan, Korea, Germany, Switzerland, the United States attended, along with several invited guests from the IEA Secretariat and industry. The group welcomed two new representatives from Japan and announced that a new two-year contract had been finalized with the TCP's task managers to continue their support of the IEA HTS TCP. Other business the TCP discussed included a review of the TCP's active projects, the undertaking of a new paper on the latest developments in HTS standard making, the development of a messaging document for external audiences, the status of the group's membership recruitment drive, and updates from the Chairwoman's attendance at the TCP Universal Meeting.

The TCP also welcomed a guest presentation from Rafael Varela Della Giustina of Renaissance Fusion, a French fusion start-up that is manufacturing HTS into 1-meter-wide sheets rather than tapes or wires. These sheets allow them to wrap their tokamaks more easily, and it reduces their costs because it enables higher manufacturing volumes with lower capital expenditures. One-kilometer-long HTS sheets are Renaissance Fusion's minimum viable product as they ultimately transition into designing, building, and commercializing a fusion power-plant based on the stellarator, HTS, and liquid metal technologies.

## Participation in IEA TCPs and Secretariat Events

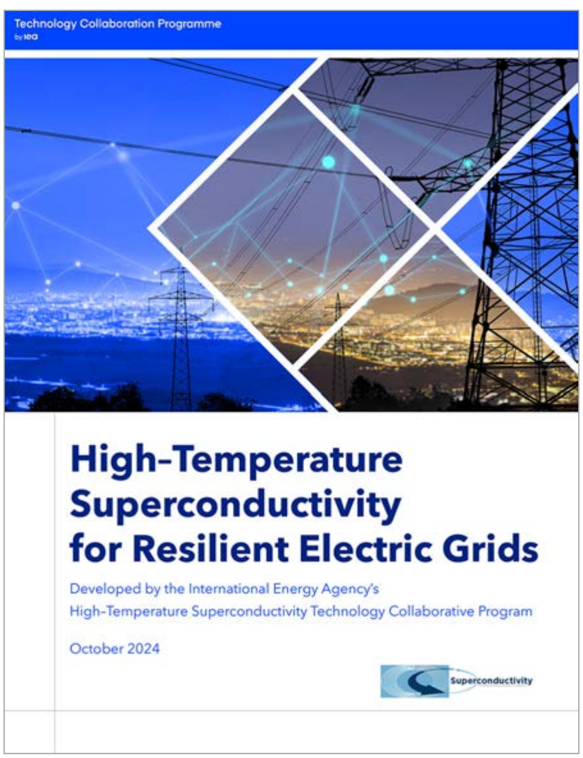
The Chairwoman, Task Managers, and other members of the TCP's Presidium deepened their relationships with multiple IEA divisions in 2024. The TCP received a new IEA Desk Officer liaison who significantly facilitated the TCP's onboarding into the Renewable Energy Working Party (REWP) after many years in IEA's End Use Working Group. He also helped the TCP resolve questions on TCP membership, IEA's new Request for Extension process, coordinate with IEA Legal, and learn how best to connect and work with other TCPs.

In 2024, the TCP coordinated with IEA Wind to identify areas of mutual interest and expertise to organize joint tasks and activities, such as formulating reference documents for developing superconducting wind turbine generators and their components or formulating levelized costs of electricity for HTS-enabled wind turbines and their sustainability indicators. The TCP also exchanged information with IEA's fusion TCPs to keep each party abreast of the latest developments relevant to each industry's progress.

The HTS Chair also introduced the HTS TCP at the Advanced Materials for Transportation TCP's Spring ExCo meeting and held subsequent conversations to identify overlapping expertise and interests. The HTS TCP also fielded contributions and reviews from the International Smart Grid Action Network (ISGAN) on the HTS for grid resilience paper and submitted information on the HTS TCP's activities and expertise on hydrogen to the Hydrogen Coordination Group. The TCP Chairwoman participated in each of the REWP's meetings to learn best practices, identify common experiences, promote HTS's interests, implement IEA's directives, and network with other TCPs of interest.

Select members of the TCP coordinated closely with the newly established Superconductivity Global Alliance (ScGA) in 2024 to explore and coordinate complementary activities intended to increase investments in superconductivity research, demonstrations, and deployments in new industries. Areas of mutual interest include conducting technoeconomic analyses of superconductivity applications across numerous industries and hosting joint workshops or special sessions at EUCAS 2025.

