DOE SBIR/STTR SUCCESS

Close-up of the CORC® cable made from individual tapes of second generation high-temperature superconductor REBCO.

ADVANCED CONDUCTOR TECHNOLOGIES

High-temperature superconductor (HTS) cables offer a potential breakthrough for developing a lower cost path to fusion energy, as well as for the next generation of proton-proton colliders. Current fusion and accelerator magnets are built using low-temperature superconductors (LTS) made of Nb-Ti and Nb_3Sn, in which superconductivity breaks down not far above the temperature of liquid helium (4.2 K) and at relatively small applied fields of nearly 16 T. In Fusion Energy applications, limitations in current vs. magnetic field characteristics of LTS result in very large reactor structures like ITER and in associated costs in the range of tens of billions. Because HTS can sustain much larger operating currents at higher magnetic fields than LTS, HTS cables can be used to produce fusion magnets generating fields of over 20 T in a much smaller machine.

FACTS

PHASE III SUCCESS
Three years from the end of its first SBIR award Advanced Conductor Technologies has achieved a sales revenue of over $0.5M, including several purchases by LBNL to build the first CORC®-based accelerator magnet.

IMPACT
Advanced Conductor Technologies' CORC® cable will enable magnets producing fields of 20 T and above for the next generation fusion reactors, research and medical particle accelerators.

DOE PROGRAMS
Fusion Energy Sciences (FES), High Energy Physics (HEP).

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A higher magnetic field means that the fusion plasma can be confined to a much smaller region, enabling fusion reactors many times smaller than ITER with equal fusion power, and considerable cost saving. Similarly, HTS cables can significantly increase the performance of future accelerator magnets beyond what is currently possible with LTS.

The discovery of HTS materials including $YBa_2Cu_3O_{7-x}$ (YBCO) in 1987 and later REBCO (where RE = rare earth replaces yttrium) launched a tremendous excitement in the scientific community. In HTS, superconductivity persists at temperatures well above that of liquid nitrogen (77 K), for current densities in excess of 10,000 A/mm^2, and for applied magnetic fields of the order of 100 T. Given these remarkable figures, it seemed inevitable that REBCO-based cables would rapidly replace LTS cables. Nevertheless, due to complicated materials science issues related to anisotropy of shape and transport properties, and current-degrading grain boundary effects, REBCO conductors have had great difficulty in displacing LTS conductors in applications such as the Tevatron, the Large Hadron Collider (LHC), ITER, and within the private sector, in MRI and NMR magnets. REBCO wires composing a cable are usually referred to as tapes because of their rectangular cross section, which originates from the fact that the brittle superconductor has to be deposited as a single crystal-like film on a metal-based substrate through a complex multilayer, hetero-epitaxial technology. REBCO tapes are also known as coated conductors or 2nd generation HTS wires.

Due to the issues listed above, Bi-based 1st generation HTS materials (so called Bi-2212 and Bi-2223 materials) with much larger grain boundary connectivity and more straightforward wire processing, but with overall lower performance have been recently pursued to replace LTS conductors. However, because of the vast electronic anisotropy of both Bi-based compounds, the complex high-temperature reactions needed to form the superconducting state, and their relative low strength, neither conductor has provided a practical path to high-field magnets. The ability of depositing REBCO on strong metal substrates to introduce the biaxial texture needed for current transfer between grains means that this material enables a straightforward path to produce magnets of 30 T at temperatures up to 55 K. Due to helium shortages and recent price rises, there is great interest in a liquid helium-free, cryocooler-driven superconducting magnet technology capable of producing fields over 3-15 T and operating in the 20-60 K temperature range.

The outlook for a widespread application of REBCO cables has completely changed beginning a few years ago thanks to the level of industrial maturity HTS has reached and to the innovative work of Advanced Conductor Technologies LLC, a high-tech small business founded by President Danko Van der Laan in 2011. Having performed R&D in superconducting cable technologies for many years while working at the University of Colorado Boulder and at the National Institute of Standards and Technology (NIST), Dr. Van der Laan realized that, starting in 2011, REBCO tapes had reached adequate performance and mechanical strength to implement an innovative cable assembly out of a multitude of REBCO strands. Dr. Van der Laan’s insight evolved in the invention of the Conductor on Round Core (CORC®) cable technology, which allowed him and his team to solve the main complication affecting REBCO cables and holding up their employment—precisely, the extreme difficulty involved in fabricating REBCO tapes in the ideal configuration for a versatile, flexible conductor, which is round, multifilament, and strong, in order to minimize ac losses and sustain the large Lorentz force generated at the large operational magnetic fields. The CORC® technology involves a series of proprietary engineering solutions to enable winding and transposing the individual tapes around a small former, which is necessary to sustain the high stresses imposed by the magnet design, without causing a degradation in the tape's performance under recurrent cycling. "CORC® cable technology opens the door for rapid development of the next generation of high-field accelerator magnets using REBCO" stated Dr. Van der Laan during an interview by the Department of Energy's (DOE) SBIR Office.

DOE funded R&D of 2nd generation HTS wires and cables until 2010 at several of the DOE's National Laboratories, hosting annual peer review meetings in Washington D.C. At one of these meetings Dr. Van der Laan learned about a major interest from the Department of the Navy in REBCO cables in order to develop dc power transmission for confined environments such as Navy ships using helium gas as a coolant. In these environments, but also for instance in data centers, an equivalent 10 MW station built with Cu cables would be prohibitive because of intolerable size/weight or amount of heat generated. In the same venue, Dr. Van der Laan learned about the SBIR Program as a suitable route to fund a prototype REBCO cable. Advanced Conductor Technologies LLC was thereafter founded in response to various SBIR calls for the development of 2nd generation HTS cables posted by the DOE, the Air Force Research Laboratory, and the U.S. Navy.

