Cryogenic Roadmap

U.S. Department of Energy
Superconductivity Program for Electric Systems

Executive Summary

Cryogenic systems providing 100-1000 watts of cooling power at 65-80 K are required if devices utilizing high-temperature superconductors (HTS) are to become a part of the national electric power delivery and utilization system. These systems must have lower capital costs (< $25/cooling watt) and operate more efficiently (30+% of Carnot) and reliably than present day off the shelf cryogenic systems. This document addresses the various pathways for the development of cryogenic systems that will enable these systems to advance to meet these desired characteristics. Consequently, it is called a “roadmap”. The roadmap provides goals and objectives along with the desired outcomes that may result if these goals and objectives are completed. In addition, the editors have provided a list of technology drivers together with the anticipated impacts on the desired outcomes.

The suggested research goals and objectives with resulting outcomes or impacts on the cryogenic systems needed to support HTS power systems apparatus are shown in Table ES-1.

This roadmap is offered to the U.S. Department of Energy by the assembly of utility, industry and national lab researchers who believe that now is the right time to develop cryogenic systems that will allow HTS devices to become standard components of electric power systems. Utility equipment is the sum of its parts; in this case, both superconductors *and* cryogenics are required to make the system work. Advances in both the HTS materials and in refrigeration technology (either applied or new) will determine the eventual level of success of these products.

There is widespread agreement that much science is yet to be learned in superconductivity. On the other hand cryogenics has been dismissed as working out a few engineering details to meet the specific needs of the application, and that can be handled mostly by industry. This roadmap opposes that line of thinking. We feel it takes much more than simply providing a few engineering details. To get from where we are now to where we need to be, there is need for much new science in cryogenics to improve the efficiency and reliability and to reduce costs. Understanding how to provide the required refrigeration with fewer and more reliable moving parts and having the process work efficiently requires research.

Because of two previous workshops, this document devotes only a little space to reviewing where we are today. Much more important is where we want to be – where we must get to if commercial success is to be achieved. We establish specific numerical performance goals for cost, efficiency, and reliability. We examine the various possible pathways to reach these performance goals, taking note of both the technologies that can be pursued, as well as the business constraints that must be considered. We also recommend an R&D strategy of forming teams of knowledgeable specialists, in order to improve the probability of achieving success. Finally, we suggest a typical timetable spanning several years over which these activities would take place.

We expect the benefits of this program to be very widespread. Concepts that increase the efficiency, improve reliability, and reduce costs would apply to almost all areas of superconducting power applications, as contrasted to only individual devices developed by SPI projects. This cryogenics R&D would be an "umbrella" program in parallel with other ongoing efforts.

It is too early to specify a detailed research plan, and trying to "pick winners" has always proved futile. Rather, our purpose in this roadmap is to identify the broad scope of collaborative R&D effort involving partners drawn from industry, utilities and the national labs. The details are to be filled in by those (in the private sector) who believe in their potential accomplishments enough to risk their own money in this endeavor. The program described here is definitely an *industry-led* enterprise.

Primary Goals	Objectives	Outcomes
Increased Efficiency (present nominal 20%)	> 30% Carnot by 2005	Reduced operating expenses and market viability
Lower Capital Cost (present nominal $100/watt)	< $25/cooling watt by 2007 with cryogenic components costing < 10% total system	Reduced capital cost and market viability
High reliability (present systems depend heavily on redundancy)	Operating availability > 99.8% by 2007	Mean time between failures of operating cryogenic system > 30 years using redundancy and increased component reliability
Secondary Goals		
Size (present closed cycle systems including auxiliary systems are much too large)	System & cryogenics 50% smaller by 2007	Utilization of full HTS systems increased power density
Variable cooling capacity (present systems might use staged smaller, less reliable, less efficient, more expensive equipment resulting in excess size and cost)	Cryogenics follow load using storage capacity or optimized variable speed drive techniques on HTS system by 2009	Significantly reduced penalty for operating costs (utility cost of base load losses are 2.5-3 x larger than losses which follow load with similar impact on industrial demand charges)
Historic price decline with volume and experience	Reduced costs as HTS systems penetrate market	Commercial units at reasonable cost
Transparency (present MRI systems suggest feasibility)	Customer acceptability by 2007	Low awareness of cryogenic system
Minimal Disruption (present MRI systems suggest feasibility)	Customer acceptability by 2007	No interference of normal operations
Maintainability (present MRI systems suggest feasibility)	Customer acceptability by 2007	Average technicians can operate the system
Soft failure mode (present MRI systems suggest feasibility)	Customer acceptability by 2007	Cryosystem failures allow alternate operational schemes

Table ES-1. Cryogenic R&D needs expressed as goals, objectives, and desired outcomes.