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Summary

During 1987, high-temperature superconductivity (HTS) became a symbol—of the new and unexpected, of what was right and wrong in U.S. science, technology, and industry, of U. S.-Japan competition in high technology. In December of the preceding year, two scientists at IBM's Zurich research laboratory caught the world's attention with their discovery of superconductivity in the range of 35 to 40 'K (degrees Kelvin, i.e., degrees above absolute zero)—nearly double the record temperature for total loss of resistance to electricity. Within 2 months, transition temperatures had doubled once more—to over 90 "K—with near-simultaneous discoveries of a second family of ceramic superconductors in the United States, China, and Japan.

In March 1987, thousands of scientists jammed a hotel ballroom in New York to hear the latest findings—a meeting dubbed the Woodstock of physics. The race to higher temperatures was on. With it came warnings that the United States could lose out to foreign competitors in commercializing a technology with potentially revolutionary impacts. Indeed, one of the principal findings of this assessment is that American companies may already have begun to fall behind. Japanese firms have been much more aggressive in studying possible applications of HTS, and have more people at work, many of them applications-oriented engineers and business planners charged with thinking about ways to get HTS into the marketplace.

In the midst of the excitement, four congressional committees—the House Committee on Science, Space, and Technology, and the Senate Committees on Governmental Affairs, Energy and Natural Resources, and Commerce, Science, and Transportation-asked OTA to examine a series of questions that ranged from public and private sector responses to HTS (here and abroad) to the advantages and disadvantages of a new Federal agency for supporting the development of commercial technologies.

This special report begins with a look at U.S. strengths and weaknesses in technology development and commercialization (ch. 2), both in general and for HTS. The analysis then goes on (in ch. 3) to the strategies of U.S. and Japanese companies, as managers in each country look ahead to the new opportunities. The fourth chapter presents 20 policy options for congressional consideration; the context is U.S. technology policy as a whole, with HTS as a special case. Most of the policy options deal, in one way or another, with the management of the Federal R&D budget. Chapter 5, the last, considers three broad alternatives for speeding commercialization.[1]

[1] App. B, at the end of this report, summarizes the technology of superconductivity, including prospective applications, with estimates of time horizons for commercialization. (The glossary in app. A includes many of the specialized terms that apply to superconductivity.) OTA will follow this special report with a more detailed examination of the science and technology of superconductivity, the research agenda, and potential applications, to be published in 1989.

COMMERCIALIZATION: PUBLIC AND PRIVATE DIMENSIONS

U.S. competitiveness in both smokestack and high-technology industries has been slipping for years. Loss of technological advantage has been one of the reasons (box A). On the face of it, this seems paradoxical. The U.S. Government spends more on R&D than government and industry together in Japan. Federal R&D dollars help create a vast pool of technical knowledge that the private sector (including foreign firms) can draw upon. Beyond this, U.S. technology policies have relied heavily on indirect incentives for innovation and commercialization by industry.

This approach — leaving R&D priorities largely to the mission agencies, trusting to in-

Box A.—The U.S. Position in Technology

Before World War II, U.S. technology was seldom better than foreign technology. Sometimes it was inferior. After the war, American industry took a decisive lead in applications of technical knowledge. Even so, the United States often found itself developing or adapting technologies that had originated elsewhere. Examples include the jet engine, ballistic missiles and satellites, and, more recently, a host of innovations in the automobile industry (radial tires, anti-skid braking systems, viscous-coupled four-wheel drive).

Like Japanese and European firms, American companies have always been imitators and adaptors, but in recent years the United States has neglected to tap the world's store of technical knowledge. Other nations grew economically, revived their scientific establishments, and regained their accustomed places in technology. Meanwhile, the sources of advantage that once bolstered the international competitiveness of U.S. industries narrowed:

