Chapter 7

Policy Issues and Options

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INTRODUCTION

The discovery of HTS has come at a time of increasing doubts about the capability of the United States to compete in global high-technology markets. The list of markets in which U.S. industry has slipped badly is growing: e.g., consumer electronics. memory chips, automobiles, and machine tools. Moreover, the U.S. private sector is investing less than its main competitors in a number of emerging technologies such as x-ray lithography, high--definition television (HDTV), and—as shown in the previous chapter—in superconductivity research. There is a serious question whether U.S. industry, as it is currently financed and managed, can compete in markets for these technologies in the next century.

While there is a reluctance within the Administration and Congress to talk openly about “industrial policy,’ there is a growing recognition on both sides that changes in the technological relationships between the Federal Government and the private sector may be necessary to firm up flagging U.S. competitiveness. This new attitude is reinforced by the recognition that foreign competitors have targeted the most promising emerging commercial technologies with coordinated, government/industry efforts. In Japan, the progress achieved by close cooperation between the government and industry is legendary, and the newly industrialized countries on the Pacific Rim (South Korea, Taiwan. Hong Kong, and Singapore) are following closely behind. In Western Europe, cooperation among governments and major corporations has long been the hallmark of science and technology programs, and the prospect of a unified European market after 1992 suggests that U.S. firms can anticipate tougher competition from these large European companies in the future, in both European and U.S. markets.

Unfortunately, the growing interest in new Federal policies to promote commercial technology development comes at a time of growing pressures to reduce the Federal budget deficit. After all, high-temperature superconductivity (HTS) is only one of many emerging technologies---optoelectronics, ceramics, and HDTV, to name a few—that could become commercially important in the future. When added to such big-ticket Federal R&D commitments as the NASA space station, the Superconducting Super Collider, mapping the human genome, and the Strategic Defense Initiative, it is apparent that difficult budgetary choices will have to be made.

In 1987, shortly after the discovery of HTS, optimism was rampant and room-temperature superconductivity seemed just around the corner. The United States was seen to be engaged in a heated race to commercialize HTS products before its competitors. By 1989, as the scope of the remaining challenges became clearer, a more realistic view had taken hold. HTS became a test case, not of the United States’ ability to commercialize a new technology rapidly, but of its ability to look beyond the immediate future and sustain a consistent R&D effort over the long term.

It is now apparent that the real race will begin after practical HTS conductors are developed, and will involve the incorporation of these conductors into larger, integrated systems. The race will not be a sprint, won by a technical breakthrough; rather, it will be a marathon, won by painstaking attention to design, low-cost manufacturing, and high quality—the same factors that determine competitiveness in any other industry. Thus, the so-called "superconductivity race" should be seen in the broader context of the competitive prowess of the entire U.S. manufacturing sector.

This chapter ranks a series of policy issues raised by HTS in three categories: first, those considered by OTA to be of minor importance; then, several issues that bear watching in the future; and finally, those that OTA considers to be of critical importance. Where appropriate, specific options for addressing these issues are discussed. The importance of stable funding for superconductivity is stressed, if the potential of this technology is to be realized. Finally, the chapter concludes by placing HTS in a broader policy context of U.S. competitiveness, noting that while the Federal Government’s R&D policies are important. its fiscal policies are even more important

MINOR ISSUES

As the realization sank in that HTS is a long-term technology, several issues that were earlier thought to be urgent now appear to be of minor importance

Adequate supplies of raw materials, chemical precursors, and powders for HTS are not a problem now, nor are they likely to be in the foreseeable future.

At present, the United States is heavily dependent on imports for yttrium, bismuth, and thallium, key ingredients in three of the most promising HTS materials.[1] These metals are byproducts of the production of primary metals, e.g., lead. Since HTS is still at the research stage, the incremental demand due to HTS materials is relatively small. Moreover, as discussed in chapter 3, the most probable near-term HTS applications are likely to be in electronic devices, which will require only very small quantities of material. Present supplies appear sufficient to support even significant growth in large-scale applications.[2]

HTS does not appear to raise unmanageable health and safety problems, though this deserves further study.

There appear to be two principal health and safety issues associated with HTS: the toxicity of the materials themselves (and of their chemical precursors), and the potential health effects of human exposure to the high magnetic fields produced by superconducting magnets.

The main toxicity problem with HTS materials appears to be the risk of poisoning by inhalation, ingestion, or skin contact with heavy metals such as barium, yttrium, bismuth, and thallium.[3] For instance, thallium-a key ingredient in the HTS material having the highest known transition temperature—is dangerous not only because it is extremely poisonous,[4] but also because it readily evaporates when heated to process temperatures, and can be easily inhaled. Present techniques are adequate to minimize exposure to these heavy metals on a research scale, but further studies are needed to ensure that laboratory processes are scaled up safely to production quantities. The potential hazards of disposing of these materials also deserve further study.

