Superconductivity Market Forecasting

Presented to the 2001 HTS

Superconductivity Peer Review

August 2, 2001

by

Ben McConnell – ORNL

Tom Sheahen – SAIC

Background

- The Mulholland Model
  - During 1997-99, Joe Mulholland developed an Excel spreadsheet model characterizing how over time HTS power devices might enter the market.
  - Without Joe's work, we would not have the basic model.
- A draft report was completed in March 2000.
- Model was first presented at the 2000 Wire Development Workshop.
- ***Results*** dominated the discussion
  - *not* the ***model's versatility*** as a *tool for forecasting* needs and directions for research and development.

Project Purpose and FY 2001 Objectives

- Objective – Make the model accessible and easy to use for other analysts.
- Steps to the Objective –
  - Check and revise the methodology as needed,
  - Identify data and analysis pathways in the existing spreadsheets,
  - Provide written descriptions of the analysis methods,
  - Revise the spreadsheets and rewrite the draft report where necessary.

Original Project and Modeling Objectives (1997-1999)

- Develop a method of modeling markets and performance that allows estimates of the future markets for HTS technology.
- Project energy savings and the associated monetary value of power and energy savings.
- Compare the savings projected for HTS power devices to the estimated costs of HTS power devices.
- The model **does not attempt to assign value to benefits other than <u>energy savings</u>**; e.g., power density, longevity, safety etc.

Project Scope and Limitations

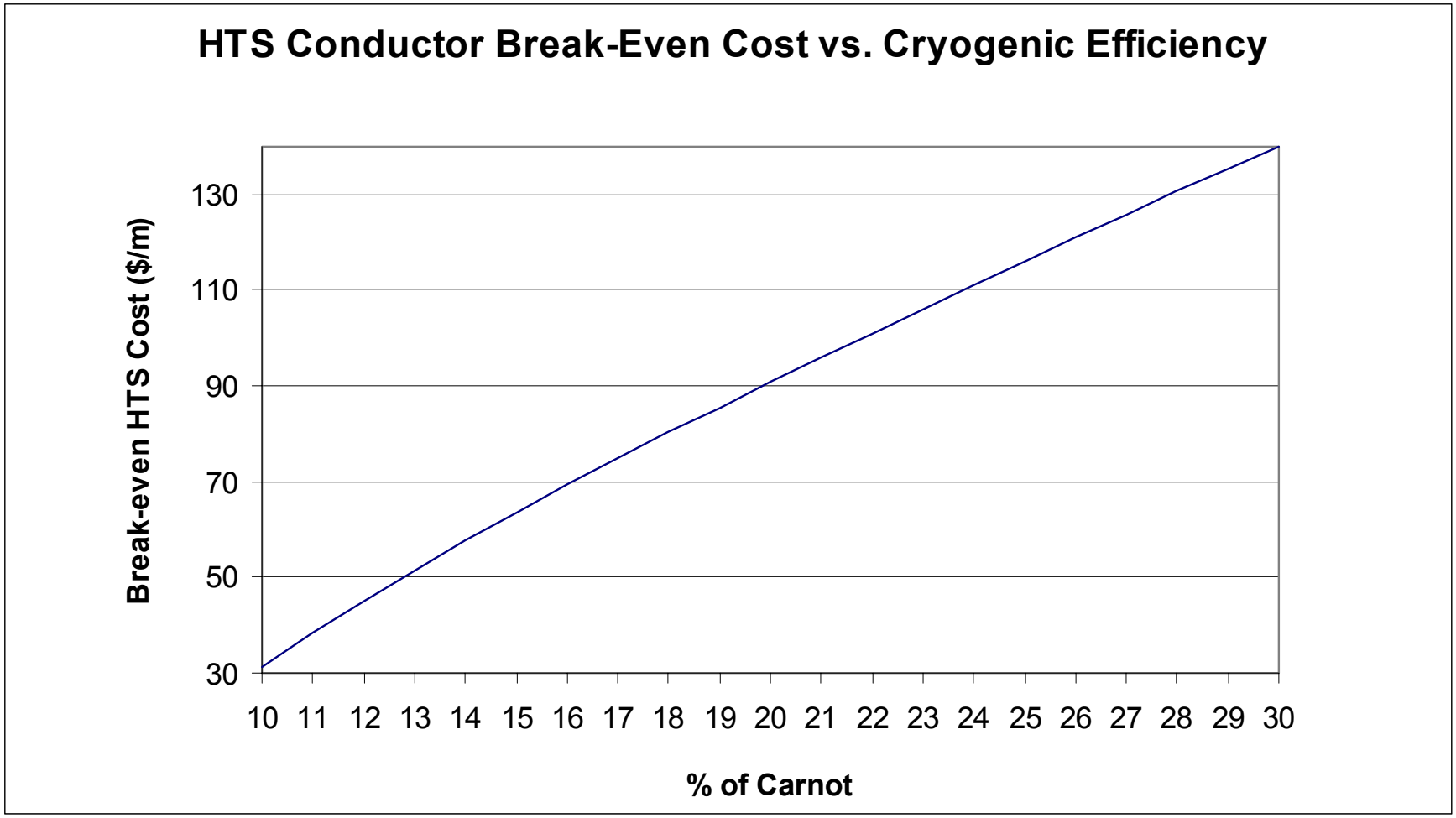
- Limited to four power devices
  - Motors > 500 hp
  - Generators > 100 MVA
  - Transformers > 20 MVA
  - Transmission cables at intermediate voltages.
    - Distribution voltage applications are not considered.
- Limited to the U. S. market for electric power equipment.