- In sectors ranging from steel to automobiles to high-technology electronics, U.S. technology today is no better than foreign technology. Sometimes it is poorer, especially when it comes to process (rather than product) know-how. The problems are in technology, not in science; a healthy scientific enterprise has not been enough for the United States to maintain a useful lead in (non-military) technology.
- The United States still spends far more on R&D than any other market economy. But increases in the U.S. R&D budget have not been as rapid or steady as in Japan and several of the major European nations. Nor have resources devoted to commercial technology development (as opposed to defense) grown as quickly. By several measures, priorities for commercial R&D are lower in the United States than in Japan.
- A few hundred major corporations account for the great majority of U.S. industrial R&D. While some of these companies maintain central research laboratories for projects with longer time horizons, much of this work has been scaled back in recent years; most U.S. firms that conduct R&D limit their investments to projects promising rapid paybacks. American industry, by and large, looks for safe bets; few managers view research as a major element in long-term competitive strategy.

Given these circumstances, the policies followed for the past 40 years by the U.S. Government—reliance on military R&D and on funding for basic science to support the Nation's technology base—no longer appear adequate. Although military spending still leads to major new commercial products and processes, spinoffs are less likely today than in earlier years. The education of American engineers seems increasingly divorced from the realities of the marketplace and the factory floor.

Japanese and American firms start out even in the race to commercialize HTS.[1] Broadly speaking, Japan is behind the West in science, but superconductivity is one of Japan's research strengths. And in engineering, Japanese firms have long since proved their capabilities. In years past, Japanese companies began with foreign technologies and improved them; today, they compete quite effectively with home-grown know-how. If Japan were to surpass the United States in a new science-based technology like HTS, U.S. competitiveness could be very broadly threatened. The stakes have quickly come to seem a good deal greater than superconductivity itself.

[1] Europe's ability to compete in high technology, [illegible], has continued to slip in the 1980s. Notwithstanding an array of new policy initiatives intended to reverse the trend, European industry will probably have great difficulty keeping up in HTS (see box D, ch. 2). This assessment, therefore, focuses on the United States and Japan.

direct policies to stimulate commercialization—worked well in the earlier postwar period, when American corporations were unchallenged internationally. On the evidence of steadily declining competitive ability across much of the U.S. economy, it no longer works well enough. In recent years, many U.S. companies have had trouble turning existing technical knowledge into successful products and processes, and getting new technology out of the laboratory and into the marketplace (ch. 2).

Of course there is more to commercialization than R&D and technology development. Government policies affect business decisions and competitiveness, not only through technology and science policy, but also through sector-specific measures (e.g., Government funding for the microelectronics consortium Sematech), and regulatory and macroeconomic policies. U.S. financial markets, for example, have been steadily deregulated. Among the results: greater pressures on industry for short-term investment decisions.

OTA has examined the broad range of policy influences on U.S. competitiveness in many other assessments. Here, the analysis focuses on those linked more or less closely to technology itself. They fall into two groups:

- policies that affect innovation and commercialization directly, notably the Federal R&D budget;
- those with indirect impacts.

Federal R&D helps create a technology base that private firms draw on during commercialization. Sometimes companies start development projects because of new research results; other times, they find they need critical pieces of knowledge, perhaps from earlier R&D, to complete a project, or to solve a manufacturing problem. Federally funded projects in low-temperature superconductivity (LTS), for example, laid the foundation for applications of superconducting magnets in medical imaging equipment.

The second group of policies works indirectly-through incentives (or disincentives) for private firms. Some of these policies reduce financial or technical risks, or increase rewards for successful innovators. Tax treatment of capital gains, for instance, affects decisions by prospective entrepreneurs; R&D tax credits make a difference for companies with profits that can be offset. Other such policies work through their influence on demand. Governments purchase military systems and computers, cars and trucks, consulting and construction services. Sometimes, they regulate prices or allocate production among suppliers (as the U.S. Government has done for years in agriculture).

With the knowledge base ever larger and more specialized, the great majority of American firms, large and small, can no longer expect to be self-sufficient in technology. The pace and complexity have simply outstripped their ability to keep up. Industry depends more heavily than ever before on the huge Federal R&D budget–$60 billion, about half of all U.S. R&D spending. Nonetheless, the U.S. Government has left most questions of R&D funding to the mission agencies, with their focused interests and immediate needs. While other countries have crafted policies for direct support of commercial technologies, the United States has not. policy makers here have argued that direct measures lead to harmful economic distortions. Instead, many say, deregulation—removing the roadblocks to innovation—will tap reservoirs of American ingenuity and entrepreneurial vigor that would otherwise be stifled, But most of the roadblocks have come down over the past 15 years, while U.S. competitiveness has continued to slip.

