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U.S. DEPARTMENT OF ENERGY
SUPERCONDUCTIVITY PROGRAM FOR
ELECTRIC SYSTEMS

- PROCEEDINGS -

CRYOGENICS VISION WORKSHOP FOR HIGH-TEMPERATURE SUPERCONDUCTING ELECTRIC POWER SYSTEMS

July 27, 1999
Loews L'Enfant Plaza Hotel
Washington, D.C.

Compiled by
Energetics, Inc.

MANAGED AND OPERATED BY
LOCKHEED MARTIN ENERGY RESEARCH CORPORATION
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

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

CRYOGENICS VISION WORKSHOP

FOR HIGH-TEMPERATURE SUPERCONDUCTING ELECTRIC POWER SYSTEMS

— PROCEEDINGS —

Loews L'Enfant Plaza Hotel
Washington, D.C.

July 27, 1999

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Executive Summary

CRYOGENICS VISION WORKSHOP

July 27, 1999

EXECUTIVE SUMMARY

The U.S. Department of Energy's Superconductivity Program for Electric Systems sponsored the Cryogenics Vision Workshop, which was held on July 27, 1999 in Washington, D.C. This workshop was held in conjunction with the Program's Annual Peer Review meeting. Of the 175 people attending the peer review meeting, 31 were selected in advance to participate in the Cryogenics Vision Workshops discussions. The participants represented cryogenic equipment manufactures, industrial gas manufacturers and distributors, component suppliers, electric power equipment manufacturers (Superconductivity Partnership Initiative participants), electric utilities, federal agencies, national laboratories, and consulting firms. Critical factors were discussed that need to be considered in describing the successful future commercialization of cryogenic systems. Such systems will enable the widespread deployment of high-temperature superconducting (HTS) electric power equipment. Potential research, development, and demonstration (RD&D) activities and partnership opportunities for advancing suitable cryogenic systems were also discussed. The workshop agenda can be found in the following section of this report. Facilitated sessions were held to discuss the following specific focus topics:

- Identifying Critical Factors that need to be included in a Cryogenics Vision for HTS Electric Power Systems (From the HTS equipment end-user perspective)

- Identifying R&D Needs and Partnership Roles (From the cryogenic industry perspective)

The findings of the facilitated Cryogenics Vision Workshop were then presented in a plenary session of the Annual Peer Review Meeting. Approximately 120 attendees participated in the afternoon plenary session. This large group heard summary reports from the workshop session leaders and then held a wrap-up session to discuss the findings, cross-cutting themes, and next steps. These summary reports are presented in this document. The ideas and suggestions raised during the Workshop will be used by the DOE Superconductivity Program for Electric Systems in preparing subsequent planning and strategy documents such as a Cryogenic Technology Development Roadmap.

MAJOR FINDINGS

- A modular, generic cryocooler design would be helpful if it can meet the needs for all applications.

- Reliability and safety are paramount to utilities. Maintenance intervals of 5 to 10 years are acceptable. Cryogenic system must be transparent to the user with fail-safe performance.

- Need to know "What is the market?", "Who will buy it?" and "How big is this market in number of units and dollar value?"

- Utilities want to buy "cold" as a service. They desire reliable, low-cost solutions. There are cost trade-offs between hybrid and non-redundant systems.

- Cryogenics cost needs to be less than 10% of the total system cost.

- Efficiency goal should be 40% of Carnot efficiency. This may be achieved by reducing heat leak in half, understanding the losses, and using new types of compressors requiring less power consumption.

- System integration studies and designs need to be conducted. A cryogenic substation needs to be integrated.

- Dynamic operations of the cryosystem need to be studied, such as cool-down and recovery behavior in cases of perturbations.

CONCLUSIONS AND NEXT STEPS

- The Department should ensure that any new RD&D efforts involving cryogenic systems take advantage of ongoing programs at the Navy Research Lab (NRL), the DOD Advanced Research Project Agency (ARPA), National Institute of Standards and Technology (NIST), NASA, national laboratories, and RD&D at private companies. (See next page of recommendation from National Action Plan on Superconductivity).

- A vision and roadmap process for cryogenic systems, possibly modeled after the Industries of the Future initiative, could be useful in developing a cross-cutting R&D plan. The Department should consider developing a draft cryogenics technology development roadmap from the information received at the Workshop and other information from the participants, and to then use the draft plan as a focal point in the vision and roadmap implementation process.

- Future meetings and workshops to encourage interactions between cryogenic system developers, utilities and potential users, power equipment manufactures and vendors, and government agencies could be beneficial in raising awareness about the critical window of opportunity that exists to have commercial-ready cryogenic systems available in order to ensure market acceptance of developed HTS electric power systems.

The National Action Plan on Superconductivity

- Issued by Office of Science and Technology Policy (OSTP), Executive Office of the President, February 1991

- Major Recommendation for Compact Refrigeration: Increased attention should be paid to the development of the enabling technology of compact refrigeration to enhance the performance and reduce the cost of superconducting devices. DoD and NASA should continue to play leading roles in this activity.

Agenda

- Facilitated Sessions

- Workshop

Cryogenics Vision for HTS Electric Systems Meeting

Facilitated Sessions - July 27, 1999

AGENDA

8:30 am - 12:45 pm

8:30-10:30 AM	**Identifying the Cryogenics Vision for HTS Electric Power Systems** (Defining our end-point: HTS equipment needs—driven discussion) **Focus Question:** What kind of future do we want to create for the cryogenic refrigerator industry that will enable the widespread deployment of HTS electric power equipment? - What are the critical factors that need to be included in a shared vision statement between cryogenic system suppliers and HTS equipment developers that describes successful future commercialization?
10:30-10:45 AM	Break
10:45-12:45 PM	**Identifying R&D Needs** (Defining how to reach our end-point: Cryogenic industry driven discussion) **Focus Questions:** - What cryogenic system goals are needed to meet future commercial HTS power equipment requirements? - What are the technical barriers in attaining a commercial cryogenic capability for these power applications? - What R&D activities are needed to overcome the technical barriers? - What R&D partnership roles can be identified?
12:45 PM	Adjourn for Lunch
2:00-5:00 PM	Cryogenics Workshop

Cryogenics Vision for HTS Electric Systems Workshop

July 27, 1999

AGENDA

2:00-5:00 pm

2:00-2:10 PM	Introduction - *J. Daley, DOE*
2:10-2:30 PM	Recap of Last Year's Workshop, "Cryogenics Needs of Future HTS Electrical Power Equipment" - *T. Sheahen, Western Technology Inc.*
2:30-2:40 PM	Long Flexible Cryostat: Materials, Testing and Manufacture - *J. Fesmire, NASA, KSC*
2:40-2:50 PM	Cryogenic R&D Activities at NRL - *M. Nisenoff, NRL*
2:50-3:15 PM	Technology Roadmaps - Approaches and Lessons Learned - *J. Badin, Energetics, Inc.*
3:15-3:30 PM	Break
3:30-4:30 PM	Report of Results from Facilitated Vision Meetings - *Group Spokespersons*
3:30-4:00 PM	Report and Discussion: Vision Statement
4:00-4:45 PM	Report and Discussion: Goals, R&D Needs, Partnerships
4:45-5:00 PM	Next Steps - *J. Daley, DOE*
5:00 PM	Adjourn

Workshop Highlights

WORKSHOP HIGHLIGHTS

On the afternoon of July 27, 1999, a workshop was held to examine the concept of forming a "roadmap" for future cryogenics R&D. This followed two morning sessions attended by a select group in which certain aspects of the task were considered in more depth.

A year earlier, on July 22, 1998, a workshop took place that looked at the present state of the art in cryogenic refrigerators, and asked the Superconducting Partnership Initiative (SPI) participants to state what they foresaw as their future cryogenic needs. That conference (the proceedings of which have been published under the title Cryogenic Needs of Future HTS Electrical Power Equipment) is summarized in the next section.

The existence of a desired future state constitutes a goal, but so what? At this year's workshop, Dr. James G. Daley of DOE explained that we ask the question "How do we get from here to there?" Our goal is to produce a roadmap, and this 1999 workshop is the beginning of that process. Jim Daley also pointed out that there is no guarantee that DOE is going to conduct any particular research as a result of this effort; indeed, it is possible that DOE should not be involved in cryogenics research at all. Jim reminded the attendees that in 1991, OSTP basically said that NASA and DOD should lead the cryogenics effort. Thus, it is fair to ask at the outset: "What role, if any, should be assigned to the government, and to DOE in particular?" Because America already has a cryogenics industry, it must be recognized that one possible answer is "none!"

The role of NASA in contemporary cryogenics research was described by James Fesmire. NASA is focusing on insulation. NASA tests long lines (flexible or rigid) up to 40 m in length. For their applications, thermal performance dominates their criteria. Thermal insulation must be robust, and therefore several things need to be developed. In conventional devices, either foam or Multi-Layer Insulation (MLI) is used, and the k-values are around 30, which implies losses of about 0.1 mW/meter-K. MLI has many drawbacks, but NASA hopes to reach a k-value of 0.01 mW/meter-K; in the lab, they've hit 0.05, but in actual devices it's more like 0.1. (All this is for systems running between 300 K and 77 K.) Mr. Fesmire showed a chart on which 150 different tests were plotted; the values tended to coalesce around a certain relationship, at least on log-log paper. Jim Fesmire pointed out that the actual performance of a flexible cryostat is 3 to 10 times worse than you would like to expect. In conclusion, he noted that an overall heat leak of 1 W/meter is achievable, but not easy. NASA will continue its testing program, in cooperation with Oak Ridge National Laboratory.

Dr. Marty Nisenoff described ongoing cryogenics research at DOD. The military makes infrared detectors that operate at 77 K, and there is a need to remove about 1 watt. However, the bigger applications are too big for the military at this time. Nisenoff reported that Carrier's Stirling cooler removes 350 W @ 77 K, with only 3500 W input; this means the efficiency is above 30% of Carnot efficiency, which is quite good. More and more people are working on small cryocoolers. Pulse-tube Gifford McMahon (GM) machines are used to cool to 55 K and remove 15 W.

Nisenoff also drew attention to the importance of cost: Knowing that large quantities drive the price down, you would have to manufacture 10,000 units to get the price down to $1,000. A market of only 1,000 such units would be too small to interest the cryogenic manufacturers.

Marty made an additional point about reliability: It is important to use proven design concepts that really work in hardware. When you get to quantity production (hundred's per month), then you get high reliability. Between this and the cost, you cannot "technology push" here -- there has to be "market pull" if commercial applications are ever to be realized.

(Earlier, during a morning session, Carl Rosner of Intermagnetics General Corp. had sketched the history of MRI units. Their first unit was built in the 1960s, and needed refilling with liquid Helium weekly, because it lost 1 liter/hour of He. Today, their MRI units lose only 5 - 10 cc/day, and need refilling every 3 to 5 years. That's good, sound engineering progress, of course; but it took 30 years to get there.)

Following the presentations about NASA and DOD research, Joe Badin of Energetics explained what a roadmap consists of: Basically, we define the endpoint and state where we are now, and then work backward. We seek to find the technology path that connects the two. To form a good roadmap, a collection of interested parties gets involved. The vision is to be defined by industry. A technology roadmap is a way to achieve that vision. Implementing this requires a multi-year action plan. There are complementary roles for industry and government. Government is a partner, not necessarily a sponsor. The government tends to facilitate, coordinate, leverage and disseminate results; but the real work gets done by industry. Various "industries of the future" have constructed roadmaps; Joe Badin cited some examples. A workshop such as this is a tool to get you to the roadmap, not the roadmap itself. It is important to get the right people together for the task.

Following a break, the two morning meetings were summarized.

1. First Nathan Kelley of Pirelli Cable discussed the vision meeting. The basic question was "What will the cryocoolers of the future look like?" A modular, generic design would be helpful, one that meets everyone's needs; but their own project (cables) may not have exactly the same needs as other applications. To the utilities, reliability and safety are paramount. What will have to be proved before the cryosystem is acceptable? We need to ask how to make the cryogenic system "transparent" to the user. Also, we must ask "What is the market?" and "Who will buy it?"

For the most part, the utilities just want to buy "cold" as a service -- they don't care about the details. However, the system needs to be unmanned, with no intervention by utility technicians required. But having the "cheapest" solution is not the only criterion. We must ask whether a customer wants on-site refrigeration, or trucked-in LN2. The idea of a hybrid system, combining a cryocooler with LN2 backup, was considered more reliable; the roadmap should examine the cost trade-off between hybrid and non-redundant systems.

Other criteria include maintenance, where 5 to 10 years intervals is expected; on the electronics side, 3 to 5 years is acceptable. It is desirable to "swap and drop" at maintenance times. Utilities are not going to have a staff of trained cryo-engineers.

Kelley also reported that the morning meeting had examined the trade-off between reliability and temperature. For example, if you're already at 77 K, is it worth it to spend money on a mechanical system to reach 70 K or 64 K? Certainly, the roadmap needs to look at temperatures other than 77 K.

Among other things, the operating requirements call for running at ambient temperatures up to 75 C. Moreover, the footprint must be small for the cryosystem to be acceptable.

2. The second morning session, dealing with R&D needs, was summarized by Ken Kreinbrink of PHPK Technology. *He enumerated several priorities:*

1. The first goal is to reduce cost. The cryogenics needs to comprise less than 10% of the total system cost. For example, a 600 W system should cost under $70,000.

2. Efficiency needs to increase. We think we can get 30% of Carnot efficiency; we'd like to reach 40%.
3. Most operating systems will be at 77 K or above.
4. The system needs to operate for 5 years without maintenance, so it must be very simple and very reliable. We want fail-safe performance, too; can that requirement tolerate delivery of cryogens?
5. There must be system integration, for example in the design of a hybrid system.

Another way to express this is to observe that there are five things to do:

A. Cut the heat leak in half.
B. The cryogenic substation needs to be integrated together.
C. Efficiency: understand the losses, in order to get 30% or 40% efficiency.
D. Dynamic environment: study cool-down and recovery of the cryosystem in case of perturbations.
E. Equipment R&D: new types of compressors with less power consumption, etc.

Following these presentations, Tom Sheahen presided over a general discussion from the floor, wherein the concerns of the HTS community could be voiced.

The next step is to form a working group who will actually produce the roadmap.

Recap of Last Year's Workshop

"Cryogenics Needs of Future HTS Electrical Power Equipment," *T. Sheahen, ANL*

Summary of 1998 Workshop:

Cryogenics Needs of Future HTS Electric Power Equipment

July 22, 1998

This workshop addressed the question: Will practical cryogenic refrigerators be available to meet the needs of emerging superconducting power systems over the next five to ten years? Dr. Christine Platt chaired the event.

There were two panels, consisting of

a) SPI partners making HTS devices, and

b) Cryogenic manufacturers.

Marty Nisenoff of Naval Research Laboratory gave a *Keynote Presentation*, describing the R&D goals of DARPA, aimed toward low-cost, high-reliability cryocoolers. In a pair of memorable lines reminiscent of the movie *Field of Dreams*, Nisenoff characterized the current relationship between users and manufacturers as:

HTS Community: "If we will build it (HTS systems) they (cryocooler community) will come;

Cryocooler community: "If they (HTS community) will come with <u>*large*</u> *orders, we will build it (low-cost, reliable cryocoolers).*

Any goal looks much more attainable on log-log paper, and that is certainly true of cryocoolers and their cost. Figure 1 here is taken from Nisenoff's presentation, and shows where coolers are today and what the DARPA goals are.

