Chapter 5

High-Temperature Superconductivity Programs in Other Countries

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Chapter 5
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How do U.S. and foreign efforts compare in high-temperature superconductivity (HTS)? This chapter briefly assesses foreign programs in superconductivity, focusing primarily on government programs.[1]

JAPAN

History of Japanese Superconductivity Programs

Unlike the case of HTS, where Japanese researchers have made major advances, the Japanese made few contributions to the initial development of low-temperature superconductors (LTS). LTS research in Japan began in the early 1960s, and for many years Japanese researchers followed closely the LTS developments in the United States. It was nearly a decade before the Japanese began to catch up. During the 1970s, though, the Japanese Government initiated a number of collaborative LTS programs, featuring long-term commitment from its national laboratories, universities, and companies, that allowed Japan to surpass U.S. capabilities in several areas----e. g., Josephson Junction (JJ) technology,[2] maglev transportation, and superconducting rotating machinery. The principal Japanese Government programs are outlined in table 5-1.

Several observations can be made about these programs. First, their goal was and is to develop commercial-not military-technologies. Second, they were long-term programs, typically lasting 8 to 10 years. Their funding was sustained at a relatively constant level, in contrast to the erratic funding of corresponding U.S. programs over this period. Third, they featured strong emphasis on national laboratory facilities and personnel, although a large part (often 50 percent) of the funding and research were provided by the participating Japanese companies. Since the discovery of HTS, considerable thought has been given to how HTS can be integrated with ongoing LTS programs. Today, the Japanese Government is funding a mix of LTS and HTS programs in parallel, with the intent of incorporating HTS materials into more mature LTS projects as soon as the new materials can satisfy the necessary requirements.

The Japanese HTS Budget

Table 5-2 gives a budget breakdown for the principal Japanese agencies involved in superconductivity R&D. Major funding comes from the Ministry of International Trade and Industry (MITI), the Science and Technology Agency (STA), and the Ministry of Education (MOE). In 1989, HTS R&D accounted for slightly less than half of superconductivity R&D budget, compared with two-thirds in the United States. Japanese agency budget figures typically do not include salaries and overhead. When adjusted to include these costs, the nominal HTS total of $43 million in 1989 scales to over $70 million[3]—still considerably less than total HTS spending of the U.S. Government ($129 million) in 1989. Counting researchers in universities, national laboratories, and industry, OTA estimates that around 1,200 researchers are active in HTS R&D in Japan, compared with perhaps 1,000 in the United States.[4]

The most important new thrusts in superconductivity are given in table 5-3. These have been described in detail previously.[5] Programs especially well-known outside Japan are the International Superconductivity Technology Center (ISTEC) and the Superconductive Generation Equipment and Materials (Super-GM) program (see boxes 5-A and 5-B). Overall, OTA finds that there is a rough parity between Japan and the United States in HTS R&D. This parity does not extend to all technical areas, though: one recent report notes that Japan surpasses

[1] A comparison of U.S. and Japanese industry programs is presented in the next chapter

[2] U.S. Congress, Office of Technology Assessment, *Commercializing High-Temperature Superconductivity*, OTA-ITE-388 (Washington, DC: U.S. Government Printing Office, June 1988), pp. 71-72.

[3] International Superconductivity Technology Center estimate, October 1989.

[4] In 1988, Japanese industry had about 700 full-time researchers in HTS (see next chapter).

[5] U.S. Congress, Office of Technology Assessment, op. cit., footnote 2, p. 51.

Table 5-l—History of Japanese LTS Programs

Project	Supporting agency, R&D laboratory	Duration	Results	Comments
MHD power generation	MITI:ETL various companies	1966-1975	Mark V supermagnet.	Matching funds from companies, which gained experience in LTS magnet construction.
High-energy physics	MoE:KEK various companies	1971 -present	60-Gev collider (TRISTAN) including superconducting magnets for beam control, detection; also rf cavities and refrigeration systems.	Minor funding from companies.
Supermagnets for fusion research	STA:JAERI Nagoya U., Kyushu U Nihon U Osaka U,, MoE	Early 1970s-present	Large Coil Task coil tested 1987. J-60 Experimental Reactor. Toroidal and poloidal coils for new Fusion Experimental Reactor.	Program is expected to continue at present levels. No specific clans to incorporate HTS.
Maglev tram	MOT.JNR (now7 regional JR compames)	1970-present	44-seat test vehicle; 7km test guideway; 375km/hr manned test.	New50km test guideway planned. Funding IS 95 percent from private sources. No serious plan to incorporate HTS.
Electromagnetic ship propulsion	Ad-hoc group, Japan Foundation for Shipbuildmg Advancement (organized 1985) various companies	1970-present	Model vessel tests (1970 to 1979) Design for 22-meter, 150-ton oceangoing vessel for 1990 ("Yamato") miniature model tested in 1986. Total cost est. 40 million dollars.	Efficiency is low, requires very high magnetic field (>1 O tesla).
Basic technology for superconductivity and refrigeration	STA.NRIM various companies	1982-1986	Advancement of basic technology related to LTS and refrigeration.	Researchers became core of the New Superconducting Materials Forum and Multicore Project of STA.
Superconducting magnetic energy storage (SMES)	MIT I various companies	1986-?	Feasibility studies.	Candidate for new national R&D project. Designs for smaller, toroidal SMES being considered by electric utility industry (as opposed to larger, solenoid designs under study in the United States).
Superconductive generation equipment and materials (Super GM) (See box 5-B)	MIT I (NEDO) various companies	1988-1995	Design and construct 70 MW model generator Design components for 200 MW pilot generator.	Culmination of many years of research and engineering experience with superconducting magnets and prototype generators, beginning with MHD program HTS materials being developed.
Superconducting quantum electronics	MoE unversitles	1979-1981	Advances in fabrication methods for JJs and devices.	Provided experience base in unversities now being tapped for HTS-based electronics R&D.
Josephson Junction Devices	MIT I:ETL NTT, various companies	1982-1989	989 Prototype large-scale i containing thousands computer based on 16 microprocessor and 2 possible by 1990.	Program continued after U.S. effort stopped in 1983. Japanese companies now have a strong base for future thrusts in superconducting electronics, including HTS.
New superconducting materials	MoE universities	1984-1986	986 Training for university at development of higt	Predated discovery of HTS but served as a springboard for rapid Japanese involvement. Program extended 1 year after discovery of HTS.