To be sure, Federal agencies are paying more attention to the impacts of day-to-day decisions on competitiveness than during the *1970s*. Antitrust enforcement reflects global, rather than simply domestic, competition. The national laboratories—particularly those overseen by the Department of Energy (DOE)—have been seeking ways to work more effectively with industry. With recognition spreading that military R&D spending may not offer the spinoffs and synergies of earlier years, Congress has been debating the merits of a change in direction for technology policies. But it is fair to say that international competitiveness still plays a minor role in U.S. policies compared with those of countries that have learned to export as effectively as Japan, West Germany, or South Korea. The United States is still searching for workable approaches to competing in a relatively open international economy, one in which American companies no longer have big advantages in technology or management skills.

HIGH-TEMPERATURE SUPERCONDUCTIVITY: U.S. AND JAPANESE RESPONSES

Why all the excitement over HTS? The media have held out the promise of more efficient generation and transmission of electric power, magnetically levitated trains, electromagnetic launchers for space weaponry. Perhaps more important, HTS-based electronics could eventually become building blocks for more sensitive medical diagnostic systems, and faster, more powerful computers. The most important impacts will probably be those that cannot yet be anticipated–the point maybe facile, but it is true.

Even at liquid nitrogen temperatures—far below room temperature but far above the operating temperatures of older LTS superconductors—the prospects have attracted as much attention as any scientific development since the laser or gene splicing. Although no one had made a practical conductor or electronic device from the new materials, the Nobel Prize committee gave its 1987 physics award for the Zurich discoveries—the quickest in history. Early 1988 saw the discovery of several more families of HTS ceramics. Yet the ultimate prize—superconductivity at room temperature—lies ahead, and no one knows whether it can be achieved, even in theory.

Activity has been feverish on the policy front as well as in the research laboratory. Within a few months of the initial discoveries, Federal agencies redirected $45 million in fiscal 1987 funds from other R&D to HTS (ch. 4, table 8). The scientific breakthroughs prompted a dozen bills during the first session of the 100th Congress, proposals ranging from study commissions to a national program on superconductivity. All reflected, in one way or another, concern over commercialization.

The policy drama reached a peak in July 1987, when President Reagan brought three ranking cabinet officers to the Federal Conference on Commercial Applications of Superconductivity; in an unprecedented appearance, he announced an n-point initiative for the support of HTS (box B, ch. 2). In a similarly unprecedented move, the Administration closed the meeting to all foreigners except representatives of the press. Although the President's message focused on executive branch actions, he stated that the Administration would also be proposing new legislation.

The following months brought a sense of anticlimax, with no sign of the promised legislative package. Questions of R&D funding then came to the fore, as the end of the fiscal year passed with no resolution of the budget impasse between the President and Congress. Only at the end of the calendar year—several months into fiscal 1988—did Federal agencies know for certain how much money they would have for HTS R&D.

Taken together, Federal agencies will spend nearly $160 million for superconductivity R&D in fiscal 1988, over half ($95 million) on the new materials (and the rest for LTS). The Department of Defense and the Energy Department together account for three-quarters of the HTS budget, and received most of the increase. DOE, for instance, will have nearly twice as much HTS money as the National Science Foundation (NSF). With NSF a primary patron of university research, the government's priorities seemed rather haphazard, given the great strength of the Nation's universities in basic research. Most of the Federal HTS money will go to government laboratories, contractors, and universities that are well removed from the commercial marketplace.

The President's legislative package, which reached Congress in February 1988, did not address R&D funding. Consistent with the Administration's emphasis on indirect incentives for commercialization, the package included provisions that would further liberalize U.S. antitrust policies, and extend the reach of U.S. patent protection.