Another useful summary appears in Table 1: this is a summary of *Cryocooler Requirements* as stated by the SPI partners building each of the HTS applications. It was compiled <u>after</u> the 1998 workshop, with entries drawn from the presentations.

Each of the two panels consisted of a series of presentations by the panelists. The slides that each speaker showed are assembled in the volume of the Workshop Proceedings, and adequately describe those talks.

Open discussion among all the attendees followed the second panel. The intent of that discussion was to identify the most important issues for further attention. Pp. 139-141 of the *Proceedings* enumerate some of the major points of discussion. The topics broke into two broad categories: *Performance Gaps* and *Technology Development Needs*. The key points are as follows:

Obvious: Reduce the heat load !

Higher efficiency, greater reliability and smaller size are always needed.

Since the electrical load varies, so does the cooling load. A variable cooling-power capability is desirable.

There is a "gap" in available cryocoolers between 100 W and 1 kW. For most SPI projects, the cooling requirement lies in between Gifford-McMahon and Brayton-cycle units. The feasibility of scaling up small systems or scaling down large systems needs to be explored. Pulse-tube refrigerators and closed-loop Stirling cycles are particularly interesting here.

The losses in transformers are so small to begin with that the available i^2R savings will be squandered on cooling losses unless the refrigeration system is very small.

Cables have a large surface area per unit length, and generate a large thermal load. 50 kW is a typical requirement, so the refrigeration system will comprise a significant percentage of the total cost.

Cryogenic manufacturers are confident they can build suitable refrigerators, but they await evidence of real demand for their systems before going ahead with the expense of development efforts.

Research needed includes: better insulation; and better transport of fluids in a cryogenic environment.

"There needs to be a collaborative approach in working with HTS equipment manufacturers, cryogenic system manufacturers, the national labs and DOE."

The 1999 Workshop is intended to take up where the 1998 Workshop left off. Specifically, we need to answer two questions:

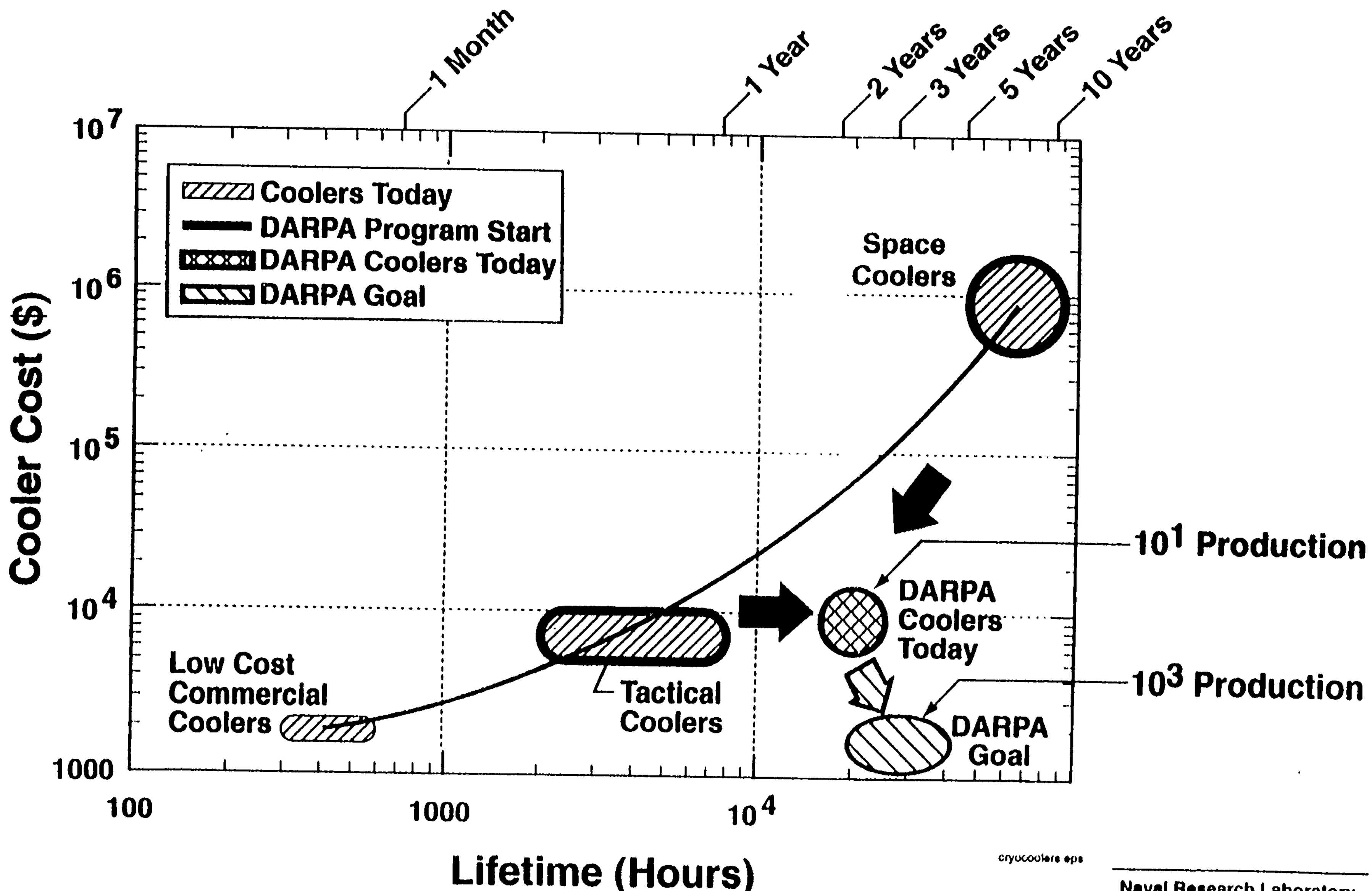
What exactly is needed to meet the cryogenic needs of future HTS power devices?

And

What program of collaborative R&D will get us there?

Of course it is exceedingly difficult to say that some R&D path *will* reach a goal. The activity of *roadmapping* is an endeavor to set goals, identify the obstacles to success, and devise a plan for overcoming them. A good roadmap will say what each partner will contribute to the R&D effort, and in what time-frame. Our purpose in holding the 1999 Workshop is to begin the process of making that roadmap.

Cryocooler Cost/Life Performance



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Naval Research Laboratory
Washington, DC 20375-5320

TABLE 1
Summary of Cryocooler Requirements

	HTS APPLICATIONS				
Requirements	**Motor**	**Fault-Current Limiter(a)**	**Transformer**	**Cable**	**Flywheel**
Cost (Capital)	$25,000	$55,000	<20% of total cost	$20,000(d)/kW cold power	$2,000 - $10,000
Temperature	<33 K	30-60 K		67 K pressure: 5-25 bar	70 - 77K
Power (Cooling at T_{op})	< 10 kW	15 kW			1W/kWh
Performance	60 W	280 W at 60 K 15 W at 30 K		5-10kW/km 5 kW (pilot system) 50 kW (large scale)	
Reliability	9,000 hrs (b)	10,000 hrs (c)		26,000 hrs (e)	
Operating Environment	313 K	323 K (max)		313 K	
Size	Compact			Compact for 50 kW cold power 9x9x3.5 m	1 ft^3 (a few ft^3)

(a) Three G-M cycle cryocoolers (single coil)
(b) MTBF: meantime between failures
(c) MTBM: meantime between maintenance
(d) Target investment cost. Today for 20 kW cold power investment $60,000/kW cold power. O&M should be 5-8% of the total investment per year.
(e) About 3 years for maintenance; 40 year operating life

Long Flexible Cryostat: Materials, Testing and Manufacture

J. Fesmire, NASA/KSC

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Long Flexible Cryostat: Materials, Testing, and Manufacture

TEAM

Karen Thompson, NASA Kennedy Space Center
Maria Littlefield, NASA Kennedy Space Center
James Fesmire, NASA Kennedy Space Center
Stan Augustynowicz, Dynacs Engineering Co. at NASA KSC

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Introduction

- Main Point: Bring together aspects of the refrigeration side and the conductor side, along with operations and maintenance considerations, for lowest total cost.

- Second Main Point: Consider the energy balance of the total system over its lifetime for accurate economic trade-off of subsystems.

Insulate (insulatus) = to set apart, detach from the rest, isolate

Cryogenics Testbed Capabilities at the NASA Kennedy Space Center

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- Network of industry, aerospace, and research partners
- Test Facilities
  - Materials evaluation
  - Systems integration, controls, and data acquisition
  - Design and operation points of view
- Cryogenics Test Laboratory
  - Cryostat-1, for thermal conductivity measurement of thermal insulation
  - Cryostat-2, for evaluation of cryogenic insulation systems
  - Pipeline Test Apparatus, for long (40 m) rigid or flexible lines

Power Transmission Application

- Urban retrofit application is initial market.
- Design the long flexible cryostat for power transmission over medium to long distances (from 100 m to 1000 m) for 30 years service life.
- Top level requirements
  - Flexible, bellows inside bellows
  - May be segmented at intermediate points with rigid lines
  - No feed-through connections allowed
  - Very limited maintenance at long intervals
  - Manufacturing must be practical and at reasonable cost

Thermal Insulation System

- Thermal performance considerations
  - Refrigeration system
  - Liquid nitrogen flow through corrugated and rigid lines
  - Thermal insulation system
- **Materials:** Thermal insulation and vacuum enclosure must be "robust"
- **Testing:** Determine performance margins and limits for basic questions such as outgassing, possibility of cryogen flow change from 1-phase to 2-phase, compression effect as a function of bending radius, extra mechanical support structures, variation of apparent thermal conductivity (k-value) in the annular space.
  - Example: Vacuum only, k-value is up to 5 mW/m-K; Standard MLI, k-value is as low as 0.1 mW/m-K. [For cold vacuum pressure (CVP) below 1×10^{-4} torr and boundary temperatures of approximately 300 K and 77 K]
- **Manufacturing:** Methods will determine actual performance, cost, and service life. Economic trade-offs are numerous here, but first....What are the limiting factors with today's technology?

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Conventional Insulation Systems

- Foam or MLI? Extreme choice between k-value of 30 or 0.1 mW/m-K.
- Drawbacks to standard multilayer insulation (MLI)
  - High vacuum requirement (below 0.0001 torr)
  - Sensitivity to compression and edge effects
  - High inplane heat conduction
  - Extreme care during installation
  - Limitation to simple structures
  - Manufacturing steps of evacuation, heating, and vacuum retention are costly
- Three levels of performance for standard MLI
  - Ideal k-value = 0.01 mW/m-K
  - Laboratory k-value = 0.05 mW/m-K
  - Actual k-value = from 0.1 to 1.0 mW/m-K

Note: Boundary temperatures of approximately 300 K and 77 K.

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Thermal Insulation System Testing (extracted results)

CVP (torr)	k-value (mW/m-K)	ΔT (K)	(Q/L)ins (W/m)	(Q/L)struc (W/m)	(Q/A)ins (W/m²)	(Q/A)struc (W/m²)
Standard Multi-layer Insulation						
1x10^{-4}	0.08	194	0.42	n/a	0.70	n/a
1	9.0	104	25.2	n/a	42.0	n/a
Cryogenic Insulation System						
1x10^{-4}	0.09	190	0.42	n/a	0.69	n/a
1	2.4	179	10.5	n/a	17.3	n/a
Syntactic Foam Composite						
1	12.8	112	23.4	n/a	35.9	n/a
760	24.4	90	35.9	n/a	55.0	n/a
Typical Vacuum Insulated Piping (RIGID, 4"x 6")						
1x10^{-4}	0.34*	220	n/a	1.25	n/a	2.84
Typical Vacuum Insulated Piping (FLEX, 4"x 6")						
1x10^{-4}	1.02*	220	n/a	3.71	n/a	8.46

*Overall k-value for actual field installation

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Conclusions

- Overall heat leak of around 1 W/m is achievable but manufacturing and maintenance can be a problem due to the high vacuum requirement (below 0.0001 torr).
- Soft vacuum (1 to 10 torr) systems have much less "vacuum burden" costs which must be considered in the overall cost effectiveness of building, operating, and maintaining the long flexible cryostat.
- Basic heat transfer and fluid flow questions regarding the performance of flexible lines versus rigid lines should be addressed
- Testing program in collaboration with ORNL is planned
  - System design to meet requirements of cable and refrigeration equipment
  - Thermal analysis
  - Testing and evaluation of performance under static and dynamic flow conditions

Cryocooler Performance

M. Nisenoff, NRL

STATUS OF DOD AND COMMERCIAL CRYOGENIC REFRIGERATORS

M. Nisenoff
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P.O. Box 2748
Kensington MD 20896-2748

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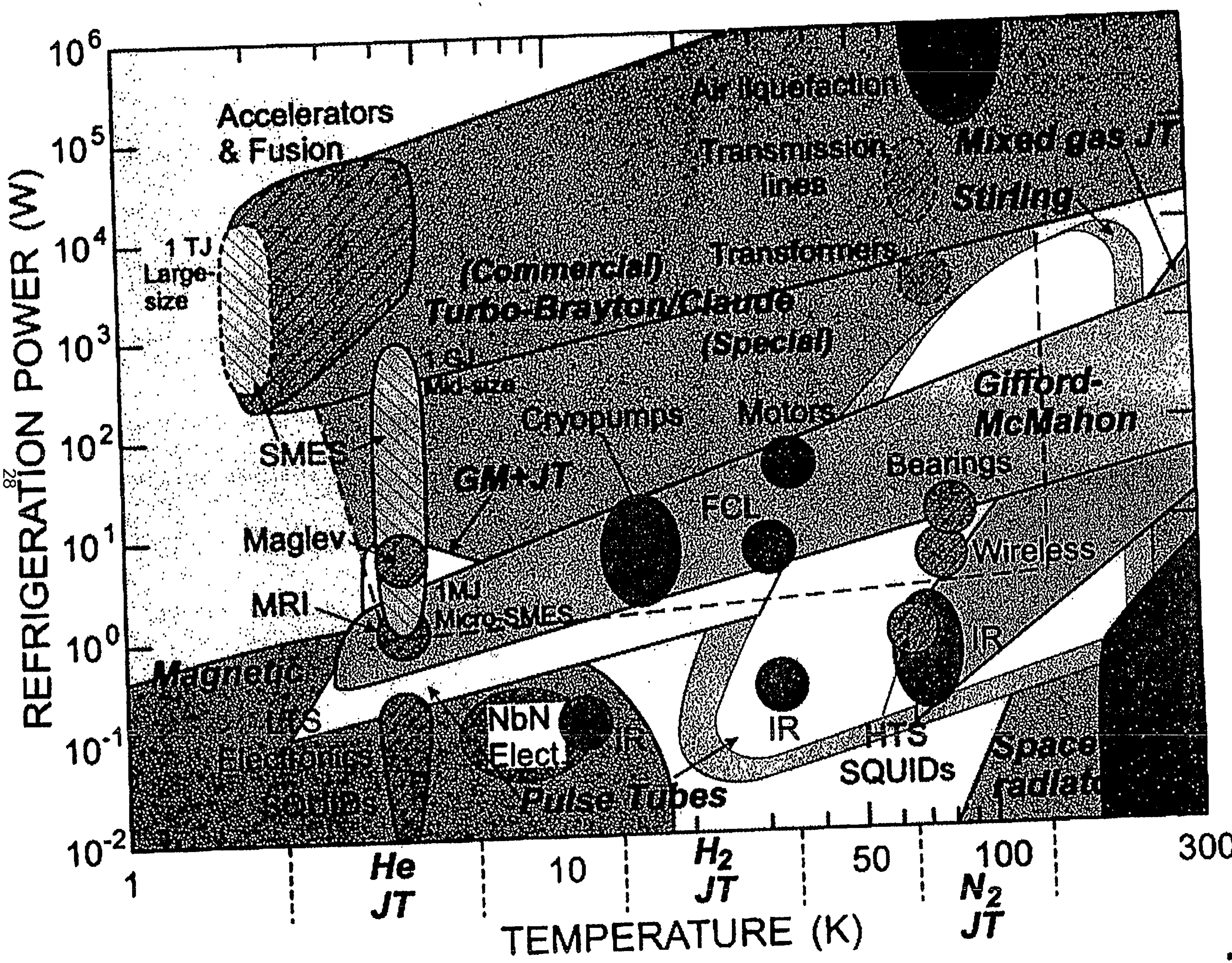
DoE Superconductivity Program for Electric Systems
Annual Peer Review Meting
Washington DC
27 July 199