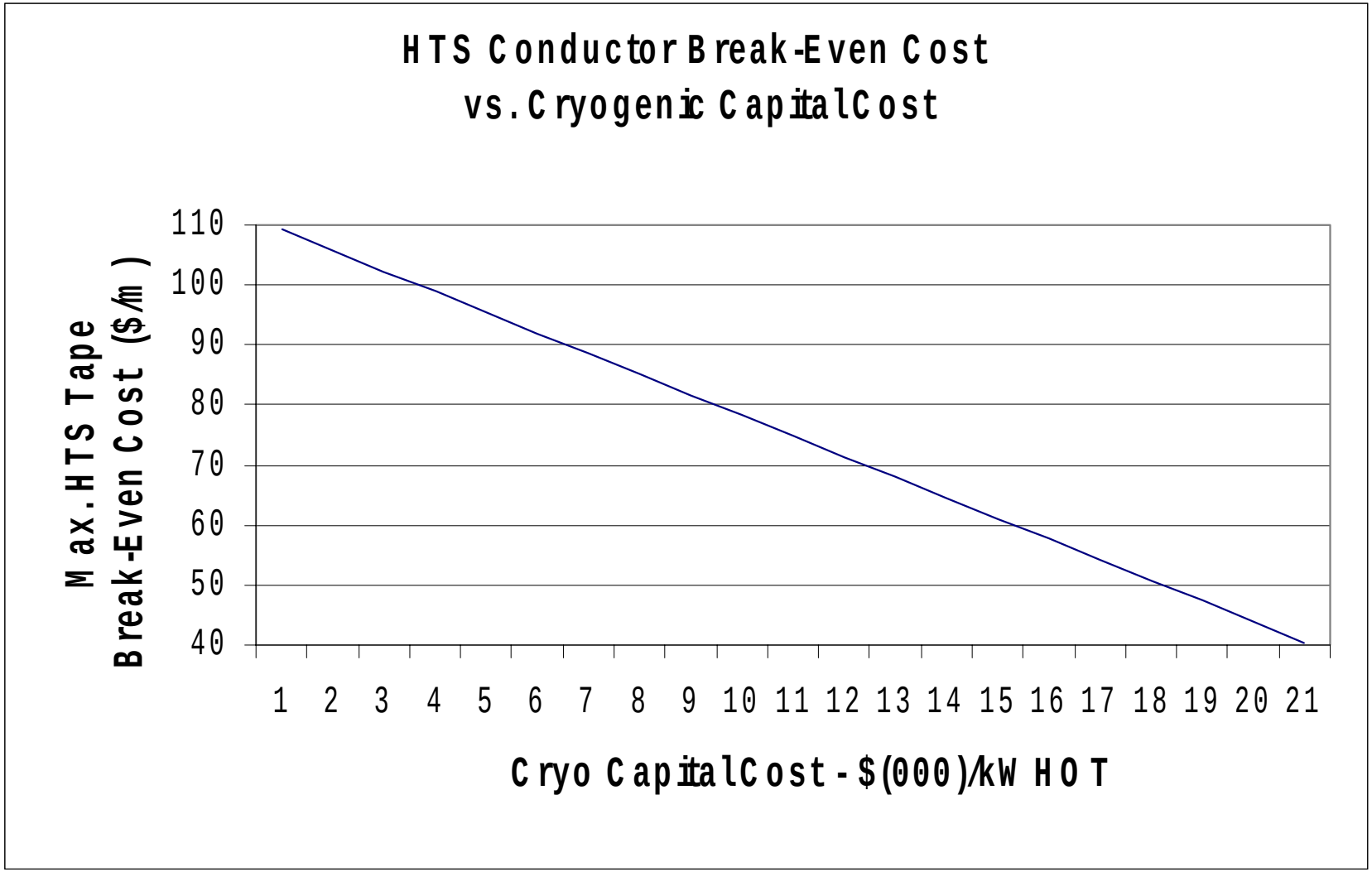
Project Scope and Limitations (cont.)