KEY: ETL: Electrotechnical Laboratory; JAERI: Japan Atomic Energy Research Institute; JJ: Josephson Junction; JNR: Japan National Railroad (now broken up into 7 regional companies); KEK: National High-Energy Physics Laboratory; MHD: Magnetohydrodynamics; MITI: Ministry of International Trade and Industry; MOE: Ministry of Education; MOT: Ministry of Transportation; MW: Megawatt; NEDO: New Energy and Industrial Technology Development Organization; NRIM: National Research Institute for Metals; NTT: Nippon Telephone and Telegraph; STA: Science and Technology Agency

SOURCE: Advanced Materials Technology, "Assessment Study of the History of Japanese Superconductivity Efforts," contractor report prepared for the Office of Technology Assessment, November 1988.

Table 5-2-Japanese Government Fiscal 1989[a] Superconductivity Budget ($ millions)

Agency	HTS	LTS	Total
Ministry of International Trade & Industry	10.6	24.0	34.6
Science & Technology Agency	24.3	6.8	31.1
Ministry of Education	7.2	8.7	15.9
Ministry of Transportation	0.0	7.0	7.0
Ministry of Posts & Telecommunications	0.5	0.0	0.5
Total	42.6[b]	46.5	89.1

aDraft budget. The Japanese fiscal year begins April 1.
bCannot be compared directly to U.S. figures because Agency budgets often do not include salaries and overhead. When these are included, the total is estimated to beat least $70 million.

SOURCE: Adapted from *Superconductor Week*, vol. 3, No. 8, Feb. 20, 1989, p. 6.

Table 5-3-Recent Japanese Government High-Temperature Superconductor R&D Programs

Agencyl Program	Comments
Ministry of International Trade and Industry:	
Superconducting materials and process technologies	10-year program beginning 1988, includes funding for ISTEC and national laboratories.
Superconducting electron devices	10-year program beginning 1988, about half going to the private sector, focusing on development of HTS transistors.
Superconducting generator (Super-GM)	8-year program beginning 1988, primarily LTS; includes parallel HTS research component.
Science and Technology Agency:	
Multi-Core project	Coordinated effort of nine STA-funded national laboratories participating in HTS R&Din four "core" areas: theory/ database, processing, characterization, and technology transfer.
New superconducting materials forum	Professional forum on HTS development with 135 member companies and research associations. Interfaces between Multi-Core project and private industry efforts.
Ministry of Education:	
Mechanism of superconductivity	3-year program beginning 1988 involving some 100 researchers under the direction of Prof. Y. Muto, Tohoku University.
Chemical design and processing of new oxide superconductors	3-year program beginning 1989 under the direction of Prof. K. Fueki, Science University of Tokyo.
Development of electronics with new superconducting materials	3-year program beginning 1989 involving three research groups under the direction of Prof. K. Hara, Chiba Institute of Technology.
Special research project on new superconductors	3-year program beginning 1987 involving four research groups under the direction of Prof. S. Tanaka, University of Tokyo.
Ministry of Posts and Telecommunications	
Development of HTS mixer at terahertz frequencies	
HTS characterization and thin films for infrared detectors	Carried out at NIT laboratories.

ISTEC: International Superconductivity Technology Center

SOURCE: Office of Technology Assessment, 1990.

the United States in synthesis and processing of HTS materials, and in organic superconductor research.[6]

Japanese HTS programs are well integrated with previous LTS efforts, both in terms of personnel and research goals. For example, the core participants in STA'S New Superconducting Materials Forum and Multi-Core Project (table 5-3) also participated in a previous 5-year STA-sponsored LTS project on Basic Technology for Superconductivity and Refrigeration (table 5-1). In Japan's fiscal year 1988, MITI also initiated a new 10-year program to develop practical HTS transistors, following on the conclusion of an 8-year program to develop niobium JJs.