REFRIGERATION POWER (W)
TEMPERATURE (K)
Accelerators & Fusion
1 TJ Large-size
SMES
Maglev
MRI
1MJ Micro-SMES
Magnetic
LTS Electronics SQUIDs
NbN Elect.
Pulse Tubes
Air liquefaction
Transmission lines
Mixed gas JT
Stirling
Transformers
(Commercial) Turbo-Brayton/Claude (Special)
Gifford-McMahon
Cryopumps
Motors
GM+JT
FCL
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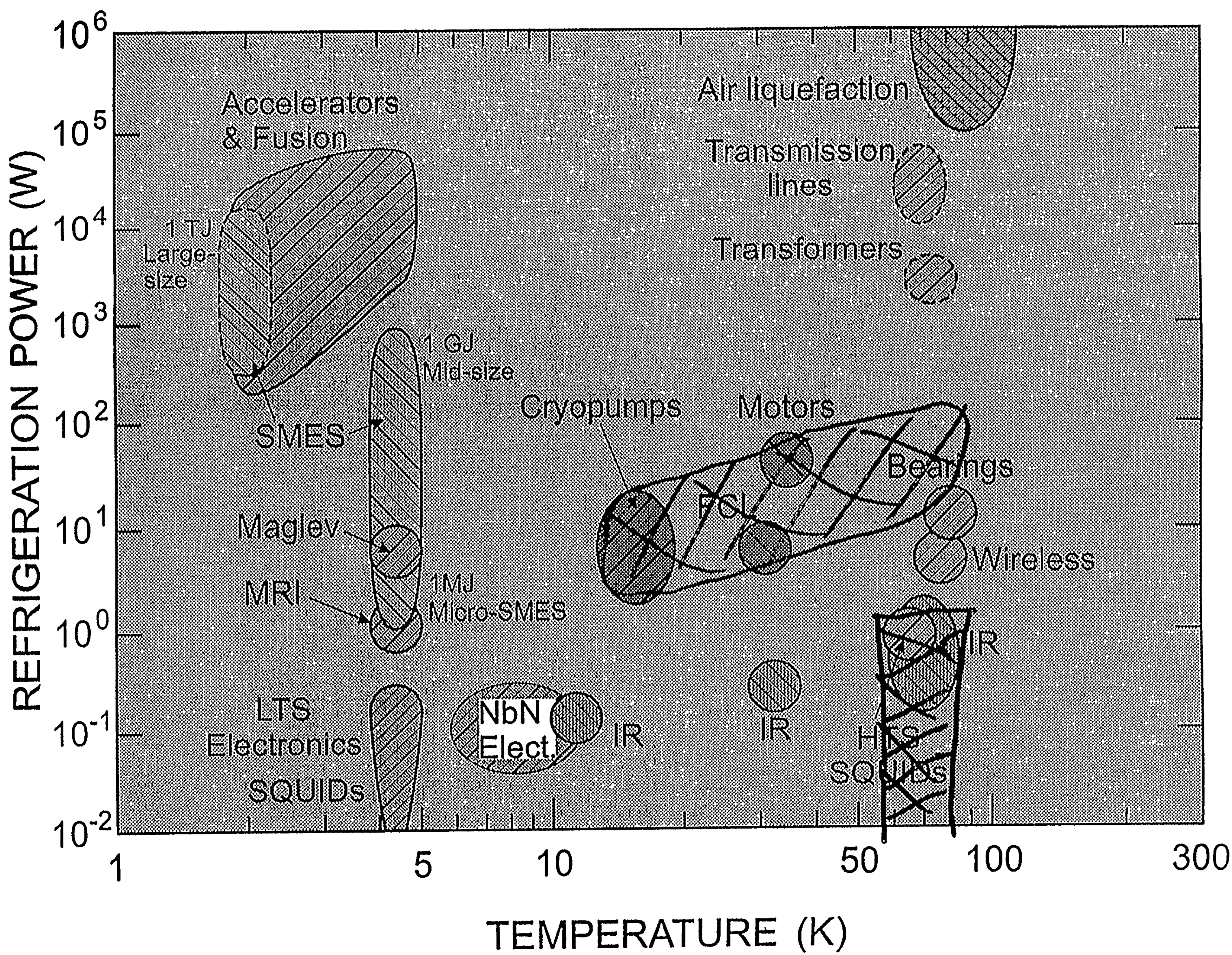
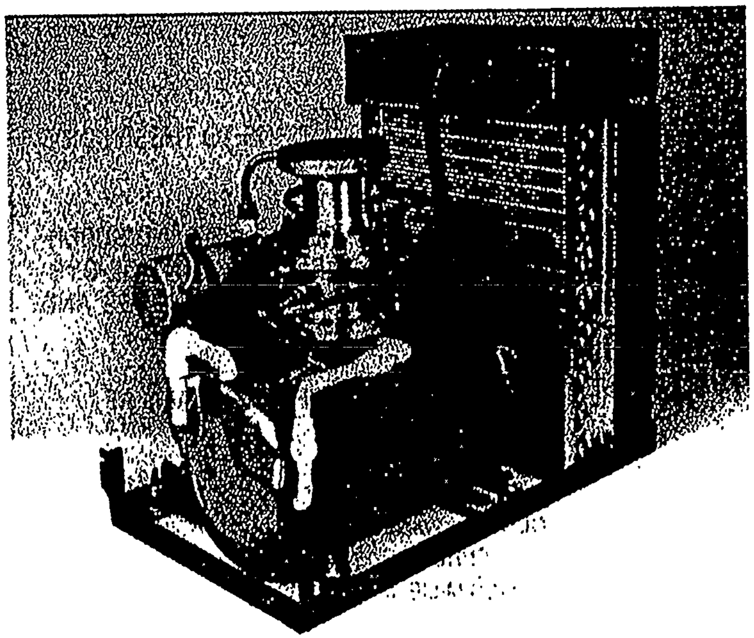
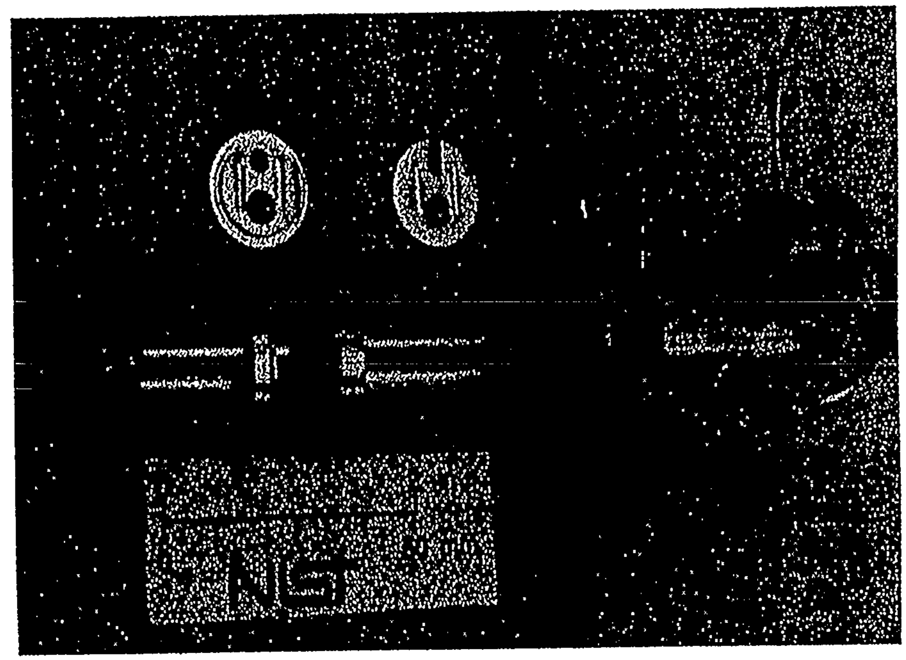

REFRIGERATION POWER (W)
TEMPERATURE (K)
Accelerators & Fusion
1 TJ Large-size
SMES
1 GJ Mid-size
Maglev
MRI
1MJ Micro-SMES
LTS Electronics
SQUIDs
NbN Elect.
IR
Cryopumps
Motors
FCL
Bearings
Wireless
Air liquefaction
Transmission lines
Transformers
HTS SQUIDs

PICTURES OF REAL CRYOCOOLER

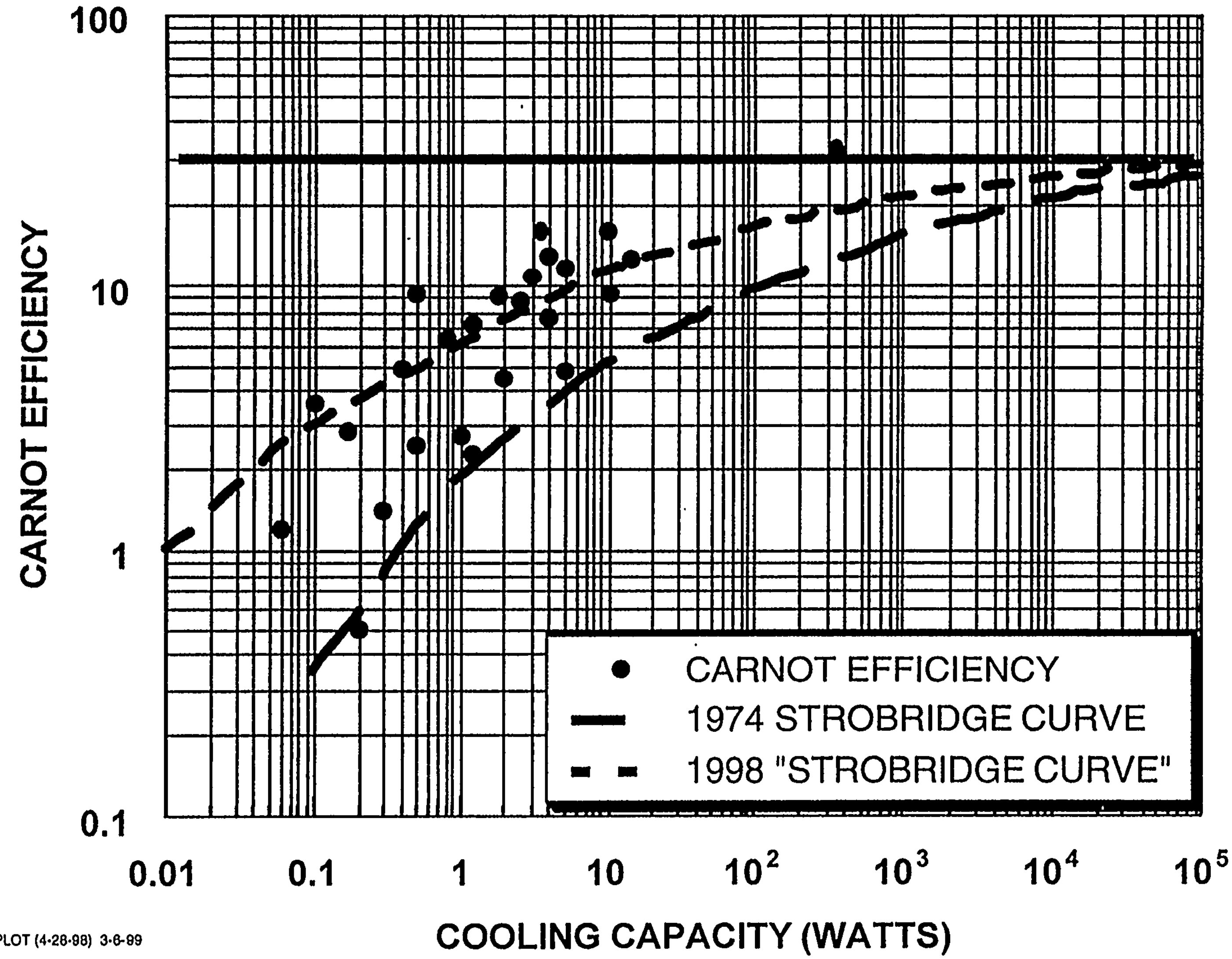


Carrier Stirling Cooler
350 W @ 77 K
3,500 Watts Input
168 kg mass



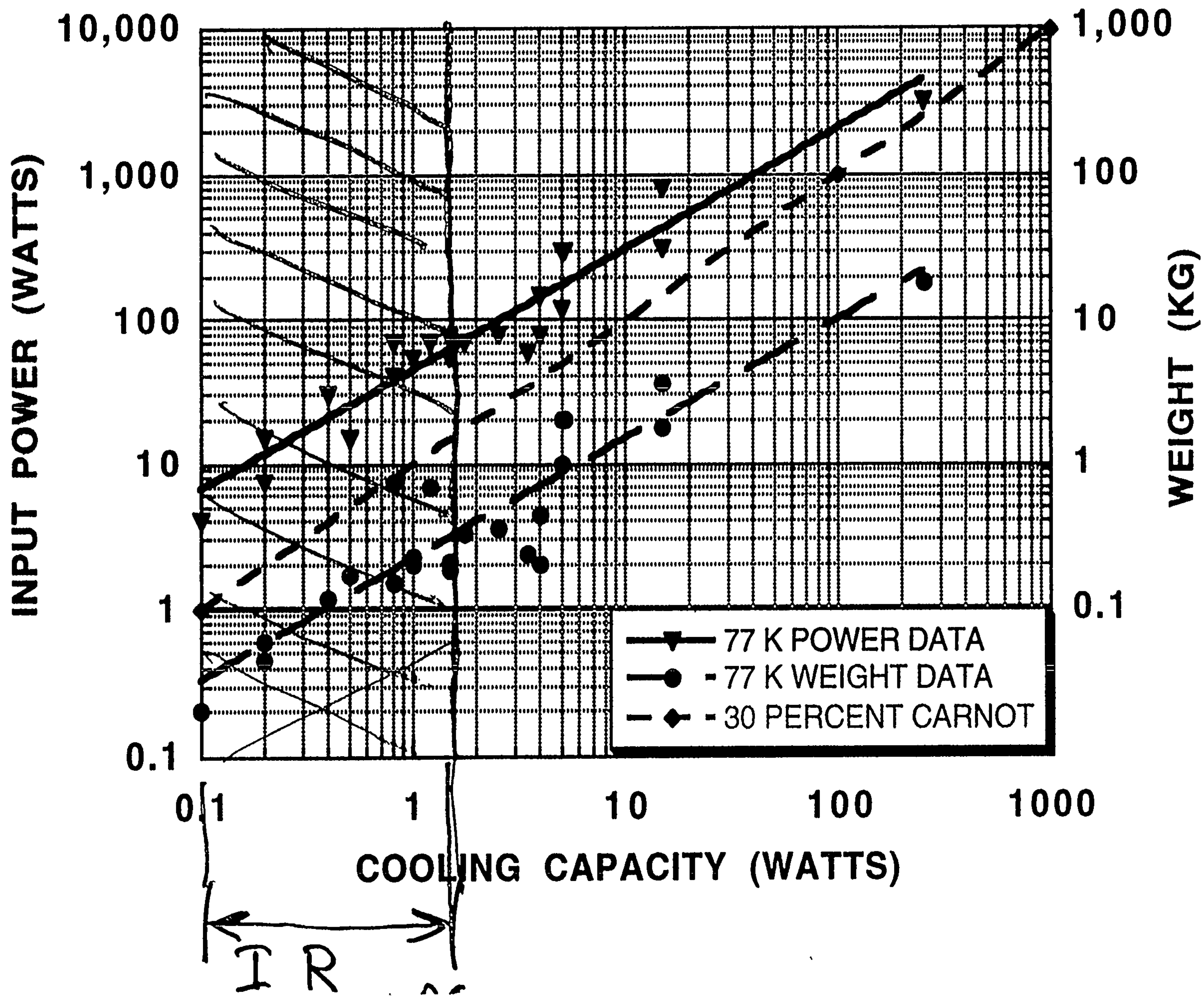
NIST Pulse Tube Cooler
50 mW @ 90 K
24 Watts Input
0.65 kg mass