## Publication of HTS for Resilient Electric Grids




In October 2024, the TCP published *High-Temperature Superconductivity for Resilient Electric Grids*, a publication for electric utilities and policymakers that illustrates how grid applications of HTS can outperform traditional technologies and improve grid resiliency. The paper describes how more than ten planned, operational, or de-energized applications of HTS can or already have solved specific, real-world challenges grid operators face today. The paper leveraged findings from the TCP's previously published *application readiness map on energy delivery* to focus case studies on only the most mature HTS-enabled grid components, such as HTS cables and fault current limiters. *HTS for Resilient Electric Grids* outlines four grid challenges that HTS technologies are well suited to address: meeting N-1 redundancy requirements; increasing power density in space-constrained places like densely populated cities and suburban load centers; renewables integration and load flexibility; and increasing fault currents. The paper then illustrates four advantages HTS technology holds over conventional solutions on each of these challenges and describes how ten real-world projects address them.

## Oral Presentation at the Applied Superconductivity Conference (ASC) in Salt Lake City

Multiple members of the TCP and its Task Managers attended the 2024 Applied Superconductivity Conference (ASC), the world's largest superconductivity gathering, in Salt Late City, Utah. Several members gave oral and poster presentations of their individual research on HTS components, and the Task Managers gave an oral presentation on the HTS for Resilient Electric Grids paper. While in attendance, the Task Managers surveyed the state of HTS research, gathered milestones made by the industry on manufacturing improvements and costs, made deeper connections with ScGA and their working parties' roadmap development, and recruited participants to join the TCP.

## Fall 2024 ExCo Meeting in Karlsruhe, Germany

At the end of October, TCP members and many guests from Germany's superconductivity industry gathered at the Karlsruhe Institute of Technology (KIT) in Karlsruhe, Germany for the Fall 2024 ExCo Meeting from October 29$^{th}$ to October 31$^{st}$. Delegates from Italy, Japan, Germany, Switzerland, the United States, Nexans (sponsor) and ASG Superconductors (sponsor) joined observers from the IEA Secretariat, Gauss Fusion, Bruker, and the Technical University of Denmark / IEA Wind TCP.

Germany's delegates from KIT gave attendees a technical tour of their North Campus, where their Energy Grids Simulation and Analysis Laboratory (EGSAL) is located. ESGAL is a research platform for testing energy systems, including microgrids, that models the actual campus grid and larger European networks for energy transition research. The tour also showcased an HTS manufacturing line associated with $KC^4$, the KIT-European Organization for Nuclear Research (CERN) Collaboration on Coated Conductors (CC), which is part of CERN's High Field Accelerator Magnets R&D program. The collaboration is a joint, open HTS CC synthesis lab that bridges the gap between small scale materials research on CC and larger scale component requirements of tailored, high quality full CC architectures in sufficiently long lengths. An HTS tape manufacturing line, funded in part by the German Helmholtz R&D program, is based on Bruker's manufacturing techniques for long CC and wide tapes, but the project is focused on resolving R&D CC issues, not low-cost CC production. The line is one component of a 500-square-meter laboratory space at KIT dedicated entirely to $KC^4$.

During the two-day ExCo business meeting over the following two days, attendees presented updates from their respective countries' activities on HTS R&D and heard from industry representatives about their challenges and technology forecasts on production volumes, target markets, and overall prospects of HTS in the energy sector and others. After reviewing the TCP's interactions with other facets of IEA in 2024, the TCP unanimously resolved to pursue an extension of the TCP for another five years. It then held its first strategic planning discussion to develop a new five-year workplan and chart a timeline for developing the Renewable Energy Working Party's (REWP) Request for Extension materials. Other business the ExCo discussed included the group's strong fiscal health, the development of a technical workshop on the costs of HTS at the 2025 European Conference on Applied Superconductivity (EUCAS) in Porto, Portugal, plans for the next in-person ExCo meeting, a review of task manager assignments for the current year and next, and the TCP's membership recruitment and retainment efforts. Notably, the group considered a pitch from Denmark to the IEA HTS TCP as a contracting party to lead a task on developing reference models for superconducting wind turbines, which the TCP unanimously accepted.

STATUS OF

# HTS Projects Around the World in 2024

*Around the world, projects are demonstrating the technical feasibility of electric power equipment that incorporate HTS tapes. Here are some of the latest advancements TCP members made in 2024, along with some notable HTS activities in non-member countries.*

## Germany

Germany has one of the most extensive portfolios of HTS projects in Europe, with R&D activities spread across numerous corporations, universities, and research centers in a variety of energy sector applications. Projects are underway in 2024 on HTS cables, fault current limiters, cryogenics, magnets, wind generators, HTS tape materials, busbars, and even electric aircraft, building on the country's long legacy of established LTS applications like MRIs and particle accelerators.