One common belief about Japanese companies is that they have become successful competitors because of their ability to work together in consortia organized by the Japanese Government. ISTEC, a single consortium of most major companies involved in HTS R&D that was organized under the auspices of MITI, is often held up as a trump card that will put Japanese companies ahead in the race to commercialize HTS. But although the formation of ISTEC is an impressive achievement, *its agenda is deliberately focused at a basic research level--+-e., materials development—similar to the research program of a university or national laboratory in the United States.* Members' motives for joining ISTEC are complex, but typically do not include the expectation that research at ISTEC will lead directly to commercial applications. For that, the member companies are relying on the major efforts underway at their own R&D laboratories, and the accumulated expertise built up over years of experience with LTS, semiconductor processing, and ceramics technology.

EUROPEAN COOPERATIVE PROGRAMS

The two most important existing European cooperative programs that sponsor HTS projects are Framework, an EC activity, and the EUREKA

[6]Japanese Technology Evaluation Center Superconductivity Panel, "High-Temperature Superconductivity in Japan," a report for the National Science Foundation, NTIS PB 90-123126, November 1989.

Box 5-A—Intm#ationd Supereonductivity Technology Center (ISTEC)

ISTEC is a consortium of companies organized under the auspices of MITI. Established in January 1988, its laboratory facilities, located in a building leased from Tokyo Gas, were officially opened in October 1988. ISTEC was established to pursue several activities related to superconductivity: conduct basic R&D on HTS and processing technology; review research progress and feasibility of various applications; organize international symposia, seminars, and workshops; promote international exchange of scientists; and disseminate information.

Resources

ISTEC has 111 members, under two kinds of memberships: associate and full. Full members participate in the laboratory and can send one or two researchers each. Full members give an additional one-time donation of 100 million yen (about $800,000) and pay an additional annual fee of 12 million yen (about $100,000) to support the laboratory. Companies pay the salaries of the researchers they send, and a lo-year commitment is expected. Most companies-viewing ISTEC as a training opportunity-are sending relatively young researchers, rather than their seasoned superconductivity veterans.

Associate members may participate in the seminars and receive the publications, but do not participate in the actual research or intellectual property rights. (However, associate members may share some benefits such as reduced royalty payments for licenses.) Associate memberships require an initial donation of 1 to 2 million yen (about $8,000 to $16,000) and a 0.5 to 2 million yen annual fee. A listing of ISTEC membership as of June 1989 is given in appendix 5-A.

At that time, 46 companies had joined as full members, yielding an initial capitalization of about $34 million. In addition, they contributed about $4.2 million in *operating* expenses. As of October 1989, there were 89 research staff, **including 77** dispatched from the member companies.

In Japan's fiscal year 1988, MITI's contribution was 440 million yen *($3.4 million), which incresed to 890* million yen ($6.4 million) in Japan's fiscal year 1989. These figures do not include salaries. According to one estimate, ISTEC'S operating budget if salaries are included, comes to about $17 million per year; thus, in Japan's fiscal year 1989, ISTEC received about one-third of its support from MITLl

Research organization

The research at ISTEC laboratory is organized according to seven groups as follows:

1) Characterization and analysis of fundamental properties of superconductors; 2) HTS oxides and search for new superconducting ceramics; 3) Research on organic superconductors. 4) Fundamental research on chemical processing; 5) Fundamental research on physical processing; 6) Organization of an HTS database; and 7) Research on high-critical-current density superconductors {presently at the Japan Fine Ceramics Center in Nagoya).

Each group is headed by a leading expert drawn from a major university or national laboratory, and when fully staffed, will have 10 to 22 members. Research is expected to remain at a very basic level, not directed toward particular applications, since competing companies are involved.

ISTEC's policies on intellectual property were finalized in March 1989.[2] In general, patent rights are shared between ISTEC and the company that dispatched the researcher who did the work.

International Aspects

ISTEC has actively encouraged foreign companies (and individual researchers) to join the laboratory. At this writing, though, only four U.S. companies had joined as associate members (DuPont-Japan, Rockwell, IBM-Japan, and Intermagnetics General), plus the Electric Power Research Institute (EPRI) (see app. 5-A). There are two European associate members, British Telecom and Rhone-Poulenc Japan; there are no non-Japanese full members. Given the substantial investment involved (perhaps $1.5 million the first year and $400,000 per year thereafer-to cover salaries and expenses for two researchers), most U.S. firms would apparently rather invest their external R&D dollars in domestic collaborations where there is no language barrer, where it is easier for researchers to make the necessary career adjustments, and where U.S. companies have more control over the R&D agenda.

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[1]According to ISTEC management sources.

[2]Takashi Akutsu, "The Establishment of the 'Guideline on Handling of Intellectual Property Rights,' of ISTEC," *ISTEC Journal*, vol. 2, No. 2, July 1989, p. 38.

SOURCE: Office of Technology Assessment, 1990.

initiative, a European-based program with close ties to the European Community.[7] While the budgets of EUREKA and Framework are relatively small compared with the overall R&D efforts of the national member States, these cooperative programs are considered by European observers to be important for a number of reasons: they allow organizations with different strengths to combine R&D resources necessary to maintain competitiveness; they are focused on commercial applications of high technologies; and they help to lower legal and regulatory barriers within Europe.