Several large-scale applications of superconductors, e.g., magnetic energy storage, maglev vehicles, and MRI, produce high static magnetic fields, and raise the issue of the potential health effects of public exposure to these fields. In the past 20 years, there have been numerous studies investigating the biological effects of both static and time-varying magnetic fields. While the health effects of exposure to power frequency (60 hertz) fields remain controversial,[5] there is no evidence for adverse effects in healthy individuals exposed to static fields up to **2** tesla (20,000 gauss).[6] Nevertheless, because relatively small magnetic fields can interfere with heart pacemakers and a variety of paramagnetic body implants, public exposure must be limited to around 10 gauss. The shielding and/or exclusion zone required to reduce the field to this level can add significantly to the cost of the application.

Antitrust restrictions are not a serious inhibitor to U.S. competitiveness in HTS technology.

The first item of President Reagan's 1 l-point Superconductivity Initiative (see ch. 4) proposed exempting certain joint production ventures in the private sector from antitrust litigation under the Clayton Act (15 U.S.C. 18). This was intended to facilitate the formation of joint ventures to commercialize products featuring HTS, thus permitting U.S. firms to share the risks and expenses. Similar relaxations of antitrust restrictions have been suggested as a means of encouraging the formation of consortia to commercialize several other technologies, including semiconductor memory chips (DRAMs) and HDTV. Proposed legislation to relax the antitrust laws is under consideration at the Justice Department.

The National Cooperative Research Act of 1984 (Public Law 98-462) cleared the way for companies to form joint ventures or consortia to conduct R&D,

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[1] Charles A. Sorrell, U.S. Bureau of Mines, "The New Superconductors—An Overview," *Minerals and Materials*, June-July 1988, p. 7.

[2] S. Beggs et al., "Long-Run Supplies of Raw Materials for Commercialized High-Temperature Superconductors," Argonne National Laboratories, ANL Project 85923, Mar. 23, 1989.

[3] S.D. Arnold and G.M. Halley, "Health and Safety Guide for Inorganic Compounds and Metals Used in the Fabrication of Superconductive Compounds," Los Alamos National Laboratory, to be published, 1990.

[4] Thallium oxide was used as a household rodenticide prior to 1986, when it was banned in the United States because of its toxicity to humans.

[5] For a recent review, see U.S. Congress, Office of Technology Assessment, *Biological Effects of Power Frequency Electric and Magnetic Fields—Background Paper*, OTA-BP-E-53 (Washington, DC: U.S. Government Printing Office, May 1989).

[6] T.S. Tenforde, "Biological Responses to Static and Time-Varying Magnetic Fields," *Electromagnetic Interaction With Biological Systems*, J.C. Lin (ed.) (New York, NY: Plenum Press, 1989), p. 83.

as distinct from commercial production. As discussed in chapter 4, several HTS R&D consortia of this type are either being planned or are already in operation. OTA found no evidence from its industry interviews that fear of antitrust litigation is holding back U.S. progress in HTS. In fact, most companies feel that HTS is not yet mature enough for commercial joint production ventures to be considered seriously.[7] Therefore, changes in the antitrust laws are more likely to be driven by the needs of more mature technologies, such as HDTV, rather than HTS.

Fears that the prolific HTS patenting by Japanese companies could block U.S. companies from participating in major superconductivity markets appear to be exaggerated.

In one year, Japanese companies filed some 5,000 patents on various aspects of FITS in Japan. Sumitomo Electric Co. alone is said to have filed over 1,000. The U.S. Patent Office reports that 1,200 patents relating to superconductivity have been filed in the United States since 1985, about 40 percent by foreign companies.[8]

Some observers have become alarmed by these developments, worried that the Japanese could "lock up" the technology with patents, and force U.S. companies into an inferior position. OTA's analysis suggests that these concerns are exaggerated:

- U.S. firms have also taken an aggressive approach to patents in HTS. In fact, five separate U.S. laboratories (University of Alabama, University of Houston, AT&T, Naval Research Laboratory, and IBM) have applied for patents on the original YBaCuO materials. Resolution of this patent conflict could take years; meanwhile the technology moves on.
- Although it is conceivable that there will be one "best" patentable material, it is at least as likely that a range of compositions and structures will be available to the designer of HTS products. The recent discoveries of much broader classes of oxide compositions and structures supports this view.

These considerations suggest that, although HTS patents may have value in the context of specific narrow markets, the possibility of global Japanese dominance of the technology based on a few key patents seems remote. In the long run, the real significance of HTS patents may be as trading property in cross-licensing negotiations between competitors. On the whole, patent attorneys interviewed by OTA did not think that HTS raises any patent issues that are substantively different from those encountered in other fields, such as electronics, polymers, or pharmaceuticals.

ISSUES THAT BEAR WATCHING

There are several aspects of the U.S. HTS effort that may not be a problem now, but are potential areas of concern for the future.

Federal laboratories may be receiving a disproportionately large share of the HTS budget.