As part of Germany's efforts to expand its transmission grid and support the energy transition, Germany initiated the SuperLink project in 2020 to connect two substations in Munich, Germany with what will become the world's longest HTS cable once built. In October 2024, this high-profile large-scale project took a significant step forward when TCP member KIT along with NKT, Stadtwerke München Infrastruktur, and other partners commissioned the installation of a 150-meter (m), 110-kilovolt (kV), 500 megawatt (MW) HTS cable system (pictured) at Menzing substation in Munich. The cable's design is a three-phase cable in a single cryostat with low AC losses and fault current resilience.

A 6-month-long testing program, ending in 2025, will measure cryogenic heat losses associated with two different cooling designs and the cable's overall performance under different load conditions. Together, these tests will inform the design, construction, and operation of a 12- to 15-km-long HTS distribution cable that will run underground through the center of Munich. The HTS cable is attractive grid solution with three to five times more power at all voltages, giving utilities higher power transmission capacity for the same cross section with no added thermal loads and no electromagnetic field. Discussions with utilities and early indications from the recently initiated test campaign suggest that closed-loop cooling is what utilities will ultimately prefer.

Members of SuperLink at the commissioning event in October 2024 (Courtesy of KIT)

German manufacturers are beginning to see the gains HTS unlocks, as well, with two notable industrial projects, SuprAl and Rowamag. SuprAl is a permanent installation of a 600 m, 200 kiloamp (kA) busbar in an aluminum factory. The HTS busbar uses an almost 95% less electricity than conventional technology and cuts costs by nearly the same magnitude, leading to major orders of the technology. Rowamag, an HTS magnetic heater, is another industrial application of HTS in Germany showing similar improvements over conventional technology.

# Italy

Many projects were underway in 2024 across a variety of HTS applications in Italian universities and research institutions like TCP member Ricerca sul Sistema Energetico (RSE S.p.A), multinational collaboratives, and its growing industry of HTS tape manufacturers. As just one indicator of Italy's longstanding commitment to advancing HTS technology, Italy has invested €60 million of public funding into HTS research and development projects through its Innovative Research Infrastructure on Applied Superconductivity (IRIS) program, which currently supports nearly 40 fixed-term positions. While two-thirds of IRIS funding is supporting applications of HTS in scientific instruments, many of the country's most notable energy system projects are focused on HTS cables, including one of the most ambitious multinational HTS cable projects in not just Europe, but anywhere in the world: SCARLET.

SCARLET, or "**S**uperconducting **CA**bles fo**R** sustainable **E**nergy **T**ransition," is a five-year project (2022-2027) funded by the European Union with fifteen partners including this TCP's Operating Agent RSE S.p.A. and sponsors ASG Superconductor (Italy's largest superconducting manufacturer) and Nexans. SCARLET's goal is to develop and industrially manufacture superconducting cable systems–specifically HTS cables and

SFCLs–at the gigawatt level, bringing them to the last qualification step before commercialization. SCARLET's partners, including members of European industries and research organizations in the fields of material sciences, cryogenics, energy systems and electrical engineering, are working across six work packages, including three demonstrations of long-length onshore superconducting cable systems rated at 1–4 gigawatts (GW) per circuit, superconducting cables in liquid hydrogen, and a resistive SFCL module rated at 50 kV DC – 10 kA.

One of the biggest motivators of this project's goals–and virtually every other commercial installation of HTS in energy systems around the world–is the limitation of conventional technology to provide a service that only superconductors can. Offshore wind farms are moving farther from shore, making conventional AC cables inefficient due to energy leakage. High-voltage direct current (HVDC) systems are effective, but they require massive, costly converter platforms that cost approximately $1 billion and weigh 40,000 tons. SCARLET is developing cables that would shatter HTS cable length records at 50 to 250 km in length. These cables will transmit power directly at turbine output voltage, simplifying the system's overall architecture. Type testing is scheduled for 2028, and standardization efforts underway through France's International Council on Large Electric Systems (CIGRE).