Framework

The Framework program of the Commission of the European Communities, as its name implies, provides an overall strategy, structure, and financial package through which specific R&D programs operate. Three EC programs within Framework support HTS research: ESPRIT II, Stimulation of Science (now in its second phase, called Science) and BRITE/EURAM. ESPRIT is a basic/applied research program in information technologies. BRITE/EURAM (1989-1992) is a recent industrial research program that builds on the successful activities of two previously separate programs covering research in industrial technologies (BRITE) and advanced materials (EURAM). "Science" was established to address three goals: better mobility of researchers, large facilities and projects, and a more integrated, multidisciplinary approach to research.

Several EC projects on HTS research were launched in May, 1988. A budget of about $16 million has been approved for HTS through 1989.[8] Nearly all of the HTS budget is expected to support collaborative industrial applied research within the member countries, with matching funds to be supplied by industry. A standing committee of representatives of key research institutions in the member countries has been established to provide information on national HTS programs, staff exchanges, and scientific meetings.

Eureka

EUREKA is a product of the French concern that the United States' Strategic Defense Initiative would vastly add to the U.S. storehouse of commercial technologies, and represents a civilian attempt by Western European countries to keep up with this expected U.S. technology development. It is a $1 billion, industry-led program directed independently of the EC. The EUREKA program hosts two LTS superconductor projects.[9]

FEDERAL REPUBLIC OF GERMANY

West Germany has supported superconductivity research consistently for the past 20 years. Most of the government funding is provided by the Ministry for Research and Technology (BMFT), which has supported LTS R&Din three principal areas: generic technology development (materials, magnets, cryogenics, devices); energy research (primarily superconducting generators); and medical technology (magnetic resonance imaging, biomagnetic measurements). As a result, West German firms have capabilities comparable to those of U.S. firms in large-scale applications, and are stronger competitors in some emerging commercial applications of LTS-e.g., magnetoencephalography (see ch. 3)—than are Japanese firms.

In 1988, BMFT HTS project funding was about $10 million, 90 percent of which went to research institutes, The remaining 10 percent went to support industrial research, and was matched by the recipient companies. In subsequent years, BMFT funding has grown, and is expected to reach some $33 million.

Some 90 research teams, with a total of about 500 research personnel, are estimated to be active in HTS at West German institutes and industrial laboratories. Information exchange and coordination among these groups is excellent, and is carried out under the auspices of BMFT

Private industry investment in HTS is higher in West Germany than in any other European country. Major investors include Siemens, Hoechst, Daimler-Benz, Degussa, Dornier, and Villeroy & Boch. Hoechst is concentrating on materials research; Siemens and Daimler-Benz have more of an applications focus (Siemens is developing an LTS generator, for example). However, there appears to be an informal agreement in effect among these compa-

[7] EUREKA was created in 1985 by 19 European countries and the Commission of the European Communities.

[8] For comparison, the combined budgets for ESPRIT II, Science, and BRITE/EURAM are about $3.8 billion over 3 years.

[9] "Two European Projects Receive Funding Approval," *Superconductor Week*, vol. 1, No. 11, Oct. 12, 1987, p. 6.

Box 5-B-Superconductive Generation Equipment and Materials (Super-GM)

Super-GM is an engineering research association that provides an excellent example of a Japanese demonstration project in action.

Goals

Super-GM is an 8-year (Japanese fiscal years 1988 to 1995), $200 million MITI "Moonlight Project" program aimed at producing a 70-MW class LTS generator scale model, and the basic design of a 200-MW class machine. It is expected to be succeeded by a program to develop a 200-MW class prototype machine. The initial 7-MW class size is considered to be small enough to facilitate construction and transport, and at the same time large enough (about one-third scale) that no unexpected scale-up problems to 200-MW class are anticipated.

History

In 1983, the Japan Electric Council looked into the feasibility of various superconductor applications in the power sector, and classified them in order of priority. Transformers and generators were the two applications that survived this review. However, the efficiency of existing transformers is already very good, and superconducting wires with low alternating current losses are difficult to make, so priority went to the generator. A consensus was reached in 1985-86 that superconducting generators were going to be important in the 21st century. Generators now in service are expected to require replacement by the year 2000, and smaller machines will be needed. The advantages of superconducting generators were considered to be improved efficiency (by 0.5 to 1.0 percent) and increased system stability. Therefore, a 2-year feasibility study was initiated by MITI.

After the feasibility study, MITI called for the formation of an industry research association and for proposals from prospective members. MITI then chose the participants and created the vertically integrated structure of Super-GM (see table 5-4),

Organization

Super-GM consists of 16 member companies and organizations. Membership consists of end users, system and subsystem manufacturers, superconductor material manufacturers, and associated organizations.

The end users will provide test and evaluation facilities for the various generator designs being pursued in parallel by the systems manufacturers. There is a loose vertical organization to the companies along competing design lines (similar to the competition between the Bechtel and Ebasco teams on the SMES program in the United States), but there is also some horizontal overlap among projects, particularly at the level of the cable/component manufacturers.