In fiscal year 1988, 45 percent of Federal HTS funding went to support work in Federal laboratories of the Department of Defense (DoD), Department of Energy (DOE), National Aeronautics and Space Administration (NASA), and Department of Commerce (DOC). These laboratories conduct a broad range of research, from very basic to prototype development, in support of their agency missions. Some of this research uses the unique facilities available only in the Federal laboratories, and some is simply not being done anywhere else.

But questions remain about whether Federal laboratories should have such a large share of the HTS budget-especially given the scarcity of resources for university research (see below). To assess the quality and relevance of HTS programs in Federal laboratories, Congress may wish to establish a single, independent advisory committee with strong industry representation to evaluate the quality of HTS research at Federal laboratories (including military laboratories).

Historically, Federal laboratories have not considered it part of their mission to transfer technologies of commercial interest to U.S. industry. With the advent of HTS, traditional attitudes and cultures in both Federal laboratories and U.S. companies have begun to change. Programs such as DOE's Superconductivity Pilot Centers represent good faith efforts to address the needs of industry, and they

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[7] Kay Rhyne Adams, "The DARPA Manufacturing Initiative in High-Temperature Superconductivity," *Superconductor Industry*, vol. 2, No. 2, summer 1989, p. 12.

[8] *Superconductor Week*, vol. 3, No. 37, Sept. 25, 1989, p. 1.

have attracted a large number of industry collaborators. Such experiments are valuable and if successful, could be extended to other Federal laboratory programs.[9]

One area of research where a Federal laboratory makes a unique contribution is the National Institute of Standards and Technology's (NIST) work on standards for making measurements that are reproducible and accurate. Standard techniques for measuring key HTS materials properties such as critical current density in the presence of magnetic fields are crucial for timely progress in developing the materials. The need for standard measurement techniques was explicitly recognized in President Reagan's 11-point Superconductivity Initiative. Nevertheless, the NIST effort in standard HTS measurement techniques in 1989 was only about $200,000 per year.[10]

NIST is already recognized as the world leader in LTS standards development. By increasing NIST's annual budget by about $300,000 (the equivalent of fill support for two or three additional staff), the United States could also become a world leader in standards for HTS. As HTS matures and begins to be used in applications, a strong U.S. position in HTS measurement standards will not only facilitate trade by U.S. firms, but will help ensure that the United States has a strong voice in the formation of international standards.

At present, defense and civilian requirements for HTS technology are similar, but this could change as the technology mutures.

As pointed out in chapter 4, Federal funding for HTS R&D is dominated by DoD (about 45 percent in fiscal year 1989) and DoD provides most of the Federal HTS R&D funds going out to U.S. industry. This has raised concerns that DoD involvement might skew the U.S. agenda for HTS development toward high-cost, specialty materials designed for one-of-a-kind military weapons systems, while foreign competitors develop low-cost, easily manufactured HTS materials well-suited for profitable commercial applications. A second concern is that heavy military involvement might lead to the lowering of a cloak of secrecy over Federal HTS R&D efforts, preventing timely access of U.S. firms to research results that could lead to commercial applications.

At the present stage of HTS technology development, OTA finds that military and civilian agency objectives for HTS are the same. The great majority of DoD-funded HTS R&D (with the possible exception of some Strategic Defense Initiative work) remains at a very basic or generic level, and the results are useful for both military and civilian purposes. Without the DoD HTS programs, the HTS R&D funding pie would undoubtedly be much smaller, and many programs of potential value to the commercial sector would not be going forward at all. For example, the Defense Advanced Research Projects Agency (DARPA) HTS initiative provides an emphasis on HTS processing technologies that is unique among government efforts. Also, without 95 percent funding from the Strategic Defense Initiative Organization, the Superconducting Magnetic Energy Storage project would never have started; only 5 percent of the program's support comes from the electric utilities.

As HTS matures and begins to be incorporated into specialized weapons systems, DoD and commercial interests could well diverge. The special demands made on materials for military and space applications, e.g., high radiation hardness or ultrahigh frequency operation (as well as a lower priority placed on cost, manufacturability, or long-term stability), are likely to cause this divergence. One area of special concern is superconducting electronics, widely predicted to be one of the earliest and largest commercial application areas of HTS. With the exception of a small program at NIST, DoD is the only Federal agency that considers development of superconducting electronics to be part of its mission, If DoD funding concentrates on solving problems of primarily military interest as the technology matures, U.S. commercial competitiveness in HTS could suffer,

Thus far, Federal agencies have not restricted access to HTS research results for national security reasons. However, HTS was one of 22 technologies recently identified as critical to future military missions.[11] This designation could lead to greater

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[9] Funding for the Pilot Centers, which stood at $6 million in fiscal years 1989 and 1990, is slated to increase to $15 million in the Administration's fiscal year 1991 budget request.

[10] NIST's budget for HTS stayed constant in fiscal year 1990 but is slated for a 70 percent increase in the Administration's fiscal year 1991 budget request.