Among the SBIR Phase II projects funded by DOE, the most challenging have been those targeting the development of new accelerator magnets. "These applications", explains Dr. Van der Laan "are the most demanding because they require pushing cables' operation to the highest magnetic field possible while still sustaining a current density of 400-600 A/mm^2, a factor of 5-10 higher than required for fusion magnets." In addition, accelerator magnets require very tight bending diameters of 3-6 cm; therefore, the conductor needs to be very flexible. These requirements induced Dr. Van der Laan to encourage fabrication of higher performance REBCO tapes with reduced substrate thickness from his vendor SuperPower Inc., one of the major coated conductor manufacturers, which, together with American Superconductor Corporation successfully acquired the coated conductor technology from the DOE's National Laboratories (Particularly LANL and ORNL) in the timeframe from 1998 to 2010, and subsequently perfected it further.

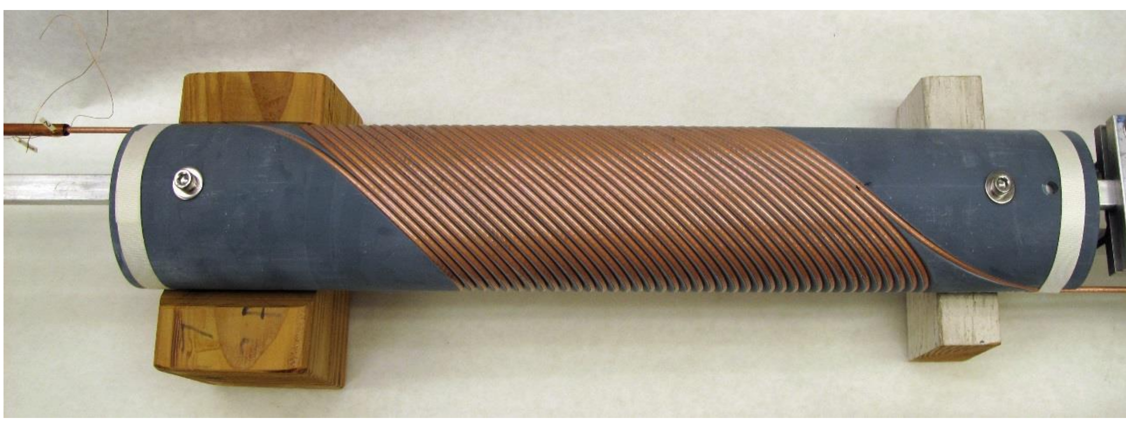
In addition to having developed CORC® with the help of SBIR grants, Advanced Conductor Technologies is presently using its highest performance CORC® cable to actually build a new accelerator magnet in collaboration with Lawrence Berkeley National Laboratory (LBNL). The magnet will operate first at 15 T and subsequently at 20 T.

Advanced Conductor Technologies' cabling method has kept ahead of the competition and the company works hard to protect its IP and constantly improve its product's performance to continue stay ahead of the game. Customers for CORC® cables include not only government facilities funded by the Fusion Energy Sciences (FES) and High Energy Physics (HEP) Programs, but also international clients, including CERN (the European Organization for Nuclear Research) and private industries that seek to develop high-field magnets for medical applications, rotating machines such as generators for wind mills, or high energy density power transmission and degaussing systems, which include not only cable development in itself but also the complex cryogenic interface and current leads engineering that makes up the whole system.

Advanced Conductor Technologies' business model does not involve licensing its technology to others, but instead, seeks to fabricate and sell products manufactured in the company's 3000 sq. ft. R&D and manufacturing facility in Boulder, Colorado.

Different aspects of Advanced Conductor Technologies' cable development have been carried out through 4 Phase II grants from DOE's HEP and FES Programs in the period from 2013 to 2017. Since its first DOE Phase II award funded by FES, Advanced Conductor Technologies has achieved a revenue from sales of over $0.5M, including purchases by LBNL of a 50 meter long and a 75 meter long CORC® wire, the latter showing the highest performance achieved to date. This purchase is particularly significant because it represents a Phase III from a DOE National Laboratory following SBIR awards from fundamental science programs within the DOE's Office of Science. Advanced Conductor Technologies has succeeded in developing a REBCO cable with unmatched performance, and currently, there are no other sources for this type of conductor. LBNL is using the CORC® wire to wind accelerator magnets through a technique known as canted cosine theta (CCT) as part of the Magnet Development Program (MDP) initiated by the DOE's HEP Program. The magnets LBNL is building will be the first CCT accelerator magnets wound from high-current REBCO conductor, and together with other MDP goals will position the U.S. for leadership in the development of the next generation high energy proton-proton colliders and, in the nearer term, establish a technology base for an energy upgrade of the LHC.

In addition to the next generation of High Energy Physics magnets and practical fusion magnets, Advanced Conductor Technologies' superconducting magnet cables with large current density at 20 T, and bendable to diameters less than 30 mm will enable the next generation of proton cancer treatment facilities, scientific magnets, and benefit superconducting magnetic energy storage systems for use in the power grid and for application within the Department of Defense. Dr. Van der Laan has filed a number of successful patent applications related to the CORC® cable technology and received multiple awards including a 2011 R&D 100 Award.



A single layer of the CCT magnet wound using CORC® wire at LBNL

Written By Claudia Cantoni, Commercialization Program Manager, DOE SBIR/STTR, May 2018.