- Assume that HTS devices will be used in the U.S. market in the years 2000-2025 and calculate the following:
  - Cost and volume of HTS Wire,
  - Production dollar volume versus cost,
  - Costs and sales volume of cryogenic components,
  - The sales market for HTS devices,
  - The energy savings by device, and
  - The reduction in emissions that result.

Sensitivity of Inputs and Trade-Off Analysis

- The results (output) are highly sensitive to certain inputs; e.g.,
  - % of market captured asymptotically
  - % of replacement market captured
  - Energy savings per device
  - Cryogenic trade-offs
    - Efficiency
    - Capital cost.
- Implies the model is useful for trade-off analysis.
- Consider the Cryogenic trade-offs


HTS Conductor Break-Even Cost vs. Cryogenic Efficiency
Break-even HTS Cost ($/m)
130
110
90
70
50
30
10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
% of Carnot


HTS Conductor Break-Even Cost
vs. Cryogenic Capital Cost
Max. HTS Tape
Break-Even Cost ($/m)
110
100
90
80
70
60
50
40
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
Cryo Capital Cost - $(000)/kW HOT

FY 2001 Results

- First and foremost, the Mulholland Model is a *tool*, to be used by many analysts.
- We are <u>not</u> the high priests.
- Results are there only to illustrate the use of the *tool*.
- Therefore, activity in 2001 has been aimed at increasing accessibility by others
  - *Not* trying to "improve" results

FY 2001 Results (Cont.)

- Four categories of action:
  - Properties of the model itself
  - Accessibility of assumptions, including hidden inputs
  - Variability and sensitivity
  - Written report

Properties of the Model

- Time extended to 2025
- Reorganized into a workbook of four separate spreadsheets
- Results are strongly dependent upon the individual "device" models

Individual "Device" models

- Each device has an associated model;
- These are described in Appendices 6, 7, 8 & 9.
- The components of these models are:
  - Energy saved by HTS technology
  - Refrigeration (operating) penalty
  - Higher capital costs
    - Wire
    - Cryogenic system
- NPV of savings compared with higher capital cost.

Individual "Device" models

- Example: Electric Motors
  - Appendix 6 -- Table 6-1
  - Savings obtained from
    - Eliminating i^2R losses = 0.61%
    - Reduced friction and windage = 0.28%
    - Reduced iron loss = 0.51%
  - These numbers are not firm, but they affect the net energy savings;
  - And this in turn affects NPV, profitability and therefore market penetration.