On the industry side, most American firms—viewing payoffs from HTS R&D as uncertain and distant—have declined to invest heavily (ch. 3). A few major corporations—e.g., Du Pont, IBM, AT&T—are mounting substantial efforts. A number of small firms and venture startups have also been pursuing the new technology. By and large, however, American companies have taken a wait-and-see attitude. They plan to take advantage of developments as they emerge from the laboratory—someone else's laboratory—or buy into emerging markets when the time is right. Unfortunately, reactive strategies such as these have seldom worked in industries like electronics over the past 10 to 15 years, while many American firms seem to have forgotten how to adapt technologies originating elsewhere.

Corporate executives in Japan, in contrast, see HTS as a major new opportunity—one that could set the pattern of international competition for the 21st century. Japanese companies have made substantial commitments of people and funds, pursuing research and applications-related work in parallel. Firms in more lines of business are at work than in the United States. Steel companies and glassmakers, as well as chemical producers and electronics manufacturers, are seeking new businesses, ways to diversify. Japanese managers see in HTS a road to continued expansion and exporting, and are willing to take the risks that follow from such a view.

For years, the claim was common that Japanese firms got a free ride from U.S. R&D. More recently, Americans have realized that Japanese corporations have no need to imitate or to be followers; they have highly competent and creative technical staffs, fully capable of keeping up or taking the lead in fields ranging from automobile design to gallium arsenide semiconductors, opto-electronics, and ceramics. Giving the Japanese the credit they deserve has intensified U.S. anxieties over commercialization. Only in science—in basic research—do Japan's capabilities remain in question. For the Japanese, HTS presents an opportunity to show the world—and themselves—that they can be leaders there too.

Companies like IBM and Du Pont—or Hitachi and NEC—have R&D budgets exceeding a billion dollars. They have skilled engineers and scientists to put to work on the technical problems of HTS, money to bet on new opportunities. But these firms are a small minority in both countries, and the competition will not depend on them alone.

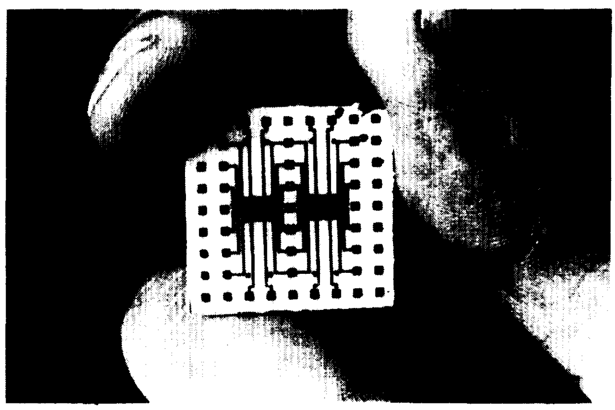

Photo credit: IBM

Conducting strips of HTS material deposited on substrate.

PRINCIPAL FINDINGS

Federal Funding for HTS R&D

It would be hard to criticize the magnitude of U.S. Government spending on HTS. Federal agencies have about $95 million for HTS R&D in fiscal 1988, more than twice the 1987 total. Although little of this represents new budget authority, the U.S. Government will spend more this year on HTS than Japan's Government has budgeted for HTS and LTS together.

With the Administration seeking $135 million for HTS in fiscal 1989, current and proposed spending might seem more than enough to support rapid commercialization. But totals can be misleading. After all, the United States spends far more on R&D than competing nations, yet U.S. industry has been unable to keep a useful lead in technology. There are many reasons, some of them having to do with the allocation of R&D funds. Nearly 70 percent of

Federal R&D spending goes for national defense; some of this money helps build the technology base for commercial industries, some does not. The story will be the same in HTS.

1. Of $95 million that the U.S. Government has budgeted for HTS R&D during fiscal 1988, the Department of Defense (DoD) will spend $46 million and DOE $27 million. NSF is next at $14.5 million. No other agency has more than about $4 million. R&D funded by DoD and DOE will help support commercialization, but a dollar spent by one of these agencies will probably buy substantially less in terms of the Nation's technology base than a dollar spent by NSF.