[11] U.S. Department of Defense, "Critical Technologies Plan," a report to the Committee on Armed Services, U. S. Congress, Mar. 15, 1989.

funding, but as HTS is used more widely in weapons systems, pressures will probably increase to control access to information about the superconducting components and to prevent their export to unfriendly nations. In the past, such restrictions have proven to be a nuisance for companies interested in commercialization of advanced materials, electronics, and computer technology originally developed for military applications,[12] and this situation needs to be watched closely.

Congress could move to forestall these concerns by requiring DoD or other relevant agencies to inform Congress in advance of intentions to place HTS on the Militarily Critical Technologies List, Commodity Control List, Munitions List, etc.[13] In addition, it could establish an independent advisory committee of government and industry researchers to conduct periodic review of progress in dual-use military projects and report on the extent to which military and commercial objectives may differ.

If progress in HTS technology continues to be incremental, small HTS startup companies could face a critical shortage of capital.

In recent years, the manufacture of commercial products having LTS superconducting components has shifted from large companies to medium and small companies. While several large companies maintain substantial LTS R&D efforts (often supported in large part by government contracts), most have backed away from commercial markets, finding them insufficiently profitable in the near term. The only large U.S. company presently producing a commercial LTS product is General Electric Co., with its MRI system.

OTA's survey (see ch. 6) identified a dozen venture capital-financed startup companies in HTS. These companies are conducting innovative research, and two are spending more than $1 million per year on HTS R&D. During 1987-1988, first round venture capital funding for seven of these firms was quite plentiful, averaging more than $3 million per startup.[14] However, a second round infusion will be needed soon to keep these companies going.

If markets for HTS products develop as slowly as those for LTS have done over the past 30 years, we may see large firms backing out, and the venture capital sources could dry up, leaving the field to a number of undercapitalized small companies largely supported by government/military R&D grants and contracts. It is unlikely that these small companies could carry the standard of U.S. competitiveness against their better-financed and more diversified foreign competitors. In fact, most small HTS startups report that they have received buyout offers from large foreign companies. If U.S. sources of capital begin to dry up, such offers will become more and more difficult to resist.

The importance of active U.S. participation in international superconductivity meetings and programs is growing, while Federal funding to support these activities is stagnant or declining.

At present, the United States does not have a qualitative lead over its competitors in superconductivity R&D, and indeed, it lags in several areas of LTS technology (e.g., large-scale integration of Josephson Junctions for LTS electronics, and rotating LTS machinery). The pace of HTS research abroad is rapid, and U.S. scientists—both in Federal laboratories and universities-have an urgent need to know about the most recent developments.

The opportunities for tapping into foreign research and for conducting international collaborative research are growing, and occur on several levels: formal government-to-government programs; long-term fellowships for U.S. scientists conducting joint research in foreign laboratories, and short-term visits and attendance at international meetings. Examples include the U.S.-Japan Agreement on Cooperation in Science and Technology (specific projects still under negotiation), and the postdoctoral research fellowship slots in Japan that were recently made available to U.S. scientists and funded by the Japanese Government through NSF.[15]

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[12] National Academy of Sciences, "Balancing the National Interest: U.S. National Security Export Controls and Global Economic Competition" (Washington, DC: National Academy Press, 1987).

[13] See U.S. Congress, Office of Technology Assessment, *Advanced Materials by Design: New Structural Materials Technology,* OTA-E-351 (Washington, DC: U.S. Government Printing Office, June 1988), p. 272.

[14] A.M. Rosa and C. Suchors, "The Venture Capital Viewpoint," *Superconductor Industry*, vol. 2, No. 1, Spring, 1989, p. 11.

[15] In 1988, the Japanese Government provided NSF with $5 million to pay the expenses for 100 U.S. postdoctoral fellows to conduct long-term research projects in Japanese laboratories. In the past, this program has been undersubscribed, but the number of applicants continues to grow. With about one-third of the funds left, NSF program managers are concerned that they may succeed in filling these slots just when the money runs out.

There is a growing recognition among U.S. scientists of the importance of taking advantage of these opportunities. But although it is hard to quantify, there is considerable anecdotal evidence that Federal agency funding for these activities is not keeping pace with the demand. Key superconductivity experts in Federal laboratories and universities interviewed by OTA report that funding for travel to international meetings is becoming more difficult to get, and the time required for approval of such travel is as long as 3 to 6 months.[16]

Important international exchange programs could also be caught in the budget squeeze. For instance, several new joint superconductivity projects are under negotiation in the U.S.-Japan Agreement mentioned above,[17] but U.S. agencies are expected to fund the costs of their participation out of other budgets.[18] In contrast, Japan has been much more generous in supporting the participation of its scientists in international collaborations.

Many observers have expressed concern that the United States gives away more technical information than it gets from abroad. By failing to support strongly U.S. representation in international technology agreements, the Federal Government may be ensuring such an unequal exchange.