Table 6-1 HTS versus Conventional Motors Loss Analysis Motors > 500 HP

	A	B	C Source
1	Average Size (HP)	1,160	*1*
2	Average Size (kW)	865	
3	Number of Motors	39,005	*1*
4	Energy Used (GWh/Year)	167,545	*1*
5	Operating Hours per Year per Motor	7,256	*1*
6	Average MWh/Motor/Year	4,295	B(4)/B(3)
7	Average Use per Motor (kW)	592	B(6)/B(5)
8	Capacity Factor	68%	B(7)/B(2)

Table 6-1 HTS versus Conventional Motors Loss Analysis Motors > 500 hp (cont.)

	Conventional Motor		
9	Magnetic and Iron Loss Penalty Saved by HTS	0.51%	*2*
10	Windage and Friction Penalty Saved by HTS	0.28%	*2*
11	Average Field Winding Losses	0.61%	*2*
12	Average Loss Savings	1.40%	
13	Average Loss Savings (MWh/Motor/Year)	60	B(6)*(B(12))

Table 6-1 HTS versus Conventional Motors Loss Analysis Motors > 500 hp (cont.)

	HTS Motor Losses		
14	Average No-Load Loss (W/Motor)	48	*3*
15	Average Losses, Use-Related (W Loss/kW Used)	0.03	*3*
16	Coolant Operating Temperature (Deg. K)	70	
17	Efficiency % Carnot	30%	
18	SP	12.0	*3*
19	Average Cryo Energy Losses, Hot Side (MWh/Motor/Year)	6.6	(B(14)*8.76+B(15)*B(6))* B(18)/1,000
20	Peak Power Losses, Hot Side (kW/Motor)	0.889	(B(14)+B(15)*B(2))* B(18)/1,000

Table 6-1 HTS versus Conventional Motors Loss Analysis Motors > 500 hp (cont.)

	Average Net Energy Loss Savings (HTS vs. Conventional)		
21	(MWh/Motor/Year)	53.5	B(13)-B(19)
22	(%)	1.25%	B(21)/B(6)
23	Average Cost of Energy in 2020 ($/MWh)	$35.00	*EIA*
24	Average Savings ($/Motor/Year)	1,874	B(23)*B(21)
25	Average Life (Years)	31	*1*
26	Total Savings ($)	57,329	B(24)*B(25)
27	Discount Rate	10%	Industry estimate
28	Net Present Value of Savings ($)	18,587	

Table 6-1 HTS versus Conventional Motors Loss Analysis Motors > 500 hp (cont.)

29	Cost of HTS Wire in 2020 ($/Meter)	20	*5*
30	Meters of HTS Wire/Motor	580	*5*
31	HTS Wire Cost ($)	11,307	B(29)*B(30)
32	Cryogenic Capital Cost/Motor ($)	3,829	B(20)*4,306
33	Net Savings ($/Motor)	3,451	B(28)-B(31)-B(32)
34	Net Savings ($/kW)	4	B(33)/B(2)
35	Conventional High Efficiency Motor Cost ($)	97,746	113*B(2)

Four Linked Spreadsheets

- Assumptions
  - This is where the analyst inputs major variables.
- Database
  - EIA data used; it can be changed to suit the analyst's desires.
    - Rate of growth (1.8% ? 2.2% ?)
    - Price of electricity ($ 0.035/kWh ?)
- Results
- Graphs

Accessibility of Assumptions

- Energy Savings per device
  - Output of individual "device" models
- Market penetration model
  - Parameters of S-curve
  - Discount rate, lifetime, replacement
- Capital costs
  - Wire
  - Cryogenics
  - Conventional alternative

Accessibility of Assumptions

- Example: Cryogenic efficiency
  - Cooling load depends on *peak* power of device.
  - Specific Power (SP) of cryocooler is key factor:
    - Optimum = 11
    - Today's technology > 15
  - Depends upon
    - Operating temperature, and
    - Percent-of-Carnot efficiency achieved
  - Now, analyst can <u>find</u> these numbers and <u>change</u> them easily.