   A good deal of DoD's R&D will go for specialized applications in defense systems—including the Strategic Defense Initiative—with limited potential for commercial spinoffs; defense missions shape even the basic research supported by the Pentagon. DOE will distribute most of its money to the national laboratories; relationships between DOE laboratories and the private sector have begun to change—a trend to be applauded—but the laboratory system has yet to demonstrate the ability to transfer technologies rapidly and effectively to the private sector. (See Policy Options 1,2,4 in ch. 4, and discussion in chs. 4 and 5.)
2. While the Federal R&D total for HTS may seem impressive, little of it represents new money. This was necessarily the case in fiscal 1987, when agencies had no choice but to redirect existing funds. For fiscal 1988, given the pressures on the Federal budget, agencies have continued to take money from other R&D categories to pay for HTS. Congress may wish to examine the trade-offs necessary at the agency level to finance HTS R&D, and consider appropriating new money for fiscal 1989. (Options 1, 2, 3, 9.)
3. R&D priorities and funding decisions—often made at relatively low levels in the agencies—have major and lasting impacts on commercialization. So do mechanisms for inter-agency coordination. The pressures on the Federal budget make good management of agency resources even more important. (Options 1, 2, 3, 6, 8.)

   But getting the most out of the Federal investment in HTS R&D will take more than inter-agency coordination and effective technology transfer. Successful commercialization will require continuity in R&D funding so that people and organizations can plan ahead. The United States will need graduate-level scientists and engineers educated in fields ranging from materials processing to the physics of electron devices. Most of these people get their training in university programs that depend heavily on Federal support. Likewise, the national laboratories and Federal mission agencies must know where they are going, and how much money they can expect along the way. Industry needs to know whether and when it can look for new research results from Federal R&D. Multiyear R&D planning and budgeting for HTS, on a trial basis, could help set patterns for the future. (Options 2, 3, 4, 5.)

R&D and Commercialization

No one can say whether superconductivity at room temperature will be possible in the near future or in the distant future. Regardless of progress in finding materials with higher superconducting transition temperatures, 5 to 10 years of R&D probably lie ahead before the technology base will be able to support substantial commercial development.

Successful commercialization, in any case, takes more than R&D. It depends on market conditions—on a company's ability to anticipate or create demand, and to exploit it. Linking engineering development, marketing, and manufacturing—something Japanese companies excel at—is crucial. So is management commitment to the long term.

1. Processing and fabrication methods will be critical for applications of HTS. American companies have fallen down in manufacturing skills across the board; the more heavily process-dependent HTS turns out

to be, the more difficult it will be for U.S. firms to keep up with the Japanese. A strong processing emphasis in Federal R&D could help compensate for low priorities in American corporations, a major source of U.S. competitive difficulty. (Options 2, 6, 15, 16 in ch. 4.)

The Defense Advanced Research Projects Agency (DARPA) solicited zoo proposals on HTS during the summer of 1987, hoping to have $50 million to spend on processing-related R&D. When the final 1988 budget figures came down (in December 1987), DARPA found itself with only $15 million. Nonetheless, even at this lower level the program should be able to make a substantial contribution to commercialization, if well managed and sustained over a number of years. (As this report went to press, the Defense Department had just imposed a freeze on new outside R&D, including this program.)

2. HTS R&D funded by defense agencies will help American companies, but the potential for commercial spinoffs will diminish as military requirements become more specialized and diverge from commercial needs. The list of new technologies and new industries that has emerged from DoD-sponsored R&D is an impressive one: computers; semiconductors; lasers; much automated manufacturing know-how. Why should things be any different with HTS? Because both the United States and the rest of the world have changed. The defense sector has grown apart from the rest of the U.S. economy; DoD money has less impact as other countries focus more of their resources, both public and private, on commercial technologies. At the least, continuing attention to technology transfer from defense contractors and Federal laboratories will be necessary to take commercial advantage of DoD (and DOE) spending. (Options 11, 12, 13, 14, 15.)
3. Just as for technologies like microelectronics, commercializing HTS will require contributions from many disciplines—physicists, chemists, materials scientists, electrical, electronic, and chemical engineers. Multidisciplinary research works in industry because it must, but does not come easily in universities (here or in other countries). Federal policies that help establish multidisciplinary R&D within the university system will contribute to strong foundations for HTS and other technologies. (Options 9, 10.)