CARNOT EFFICIENCY FOR 60- 80 K CRYOCOOLERS (Strobridge 1974: DATA 1998))

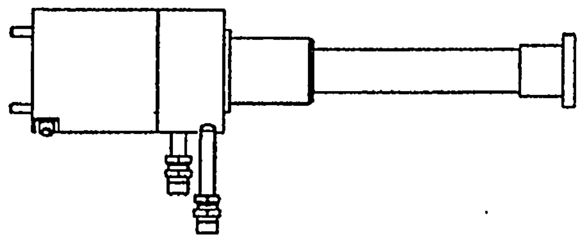


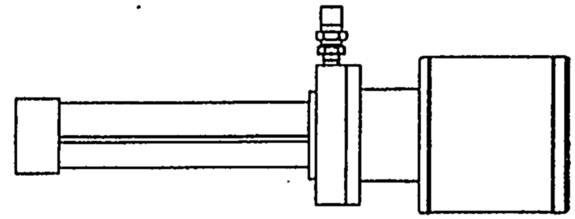
CARNOT EFF. PLOT (4-28-98) 3-6-99

INPUT POWER AND WEIGHT vs. COOLING CAPACITY FOR CRYOCOOLERS OPERATING IN 60--80 K RANGE



IN-LINE SOLVAY COLD HEAD





PTR COLD HEAD

Pulse Tube Refrigerator (PTR) Cryocoolers

Item No.	Head Model No.	Q, watts 1st @77K	Q, watts 2nd @20K	Ult. Temp. 1st, K	Ult. Temp. 2nd, K	Time to $T_{ult.}$, min	Wgt., kg	Dimensions L, mm	Dimensions Dia., mm	Comp. Model No.	AC Power, watts
13	P201	5 @123K		77		25	1.2	200	79	CA201	800
14	P201	5 @123K		77		25	1.2	200	79	CW301	700
15	P301	2		55		30	1.3	250	79	CA201	800
16	P301	2		55		30	1.3	250	79	CW301	700
17	P301	10		60		30	1.3	250	79	CW303	2300
18	2xP050*	25		55		35	6	375	123	CW303	2300
19	P050	10		55		35	6	375	123	CA201	800
20	P050	10		55		35	6	375	123	CW301	700

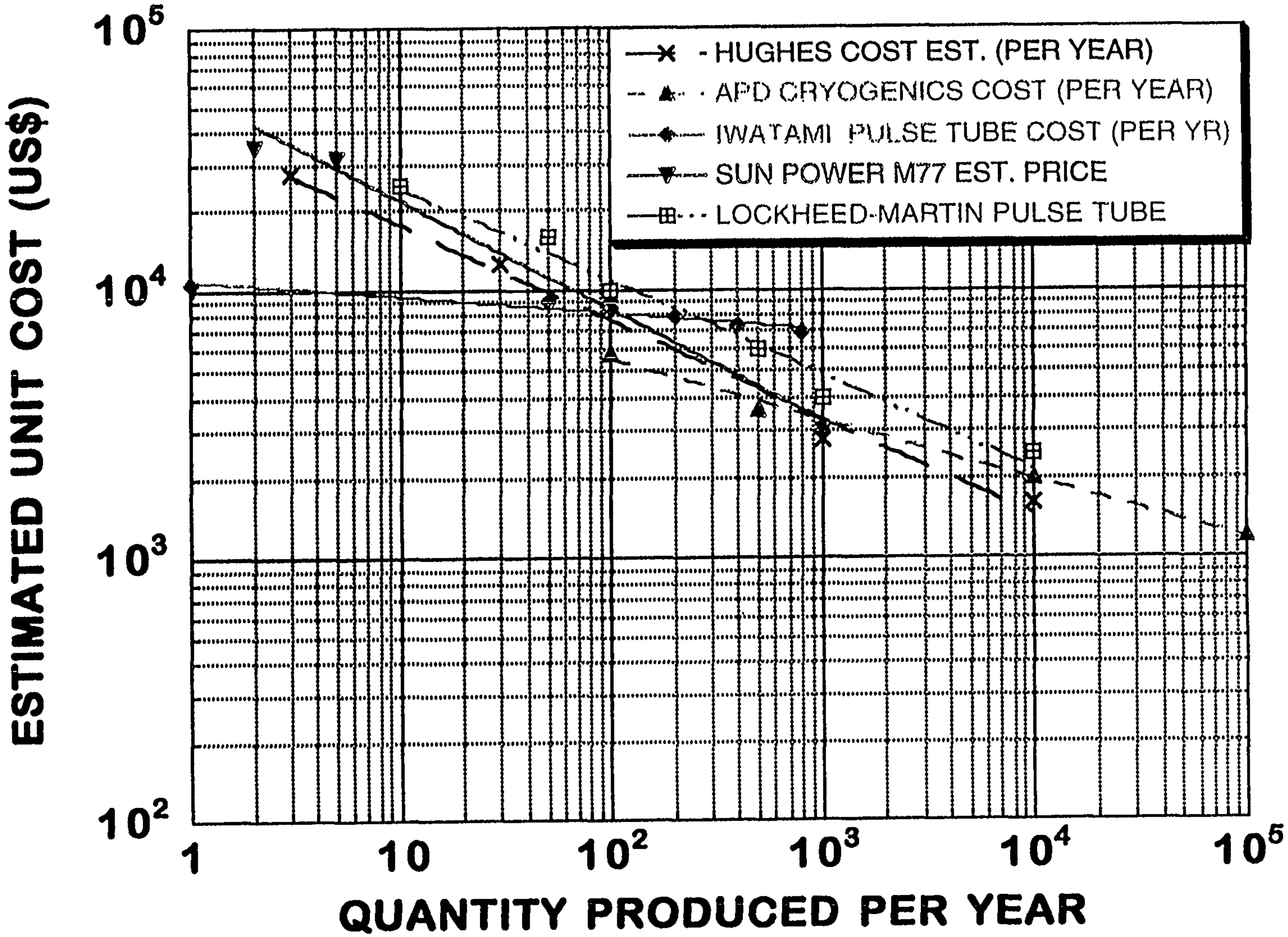
*This is 2 cold heads connected to a single compressor.

Helium Compressors for Solvay, PTR, and LN_2 Systems

Item No.	Comp. Model No.	AC Power, watts	VAC (1Φ) 60Hz	Dimensions W, mm	Dimensions D, mm	Dimensions H, mm	Wgt., kg	Water Flow, L/hr
21	CA201	800	110	330	400	386	36	
22	CW301	700	110	380	420	445	45	100
23	CW303	2300	220	313	585	660	75	200
24	CW306	4600	220	450	585	697	130	400

Sold by: Kelvin International Corporation
P.O. Box 4006 - Hampton, VA 23664 USA
Tel: (757) 851-6215 or (800) 8-KELVIN
Fax: (757) 851-5212 or (888) 8-KIC FAX
E-mail: info@kelvinic.com
Web site: www.kelvinic.com

EST. COST OF 60-80 K CRYOCOOLERS vs. QUANTIITY PER YEAR



THE REALITY OF LOW-COST HIGH- RELIABILITY CRYOCOOLERS

- SEVERAL WELL-KNOWN THERMODYNAMIC CYCLES (Stirling, pulse tube, Gifford-McMahon, Joule-Thomson, Brayton, etc.)
- SOUND MANUFACTURING PROCEDURES
  - Proven design concepts
  - Design for large quantity production
  - Sound manufacturing procedures
- LARGE QUANTITY PRODUCTION
  - Production runs of 100's per month or greater
  - Quantity production leads to

HIGH RELIABILITY

  - Quantity production leads to

LOW COST

Low-Cost,
High-Reliability
Cryocoolers
will become available
IF
there is a strong
MARKET PULL

Effects of Cryogenic Cost and Efficiency on the Competitiveness of High Temperature Superconductors (Early Results)

J. Mulholland, DOE

EFFECTS of CRYOGENIC COST & EFFICIENCY on the COMPETITIVENESS of HIGH TEMPERATURE SUPERCONDUCTORS

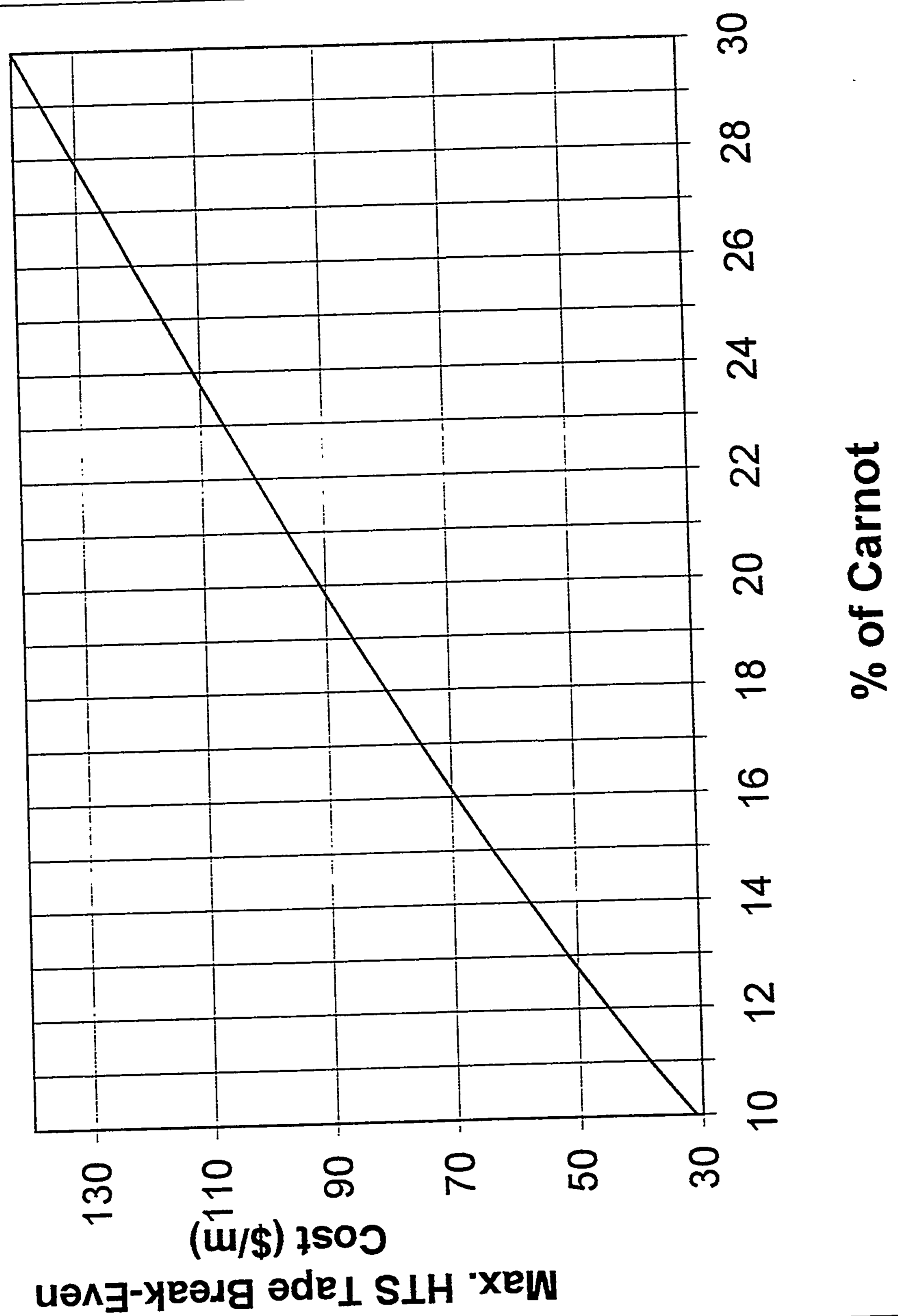
38 **HTS wire break-even cost increases $\underline{\$5.45/m}$ for every 1.0% of Carnot increase in efficiency of cryocoolers.**

HTS wire break-even cost increase $\underline{\$3.44/m}$ for every \$1000/kW_{HOT} increase in capital cost of cryocoolers.

Silver costs $\underline{\$3.88/m}$ of HTS BSCCO wire(Ag=\$5.50/Tr. Oz.).