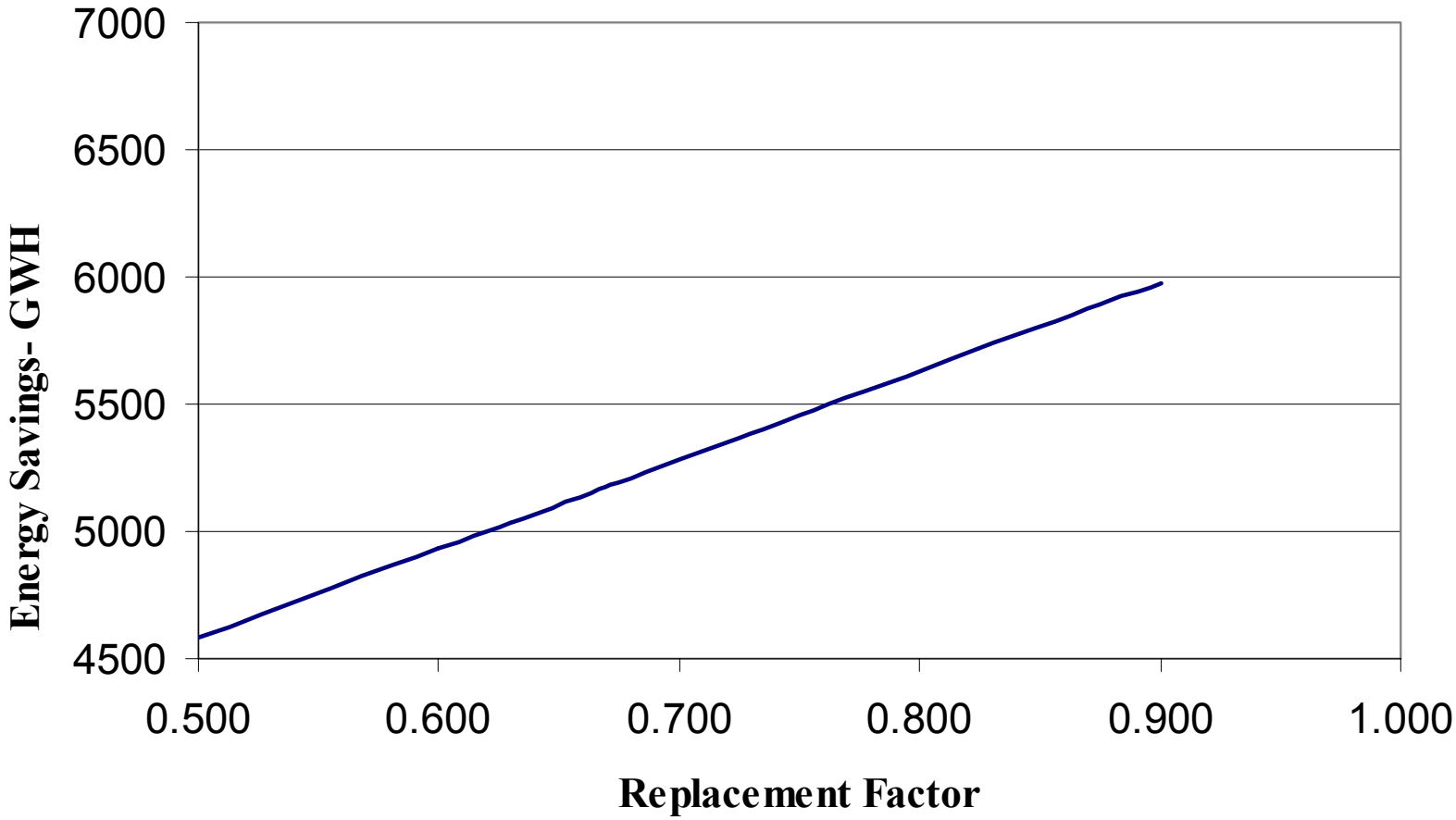
It is necessary to allow a range of variability in some inputs

- The data needed to calculate some outputs accurately is company-confidential;
- Therefore, do calculations over the entire plausible range, and let people judge for themselves where their answer lies.