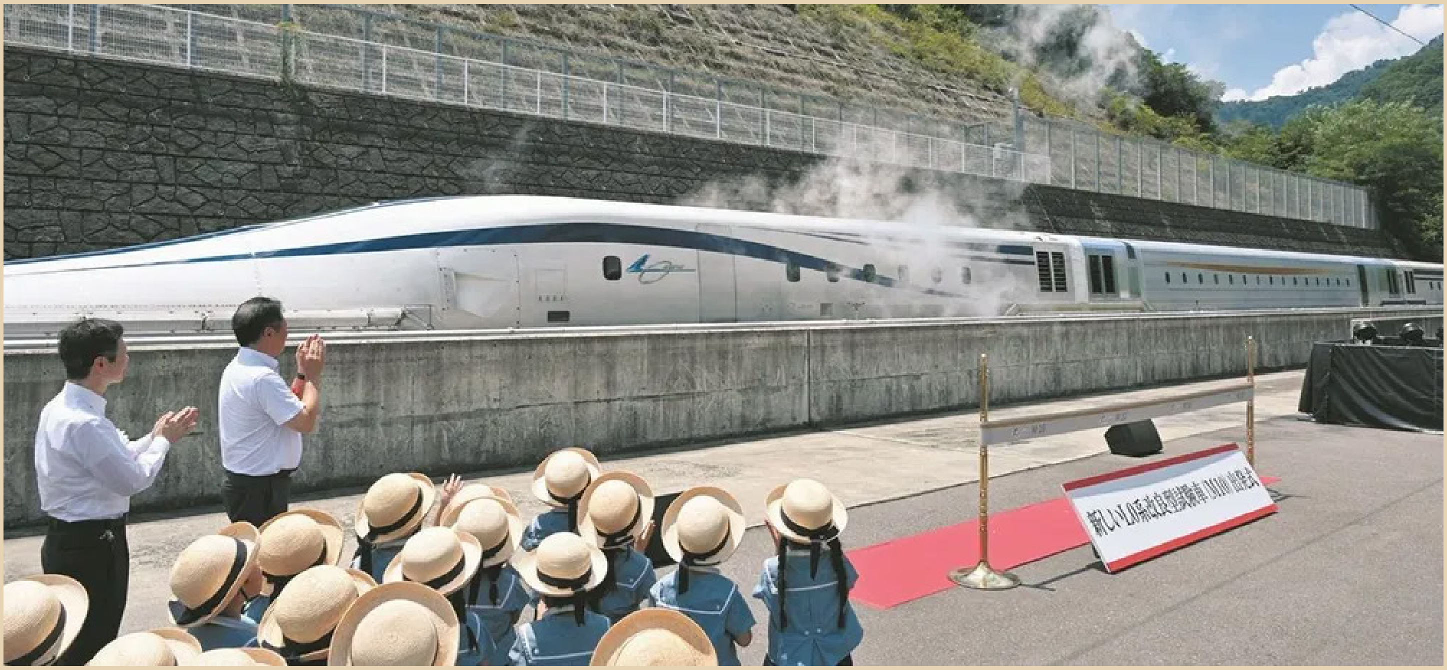
Other important activities in Italy to note are its work on developing standards and adding manufacturing capacity for producing HTS tapes. Italian representatives of this TCP (past and present) are playing instrumental roles in the establishment and advancement of international standards for superconducting materials and devices. The Italian alternate delegate and former Chairman of this are currently presiding over the Italian national mirror committee of the International Electrotechnical Commission Technical Commission 90 (IEC TC 90) Superconductivity as secretary and president, respectively. Together, they are leading 14 working groups responsible for voting and commenting on international and European standards for national adoption.

In manufacturing, a group from the Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA) founded Suprema, a new industrial-scale HTS tape manufacturer in July 2024. Suprema's goal is to become the largest European-based factory supplying 300 km per year of HTS tape (or 10% of global production capacity) by the end of 2027.

# Japan

Japan is one of the world's most influential countries in superconductivity, with a long history of pioneering research; high-quality manufacturing of HTS wire and magnets by companies like Furukawa Electric, Sumitomo Electric, and Fujikura; and major national demonstration projects, especially in the transportation sector. For instance, Japan's contracting party to the HTS TCP, the New Energy and Industrial Technology Development Organization (NEDO), began development on a 2 MW-class superconducting propulsion system for electric aircraft in 2024, while Toshiba also announced a partnership with Airbus UpNext in October to co-develop a superconducting motor for future hydrogen-powered aircraft. Much of Japan's large-scale HTS commercialization projects, though, were undertaken in its vaunted railway industry in 2024.

While the construction delay of the Chuo-Maglev-Shinkansen line between Tokyo-Shinagawa and Nagoya grabbed headlines in April, JR-Central began tests of the new M10 (L0-series) superconducting magnetic levitation (SCMALEV) trainset on the Yamanashi Maglev Test Line in July. The M10 is the first SCMALEV to use high-temperature superconducting REBCO-coated coils instead of LTS ones. It employs a riblet or "sharkskin" film to reduce drag, which reduces cooling needs, reduces weight, and consumes less energy than previous designs.



The first M10 (L0-Series) SCMAGLEV railcar (second car in the consist in yellow livery) is shown on the Yamanashi test line.