   NSF has embarked on a renewed attempt to stimulate multidisciplinary R&D through its program for Engineering Research Centers, and its proposed Science and Technology Centers. Consistent support will be required for these centers to take hold and become a permanent feature of the R&D landscape.
4. HTS will demand a good deal of trial-and-error development (as was true in LTS). With U.S. difficulties in commercialization much more a matter of technology than science, Federal policies that increase support for engineering research—even more, that seek to redirect research and education in engineering toward practical industrial problems—could have substantial long-term significance. (Options 4, 5, 9, 19.)

HTS in the United States and Japan

Japan's Government took the better part of a year to shape its policy response to HTS—a response that, when it emerged, looked not at all like the highly centralized program some Americans had expected. Much of the effort has been directed at getting the three parts of the R&D system—industry, the universities, Japan's national laboratories–to work effectively together. The Japanese see HTS as a test case for their turn toward basic research, and are giving it high priority. Moreover, lacking energy reserves, they have strong incentives for R&D (in LTS as well as HTS) promising savings in electric power consumption.

Japanese firms compete aggressively at home and abroad; they get consistent government support—for instance, from national laboratories that work effectively with the private sector—but succeed in international markets on their own merits. In some if not all industries, Japanese companies turn R&D into new products and processes faster than American firms. They target markets effectively, linking R&D to market needs better than many U.S. companies, and manage their factories at least as well as they manage their R&D laboratories. These strengths will pay off in HTS.

1. A few large American companies are putting substantial resources into HTS. But the list is short: AT&T, IBM, Du Pont, a few others. The financial criteria that drive decision-making in American corporations work against a technology like HTS— one with uncertain prospects, and profits that lie well in the future; the short-term view fostered by U.S. financial markets could put American companies behind the Japanese within 2 or 3 years, if they are not behind already.

   A handful of small U.S. companies and startups with venture funding have also been moving into HTS. Although smaller U.S. firms may well develop creative solutions to some of the practical problems of the new technology, these companies do not have the production and marketing capabilities necessary for a major role. They will have a difficult time growing and competing with integrated Japanese multinationals.
2. American managers, by and large, believe HTS should remain in the laboratory until more scientific knowledge is in hand. They emphasize the uncertainties—admittedly great—and the lack of evidence promising quick returns from R&D investments. To them, uncertainty urges caution rather than signifying opportunity. American firms have not made commitments to HTS that compare to those in Japan in terms of scale (as indicated by people at work) or scope (as indicated by people assigned to applications-related projects).

   Many American companies with the technical skills and the money to pursue HTS have taken a wait-and-see attitude. Typically, they have a few people tracking progress in the field. Some of these companies may be able to catch up and compete when applications begin to appear. Others will be left behind.
3. Most Japanese managers believe HTS to be closer to the marketplace than do their American counterparts. Seeking growth and diversification, they have assigned more people to HTS than U.S. firms, and may also be spending more money. The Japanese have committed funds, not only to research, but to evaluating prospective applications. Executives there see HTS as a vehicle for creating new businesses, while Americans are more likely to view it in terms of existing lines of business. And if American managers have been reluctant to commit resources to HTS, the Japanese seem confident that investments now will pay off—some time and in some way.

   The Japanese could be wrong. In spending money on feasibility studies and engineering analyses, they may miss other opportunities. But given the scale of current investments—in the range of $200 million dollars in each country (including both government and industry R&D), small compared to overall corporate R&D spending—there is much to be said for taking the risks. OTA's analysis suggests that commercialization of HTS will proceed somewhat faster than many American managers anticipate, though not so fast as many in Japan expect. If this proves the case, Japanese companies could well come out ahead in the race to commercialize HTS.
4. Japan's Government will spend about $70 million for superconductivity R&D (high temperature and low) in 1988.[2] Although ministries and agencies spent much of 1987 jockeying for position, Japan now has in place a set of policies intended to compensate for the bottlenecks and weaknesses in the country's R&D system: universities with only a few islands of excellence; national laboratories which, although some

'Comparisons with U.S. Government spending must be treated with caution: fiscal years in the two countries are 6 months out of phase; Japanese budget figures leave out salaries for research workers in universities; national defense has little influence in shaping Japan's HTS R&D.

have enviable reputations, cannot claim the breadth or depth of their U.S. counterparts.