About 90 percent of Super-GM's 1988 funding of $12.2 million came from MITI's Agency for Industrial Science and Technology (its research coordinating arm) via NEDO (New Energy and Industral Technology Development Organization). Industry is responsible for the remainder, which is actually raised through rate hikes by the nine utilities.[1] The research is not centralized, although there is a central administrative facility in Osaka: each participating company sends 1 to 2 people to the facility, but conducts its own research in-house. Super-GM has about 200 researchers total.

Operation

In all, three different kinds of superconducting rotors will be prepared using NbTi conductors. Hitachi and Mitsubishi are working on two rotors that are appropriate to somewhat cheaper, smaller (circa 300 MW) generators, and the overall technology is fairly well in hand. Both companies have built and tested experimental LTS generators in the past and are planning to produce for the commercial market after the year 2000. Mitsubishi is also collaborating with Fujikura and Furukawa to develop rotors using Nb_3Sn conductors.

Toshiba is winking on a third design that would be appropriate to a larger (over 1,000 MW), more expensive system, and Toshiba is considered to be "challenging the technology" in a more aggressive fashion. Toshiba has already built and tested a 3MW prototype to verify its design studies.

There are also two competing refrigeration systems being developed, one by Mayekawa and one by Ishikawajima-Harima Heavy Industries. There is a loose coupling between these two efforts.

At the end of 1991, there will be an interim evaluation of the progress of all projects, and some winnowing of the options will take place. In 1995, choices will be made among the three main designs, and another follow-up program will be started to develop the prototype 200-MW class machine.

[1]Edward Overell, "Japan Embarks on $200 Million Superconducting Generator Program," *New Technology Week*, vol. 1, No. 26, Nov. 23, 1987, p. 12.

Rote of HTS

Six companies--Mitsubishi, Hitachi, Toshiba, Furukawa, Sumitomo, and Fujikura-plus the Japan Fine Ceramics Center---am pursuing seven research projects to develop HTS materials specifically for generators and other electric power applications. Super-GM managers are reluctant to predict when HTS wire will be available, saying only that it is important to stay "flexible" with regard to the insertion of HTS.

Given the fact that LTS conductor technology is so much more mature, the HTS portion of Super-GM may most accurately be viewed as a good opportunity to pursue HTS materials development and explore new applications in the electric power sector, rather than as a serious effort to incorporate HTS into the generator design. However, Super-GM managers are delighted that HTS came along when it did, and note that "HTS fever" has given a shot in the arm to the whole superconducting generator program.

SOURCE: Office of Technology Assessment, 1990.

Table 5-4-Membership of Japan's Super-GM Project

End users:	
	Chubu Electric Power Co., Inc.
	Kansai Electric Power Co., Inc.
	Tokyo Electric Power Co., Inc.
System/subsystem manufacturers:	
	Hitachi, Ltd.
	Ishikawajima-Harima Heavy Industries Co., Ltd.
	Mayekawa Mfg. Co., Ltd.
	Mitsubishi Electric Corp.
	Toshiba Corp.
SC material/cable/component manufacturers:	
	Fujikura, Ltd.
	Furukawa Electric Co., Ltd.
	Kobe Steel, Ltd.
	Showa Electric Wire and Cable Co., Ltd.
	Hitachi Cable, Ltd.
	Sumitomo Electric Industries, Ltd.
Associated organizations:	
	Central Research Institute of the Electric Power Industry
	Japan Fine Ceramics Center

SOURCE: Super-GM, 1989.

nies not to publicize industry research results in HTS.[10]

FRANCE

French Government laboratories responded quickly to the discovery of HTS. In 1987, the Government supported some 240 researchers in HTS at the Centre de l'Energie Atomique, Centre National de la Recherche Scientifique (CNRS), Centre National d'Etudes des Telecommunications, and universities, at a cost of about $28 million.

A new $1 million HTS research center ($2.4 million operating budget) has been built at Caen that involves more than 70 full-time researchers working to develop superconductor applications. The center is supported by the largest French companies, French national agencies, and several European companies outside of France.

In the summer of 1987, the Ministry of Research announced a 2-year, $8.6 million program to promote cooperative government/industry research projects in HTS, with industry providing matching funds. A 2-year follow-on program is now under discussion.

In contrast to the rapid response of the French Government, French industry has been slower to get involved. In 1987, an estimated 60 full-time and 40 part-time researchers were active in HTS. This research is concentrated in just a few companies, chiefly Compagnie Generale d'Electricity (CGE), Thomson-CSF, and Rhone-Poulenc. CGE and Rhone-Poulenc have taken a leading role in a collaboration with CNRS and French universities to improve the performance of bulk HTS materials for energy applications. Thomson-CSF is the industrial leader in France for applications in the field of superconducting electronics, and employs some 20 full-time researchers working to develop HTS electronic devices.