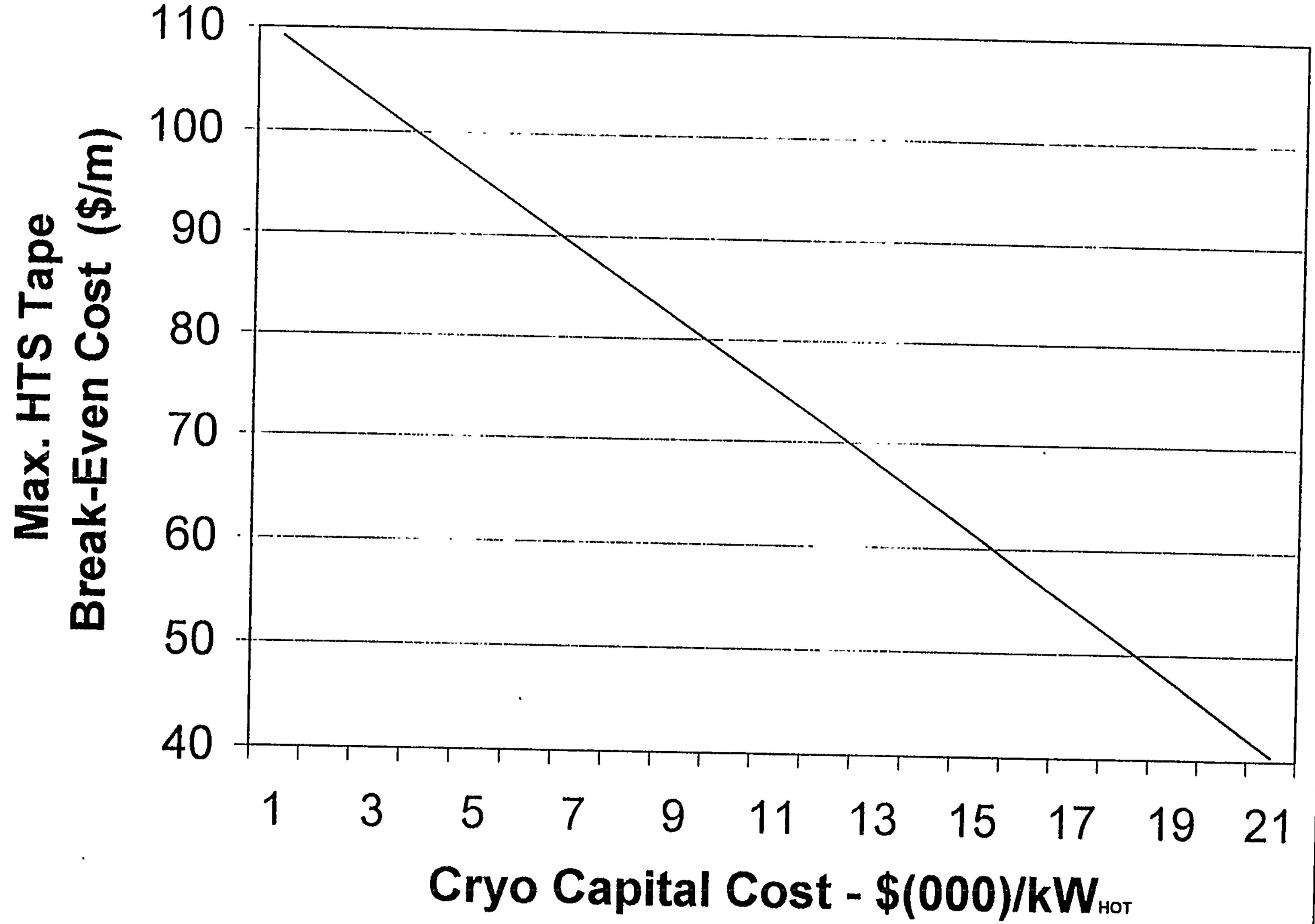
DRAFT

DRAFT



HTS Conductor Break-Even Cost vs. Cryogenic Efficiency

HTS Conductor Break-Even Cost vs. Cryogenic Capital Cost



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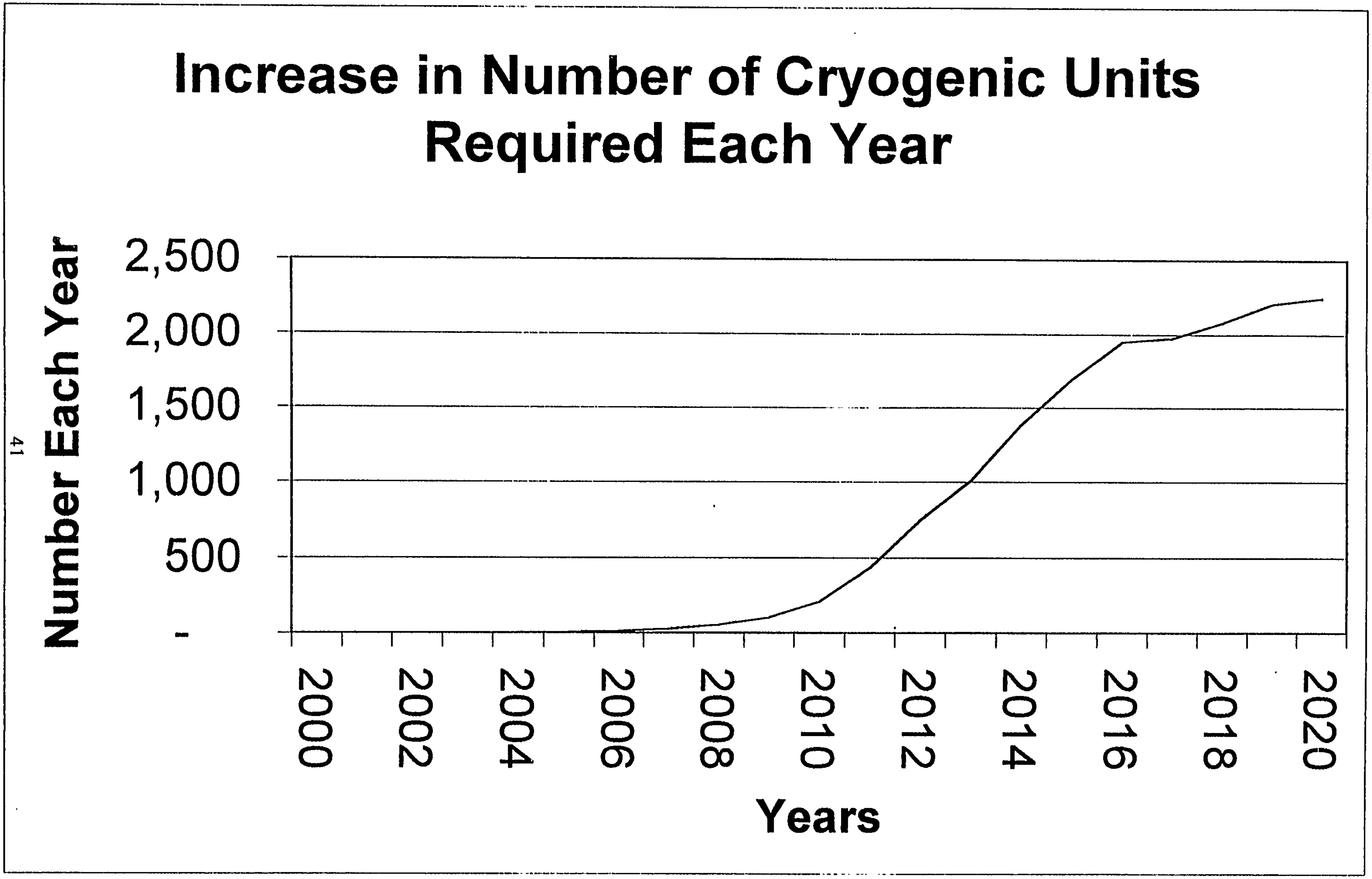
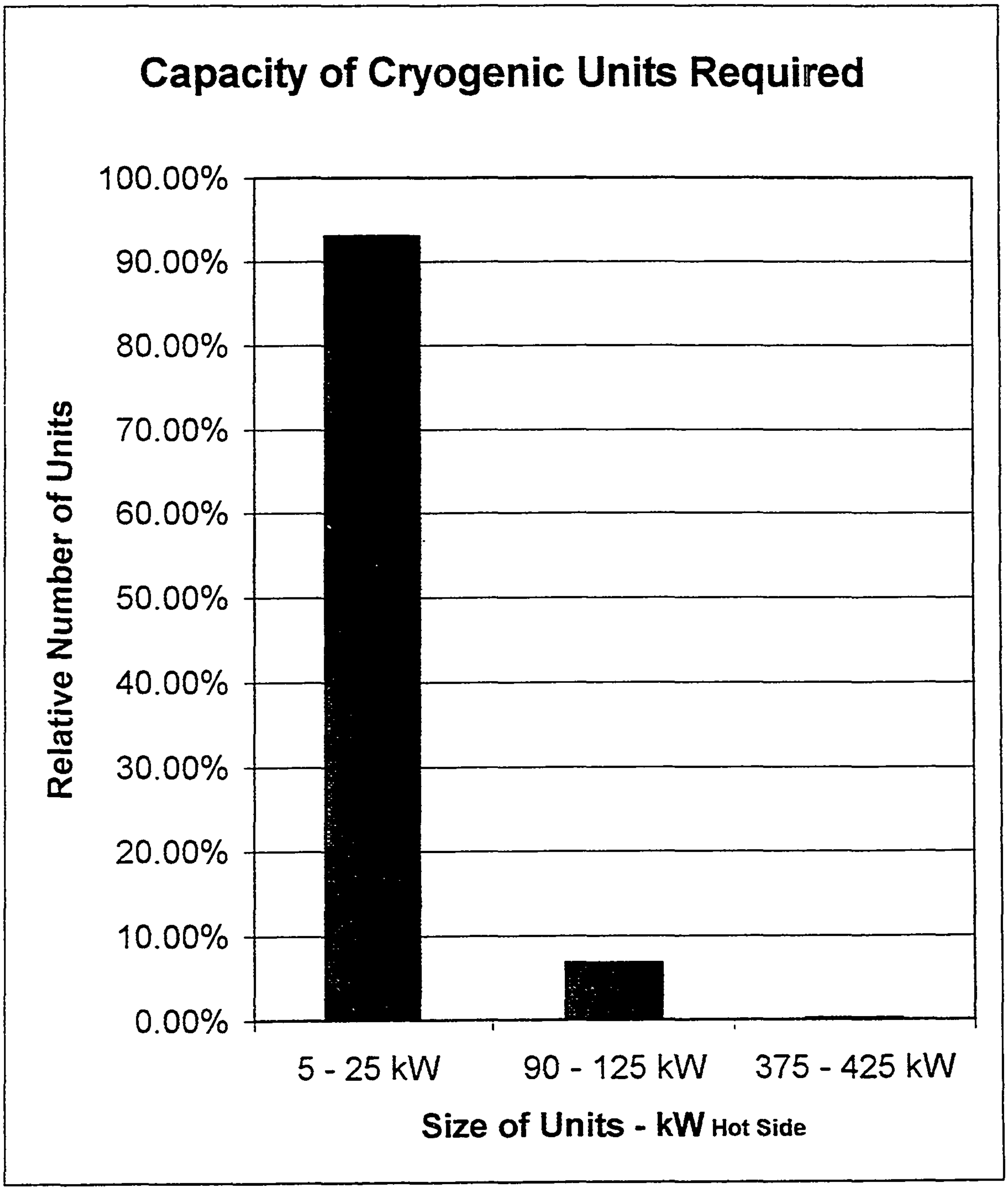

Increase in Number of Cryogenic Units Required Each Year
Number Each Year
2,500
2,000
1,500
1,000
500
-
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
Years

41

DRAFT



Capacity of Cryogenic Units Required
100.00%
90.00%
80.00%
70.00%
60.00%
50.00%
40.00%
30.00%
20.00%
10.00%
0.00%
Relative Number of Units
5 - 25 kW
90 - 125 kW
375 - 425 kW
Size of Units - kW Hot Side

Cryogenic System Issues for Utility Applications

N. Kelley, Pirelli and J. Jipling, Detroit Edison

(Issues suggested by Nathan Kelley/Pirelli and Jon Jipling/Detroit Edison)

Cryogenic System Issues for Utility Applications

1) HTS technologies are frequently cited for applications in congested regions. Therefore, the size of the refrigeration unit is a critical factor.

2) HTS cables' long length to volume ratio and restricted diameter make the continuous flow of LN_2 critical.

3) A refrigerator should be capable of operating for very long periods of time without external intervention or attention, as most utility locations are unmanned.

4) System should be designed (and guaranteed) for 100% availability.

5) The load on a refrigerator will change depending on the cable load from a minimum (equal to the thermal inleak of the system) to a maximum design point. The system must operate efficiently through this entire range and reliably follow the continuously changing load.

6) The relatively high heat loads for HTS cables requires an efficient refrigerator, not only at design load, but at all operating points. This is particularly significant for cables with daily and/or seasonal dips in loading. The overall system efficiency must be improved from the generally quoted 20W/W, as the life-cycle cost must be competitive with conventional cables.

7) The system should be able to provide larger refrigeration capacity for a short duration following transient thermal conditions, such as short circuit.

8) A system needs to be "low profile". This means that the refrigerator be as compact as possible. And, growing vertically is not always a solution.

9) Most utilities would not permit a third party (i.e. a LN_2 vendor) to make deliveries without their personnel being present. And, it is not feasible for a substation operator to be available every three days for the LN_2 refill. Subsequently, evaporative bath coolers are typically not an option as primary refrigerators.

10) Automatic circuit breakers and reconnects require some cycles to operate. The refrigerator cannot go through a complete shut-down/start-up cycle every time that the power "flickers".

11) The power requirements for different cable installations could be very different. Despite the capacity differences, it is important that there be standardization of spare parts and repair techniques.

12) Other HTS technologies are operating below LN_2 temperatures, and so will use He based systems. Different cycles or refrigerator types for cables, transformers, etc. would require large parts inventory and diverse training.

13) Major components and long-lead items will need to be stocked, because a system cannot be out-of-service for several months waiting for replacement components.

14) The utility maintenance infrastructure will need training on routine and emergency maintenance.

15) For widespread commercial deployment of refrigeration systems, a skilled field-service force will be required.

16) System availability and reliability should be very high.

17) COST!!! Final system cost must be competitive on first installed and life-cycle basis.

18) Typical utility hardware has a 40-year depreciation. Refrigerator longevity will be compared to this experience.

19) The utilities have little experience with cryogenics and refrigeration. Therefore, they have many questions and doubts. The cryogenics industry must be willing and able to work with system developers to educate the end users.

20) Remote control system capability should be integrated in the refrigeration system. Utilities are spending a lot of money to install remote monitoring and automation on their distribution systems. The refrigeration system must easily integrate with a variety of monitoring systems and protocols.

Facilitated Vision

- What are the Critical Factors in a Shared Vision Statement for Successful Future Commercialization?

- What Cryogenic System Goals are Needed to Meet Future Commercial HTS Equipment Requirements?

- What R&D Activities Are Needed?

- What R&D Partnership Roles Can Be Identified?

FACILITATED VISION SESSION

The purpose of the facilitated sessions was to discuss the key aspects of cryogenic system development. Specifically, the group discussed: 1) critical factors to be included in a vision statement for the cryogenic industry that will allow the successful future commercialization of HTS electric power equipment; 2) cryogenic system cost and performance goals needed to meet future commercial HTS equipment requirements; 3) needed R&D activities and priorities and 4) identification of R&D partnership roles. As shown on the next page, the 31 participants (and 3 observers) represented a variety of different perspectives and included individuals with experience and expertise from the business, government, and academic arenas.

Participants were given the focus questions on the agenda which formed the basis of the discussion, a list of 20 cryogenic system issues for utility applications, and a background defining discussion terms such as key drivers, vision, and strategic goals. These pages are included in this section.

Following the background pages are tables summarizing the discussion points for each focus question:

- **What are the critical factors in a shared vision statement for successful future commercialization?**

The most critical factor identified by the group was reliability. Cryogenic systems should be transparent to the user and have low-cost maintenance and have a 5-10 year maintenance cycle. Utilities want "cold" service without additional burdens. There is a need to understand the market requirements, system integration issues, and trade-offs in cost, reliability, and safety in having a hybrid system combining a cryocooler with the LN_2 back-up versus non-redundant systems.