This SCMALEV system has been developed in Japan for over half a century with this TCP's Vice Chairman and his lab at the University of Tokyo contributing foundational research on superconducting magnets, magnetic-levitation/linear-drive systems, modeling, experimental studies, and system-level analysis – all which have contributed to the evolution of technology that has propelled the Yamanashi Maglev Test Line and its trains. Now, the technology is ready for practical use, and the current M10 test will verify the long-term operational stability of the HTS magnets.

Also in the rail sector, Japan's Railway Technical Research Institute (RTRI) conducted verification tests on a 100 m superconducting cable demonstrator at the Ohito substation on the Sunzu Line (Izuhakone Railway company) to test the transmission of both supply power for accelerating trains and regenerated power from braking trains, aiming to reduce energy loss and voltage drop. It is the world's first use of a superconducting feeder on a commercial line. This superconducting feeder powered over 30,000 trains  throughout the year, and results showed that the cables improved regeneration rates and energy efficiency significantly, which reduced substation capacity so well that railroads could consolidate or even reduce the number of substations along their lines, even if transportation capacity increases.

# Korea

The Korea Electric Power Corporation, Korea's largest electric utility and representative of Korea in this TCP, has long been a pioneer in superconductor experiments. In 2019, KEPCO introduced 23 kV triple-core HTS power cables into commercial grids for the first time. The line, manufactured by LS Cable & System, runs for 1 km between KEPCO's Shingal and Heungdeok substations in Yongin, South Korea, connecting their secondary busbars. Even though the superconducting cable was four times as expensive as conventional approach–which would have required the installation of an additional transmission cable and transformer–the HTS wire was selected because it could provide the same load-transfer capacity with fewer cables, and KEPCO could install cheaper conduits instead of constructing a cable tunnel. By using a small 23kV switching station instead of a larger 154kV substation, they were able to reduce overall costs. The project now serves as a key reference point globally for the industrialization of superconducting power transmission technology, and its success, along with advancements made by its in-house research institute, KEPRI, encouraged KEPCO to pursue more superconducting projects.

KEPCO is now investigating higher voltage (154 kV) AC and DC HTS cable systems, as well as a new “Superconducting Platform” concept for urban power supply. In 2024, KEPCO initiated the site selection process for this new concept with its newly planned MunSan Project, which will install two 1 km-long 23kV HTS cables that connect KEPCO’s Munsan and Sunyu substations just as the Shingal project does. KEPCO’s idea is to turn a large 154kV substation into a small, 23kV switching station, which would reduce the footprint they need in their densely populated urban site area by 90%, avoiding major construction costs and anticipated public objections.

These substation connection projects and other research that KEPRI is undertaking lays the groundwork and business models for KEPCO to develop more comprehensive superconducting-power infrastructure–not just cables, but potentially whole “superconducting grids” that combine compact substations, HTS cables, and fault-current limiters.

# United States of America

America’s superconductivity industry is experiencing a resurgence, especially in its manufacturing and fusion sectors where several new startups like VEIR have emerged in the past five or six years to join established incumbents like American Superconductor Corporation (AMSC). AMSC, which manufactured the world’s first HTS transmission cable to operate in the live grid, is also responsible for the development of the country’s only remaining commercial installation of an HTS cable. The Resilient Electric Grid system, installed and energized in 2021 by utility Commonwealth Edison, connects two substations in downtown Chicago, Illinois to bolster the city’s electrical grid against extreme weather and catastrophic events.

Now, more cable projects are underway in the United States. With funding from this TCP’s U.S. representative, the U.S. Department of Energy (DOE), Idaho National Laboratory (INL) and VEIR concluded the final year of a joint demonstration project in 2024 to deploy, test, and operate the capabilities of an overhead 4kV AC HTS power line with an open loop cooling system. In addition to advancing VEIR’s technology, the project established a new, permanent transmission line test bed at INL’s Obsidian Test Pad/Substation for demonstrating more advanced conductor and superconductor projects in the future. VEIR also partnered with National Grid, one of the country’s largest investor-owned utilities, to advise and comment on grid integration considerations as they develop their technology.

Designed for outdoor high voltage overhead grid distribution and transmission applications, this demonstrator line’s transmission capacity can reach up to 400 MW at 69kV, but VEIR plans for a final design that could reach several gigawatts at transmission level voltage. The overhead powerline configuration with an open-loop cooling system distinguishes VEIR’s approach from previous HTS cable designs, which use complex, closed loop, active nitrogen cooling systems that limit their use to short-distance, underground applications. VEIR’s design is an open loop, “passive” cooling system that uses a proprietary distributed evaporative liquid nitrogen system that delivers twenty times the cooling power per kilogram of liquid nitrogen coolant.