The importance of U.S. participation in international superconductivity programs is emphasized in the National Action Plan for Superconductivity, recently released by OSTP.[19] Congress could require that OSTP prepare an evaluation of the adequacy of Federal funding for these international activities as part of its mandated annual progress report on the Plan, and appropriate additional funds if these are deemed necessary.

KEY ISSUES

OTA considers the following issues to be especially important in determining the future U.S. competitive position in HTS:

U.S. companies are investing less than their main competitors in both low- and high-temperature superconductivity R&D.

The OTA survey results (see ch. 6) illustrate the problem: Japanese firms are investing at least 50 percent more than U.S. firms in HTS R&D, even though they don't expect a payback on their investment until the year 2000. In contrast, U.S. firms typically projected a payback by 1992.

HTS presents a difficult problem for U.S. industry. The materials themselves are evolving rapidly. No one knows when practical conductors will be developed. There is general agreement that the most important applications have not yet been thought of. Profitable markets are not yet in sight. There is no guarantee that any one company will be able to appropriate the full benefits of its R&D investment. In short, HTS is a high-risk, long-term gamble. In the absence of major research successes in the next few years, it seems likely that U.S. firms will have difficulty continuing even their present levels of HTS R&D expenditures.

It is tempting to focus on how changes in Federal R&D policy can help companies to adopt a longer term perspective--e. g., establishing federally funded industry consortia. But while such Federal programs might be helpful, they are almost certainly not decisive, because they do not change the financial and economic climate in which U.S. companies make long-term investment decisions.

This is not to suggest that Federal R&D funding and Federal markets for superconductivity are not important; after all, Federal programs (especially those of DOE) kept LTS technologies alive during the 1960s and 1970s. Without this support, U.S. companies would not have been able to participate in today's growing commercial markets for superconducting magnets and other applications. But it is unrealistic to expect that changes in Federal R&D policies will by themselves solve U.S. competitiveness problems. Instead, Federal fiscal policies—

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[16] During the 1960s and 1970s, researchers could apply to the National Science Foundation for individual foreign travel grants that were made from a centralized fund totaling some $500,000 per year. In 1978, this central fund was eliminated and the money was distributed among the various NSF research divisions and programs, with the result that foreign travel funds became more difficult to obtain.

[17] At this writing, joint projects under consideration include: a high-field superconducting magnet facility; development of measurement standards and a database on HTS materials properties; digital superconducting electronic devices; and maglev transportation.

[18] The U.S.-Japan Workshop on High-Field Superconductors, the Versailles Agreement on Advanced Materials and Standards, and the International Electrotechnical Commission are all becoming active in promoting international standards for superconductors. There is no additional funding for U.S. participation in these activities either.

[19] ‘‘The National Action Plan on Superconductivity Research and Development,’’ Executive Office of the President, Office of Science and Technology Policy, December 1989, p. 13.

especially those that affect the cost of capital available to U.S. industry-are more important. *The availability of patient capital is the single most important policy objective for encouraging industry to invest in long-term technologies such as HTS (see* further discussion below).

University research on HTS merits a higher priority than it presently receives.

In fiscal year 1988, about 30 percent of Federal HTS resources went to support research in universities; about half of this came from NSF. Over the past 3 years, individual researchers at U.S. universities have contributed significantly to the development and characterization of new HTS materials, including the original discovery of the YBaCuO materials at the Universities of Houston and Alabama and the discovery of the thallium-based materials at the University of Arkansas. Yet there is a growing consensus that universities are not receiving a level of funding adequate to support the quality of research of which they are capable.[20] [21] [22] NSF continues to report that it is forced to turn down HTS research proposals of extremely high quality due to lack of funds. This situation is especially serious for young investigators entering the field, but even proven contributors have experienced difficulty getting funding.

As indicated in chapter 2, major questions remain about the mechanism of HTS and the relationships among the theory, structure, and properties of these materials. Because of the basic nature of this research and the long time-scales involved, much of it is best carried out in universities. Universities are an important component of U.S. industrial competitiveness; not only are they a favorite partner of companies for consulting and collaborative R&D, they also provide a pool of trained graduate students who will be hired by these companies.

Option: Increase NSF's budget by $5 million for individual investigator research grants in HTS.

While NSF's spending for superconductivity did increase from $20.4 million to $26.2 million from fiscal years 1988 to 1989, virtually the entire increase went to support the new superconductivity Science and Technology Center shared between the University of Illinois at Urbana, Northwestern University, and Argonne National Laboratory. Funding for individual university researchers stayed essentially constant. The high quality of proposals and the strong contributions in the past suggest that additional moneys invested in individual materials research grants would be likely to yield high returns.[23]

A balance between NSF funding for individual researchers and multidisciplinary centers is desirable for HTS. Individual researchers are better at investigating the physics of HTS and looking for new materials, while the resources and facilities of larger centers are needed for characterization and processing studies.

Option: Increase funding to upgrade university equipment for synthesis and processing of HTS by $10 million per year.