UNITED KINGDOM

The United Kingdom has a modest, though well-coordinated, national HTS program. National coordination is achieved through a joint committee of the Department of Trade and Industry (DTI), and the Science and Engineering Research Council (SERC), The centerpiece of the SERC HTS effort is the Interdisciplinary Research Center for Supercon-

[10]For example, Hoechst had quietly filed for patents in the United States, Japan, and West Germany for the first high-temperature bismuth-based material 2 months before it was discovered independently at Japan's National Research Institute for Metals. "Hoechst AG Filed Bismuth Patent Last November," *Superconductor Week*, vol. 2, No. 15, Apr. 18, 1988, p. 1.

ductivity at Cambridge University, funded at a guaranteed minimum of $9 million over 6 years. Complementary research projects are being funded with a separate budget of $3.5 million at other universities. DTI has made an additional $12.9 million available for joint projects with industry on a matching basis. The Ministry of Defence has a small intramural program with links to universities, bringing the U.K. annual total to about $18 million.

Industry response to HTS has been mixed. Although U.K. companies have developed a strong technology base in LTS magnets, the technology base for superconducting electronics is relatively weak (and mainly military), as have been the links between academia and industry. Active research projects under the DTI program have now started, such as the one at Harwell, where six British companies have become members of Harwell's HTS Superconductivity Club (consortium). Member companies are: Air Products, BICC, Ford of Britain, Johnson Matthey, Oxford Instruments, and BOC International. Several universities are also involved. The Club has planned a 3-year research program costing about $6.8 million, half of which will be provided by DTI. Overall, up to 100 researchers are estimated to be active in industry; key individual companies include General Electric Co. (GEC), Plessey, British Aerospace, Imperial Chemical Industries (ICI), Cooksons, and Oxford Instruments.

ITALY

Italy has had many projects in energy-related areas of LTS technology, including motor/generator sets, cables and magnet technologies for fusion, particle accelerators, and magnetohydrodynamics (MHD). Italy has a broad-based research program in HTS, including: thin-film processing, cables, magnetic storage, magnetic separation, shields, cavities, and motors.

Italian researchers quickly reproduced the YBaCuO results of the Universities of Houston and Alabama, and hosted several early international meetings on HTS. In 1989, Italy's National Research Council budgeted some $10 million to $15 million for HTS, and overall the national effort involves perhaps 200 researchers. A consortium of 27 universities has been established at the Superconductivity Applications Development Center in Genoa, including about 100 research positions. Italy's major superconductivity research centers are at the University of Genoa and the University of Salerno, near Naples.

Although little industrial research on HTS has been published, leading companies appear to be Ansaldo, Montedison, Pirelli, and Florence Industrial Metals. Ansaldo is a subcontractor on the Bechtel team designing the U.S. Superconducting Magnetic Energy Storage system and is currently developing a prototype HTS motor, jointly with the University of Genoa. Ansaldo is also a primary manufacturer of LTS magnets for the European Hadron Electron Ring Accelerator and for fusion energy projects.

THE NETHERLANDS

The Netherlands has a small-scale government program in HTS scheduled to run through 1991. It is dominated by Philips, which has enormous technical and financial clout. The government is providing about $4.5 million; another $4.5 million comes from private sources. Philips' work is coordinated with several university laboratories, especially Eindhoven [University of Technology. Consistent with Philips' main business areas, the effort is focused on superconducting electronics, with only a small part devoted to energy applications. Other Dutch institutions cooperating in the effort include the Universities of Amsterdam, Leiden, Nijmegen, and Twente, and the Netherlands Energy Research Foundation. Akzo is another Netherlands-based company active in HTS R&D.

SWEDEN

Sweden's HTS effort consists of a small government/university/industry joint program in applications research. ASEA-Brown-Boveri (ABB), Ericsson, the Swedish Defense Research Establishment, and seven Swedish universities are participating.[11] Although the Swedish program in HTS is very small (about $2.5 million over 2 years), the main player, ABB, has substantial superconductivity experience and is considered by U.S. company representatives to be a formidable competitor in potential electric power applications, i.e., generators, transmission lines, and power conditioning equipment.

[11] High-T_C Update, vol. 3, No. 5, Mar. 1, 1989, p. 9.

SOVIET UNION

It is difficult to obtain reliable estimates of the Soviet effort in HTS. The budget for the Soviet Academy of Sciences has been estimated at several hundred million rubles, plus about $40 million in hard currency for purchase of foreign equipment.[12] Estimates for the overall number of Soviet HTS researchers put the figure at about 2,000. However, these researchers often do not have access to state-of-the-art equipment that is available to U.S. researchers.

Soviet publications suggest that a broad range of HTS research is being conducted, including research in thin films for electronics and bulk materials for large-scale applications.[13] These publications also indicate a continuing commitment to LTS research, particularly in superconducting sensors and electronics, in magnetohydrodynamic (MHD) electric power production, and in fusion energy.

The Soviet Union has had a stronger program to develop MHD power plants than any other country. A 500 megawatt (MW) demonstration MHD power plant is being built at Ryasan. The Soviets are thought to have a 10-year lead in MHD, but the program has experienced some delays due to problems with winding the superconducting magnets and is in danger of being canceled.[14] The Soviet Union has also developed a 300-MW generator based on LTS, similar to U.S.-developed LTS generators.

While Western observers rate the quality of Soviet theoretical work as first-rate, its experimental work has received mixed reviews. Moreover, the level of coordination and information exchange among Soviet institutes is often poor. Many observers consider the Soviet system to be too bureaucratic to exploit HTS breakthroughs rapidly on a worldwide commercial scale, although this situation could improve as present restructuring programs move forward.