Pictured: VEIR's HTS AC cable demonstrator

In October, VEIR was selected to receive another competitively awarded grant from DOE to advance its technology further. Selected through DOE's Grid Deployment Office Grid Resilience and Innovation Partnerships Program, VEIR won a $31 million Smart Grid Grant with funding from the U.S. Congressional Infrastructure Investment and Jobs Act of 2021. The funding will support VEIR's Access Clean Energy with Superconductors project, which will deploy a 3.7-mile-long version of their overhead HTS power line in Eaton County, Michigan to connect a utility-scale solar facility to the grid. The HTS line will increase transfer capacity within the existing right of way by more than five times compared to conventional conductors operating at the same voltage, helping planners avoid the installation of a larger conventional transmission line that would require a new right of way. For a country where new transmission line right-of-way applications face considerable public opposition, siting, and permitting barriers, this advance of HTS is very compelling–especially when over 10,000 renewable energy projects are waiting to receive permission to interconnect with America's grid.

DOE also funded several other HTS projects in 2024 through DOE's Advanced Research Projects Agency–Energy (ARPA-E). In recognition of ARPA-E's contention that widely available low-cost HTS tapes could enable broader usage in energy-related applications with major implications for the energy transition, ARPA-E issued funding to three groups in 2024 to stimulate innovative manufacturing processes of high-performance, rapidly produced superconducting tapes. With the goal of reducing manufacturing costs to less than $10/kA-m, DOE awarded funds to the University of Houston, High Temperature Superconductors (HTSI), and MetOx to improve their manufacturing methods and render higher-quality HTS tapes at faster production speeds and lower costs.

# France

While not a member of this TCP, France has a bevy of manufacturers, grid operators, research institutions, and other industries who are working to advance grid applications of HTS. The highest profile, large-scale application of HTS in France is the SuperRail project, the world's first HTS DC cable system for railway traction that is a milestone for superconducting infrastructure in urban transportation. Funded by the French government as part of France 2030, this project was commissioned by SNCF Réseau for Nexans (a sponsor of this TCP) and other partners to install two superconducting DC cables near Montparnasse station in Paris. SNCF Réseau turned to HTS cables because all of the existing conduits for transmission cables were at capacity. Due to the station's location in the heart of Paris, SNCF Réseau had no other choice but to deploy HTS cables. These 60 m HTS DC cables, rated at 1.5 kV and 3.5 kA, are manufactured from 2G REBCO tape and designed to handle 67 kA for 200 millisecond short-circuit events. Construction is well underway in 2024, with commissioning expected later in 2025.

Nexans installs its HTS cable at Montparnasse Station in Paris

# China

Also not a member of the HTS TCP, China is rapidly ascending into a significant force in the global superconductivity industry, particularly in manufacture and commercial installation of HTS. SuperMag Technology (Shanghai) Co., Ltd. and especially Shanghai Superconductor Technology Co., Ltd. (SST) grew significantly in 2024, producing HTS wires and cables for high-field fusion magnets, large-scale power-transmission cables, SCMAGLEV trains, and advanced scientific instruments. Shanghai Superconductor, which uses a pulsed laser deposition manufacturing technique, is in the middle of three-year expansion plan. SST upgraded its initial factory in 2023, finished construction of a second factory in Shanghai's Kangqiao industrial park this year, and will build a third factory in Hefei next year that will elevate SST's total production capacity from 700 km/year in 2023 to 3,000 km/year by the end of 2026.

China is also home to the world's commercial installation of a transmission voltage (160Kv DC) resistant SFCL on Nan'ao Island, where it has operated since 2020 to enhance grid reliability and resilience. China also energized two, triaxial HTS distribution cables in Shenzhen and Shanghai in 2021, and their operational success helped initiate conversations in 2024 for a 5 km cable, which if commissioned, would become the second-longest HTS cable in the world. In 2023, CRCC Changchun Railway Vehicles Co. Ltd. completed China's first test run of a superconducting maglev train that could someday reach speeds of 1,000 kilometers per hour (in a low vacuum tunnel).

# TCP Working Arrangement

The Task Managers are based in the United States and work closely with the Presidium and ExCo to execute on the duties in their annual work plan. Operation of the HTS TCP is supported by a combination of cost-, task-, and knowledge-sharing. ExCo members have historically covered their own travel expenses to attend ExCo meetings and industry workshops. The expenses associated with the operation of the HTS ExCo, including the task manager's time and travel and other joint costs of the ExCo, are met with a Common Fund to which all HTS TCP members contribute. The fee structure is 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.