- **What cryogenic system goals are needed to meet future commercial HTS equipment requirements?**

Goals were discussed for system parameters such as cost, efficiency, variable loads and demands, operating temperature, market, fail-safe performance, complexity, reliability, safety, flexibility, compactness, performance, and monitoring and control.

- **What R&D activities are needed?**

Priorities were established for the R&D activities by allowing the participants to "vote." On the corresponding table, votes are shown as "stars." R&D activities are presented from highest to lowest priority (as determined by the participants).

- **What R&D partnership roles can be identified?**

The government role for the five highest priority R&D activities was identified by the group. The government role ranged from developing fundamental knowledge to prototype funding as well as funding novel and risky ideas.

CRYOGENICS VISION WORKSHOP PARTICIPANTS

Name	Organization
Tim Atkinson	BOC Process Systems
S. Augustynowicz	Dynacs Engineering
Jonathan Demko	Oak Ridge National Lab
Ronald den Heijer	Stirling Technologies
James Fesmire	NASA
Pter Gifford	Cryomech
Paul Grant	EPRI
George Harriott	Air Products & Chemicals
Michael Heil	BOC Gases
Jon Jipping	Detroit Edison
Nathan Kelley	Pirelli Cables North America
Peter Kerney	Leybold Cryogenics
Ken Kreinbrink	PHPK Technologies
Ron Lee	BOC Gases
Eddie Leung	General Atomics
Maria Littlefield	NASA
Ralph Longsworth	APD Cryogenics
Jerry Martin	Mesoscopic Devices
Marty Nisenoff	NRL (retired)
Ray Radebaugh	NIST
V.R. Ramanan	ABB
Christopher Rey	DuPont
John Royal	Praxair
John Stovall	Oak Ridge National Lab
Mike Strasik	Boeing Phantom
Ahmed Sidi-Yekhlef	American Superconductor
Robert Thorogood	BOC Process Systems
Michael Troy	Praxair
Steven Van Sciver	NHMFL/Florida State University
Philip Winkler	Air Products & Chemicals
Burt Zhang	Reliance Electric

Observers	
James Daley	DOE
Joe Mulholland	DOE
Karen Thompson	NASA

Facilitator: Joe Badin, Energetics, Incorporated

Note Taker: Tom Sheahen, Argonne National Lab

Cryogenics Vision for HTS Electric Systems Meeting

July 27, 1999

DEFINITIONS

KEY DRIVERS

These are the factors, conditions, possibilities, issues, trends, problems, and opportunities that will determine the future of the cryogenic refrigerator industry as a system supplier for commercially acceptable HTS electric power equipment over the next 20 years. Key drivers affect markets, technologies, and government policies. They impact the decision making of vendors, developers, installers, and users of new specific product lines. In retrospect, that is standing in the future and looking back in time, the key drivers will have been the factors that affected the development and deployment of cryogenic systems for HTS electric equipment the most.

VISION

At its simplest level, a vision is the answer to the question, "What kind of future do we want to create for the cryogenic refrigerator industry that will enable the widespread deployment of HTS electric power equipment?" The best visions are exhilarating. They motivate. They inspire. They create spark and lift organizations out of the mundane and foster commitment and risk taking. When people truly share a vision they are connected, bound together by a common aspiration. We are creating a common vision that will be shared by cryogenic system suppliers and HTS electric equipment developers. Visions reflect an "end-point", not the process of getting there. Vision statements are clear, concise, and to the point. They are specific and quantitative, but not overly so. They paint a picture of the future that stretches thinking about what could be but do not go beyond what realistically could be reached.

STRATEGIC GOALS

These are concrete, specific, and measurable. They answer the question, "What do we need to accomplish to reach our vision for the cryogenic refrigerator industry as a system supplier for commercially acceptable HTS electric power equipment?" They address the most important levers for accomplishing action including technology development initiatives, market deployment strategies, and government policies. They establish performance targets to guide the development of roadmaps and action plans. They are used to track progress toward achievement of the vision. They address the most significant policy, market, and technology barriers to the development and deployment of cryogenic systems. They include an action, outcome, and completion date.

J.S. Badin, Energetics, Inc.

What Are the Critical Factors in a Shared Vision Statement for Successful Future Commercialization?

- One vision: On-site machine that produces cryogenic fluid (N_2, He)
- Cooling
  - LN_2 or mechanical

  Do not lock in one now

- Market! Who will buy it?
- Cooling requirements vs. market size (applications)
- What does customer want to buy? Cold!
- Equipment suppliers: Service!

- Utilities are not monolithic
  - Business models
- Providing LN_2 on site
  - Automatic startup

- What should critical infrastructure look like?
- What proof will utilities require before widespread deployment
- Reliability, maintenance interval

- Utility wants to buy a system
- Societal issues often drive utilities

- What is an acceptable system?
  - Requirements
  - Specifications

- Reliability systems approach between vendor and customer
- Reliability is more important than temperature
  - Any system must be "bulletproof"
  - Safety
- Low cost maintenance scheduled similar to utilities

- Variable load
- What is the maintenance cycle?
  - Electronic example:
    - Base station
    - 3-5 years maintenance

- Temperature (operating) 77K below/above is major break point
  - 10 years out T>80K

- NASA: safety, reliability, efficiency
  - NASA: Cost is not important but is a consideration

- 2015? 2020? Cryocoolers
- Transformers 10 years (window of opportunity)
- Long-time between
  - Maintenance
  - Failure
- Requirements
  - Unmanned
  - Simple
- Future efficiency:
  - 30% Carnot Efficiency
  - 40% Carnot Efficiency
- Scale is a critical factor
- Hybrid systems (LN_2 and cryocoolers) enhance reliability

- LN_2 is <u>not</u> the only temperature range of interest
- 77K Cables
- 30K Motors generators
- Heat exchange to air ambient T: $-5°C < T < 75°C$
- Magnets operate near 30K; cables operate near 77K

- Compact extended range (variable load)

- Standardization on sizes (large markets)
- Size/real estate of cryogenic system
- System integration
- Cost-effectiveness trades against
  - Reliability
  - Delivery
  - Service

- Transparent operation to the user
- Hybrid vs. non-redundancy
- LN_2 hazardous material? Perception!
- Optimizing cryocoolers for each application
- Standardization is related to safety
- 60,000 W cooling in a cable system
- Cryocoolers need a generic design (modular?)
- Central facility for LN_2 R&D (universities, labs, industry)

What Cryogenic System Goals Are Needed to Meet Future Commercial HTS Equipment Requirements?

COST	• Cost ≤ 10% of total system cost • $8 K for 30K, 60W (A.S.C.) • 600 W @ 70K (A.S.C.)
EFFICIENCY	• Efficiency Goal: 30-40% Carnot Efficiency
VARIABLE LOADS AND DEMANDS	• Design point: -50% +30%
TEMPERATURE (TOP)	• Operating temperature 65 < T < 85K (cable)
MARKET	• 100-150 units/yr with input of 40-60 kW (2004) • Cryocooler for motors: many units needed to create market • Market size $10-$100 million per year
FAIL-SAFE PERFORMANCE	• Reliability, redundancy, backup • Utility wants distributed transmission systems
COMPLEXITY	• Avoid complexity in hardware (software complexity - ok) • Modular systems for scheduled maintenance • Simplicity of training - standard skills
RELIABILITY	• Maintenance cycle • Maintenance motors: Annual • Maintenance cable transformers: 5-10 years • System transparent to the end user • Unscheduled down time is very costly
SAFETY	• "Zero time loss" accident goal
FLEXIBILITY	• Ability to use different cryocoolers
COMPACTNESS	• Quick change out
MONITOR & CONTROL	• Remote monitoring and control
PERFORMANCE	• Cryocoolers vs. liquid systems

What R&D Activities Are Needed?

R&D ACTIVITY
• Cut Cryostat Losses in half • Cryogenic insulation System ✪✪✪✪✪✪✪✪✪✪✪✪✪✪✪✪✪✪✪✪✪✪✪✪✪✪✪✪ (28)
• Cryogenic substation (entire system) - serving multi-applications ✪✪✪✪✪✪✪✪✪✪✪✪✪✪✪✪✪✪✪ (19)
• R&D: Understanding losses to improve efficiency • Raise efficiency to 30% Carnot Efficiency + (40%) 2 stage ✪✪✪✪✪✪✪✪✪✪✪✪✪✪✪✪ (16)
• Cool down/recovery of cryogenics • Removing heat from lead-in wires (cold bus) • Cool-down time ✪✪✪✪✪✪✪✪✪✪✪✪✪✪ (14)
• New compressors, expanders, optimize ✪✪✪✪✪✪✪✪✪✪✪✪ (12)
• Interfacing: coupling between device and cryogenics ✪✪✪✪✪✪✪✪ (8)
• Heat transfer cryo heat exchangers ✪✪✪✪✪✪✪✪ (8)
• Pulse tube refrigerators at 100-1000W or other technologies - Cost - Reliability ✪✪✪✪✪✪✪✪ (8)
• New refrigeration cycles ✪✪✪✪✪✪ (6)
• R&D: Oil-free compressors to operate over wide ambient T range ✪✪✪✪✪ (5)
• Pumps operating at cryogenic temperature ✪✪✪ (3)
• Bearings at cryogenic temperatures ✪✪ (2)
• Transfer coupling of rotating cryocoolers ✪✪ (2)
• Fluid dynamics in a rotating environment ✪✪ (2)
• Moving fluids at cryogenic temperatures ✪ (1)
• ΔV • Dielectric design (safety) ✪ (1)
• Entire electrical system at cryogenic T
• Purity of LN_2
• System: Cool down time redundancy

What R&D Partnership Roles Can Be Identified?

HIGH-PRIORITY R&D ACTIVITY	GOVERNMENT ROLE
• Cut Cryostat Losses in half • Cryogenic insulation system ✪✪✪✪✪✪✪✪✪✪✪✪✪✪✪✪✪✪✪✪✪✪✪✪✪✪✪✪ (28)	• Measurement and characterization (losses) • Fundamental studies that are applicable across many systems
• Cryogenic substation (entire system) - serving multi-applications ✪✪✪✪✪✪✪✪✪✪✪✪✪✪✪✪✪✪✪ (19)	• Cryosubstation - government role is to: - Reduce risk - Interface • Precompetitive R&D
• R&D: Understanding losses to improve efficiency • Raise efficiency to 30% Carnot Efficiency + (40%) 2 stage ✪✪✪✪✪✪✪✪✪✪✪✪✪✪✪✪ (16)	• Losses: Fundamental studies of losses • Government role in getting the first one built
• Cool down/recover of cryogenics • Removing heat from lead-in wires (cold bus) • Cool-down time ✪✪✪✪✪✪✪✪✪✪✪✪✪✪ (14)	• Development of fundamental knowledge
• New compressors, expanders, optimize ✪✪✪✪✪✪✪✪✪✪✪✪ (12)	• Prototype funding
• General Cross-cutting R&D	• Funding ideas that are very different and very risky

Appendix A:
Technology Roadmaps–
Approaches and Lessons Learned

J. Badin

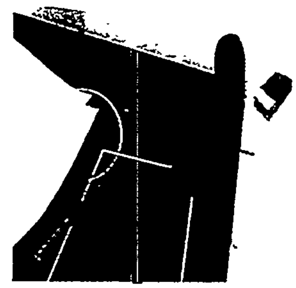
Technology Roadmaps

Approaches and Lessons Learned

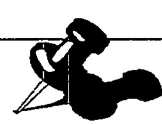
Joe Badin

ENERGETICS

July 1999



Purpose

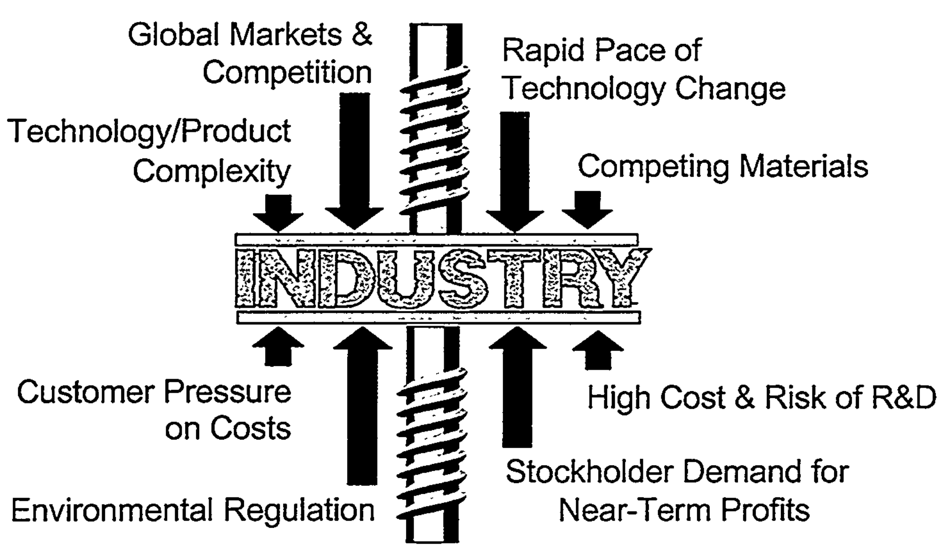


- ➤Review key features of technology roadmaps
- ➤Describe recent industry experiences with technology roadmaps

Agenda

- ► Why Are Technology Roadmaps Needed?
- ► What Is a Technology Roadmap?
- ► What Approaches Have Been Used?
- ► What Have Been the Lessons Learned?

Competitive Pressures

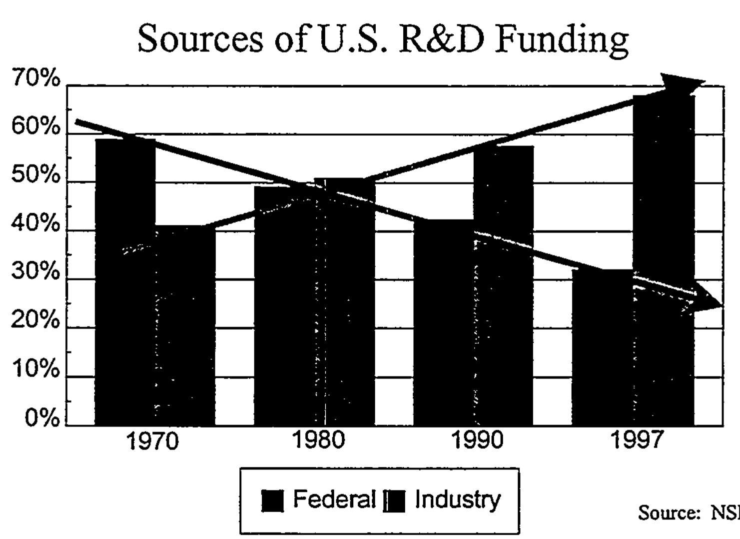


Technology Advantage in a Competitive Environment

"In an era of man-made, brain-power industries, those who win will learn to play a new game with new rules requiring new strategies. Technology is making skill and knowledge the only sources of sustainable strategic advantage."