If their system as a whole still shows weaknesses, in superconductivity, Japan's R&D is broadly based and high in quality. With R&D centered in major corporations, government policies aim to strengthen the infrastructure for developing HTS, and stimulate greater cooperation and interaction among industry, universities, and the national laboratories.

5. Japanese officials view international cooperation in HTS research as a potential complement to their country's own efforts. Much more than a matter of image, they see in internationalization a means of stimulating creativity in Japan's universities and government laboratories. In turn, U.S. industry stands to gain by testing Japan's willingness to open up its research system. (Options *18, 19, 20* in ch. 4.)

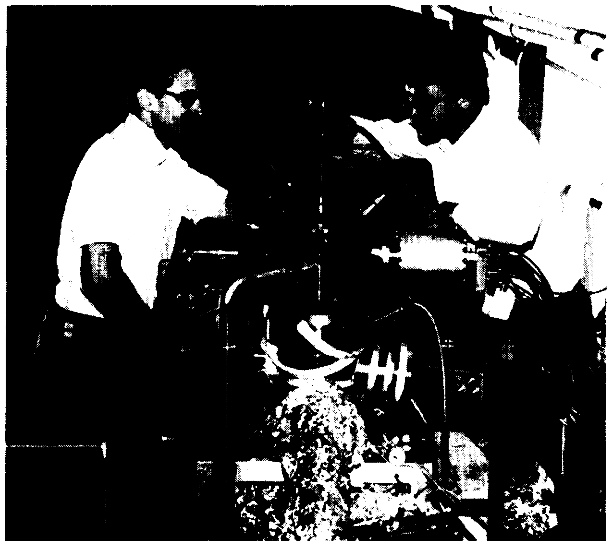

Photo credit: National Bureau of Standards

Synchrotron ultraviolet radiation equipment, used for studying electronic structure of HTS materials.

HTS and U.S. Technology Policy

Japanese companies place high priorities on technology as a competitive weapon; it is not only in HTS that U.S. companies risk falling behind. Business-funded R&D in Japan totals 2.1 percent of gross national product, compared with 1.4 percent here. Fewer high-level managers in American firms have technical backgrounds; they may not fully appreciate the role of R&D in business strategy and international competition. To executives fighting a takeover, research may look like a luxury; after a merger, it may seem expendable.

Gaps in the U.S. technology base open where neither Government nor industry has immediate requirements for R&D results. The very unexpectedness of the discoveries in HTS points to the need for ongoing Government support of long-term research. Failure by the private sector to invest in generic R&D, much of it incremental, or in risky projects with potentially big payoffs, throws more of a burden on the Federal Government.

1. Many areas of science and technology, although vital for U.S. competitiveness, get adequate financial support from neither public nor private sources. American corporations have been turning away from long-term, high-risk R&D–the kind of work called for in commercializing HTS. Knowledge that could help American firms compete is not available when needed. Underinvestment has been most serious in fields that lack glamour—e.g., manufacturing. (Options 6, 7, 8, 15, 16 in ch. 4.)
2. Like industry, the Federal Government spends most of its R&D dollars on development. Government money goes primarily for mission-oriented projects. When Federal agencies pay for R&D on civilian, commercial technologies, they have often made poor choices—particularly when the R&D goals are well removed from agency missions. Without substantial changes in U.S. technology policies, industry can expect only limited help from the Federal Government in the commercialization of HTS and other new technologies. Recently, some State Governments have been more active than the Federal Government in stimulating industrial technology development. (Options 6, 8, 15, 16, 17.)
3. Federal funding aimed at filling gaps between fundamental research and product/process development could help speed

utilization of new technologies, including HTS. Funding for long-term, high-risk projects with potential commercial applications could be even more important. But policies during the 1980s have been moving in the opposite direction; with the Administration cutting budgets for civilian applied research, the overall thrust of U.S. technology policy has turned away from support for commercial R&D. Instead, the Government has relied on indirect measures for stimulating industrial innovation and technology development. OTA's analysis suggests that **the** indirect approach, emphasizing measures such as looser antitrust enforcement and stronger patent protection, does not, by itself, go far enough.