As an example of variability consider

- The replacement market share for motors
  - Will people re-wind motors or buy anew?
  - We assume that 50-75% of replacement motors will use HTS; therefore, we model the entire range.
  - A *macro* was written to carry out the model for fractions spanning the range, and graph the results:

Energy Savings vs. Replacement Factor



Other variations that should be modeled

- % energy saved by devices
  - Motors
  - Transformers
  - Generators
  - Cables
- AC losses
- Cryogenic efficiency
- Conventional alternative costs

Written Report

- Extensive revisions to main text
  - Tables and graphs replaced
  - Portions rewritten for clarity
  - Sections added
- Some appendices rewritten
- New appendices were added
  - Compendium of assumptions
  - Explicit guide to spreadsheets
- 19 total appendices provide detail to the analyst

FY 2001 Results -- Conclusion

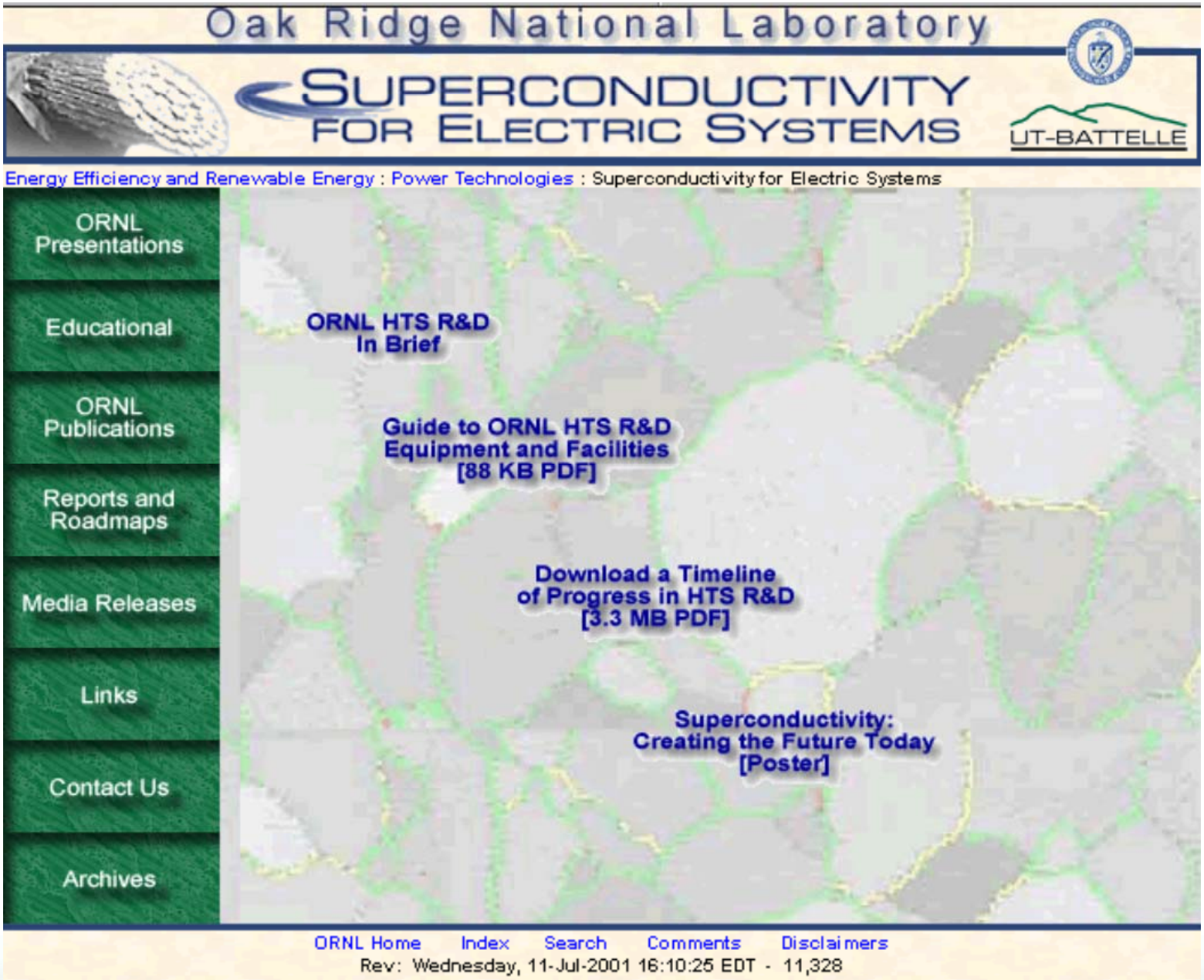
- We are now ready to begin β-testing of the Mulholland Model:
  - Others (unfamiliar with model) should now be able to make changes and run it.
  - If they can't, it means we have to fix something to make it more accessible.

