Organization: Oak Ridge National Laboratory

Project Title: Superconductivity Market Forecasting

Presenters: Ben McConnell (ORNL) and Tom Sheahen (SAIC)

FY 2001 Funding: $125K

Preamble: Because this project has not previously been peer-reviewed, it is appropriate to summarize its background and origins briefly:

During 1997-1999, Joseph W. Mulholland was on the DOE staff; he has since become the Executive Director of the Arizona Power Authority. During his tenure at DOE, Joe recognized the power inherent in the *Excel* software, and created a model of how HTS devices might enter the market over time and become part of the American electrical grid. Joe's excellent knowledge of the national utility system formed the cornerstone of that model. Aided by Ben McConnell of ORNL and Tom Sheahen of SAIC on details of superconductivity and HTS devices, Joe carried the model forward to a remarkable degree of success. By the end of 1999, what we now term "the Mulholland Model" was able to provide an estimate of the way HTS devices would penetrate the market over the next 20 years. The model was described in a draft document entitled "Analysis of Future Prices and Markets for High Temperature Superconductors," which was first circulated in March 2000. The first presentation of the "Mulholland Model" was given by Tom Sheahen at the Wire Development Workshop in February 2000. Although it was stressed at the time that the model is primarily a *tool* for others to adapt and run using their own assumptions, the fact is that most listeners only *heard* the results of the single test case that Mulholland et al had run to illustrate the model's capability. The more fundamental point about the versatility of the model was missed. Soon thereafter it was recognized that there was a lot of work ahead to achieve the goal of making the model truly accessible to other analysts, who should be free to introduce their own assumptions. There was no activity specifically dealing with the Mulholland Model during the remainder of 2000.

Project Purpose and FY 2001 Objectives: The objective of this work is to make the Mulholland Model accessible by any analyst wishing to explore future markets for HTS devices. The subordinate steps are to a) check and revise as needed the Mulholland market analysis methodology, b) identify the pathways for the data analysis in the existing spreadsheets, c) provide written descriptions that will enable others to use this methodology, and d) revise the spreadsheet and rewrite the report wherever necessary. The underlying research objectives of the original modeling effort remain and are threefold:

- First, to develop a method of modeling markets and performance that allows analysts to make estimates about the future of HTS technology;
- Second, to project the savings in electric energy and estimate the monetary value associated with HTS electric power and energy savings;
- Third, to compare the monetary savings attributable to high temperature superconductors to projected costs of HTS devices, in order to refine the estimates of future HTS markets.

Necessarily, there are limits to the scope. Primarily, the study addresses the use of HTS technology for only the following electrical devices: (1) Motors greater than 500 horsepower, (2) Generators greater than 100 MVA, (3) Transformers greater than 20 MVA, and (4) Transmission cables at intermediate-level voltages. Specifically, this effort calculates the savings based on the assumption that high temperature superconductors will be used in the above electrical devices for the years 2000 through 2025 and includes only electrical energy, sales, and HTS production in the United States. This analysis leads to calculated projections of the following: Cost of HTS wire, Amount of HTS wire required, Production dollar volume versus cost, Cost of cryogenic devices, Sales market for cryogenic devices, Sales market for HTS devices, Energy savings by device, and Emission savings.

FY 2001 Performance and FY 2002 Plans: These activities began from the draft version of the Mulholland report (March 2000). Even in 1999, the Mulholland model had confirmed that cryogenics would be a very important part of any practical application of HTS devices. Accordingly, the results of cryogenic workshops of 1998 and 1999 were developed into the *Cryogenic Roadmap*. During FY 2001, a final version of the *Cryogenic Roadmap*, as well as a *Cryogenic Implementation Plan* have been produced. A revised "Mulholland Report" (i.e., "Analysis of Future Prices and Markets for High Temperature Superconductors") that updated the market forecasting methodology was also completed. The model has been given to external analysts who are to conduct "beta tests" in order to find out experimentally if the model is truly portable.

2002: An extension of the methodology is planned for FY 2002. The revisions will include separate models for each device, hybrid cooling concepts, a natural feedback loop between the conductor and device performance, and appropriate scaling laws for device sizes. Feedback from beta tests of the present *Excel* model will be included when making these revisions.

FY 2001 Results: A clearer organization of the model was paramount. The *Excel* spreadsheet workbook inputs are now on distinct sheets (*assumptions, database, results, graphs*). Hidden assumptions (such as built-in constants) have been identified and placed on the *assumptions* spreadsheet. The *database* spreadsheet now contains EIA national energy projection out to year 2025, and the model has been extended to run to 2025. More important, that data is easily accessed and changed by any other analyst. The market analysis report has been rewritten. As one example of more accessible assumptions: The market penetration characteristics were examined for each technology and adjusted to reflect reasonable market entry dates and percent of market. Anyone else can change those assumptions easily now.

The major parameters that are input to the model (and that require the analysis's judgment) are: HTS wire cost and current carrying capability, the cryogenic capital cost (per kilowatt of cooling capacity), and the cryogenic cooler efficiency (as a percent of Carnot efficiency). There is a feedback-loop --or interaction -- among estimates for markets for HTS devices, HTS wire cost and J_e, and the cost and efficiency of cryogenic refrigeration. At present the cryogenic feedback loop is built into the model, but the wire-performance feedback must be done by hand.

A strong trade-off exists between the cost and performance of the cryogenic system and the breakeven cost of the HTS conductor; e.g., under our set of input assumptions, HTS wire break-even cost increases \$5.45/meter for every 1.0% of Carnot increase in efficiency of cryocoolers; and HTS wire break-even cost increases \$3.44/meter for every \$1000/kW_{hot} decrease in capital cost of cryocoolers. Employing reasonable assumptions and engineering judgment within the model indicates the following: 1. Of the total energy flowing through the U.S. national electrical grid, slightly under 3% can be saved via HTS devices; 2. Full penetration of utility markets by HTS devices will be at least 20 years in coming; 3. Not surprisingly, R&D is still needed to improve cryogenic efficiency and wire performance, and to reduce HTS wire and cryogenic cost.

Research Integration: Collaboration with other projects (both analytical and specific device designs) was very valuable in providing guidance and inputs to these calculations. The greatest variability in results of the market model is due to certain input data – specifically, the manner in which the performance of each device is calculated as a function of size, wire and cryogenic performance. Understandably, the industrial partners of the SPI projects hold technical details company-confidential. We hope that in the coming year, and during the beta testing phase of the spreadsheet model, ways can be found to accommodate the principle of confidentiality and still obtain accurate input data for key elements of the Mulholland Model.

T. P. Sheahen, B. W. McConnell, and J. W. Mulholland presented the paper entitled "Analysis Method for Estimating Future Markets for HTS Power Devices" at the Applied Superconductivity Conference in September 2000.