-- Lester Thurow, economist

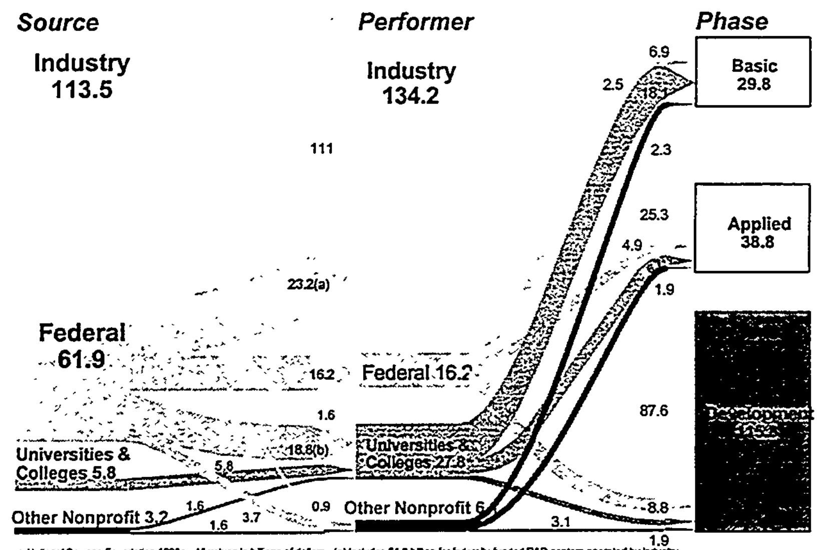
R&D Leadership Has Shifted



Source: NSF

R&D Patterns Have Changed

U.S. Research and Development Investment ($ Billion 1996)



Source: National Science Foundation 1996a. All values in billions of dollars. (a) Includes $1.8 billion for federally-funded R&D centers operated by industry. (b) Includes $5.3 billion for federally-funded R&D centers operated by universities and colleges

Business Technology Trends

- Investing in science and technology is a key business strategy.
- High profits, intensive competition, and information technology helped stimulate new R&D investment.
- Research partnerships strengthen core competencies and help maintain market share.
- External R&D investments are growing faster than internal ones.
- Government as a partner, not a sponsor or a customer

Source: NSF

Top 5 Problems for Technology Leaders

Technology Issues

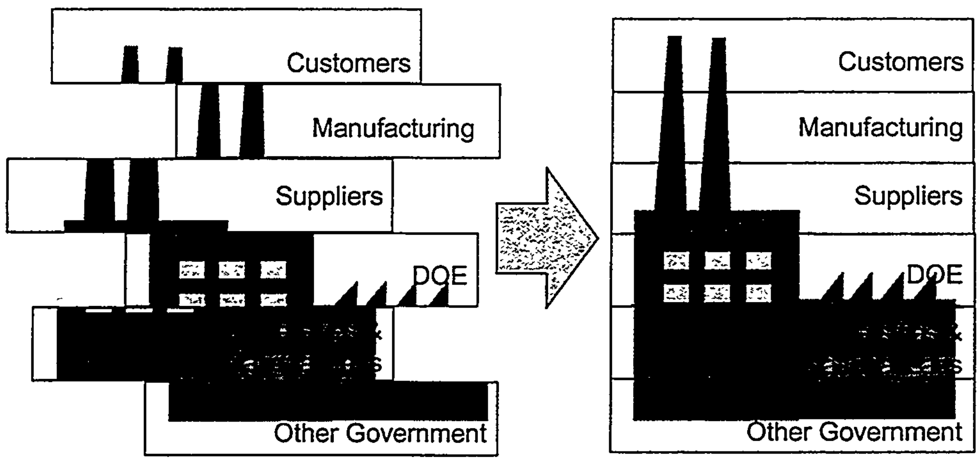
1. Managing R&D for business growth
2. Balancing long-term/short-term R&D objectives
3. Integrating technology planning with business strategy
4. Making innovation happen
5. Managing global R&D

Source: IRI

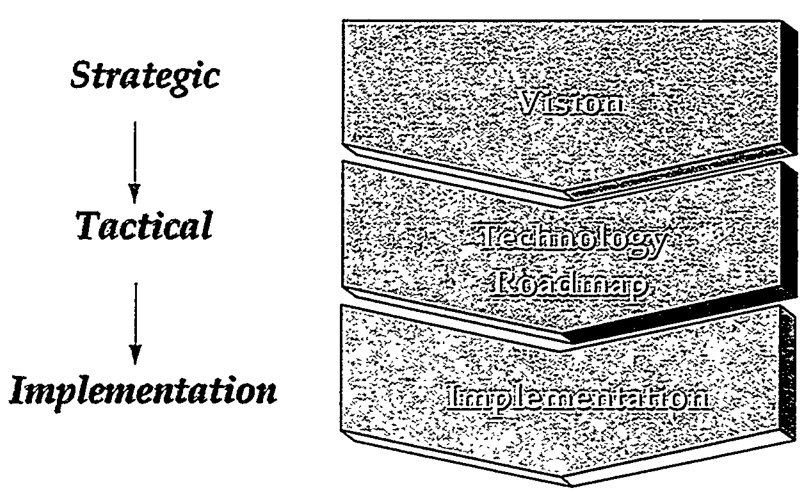
Agenda

- What Is a Technology Roadmap?

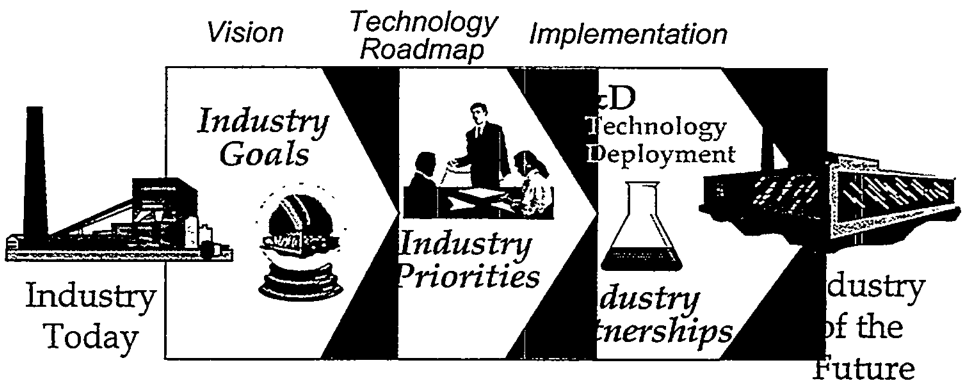
Aligning Resources



OIT's Industries of the Future Process



Industries of the Future Strategy



Vision

An industry-defined view of its desired future and the long-term strategy to attain it.

- Desired future state of the industry
- Strategic objectives and performance targets
- Market, business, and societal drivers
- Situation analysis of the industry
- Major challenges and barriers

Technology Roadmap

A comprehensive technology strategy for achieving the goals of the Industry Vision.

- Technical performance targets
- Assessment of current technologies
- Technology barriers, options, and pathways
- Research priorities organized by time frames
- Major milestones

Implementation

A multi-year action plan to implement a prioritized research agenda that accomplishes the Technology Roadmap.

- Industry priorities of proposed R&D projects
- Integration with existing research efforts
- Capabilities of R&D performers
- Project milestones and success indicators
- Resource requirements and commitments

Roles

Industry

- ☑ Leads the process
- ☑ Identifies & prioritizes technology needs
- ☑ Develops implementation strategy
- ☑ Commits resources
- ☑ Conducts R&D through partnerships
- ☑ Uses results

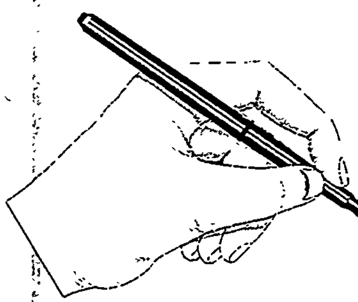
Government

- ☑ Facilitates the process
- ☑ Coordinates industry participation
- ☑ Leverages government resources
- ☑ Shares project costs
- ☑ Provides access to the national laboratories
- ☑ Disseminates results

Who Participates?

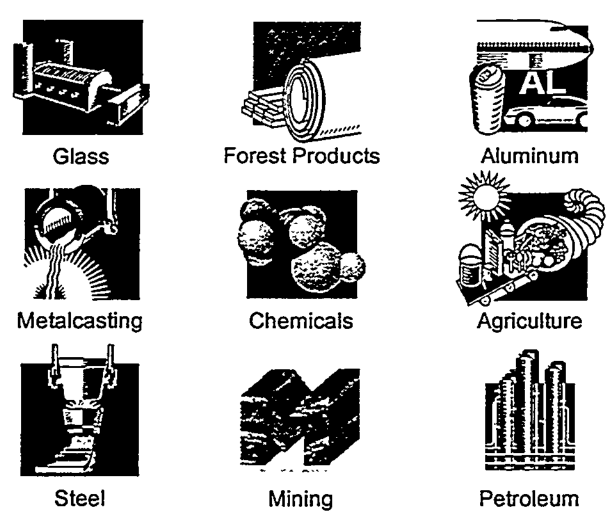
INDUSTRIES OF THE FUTURE

What's in It for Your Company?



- ☑ Conduct R&D more efficiently
- ☑ Reduce R&D cost and risk
- ☑ Compete more effectively against competitors
- ☑ Broaden your knowledge base
- ☑ Gain access to the national labs
- ☑ Boost corporate image
- ☑ Capitalize on existing research
- ☑ Coordinated access to Federal R&D

Industries of the Future

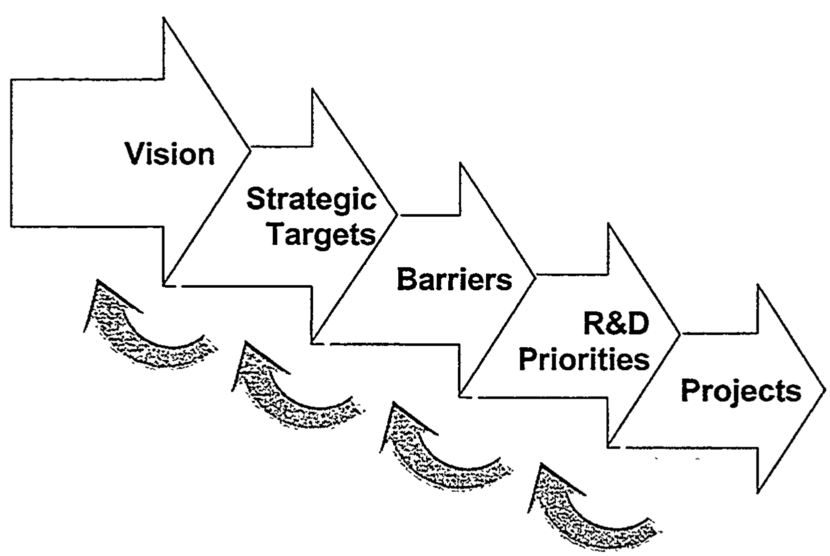


Completed Visions, Workshops, and Roadmaps

Aluminum	Yes	Yes (2)	Yes (3)
Chemicals	Yes	Yes (7/4)	Yes (?)
Forest Products	Yes	No	Yes
Steel	Yes	No	Yes
Glass	Yes	Yes	No
Metalcasting	Yes	Yes	Yes
Heat Treating	Yes	Yes	Yes
Welding	Yes	No	No
Forging	Yes	Yes	Yes
Bio-Based Renewables	Yes	Yes	No
Mining	Yes	Yes	No
Combustion	Yes	Yes	Yes
Materials	Yes	Yes (2)	Yes

Red: Prepared by ENERGETICS

Roadmap Logic



Special Features of Technology Roadmaps for Industry

- Broad representation and participation
- Multiple products, processes, and markets
- Limited ability to quantify goals and benefits
- Technology needs defined broadly
- Difficult to integrate and link R&D activities
- Often requires additional roadmaps for priority areas
- Very powerful -- widespread impact

A Good Roadmap Should . . .

- Outline technology and research requirements to achieve industry goals and targets
- Provide enough detail to quickly implement research solicitations and projects
- Reflect the concerns of the entire industry, including customers and suppliers
- Draw upon previous workshops, surveys, analyses, and studies of the industry
- Be strategic, clear, and easy to follow

Elements of Successful Roadmaps

- Set all performance targets
- Indicate near-, mid-, and long-term research needs
- Explain relationships among research activities
- Identify lead responsibility for funding research activities
- Define the roles of customers, suppliers, government agencies, universities, national laboratories, states, industry associations, and manufacturers in accomplishing the roadmap.
- Quantify research benefits and set performance measures
- Show relationship to other industry visions

How Can the Roadmap Help Me?

- Guide research priorities within the industry
- Confirm research needs within your company
- Align research within industry, academia, and government
- Strengthen leadership on environmental issues
- Provide a "technical marketing" tool that helps government programs
- Provide a communications tool to suppliers and customers

Workshops

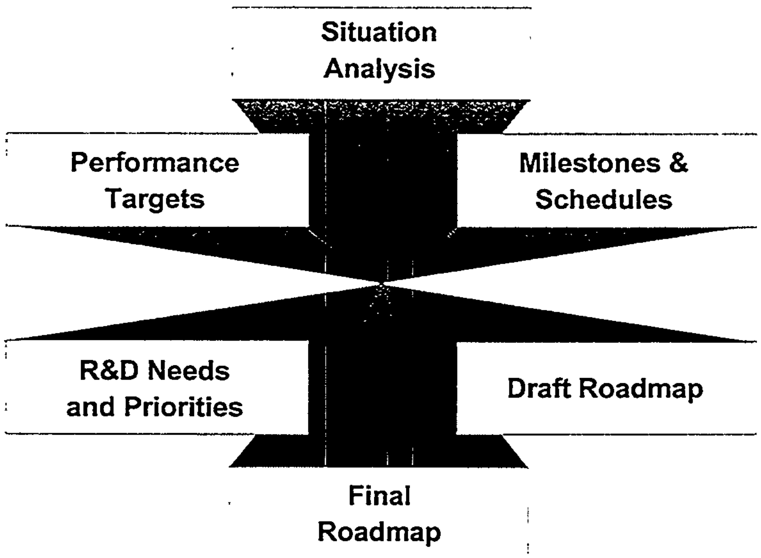
An effective way to identify research needs and priorities and to build consensus.

- Draw from previous workshops and surveys -- no need to ask the same questions
- Include a representative cross-section of industry participants
- Have a very specific purpose in mind
    - set/confirm technical performance targets
    - identify technical barriers
    - set research priorities (various approaches)
    - gather inputs to fill specific gaps

Agenda

- Why Are Technology Roadmaps Needed?
- What Is a Technology Roadmap?
- What Approaches Have Been Used?
- What Have Been the Lessons Learned?