PEOPLE'S REPUBLIC OF CHINA (PRC)

Since the early 1960s, China has conducted a broad research program in LTS materials, large-scale magnets, generators, magnetic separators, and Josephson Junction devices.[15] In recent years, it has produced some of the highest performing multifilamentary NbTi conductors.[16]

China has responded to the discovery of HTS with an intensive research program, and it has hosted several international meetings on HTS. The work is being conducted in a wide variety of research institutes and universities both inside the country and by visiting Chinese scientists doing joint research in foreign laboratories. China has large reserves of rare earths and is the world's largest producer of yttrium and other rare earths used in some HTS materials.

As part of an overall program to increase R&D in the People's Republic, the National Natural Science Foundation of China (a counterpart of the U.S. National Science Foundation) has planned to spend $5.5 million per year (not including salaries) on HTS research in universities, out of a $3 billion per year research budget.[17]

The scope of the Chinese work is broad, and the PRC appears to have allowed researchers to publish freely, often in English journals. Some 1,000 researchers appear to be involved in HTS.[18] Despite a geographically dispersed effort, there appears to be little duplication of research, suggesting a coordinated program.[19]

Although the Chinese work is prolific, it is judged by Western observers to be somewhat uneven in quality, due in part to a lack of first-rate equipment.[20] As yet there is little indication that an industrial effort is underway to exploit fully the results of the

[12] ''Interview with Academician Yurii Ossipyan,'' *Supercurrents*, February 1988, p. 8.

[13] The DOE/Ames Laboratory publication *Hi-T_C Update* contains a bibliography of recent Soviet publications in HTS.

[14] Paul Kemezis, ''Superconducting Magnets Baffle Soviet Scientists,'' *New Technology Week*, vol. 2, No. 26, June 27, 1988, p. 1.

[15] NATO Advanced Study Institutes Series, *Superconductor Materials Science*, Simon Foner and Brian B. Schwartz (eds.), vol. B68, 1981, p. 813.

[16] TMAH Consultants, ''Lessons From Low-Temperature Superconductors,'' contractor report prepared for the Office of Technology Assessment, Nov. 18, 1988, p. 8.

[17] Edward Overell, ''China Undertaking Massive R&D Effort,'' *New Technology Week*, vol. 1, No. 28, Dec. 7, 1987, p. 1.

[18] ''Zhao: 1000 Chinese Scientists Are Working on High T_C Materials,'' *Superconductor Week*, vol. 2, No. 17, May 22, 1988, p. 1.

[19] Resource Management International, Inc., ''Superconductivity in Western Europe and Other Selected Countries,'' contractor report prepared for the Office of Technology Assessment, Sept. 19, 1988.

[20] ''Aggressive Chinese Program Keeps Pace With Discoveries,'' *Superconductor Week*, vol. 2, No. 17, May 2, 1989, p. 8.

research, and no indication of the future status of the government and university programs.

CONCLUSIONS

While many foreign nations have ongoing HTS research efforts, it is apparent that the Japanese will be the strongest competitors of the United States in exploiting the potential of new HTS materials, both because of their solid foundation of LTS development and because of their strong commitment of resources to HTS research. The Federal Republic of Germany will also be a strong competitor; it produces some of the best LTS materials, and West German companies have a stronger position in some emerging areas-e. g., biomagnetic devices—than do the Japanese.

While OTA finds a rough parity between the quality of U.S. and Japanese HTS R&D, there are several areas where Japan has superior capabilities, and there are noteworthy differences in Japan's approach to superconductivity. Historically, funding for LTS programs has been sustained over a long period in Japan, and commitments to new commercially oriented LTS projects (e.g., computer electronics, maglev, and electric power generators) are being made where funding has long since been cut off in the United States. The new HTS programs in Japan have drawn heavily on the expertise accumulated during these LTS programs, and are being designed to capitalize on previous LTS research results.

Based on visits to numerous Japanese laboratories involved in superconductivity, OTA finds that National laboratories like MITI's Electrotechnical Laboratory, and STA'S National Institute for Research on Inorganic Materials and National Research Institute for Metals, as well as universities in Tokyo, Osaka, and Kyoto, Sendai, and others, are conducting first-rate research in HTS and have much to offer to U.S. visiting scientists.[21] Unfortunately, the quality of this work is not fully appreciated by U.S. researchers, who tend to focus primarily on the work in Japanese industry laboratories.

Several European countries have substantial HTS programs led by the research efforts of a few large multinational companies including Philips (the Netherlands), Siemens (West Germany), Asea-Brown-Boveri (Sweden/Switzerland), GEC (United Kingdom), Thomson (France), and Ansaldo (Italy). These companies have considerable financial and technical resources as well as a strong interest in HTS, and are already formidable competitors of U.S. firms in LTS applications.

Joint research programs in HTS within the European Community are as yet quite small, but are growing. The planned unification of the European market in 1992 is likely to strengthen the European competitive position in HTS. The combined HTS R&D budgets of the EC member countries are already considerably larger than those of the United States or Japan alone.