FY 2001 Results -- Summary

- Modification of Assumptions
- Reorganization of Spreadsheets
- Test of Sensitivity
- New Results
- Revised Written Report
  - Both the report and a copy of the model are available for download on the ORNL Superconductivity Programs Web page

ORNL Superconductivity Web Page

www.ornl.gov/HTSC/htsc.html


Oak Ridge National Laboratory
SUPERCONDUCTIVITY FOR ELECTRIC SYSTEMS
UT-BATTELLE
Energy Efficiency and Renewable Energy : Power Technologies : Superconductivity for Electric Systems
ORNL Presentations
Educational
ORNL Publications
Reports and Roadmaps
Media Releases
Links
Contact Us
Archives
ORNL HTS R&D In Brief
Guide to ORNL HTS R&D Equipment and Facilities [88 KB PDF]
Download a Timeline of Progress in HTS R&D [3.3 MB PDF]
Superconductivity: Creating the Future Today [Poster]
ORNL Home Index Search Comments Disclaimers
Rev: Wednesday, 11-Jul-2001 16:10:25 EDT - 11,328

FY 2001 Performance

- Activities began with the draft March 2000 report
- Even the 1999 model predicted the importance of cryogenic performance leading to
  - Cryogenic Workshops in 1998-99 that led to a *Cryogenic Roadmap* report in FY 2001
  - During FY 2001 a *Cryogenic Implementation Plan* was also produced.
- A revised report updating the market forecasting methodology has been completed and is being circulated for "Beta" testing by other analysts.
- All models and the report are available for download.

FY 2002 Plans

- Model the following additional variations:
  - % energy saved requires proper scaling for all devices
  - A range of ac losses
  - Update cryogenic efficiency and cost
  - Update conventional alternative costs

FY 2002 Plans (cont.)

- Include a hybrid cooling system in the model
  - LN_2 reservoir lowers cooling demand from *peak* to *average*
  - But complexity may increase (compared to regular cryocooler).

FY 2002 Plans (cont.)

- Since the data needed to calculate some outputs accurately is company-confidential, its use requires close research integration.
- A possible solution is to do sensitivity calculations over the entire plausible range.
- We will receive and respond to input from the "Beta" testers.

Future changes to model

- Example: Hybrid cooling system
  - LN_2 reservoir would lower cooling demand from *peak* to *average*
  - But complexity may increase (compared to regular cryocooler)
  - Large uncertainties in cost and performance

Research Integration

- Collaboration with other projects was and remains essential to this effort. Contacts have been made with
  - The SPI transformer, cable, motor teams
  - Cryogenics experts and equipment suppliers
  - Utilities
  - HTS wire producers
- Attended and participated in the Cryogenics workshops

Research Integration (cont.)

- We would like to reduce uncertainty in inputs by actively soliciting the data for each device
  - Size and associated scaling laws
  - Wire performance
  - Cryogenic requirements and performance
- Many of these details are company confidential and will require careful and thoughtful interactions.
- A paper was presented at the September 2000 ASC.