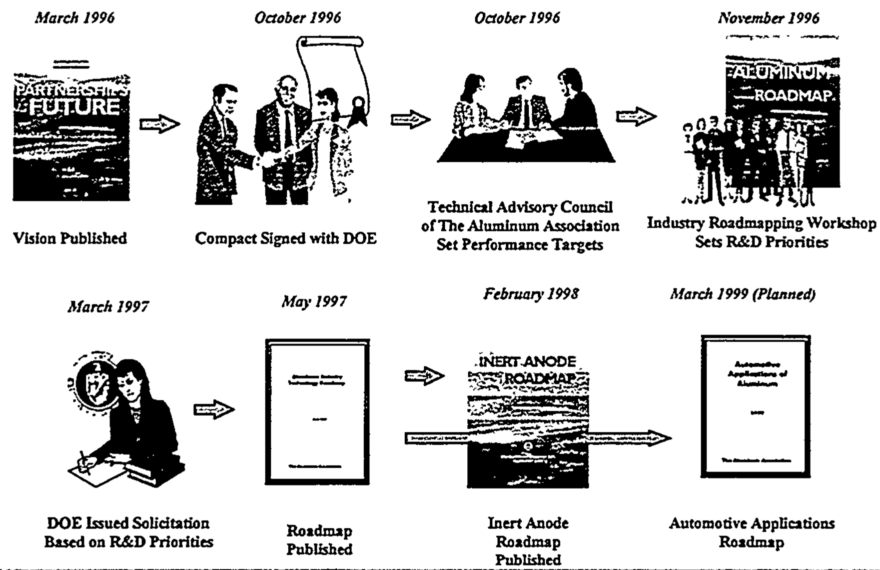
Basic Process Steps



Sources of Information

STEPS	POSSIBLE INPUTS	STEPS	POSSIBLE INPUTS
Situation Analysis	← *Vision* ← Other analysis	Milestones & Schedule	← Tech Committee ← Steering Group
Performance Targets	← *Vision* ← Tech. Committee ← Workshop	Draft Technology Roadmap	← Industry Committees ← Editing/Integration
R&D Needs and Priorities	← Workshop ← Tech Committee ← Surveys, etc.	Final Technology Roadmap	← Internal Reviews ← External Reviews

Aluminum Industry Experience



Aluminum Roadmap Participants

Aluminum Companies
Alcan Rolled Products
Alcoa
Alumax
Arco Aluminum
Kaiser Aluminum and Chemical Company
Reynolds Metals Company
Werner Company

Customers
Ford Motor Company
Chrysler Corporation

Universities
Case Western Reserve
University of Kentucky
Rensselaer Polytechnic Institute

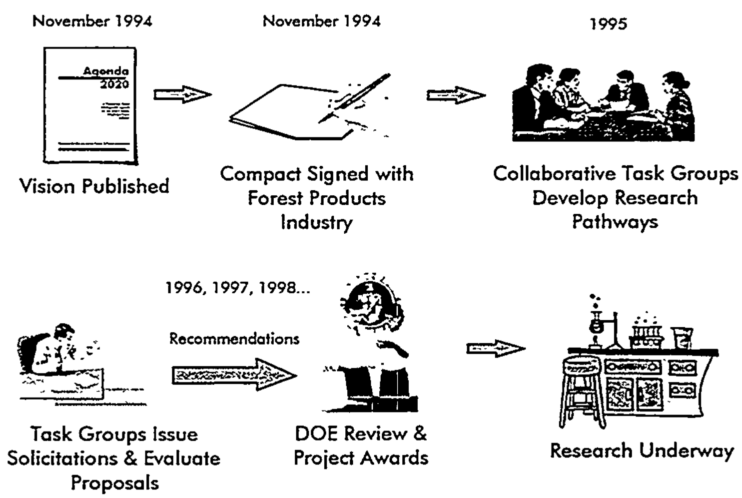
Associations
The Aluminum Association

National Laboratories
Argonne National Laboratory
Idaho National Engineering and Environmental Laboratory

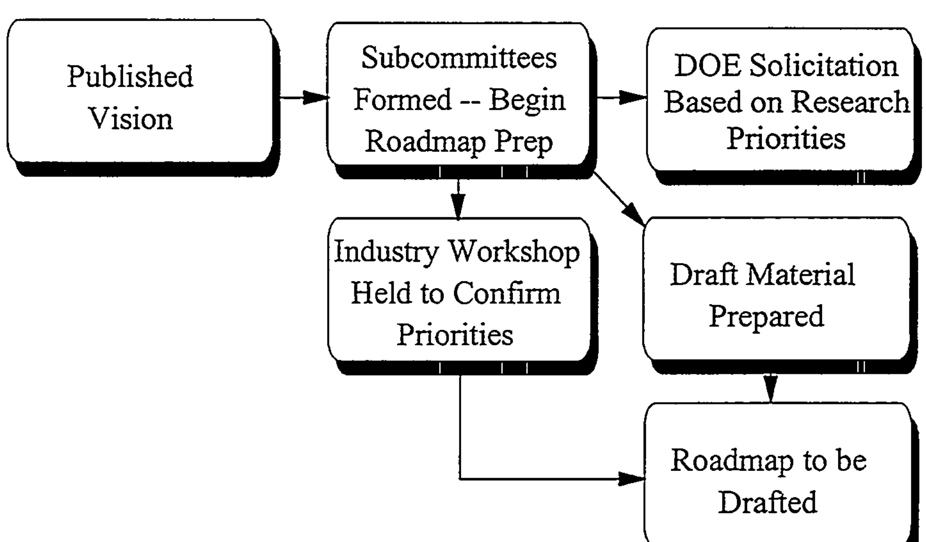
Federal Government
U.S. Department of Energy
Federal Highway Administration

Industry Consultants
John Mihelich
Nolan Richards
Elwin Rooy

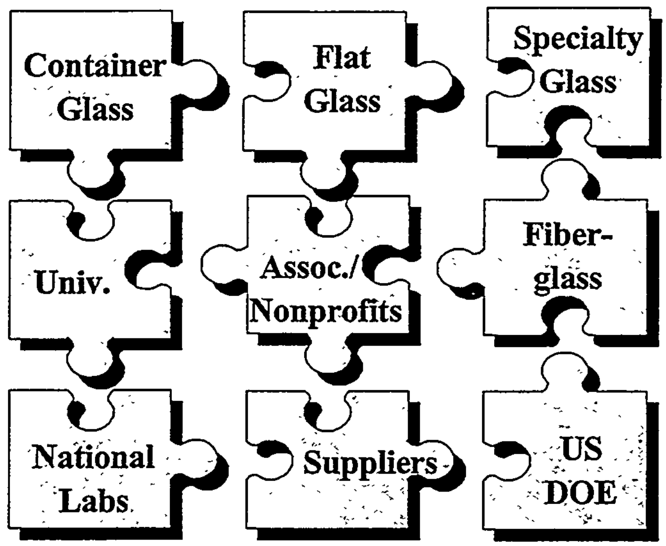
Forest Products Industry Experience



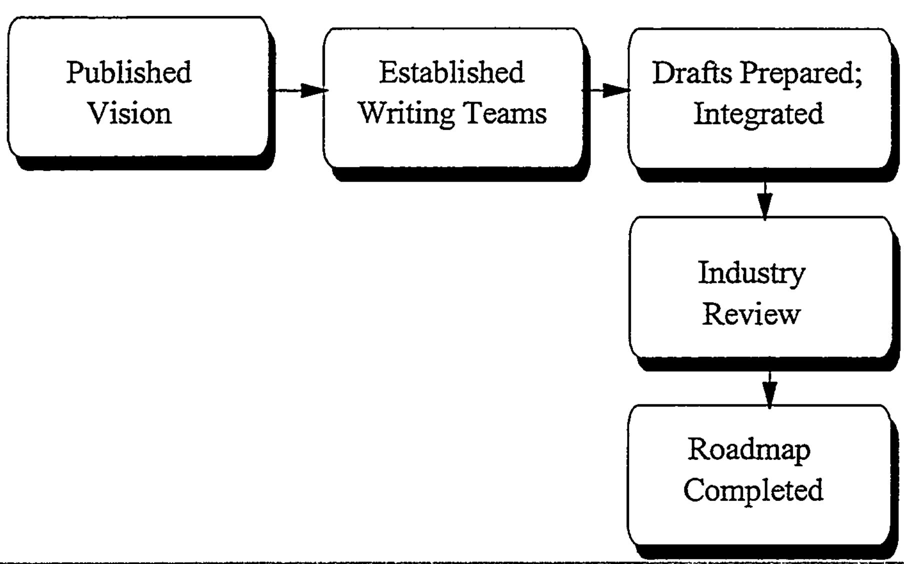
Glass Industry Experience



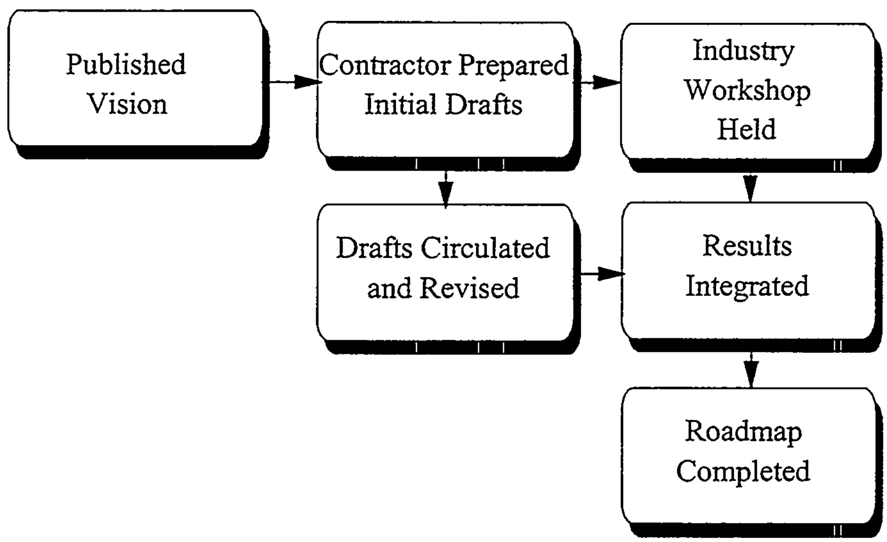
Glass Workshop Participants



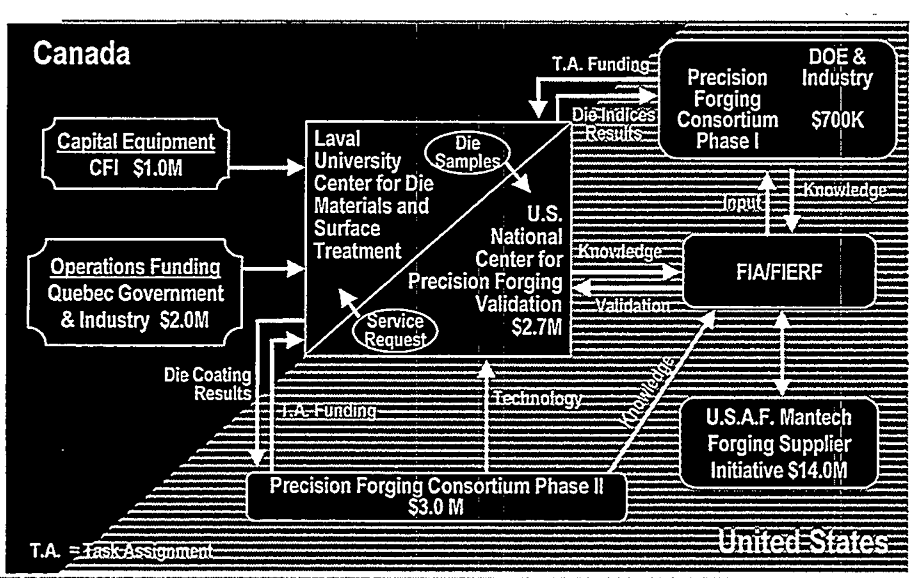
Steel Industry Experience



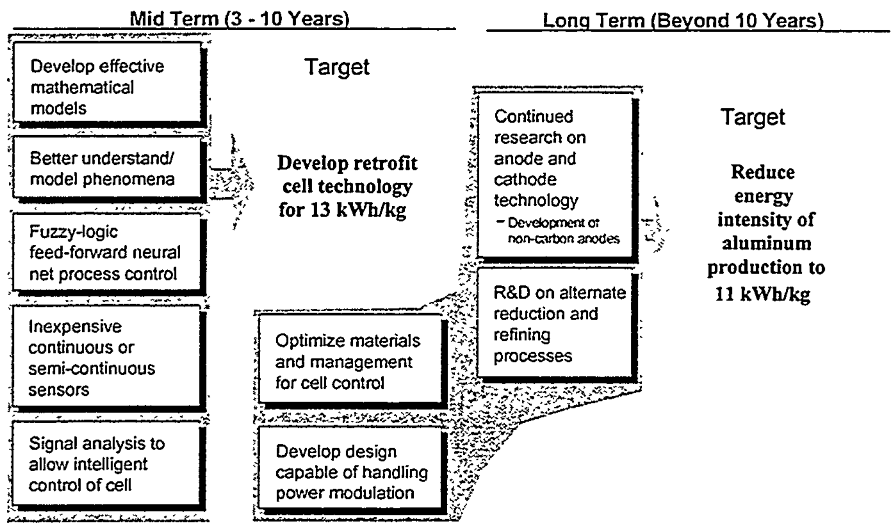
Metalcasting Industry Experience



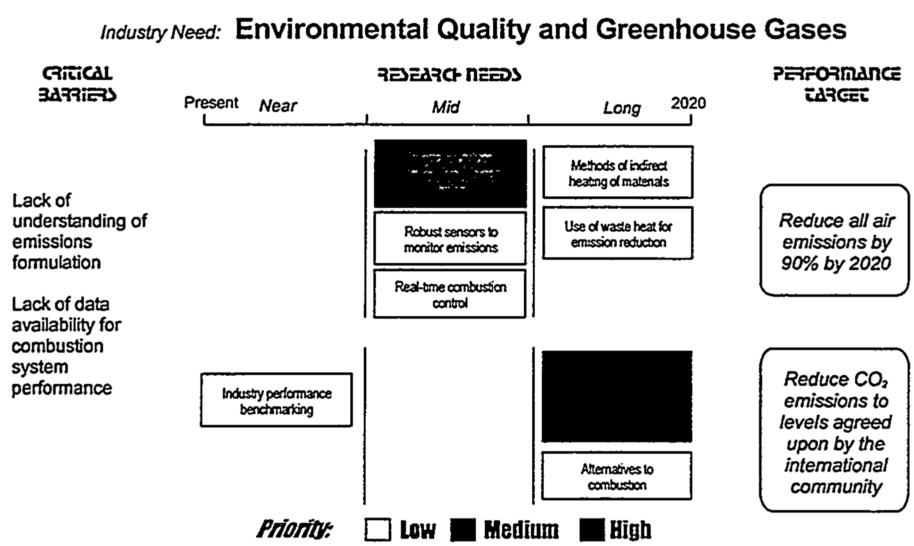
Forging Partnerships



Example: Primary Production of Aluminum



Example: Combustion Roadmap



Agenda

- [illegible]
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- What Have Been the Lessons Learned?

Lessons Learned

- Define the final roadmap and work backward
- Don't make up the process as you go along
- Pay attention to the review cycles
- Make the roadmap readable for everyone
- Show how roadmap activities will achieve vision goal
- A workshop is not a roadmap
- Workshops can be useful but you only have one shot
  - Get the right people involved
  - Don't waste people's time

Secrets of Successful Roadmaps

In The Process

- Include the right people
- Begin to build partnerships
- Design a manageable process
- Carefully plan the review cycle

Secrets of Successful Roadmaps

In The Product

- Clearly define performance targets
- Show relationships among research activities
- Define the roles of customers, suppliers, government agencies, universities, national laboratories, states, industry associations, and manufacturers
- Quantify research benefits and set performance measures

Key Issues and Next Steps

- Develop an overall process and rough schedule
- Identify participants in the technology roadmap process
- Define performance targets and technical objectives
- Conduct analysis of trends, drivers, current technologies, barriers, etc.
- Hold a workshop to lay out research needs and priorities?
- Obtain buy-in from customers, suppliers, and research community
- Coordinate/integrate with other industry visions

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