Both the Soviet Union and the People's Republic of China have major efforts underway in HTS, but these efforts are hampered by a lack of state-of-the-art equipment and unwieldy bureaucracies. Neither country appears to have the industrial muscle to compete effective y in early commercial markets for HTS, but this assessment could change in the long term.

[21] For a discussion of specific projects, see Robert J. Gottschall, ''Basic Research in Superconductor, Ceramic, and Semiconductor Sciences at Selected Japanese Laboratories,'' U.S. Department of Energy DOE/ER-0410, February 1989.

APPENDIX 5-A—MEMBERSHIP OF JAPAN'S INTERNATIONAL SUPERCONDUCTIVITY TECHNOLOGY CENTER (JUNE 1, 1989)[1]

Anelva Corp.
• Asahi Glass Co., Ltd.
British Telecom
Central Japan Railway Co., Ltd.
• Central Research Institute of the Electric Power Industry
Chiyoda Corp.
• Chubu Electric Power Co., Inc.
• The Chugoku Electric Power Co., Inc.
The Dai-ichi Kangyo Bank, Ltd.
The Dai-Tokyo Fire& Marine Insurance Co., Ltd.
Daido Steel Co., Ltd.
The Daiwa Bank, Ltd.
Dentsu, Inc.
Du Pont Japan, Ltd.
East Japan Railway Co., Ltd.
• Electric Power Development Co., Ltd.
Electric Power Research Institute (EPRl)
Fuji Electric Co., Ltd.
Fujikin International, Inc.
• Fujikura, Ltd.
• Fujitsu, Ltd.
• Furukawa Electric Co., Ltd.
Hazama-Gumi, Ltd.
• Hitachi Cable, Ltd.
Hitachi Chemical Co., Ltd.
Hitachi Metals, Ltd.
• Hitachi, Ltd.
• The Hokkaido Electric Power Co., Inc.
• The Hokuriku Electric Power Co., Inc.
Honda Research and Development Co., Ltd.
IBM Japan, Ltd.
INES Corp.
Intermagnetics General Corp.
• Ishikawajima-Harima Heavy Industries Co., Ltd.
Japan Air Lines Co., Ltd.
Japan Fine Ceramics Center
JEOL, Ltd.
Kajima Corp.
Kandenko Co., Ltd.
• The Kansai Electric Power Co., Inc.
• Kawasaki Heavy Industries, Ltd.
• Kawasaki Steel Corp.
• Kobe Steel, Ltd.
Kumagai Gumi Co., Ltd.
• Kyocera Corp.
• Kyushu Electric Power Co., Inc.
Marubun Corp.
• Matsushita Electric Industrial Co., Ltd.
• Mayekawa Manufacturing Co., Ltd.
Mazda Motor Corp.
The Mitsubishi Bank, Ltd.
• Mitsubishi Cable Industries, Ltd.
Mitsubishi Corp.
• Mitsubishi Electric Corp.
• Mitsubishi Heavy Industries, Ltd.
• Mitsubishi Metal Corp.
Mitsui & Co., Ltd.
The Mitsui Bank, Ltd.
Mitsui Mining & Smelting Co., Ltd.
Murata Manufacturing Co., Ltd.
• NEC Corp..
• NGK Insulators, Ltd.
• NGK Spark Plug Co., Ltd
• Nippon Mining Co., Ltd.
Nippon Sanso K.K.
• Nippon Steel Corp.
Nippon Telegraph and Telephone Corp.
• Nissan Motor Co., Ltd.
Nisshin Steel Co., Ltd.
NKK Corp..
Ohbayashi Corp.
• Oki Electric Industry Co., Ltd.
Okinawa Electric Power Co., Ltd.
Osaka Gas Co., Ltd.
• Railway Technical Research Institute
Rhone-Poulenc Japan
Rinnai Co.
Rockwell International Corp.
Saibu Gas co. Ltd.
Sakaguchi Electric Heaters Co., Ltd.
• Sanyo Electric Co., Ltd.
Sato Kogyo CO., Ltd.
• Sharp Corp.
• Shikoku Electric Power Co., Inc.
Shimizu Corp.
• Showa Electric Wire & Cable Co., Ltd.
Sony Corp.
The Sumitomo Bank, Ltd.
Sumitomo Chemical Co., Ltd.
Sumitomo Corp.
• Sumitomo Electric Industries, Ltd.
Sumitomo Heavy Industries, Ltd.
• Sumitomo Metal Industries, Ltd.
Taikisha, Ltd.
Taisei Corp.
Takaoka Electric Manufacturing Co., Ltd.
Takenaka Komuten Co., Ltd.
Toda Construction Co., Ltd.
Toho Gas Co. Ltd.
• Tohoku Electric Power Co., Inc.
The Tokai Bank, Ltd.
Tokai Electric Construction Co., Ltd.
Tokyo Cryogenic Industries Co., Ltd.
• The Tokyo Electric Power Co., Inc.
Tokyo Gas Co., Ltd.
Tokyu Construction Co., Ltd.
• Toshiba Corp.
• Tosoh Corp.
• Toyota Motor Corp.
• Ube Industries, Ltd.
• Ulvac Corp.

• Indicates special supporting members
[1]International Superconductivity Technology Center, 1989.