## Alignment with IEA Mission, Objectives, and Shared Goals

TCP members recognize that power sector applications of HTS technologies are approaching a critical threshold, where sufficient manufacturing volumes are beginning to stabilize, mature, and improve, which is helping many grid components move favorably along the technological readiness scale. By promoting this message and the ones that follow in a more strategic and high-profile manner, the TCP anticipates its efforts will persuade utilities and other laggards to adopt HTS technology in electric grids more rapidly than ever before, especially as HTS diffuses and succeeds in other sectors.

The increased efficiency with which HTS technology can transmit energy clearly ***Increases the Efficiency of the Energy System*** directly. Additionally, HTS components require far less copper, critical minerals, and material overall than conventional technologies, thereby ***Avoiding Environmental Impacts*** almost altogether and allowing HTS to minimize or almost decouple its viability from that of critical mineral ***Supply Chains*** that IEA is working to secure. To illustrate these advantages even further, the width of electric transmission corridors could be shrunk with HTS cables from hundreds of feet to just a few meters.

HTS technology also helps IEA's ***Ensure Energy Security*** goal, not only by improving the resilience of electric grids with additional redundancy options and fault current protections, but also by enabling the co-delivery of different forms of energy in the same pipeline (e.g. electricity and liquid hydrogen) and the delivery of higher-level electrical currents within distribution grids responding to new distribution demand such as electric vehicles, grid-interactive buildings, and other artifacts of electrification. Considering a longer period, HTS technologies can also contribute to high-level DC voltage in international DC links or connecting large renewable power plants. These advantages help HTS improve grid flexibility, ***Diversify Energy Sources***, and significantly facilitate the connection of new renewable energy capacity, thereby ***Advancing Energy Transitions*** and ***Promoting Clean Energy*** simultaneously. This outcome is especially anticipated after 2030, when HTS components should reach the commercialization phase and become a "technology enabling the use of renewables to reach the decarbonization" in line with the REWP Strategic Plan 2022-2025 and *Net Zero by 2050 – A Roadmap for the Global Energy Sector*.

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# ABOUT THE IEA TCPs

## The International Energy Agency (IEA)

At the heart of the global dialogue on energy security and clean energy transitions, IEA is the world's leading energy authority. IEA works with governments and industry to shape a secure and sustainable energy future for all. It provides reliable and comprehensive data, analysis, and policy recommendations with the goal of shaping a secure, sustainable, and affordable energy future for all while meeting the climate change objectives of the 2015 Paris Agreement.

The IEA was founded in 1974 to ensure the security of oil supplies. Energy security remains a central part of its mission, but today's IEA has a wider mandate. In 2015, the IEA's Ministerial Meeting approved the modernization strategy presented by the Agency's newly appointed Executive Director, Dr. Fatih Birol, to strengthen and broaden the Agency's commitment to energy security beyond oil, to engage with major emerging economies, and to provide a greater focus on clean energy technology, including energy efficiency.

Today's IEA focuses on a full range of energy issues, including climate change and decarbonization, energy access and efficiency, investment and innovation, and ensuring reliable, affordable and sustainable energy systems. It examines the full spectrum issues including renewables, oil, gas and coal supply and demand, energy efficiency, clean energy technologies, electricity systems and markets, access to energy, demand-side management, and much more.

Since 2015, the IEA has opened its doors to major emerging countries to expand its global impact, and deepen cooperation in energy security, data and statistics, energy policy analysis, energy efficiency, and the growing use of clean energy technologies. This “open door” policy has since allowed the IEA to deepen its collaboration with 13 new countries through the Association programme: Argentina, Brazil, China, Egypt, India, Indonesia, Morocco, Thailand, Singapore, South Africa, and most recently, Ukraine, which joined in 2022, and Kenya and Senegal, which joined in 2024. This IEA family of members and association countries now represents over 80% of global energy consumption, up from 40% in 2015.

IEA member governments agreed to further expand the Agency’s mandate at the Ministerial Meeting of March 2022, to guide countries as they build net-zero emission energy systems to comply with internationally agreed climate goals, and to broaden the Agency’s scope to include the critical minerals and metals needed to develop clear energy technologies.

## The Technology Collaboration Programme

The Technology Collaboration Programme is a multilateral mechanism established by the International Energy Agency that was created with a belief that the future of energy security and sustainability starts with global collaboration. The programme is made up of thousands of experts across government, academia and industry in 55 countries dedicated to advancing common research and the application of specific energy technologies.

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.