The need for greater investment in materials synthesis and processing at universities has been highlighted in a recent report.[24] The purpose of this initiative would be to build up the technological infrastructure of the Nation's universities in synthesis and characterization. U.S. capabilities in such areas as the synthesis of new HTS materials and preparation of large single crystals lag those of Japan.[25] To achieve optimum performance, advanced materials such as HTS must be synthesized using methods capable of control at the atomic level. This involves expensive processes, such as multi-

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[20] Committee to Advise the President on High-Temperature Superconductivity, "High-Temperature Superconductivity: Perseverance and Cooperation on the Road to Commercialization," December 1988.

[21] U.S. Congress, Office of Technology Assessment, *Commercializing High-Temperature Superconductivity*, OTA-ITE-388 (Washington, DC: U.S. Government Printing Office, June 1988), p. 11.

[22] Although at this writing the National Commission on Superconductivity had not made any official recommendations, its chairman reported a concern among Commission members about the level of support for individual investigators at universities. See David W. McCall, Chairman, National Commission on Superconductivity, testimony before the Subcommittee on Transportation, Aviation, and Materials, House Committee on Science, Space, and Technology, Feb. 21, 1990.

[23] In early 1989, NSF's Division of Materials Research announced a new $1 million program to provide $40,000 per year for 3 years to young professors entering the HTS field. However, this amount is barely enough to pay the stipend, tuition, and overhead of one graduate student at a major university, let alone the costs of supplies and equipment.

[24] National Research Council, *Materials Science and Engineering for the 1990s* (Washington, DC: National Academy Press, 1989).

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

gun sputtering, molecular beam epitaxy, and excimer laser deposition. Few U.S. universities have these capabilities, and as a result few students receive training in the state-of-the-art synthetic methods that are likely to be crucial in a wide variety of advanced materials in the future.

A second area where university infrastructure is weak is in characterization of materials. University researchers need access to a variety of expensive equipment for characterization of materials, e.g., neutron sources, photon sources, electron microscopes, high-field magnets, and magnetometers. Much of this equipment is available only in a few research institutes and Federal laboratories.[26]

The idea of enhancing university capabilities in HTS is by no means a new one. The new NSF Superconductivity Science and Technology Center in Illinois is intended exactly for this purpose, but has received only baseline levels of funding. While this is a step in the right direction, it does not adequately address the needs of the many research universities across the country. A rough estimate of the scale of the program required is $10 million per year over the next several years, providing equipment funding for some 25 research groups across the Nation at a level of $400,000 each per year.

If HTS becomes a practical success, this initiative will have created a vital source of research capability and a pool of highly trained students. But even if HTS remains largely a research phenomenon, this capability is likely to pay dividends in numerous other areas of materials science, since such equipment is also needed for research on semiconductor manufacturing, optical coatings, etc. Thus, from a national point of view, the investment would have very high utility and low risk.

Option: Provide funding—perhaps through DARPA—for a limited number of university-based consortia in HTS.

The principal recommendation of the so-called “Wise Men’s Report” on superconductivity is to establish four to six HTS R&D consortia, each involving a research university with participation by government labs and industry.[27] [28] Properly organized and managed, such consortia could help to lengthen the time horizons of industry R&D and to improve the coordination of the U.S. HTS effort. But it is important to be realistic about what these consortia can be expected to accomplish. They are more likely to accelerate generic technology development and to create a pool of trained graduate students than to aid companies directly with commercialization of HTS products.[29]

Japan’s International Superconductivity Technology Center (ISTEC)-a single consortium of all of the major Japanese companies involved in HTS—is viewed by some as a key factor that will put Japanese companies ahead in the race to commercialize HTS. But as explained in chapter 5, ISTEC’s research agenda is focused primarily on materials development, not product development. For the latter, Japanese companies are relying on extensive in-house R&D programs (see ch. 6). Similarly, research consortia in the United States are no substitute for vigorous, independent R&D programs within the companies themselves.

There is also the danger that too many consortia could dilute the U.S. effort. U.S. companies involved in superconductivity R&D already have numerous consortia to choose from, including several in the private sector, at universities, and at Federal laboratories. (Some of the more prominent consortia are listed in table 4-10.) Most are seeking Federal funding (usually from DARPA), often proposing to do similar kinds of research. Ultimately, market forces and limitations of the Federal budget will sort out which consortia will survive and which will not. But the lever of Federal funding can be used to help consolidate resources into a limited number of strong consortia having clearly complementary objectives.

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[26] The facilities for materials characterization at NIST are available at no charge for collaborative research projects with university scientists, as well as industrial and other government scientists.

[27] Committee to Advise the President on High-Temperature Superconductivity, op. cit., footnote 20.

[28] In May 1989, plans for a consortium based on the Wise Men’s model were announced by IBM, AT&T, MIT, and Lincoln Laboratories, and $4 million to $6 million in seed funding was requested from DARPA. The announced goal of this consortium is to pursue prototype electronics applications of HTS.

