Superconductivity for Electric Systems 2006
Project Summary

PROJECT TITLE:	Scale-up of 2G HTS Wire Manufacturing at American Superconductor
ORGANIZATION:	American Superconductor Corporation
PRESENTERS:	Steven Fleshler, Alexis Malozemoff and Martin Rupich
FY 2006 FUNDING:	$ 1,000,000

Project Purpose and FY 2006 Objectives: The goal of this project is to develop the technology for the low-cost manufacturing of 2G HTS wire for commercial and military applications. Essential elements of this program include: 1) achieving high performance wire above the commercial threshold for applications, 2) developing a low-cost, high production rate, continuous process for manufacturing 2G wire, 3) producing and providing wire for prototype applications and 4) qualifying a Pilot Production facility as part of the DOE and DOD Title III partnership.

American Superconductor Corporation has developed a high throughput, reel-to-reel process based on a RABiTS^{TM} template and a Metal Organic Deposition (MOD) process for the HTS layer. These processes were selected since they are amenable to the processing of wide strips, which is essential to the low cost manufacturing. To address the DOE milestone of 500 A/cm-width performance needed to achieve broad market penetration and consistent with the overall strategy of developing a low cost manufacturing technology, AMSC has focused this program on achieving high performance while minimizing the thickness of the YBCO layer in order to minimize manufacturing and capital equipment costs. AMSC's wide strip process is designed to produce 2G wire at very low cost. Multiple industry standard 4.4 mm wide wires are produced in a single manufacturing pass by slitting the wide strip to narrower width in the last stage of the manufacturing process. The wires are then laminated with copper, stainless steel or other material chosen to tune the properties of the wire for a specific application. The laminated, 4.4 mm wide wires are known as "344 superconductors." AMSC's approach to 2G development is designed to first achieve reproducible, high performance in 4 cm wide strips over 100 m on a Pre-Pilot process line of converted R&D equipment and then to scale-up capability for 1000 m lengths once its Pilot production facility comprised of full-scale manufacturing equipment is fully qualified.

Objectives for government FY 2006 were as follows:

- R&D demonstration of 500 A/cm-width at 77K, self field in 344 superconductors
- Regular production of 100 m lengths of 344 superconductors with 100 A performance
- Manufacturing output of 344 superconductors exceeding 1,000 m/month
- Order full-scale manufacturing equipment for the pilot manufacturing operation – stay on track for 300,000 m/year capacity of 344 superconductors in December 2007
- Full-scale substrate production equipment on-line for the pilot operation
- 1 T coil demonstration at 77 K (contingent on funding)

FY 2006 Performance and FY 2007 Plans: Plans and expectations for next government fiscal year are:

1. Improve Performance: Optimize the HTS coating, decomposition and reaction processes using the AMSC nanodot technology
   Expectation: 5 m demo of 150 A in 4.4 mm wire
2. Continue Manufacturing Scale-Up: Procure, install and commission additional full-scale production equipment. Demonstrate parity, or enhanced performance, of individual process compared with the equivalent Pre-Pilot process as measured by the key output variables.
   Expectation: Qualify 70% of full-scale manufacturing equipment for the pilot operation
3. Practical Conductor Favorable for Applications: Develop and sell wire according to customer requirements. Modify wire when necessitated by feedback from customer testing.
   Expectation: Sell 10,000 m of 344 superconductors for development of HTS power equipment
   Optimize prototype FCL wire

FY 2006 Results: Highlights of key accomplishments for this past year include:

<u>High Performance</u>

- *Approximately 500 A/cm-width in an MOD-based YBCO layer achieved over short length of 4 cm wide strip.* The strip was processed as a continuous length (4 cm width) through the HTS reaction step then cut into smaller segments for characterization.

- R&*D demonstration of high performance simultaneously in the H || ab orientation and H || c orientation using rare earth nanodots.*

Manufacturing Scale-Up

- *Regular100 m runs of 4 cm wide strip commenced in September2005 with Pre-Pilot output exceeding 1000 m per month.* This Pre-Pilot capacity feeds internal development needs in addition to sales to customers for applications development. AMSC exceeded its corporate goal of delivering in excess of 2500 m of 344 superconductors to 19 customers in eight countries through March 2006.
- *Full-scale substrate manufacturing equipment installed in AMSC's HTS wire manufacturing plant in Devens, MA.* The equipment includes a rolling mill, a vapor degreaser to remove lubricants and production length furnace for texture annealing Ni-W strips.
- *All major pieces of full-scale equipment for the Pilot operation are specified and ordered to stay on track for qualifying the Pilot operation in December 2007.*
- *Projected annual capacity of the Pilot operation increased from 300,000 m to 720,000 m based on production rate improvement.* Key production rate improvements include higher reaction rates achieved in the full-scale HTS reaction furnace, proof-of-principle for faster decomposition rates through modifications to precursor chemistry and sequential deposition of YSZ and CeO_2 in a single line,

Conductor Properties Engineered for Specific Application

- *344 superconductors with stainless steel cladding ("344S") developed for Fault Current Limiter applications.* AMSC's lamination process provides versatility to tailor the stabilizer for specific application requirements. Utilizing stainless steel lamination provides a high resistance stabilization layer necessary for achieving low fault currents under a short circuit situation.
- *Wire with enhanced c-axis strength tested for use in rotating machines for shipboard applications.* Certain HTS rotating machine designs subject the wire to large *c*-axis or transverse stresses and strains due to differential thermal contraction with the support structures. AMSC's lamination process, the dimensions of the laminate and the laminate alloy have been designed to increase the c-axis tensile stress limit above that of 1G HTS wire and customer specifications.

Research Integration: A broad collaboration with the Wire Development Group (comprising AMSC, ORNL, LANL, ANL, and Applied Superconductivity Center formerly at University of Wisconsin) is focused on establishing the fundamental physics and materials science for 2G HTS wire technology particularly with regard to understanding and overcoming barriers to high performance. A strong interaction with ORNL covers the development of new technology for low-cost and improved properties for the RABiTS^{TM} template (substrate and buffer layers) as well as trouble-shooting obstacles in the manufacturing process. These programs are described in detail in separate DOE program elements. In addition, AMSC has leveraged the DOE 2G HTS wire funding by developing partnerships with a broad array of government laboratories, universities, and commercial entities who provide key wire characterization, testing and feedback, to confirm performance and enable further process improvements.