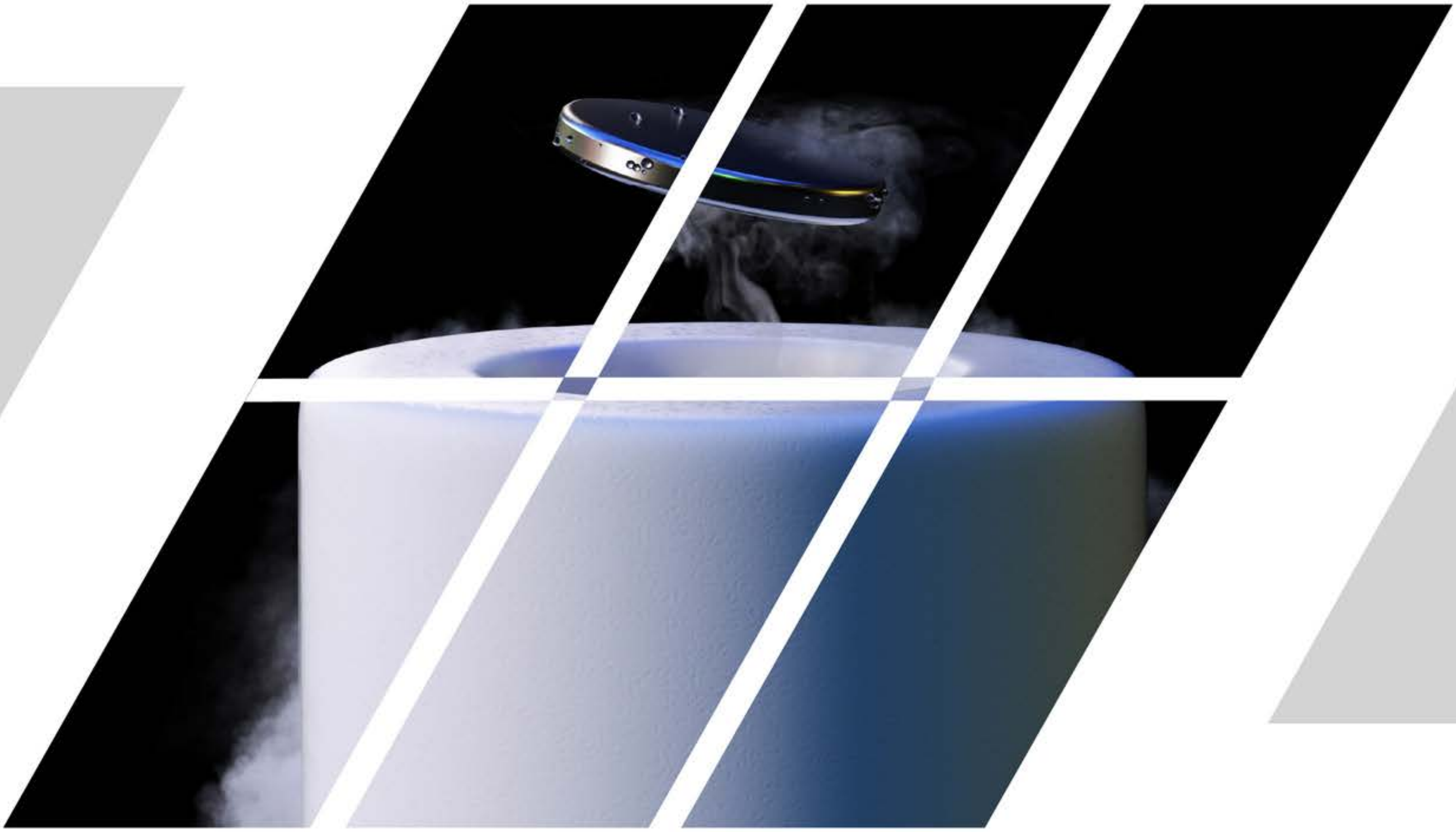
The breadth of the analytical expertise in the Technology Collaboration Programme is a unique asset to the global transition to a cleaner energy future. These collaborations involve over 6,000 experts worldwide who represent nearly 300 public and private organizations located in 55 countries, including many from IEA Association countries such as China, India, and Brazil.

Currently there are 38 individual technology collaborations working across several technology or sector categories: energy efficiency end-use technologies (buildings, transport, industry and electricity), renewable energy and hydrogen, fossil energies, fusion power, and cross-cutting issues.

## Disclaimer

The HTS TCP is organized under the auspices of the IEA but is functionally and legally autonomous. Views, findings, and publications of the HTS TCP do not necessarily represent the views or policies of the IEA Secretariat or its individual member countries.

International Energy Agency



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