[29] Previous experience with university-based consortia on the NSF Engineering Research Centers model suggests that the industrial participants are more interested in gaining access to new ideas and in hiring the graduate students than they are in the actual research performed. On the other hand, many companies view one-on-one research collaborations with universities as a far more productive vehicle for accelerating commercialization of technology. See U.S. Congress, Office of Technology Assessment, op. cit., footnote 13, p. 251.

Coordination of the Federal superconductivity R&D effort can be made more effective at the national level.

At present, U.S. superconductivity policy is essentially the sum of individual mission agency programs. Within each agency, coordination has been excellent (see ch. 4), and informal mechanisms for information exchange, e.g., the Office of Science and Technology Policy's (OSTP) Committee On Materials (COMAT) and its Subcommittee on Superconductivity, have done an excellent job in providing a snapshot of the various agency programs and budgets. But there is little in the way of a crosscutting overview of the U.S. effort that could provide a sense of coherence and direction. Such an overview is particularly important in times of fiscal austerity when difficult budgetary choices must be made-e. g., choosing which of the various HTS R&D consortia competing for Federal support should be funded.

It is this lack of a sense of direction that led Congress (in the National Superconductivity and Competitiveness Act of 1988, Public Law 100-697) to mandate that OSTP produce a 5-year National Action Plan for superconductivity, with the help of the National Commission on Superconductivity and the National Critical Materials Council (NCMC). The Act also requires that the implementation of the Plan be reviewed by OSTP in an annual report to Congress.

OSTP completed its work on the Action Plan in December 1989.[30] The Plan acknowledges the need for stronger leadership in coordinating the national superconductivity R&D effort, and proposes to initiate a crosscutting budgetary analysis of Federal HTS R&D spending in fiscal year 1991. But the Plan does not indicate how this analysis would be used to identify budgetary priorities, nor does it provide the 5-year perspective called for in Public Law 100-697.

Although several advisory committees on HTS have been appointed during the past 3 years—including the "Wise Men" advisory committee established by President Reagan, and the National Commission on Superconductivity established by Congress—these committees have been given only a temporary mandate, and cannot provide the long-term monitoring and analysis called for in the National Superconductivity and Competitiveness Act.

Option: Establish a standing advisory committee of experts on superconductivity to provide advice to Congress, the Science Adviser, and the President, and give it a mandate of at least 5 years.

There is no need for a "superconductivity czar. " But a standing advisory committee of experts could:

- identify overlaps and gaps in the Federal effort;
- help to catalyze a consensus among private sector groups on promising future directions;
- suggest rational guidelines for setting priorities where necessary, e.g., on limiting the number of consortia funded;
- evaluate the quality and relevance of HTS research in Federal laboratories, including military laboratories; and
- monitor follow-through on policy recommendations.

Ideally, such a committee would be small, with strong representation by industry-perhaps modeled on the Wise Men Advisory Committee. Its efforts would need to be supplemented by permanent staff, most appropriately at OSTP. In addition to providing assistance to the advisory committee the staff could:

- provide a central point of contact for menitoring industry concerns;
- provide a central source of information and referral regarding ongoing Federal HTS programs and activities of foreign competitors; and
- mediate disputes where the goals of different agencies conflict, e.g., disputes about restrictions on the dissemination of sensitive information.

Unfortunately, OSTP's present staff is small and poorly equipped to take on these additional responsibilities. One option for easing the burden on OSTP staff might be to give these responsibilities to the staff of the National Critical Materials Council and attach them permanently to OSTP.[31]

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[30] "The National Action Plan on Superconductivity Research and Development," op. cit., footnote 19.

[31] This action may just formalize what is already taking place. Although NCMC had no active members during the period the Action Plan was being prepared, its staff contributed to writing the Plan and is temporarily housed at OSTP.

IMPORTANCE OF FUNDING STABILITY

There is one key point that relates to all of the issues discussed above, and it is one of the most important lessons derived from the history of LTS: *funding stability is essential for meaning/id progress.*

The Federal HTS budget grew from $45 million in fiscal year 1987 to an estimated $130 million in fiscal year 1990, with a budget request of $143 million for fiscal year 1991.[32] Are these funding levels sufficient? One early study called for annual HTS R&D budgets around $100 million;[33] this goal has been met and exceeded.

Today, the Federal HTS R&D budget is larger than that of any country in the world, approached only by that of Japan. In fiscal year 1989, the Federal Government spent about as much on HTS as it did on all other advanced ceramics R&D combined, and nearly twice the amount spent by U.S. companies. OTA finds that overall, the United States has an HTS R&D effort that is second to none. Present funding levels are sufficient to make progress, although perhaps $20 to $30 million more per year could be spent effectively (see options above). But if progress in HTS continues to be incremental, sustaining these funding levels in the face of mounting budgetary pressures may be difficult.

Except for the DARPA HTS program, there has been virtually no “new” money going into HTS. Instead, the money has been taken away from other research areas, notably advanced ceramics and LTS.[34] Given the pressures of the Federal budget deficit, it is appropriate that program managers in the various agencies should set priorities, and cut some projects to make funds available for areas of special promise. But while HTS continues to be a promising area, these other fields are also promising. As the initial euphoria over the discovery of HTS wears off and its political visibility is eclipsed by other more urgent priorities, pressures will build to shift funds away to other projects.

Whatever the funding levels, it is essential that they be dependable. Universities require stability in order to support graduate student thesis research. Companies require stability in order to plan their participation and give them the confidence to commit resources. Historically, Federal LTS R&D funding has followed an on-again, off-again course due to shifting political and economic winds. This has made it difficult to maintain a consistent set of technical goals and a stable pool of LTS engineering know-how.

The need for funding stability is by no means unique to HTS; it is a general requirement of efficient technology development. Mechanisms to improve stability, such as multiyear congressional appropriations, or moving to a 2-year budget cycle, have been proposed.[35] Options such as Federal funding for R&D consortia, participation in multiyear international programs, and focused, long-term projects (for examples in Japan, see ch. 5) represent alternatives that could enhance funding stability specifically for HTS.

SUPERCONDUCTIVITY IN A BROADER POLICY CONTEXT

OTA’s finding that Japanese industry is investing about 70 percent more then U.S. industry in superconductivity R&D would not be so disturbing if it were not part of a larger pattern. But across a broad spectrum of emerging technologies—advanced ceramics, optoelectronics, robotics, etc., the story is the same. And Japan is not the only country where investment in these technologies is rising faster than it is in the United States. The common characteristic of all of these technologies is that they involve long-term, high-risk investments. Clearly, these kinds of long-term investments are becoming more and more difficult for U.S. managers to make.[36]

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[32] Testimony of D. Allan Bromley, Director, Office of Science and Technology Policy, before the Subcommittee on Transportation, Aviation, and Materials of the House Committee on Science, Space, and Technology, Feb. 21, 1990.

[33] National Academy of Sciences, *Research Briefing on High-Temperature Superconductivity* (Washington, DC: National Academy Press, 1987).

[34] Overall LTS R&D budgets have been growing, but "R" has been cut while "D" has grown rapidly, because of DOE's Superconducting Super Collider program.

[35] Office of Technology Assessment, op. cit., footnote 21, p. 88.

[36] In the first half of the 1980s, industry R&D spending grew at an average annual rate of 8.2 percent; in the last half, real growth dropped to less than one-fifth that rate. National Science Foundation, Science Resources Studies Highlights, "Slow R&D Spending Growth Continues Into 1990s," draft report to be published, 1990.

The short-term mind-set of U.S. R&D managers is not the result of stupidity or ignorance about the importance of R&D to the company's future. Instead, the R&D investment decisions in both the United States and Japan are the product of rational choices made within the prevailing economic and financial environments of the two countries.[37] For decades, Japanese industry has benefited from higher rates of economic growth, lower effective capital costs, higher savings rates, and more stable financial markets than were the case in the United States. All of these factors made it easier for Japanese managers to make long-term investments.

Policy proposals aimed at lengthening the investment time horizons of U.S. industry have been the subject of a voluminous literature. Some have argued that direct tax incentives to companies, e.g., extending the R&D tax credit, or reducing taxes on capital gains realized on longer term investments (5 to 10 years), can help to stimulate long-term R&D. Others favor indirect policies that would reduce capital costs through Federal budget deficit reduction and encouragement of higher personal and corporate savings. Still others favor curbs on merger and acquisition activity to relieve pressures on managers to maximize short-term returns at the expense of long-term R&D investments and future earnings.

None of these policy prescriptions can be readily targeted on HTS, nor should they be. Although HTS remains a promising field, superconductivity at 77 K does not appear to stand clearly above other emerging technologies in its strategic or economic impact. HTS provides only the latest example of a technology that will require years of steady investment without a well-defined payoff if it is to achieve its potential.

Thus, the challenges associated with HTS research, development, and commercialization should be viewed as a microcosm of broader challenges to the U.S. manufacturing sector in an increasingly competitive world. It is tempting to rely on Federal R&D initiatives---e. g., new federally funded industry consortia, or creation of a new civilian technology agency—to regain a strong competitive position. But such initiatives, while they may be helpful, do not change the underlying economic and financial pressures on industry that dictate long-term investment decisions. The real solution-increasing the supply of patient capital to U.S. industry-will require politically tough fiscal policy choices that involve tradeoffs among military, economic, and social goals. If U.S. competitiveness continues to decline, it will not be because the United States lost the superconductivity race with Japan, but because policy makers failed to address the problems with long-term, private sector investment that HTS helped to bring into the spotlight.

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[37] For a comparative analysis, see U.S. Congress, Office of Technology Assessment, *Making Things Better: Competing in Manufacturing*, OTA-ITE-443 (Washington, DC: U.S. Government Printing Office, February 1990), p. 93.