Direct support for commercial technologies has never had a fair trial in the United States. Indirect measures certainly have a place: for example, incentives for corporate basic research could help U.S. competitiveness. So could a supportive climate for cooperative R&D ventures (and, perhaps, Federal cost sharing). Even so, given that policies such as the R&D tax credit (in place since *1981)* have had little apparent effect in filling the holes in the Nation's technology base, it seems at least as important for the Federal Government to reconsider direct funding of applied industrial R&D.

When it comes to commercial technology development, the needs are two-fold:

- support for generic, pre-competitive technologies—those that can help a wide range of companies compete more effectively, without giving any one of them a big advantage; and
- support for long-term, high-risk projects.

Much of the generic R&D would be relatively straightforward—incremental research with a strong engineering focus. The long-term, high-risk thrust could be modeled to some extent on the work DARPA undertakes for the military.

FEDERAL GOVERNMENT STRATEGIES

The last chapter of this report discusses three strategies for commercialization. These strategies imply choices going well beyond the individual policy options referred to above and discussed in detail in chapter 4–most of which are discrete and relatively narrow.

The first of the three strategies—flexible response—the current, *de facto* approach, builds on the proven strengths of the U.S. system. These strengths include diversity in funding and conducting R&D: NSF, with its mandate for financing high-quality university research regardless of field; defense agencies, with their unmatched budgets; national laboratories, reservoirs of skilled professionals.

Despite its acknowledged strengths, the flexible response strategy seems unlikely to provide adequate support for HTS. The funding picture summarized above for HTS and discussed in detail in chapter 4 shows the drawbacks of the flexible response approach. Most of the Federal dollars for HTS will go to mission agencies with little experience in commercialization—to DoD and DOE. NSF—primary sponsor of untargeted university research in science and engineering—has not had the money to fund many of the highly rated proposals it has received. No one in Government has an overview of Federal support for HTS. Few mechanisms exist for debating and determining priorities.

Congress could, of course, choose a more aggressive response to HTS—the second of the three strategies analyzed in chapter 5. Three elements set this strategy off from the current approach:

- more money to NSF for basic research on HTS (and perhaps for one or more interdisciplinary university centers), an insurance policy against missed opportunities;
- Federal Government cost-sharing in collaborative R&D programs organized and guided by industry (with the Federal money extending the R&D time horizons, ensur-

ing more support for generic work and high-risk research); and

- a working group of experts drawn from universities, industry, and Government to help shape consensus on HTS R&D priorities, and make decisions on Federal cost-sharing.

This second strategy would direct Federal funds into HTS R&D that might otherwise be underfunded, and particularly into industry. The added cost would be modest—$20 million or $30 million per year, well spent, should make a big difference.

The last of the strategies goes beyond HTS, taking up the question of direct Federal support for commercial technology development. As part of such a strategy, OTA considers the merits of increased funding for engineering research, along with the advantages and disadvantages of a Federal technology agency.

The analysis emphasizes the problems of defining an acceptable mission for such an agency—one charged with supporting industrial technologies—and of avoiding special-interest hand-outs. Without a mission statement that can impose discipline over the agency's decisions, both day-to-day management and the establishment of broad priorities pose real difficulties. Nonetheless, a Civilian Technology Agency might be able to provide useful support for commercialization if its activities were centered on generic R&D, intended to fill holes in the Nation's technology base, and on a menu of long-term, high-risk projects.

The three strategies in chapter 5 are by no means exclusive of one another. As Federal policies shift in response to the new competitive circumstances of American industry, and as the science and technology of superconductivity continue to evolve, Congress and the Administration—along with private industry—will need to remain flexible and open to new ideas. Technological innovation may demand policy innovation. Uncertainty makes planning difficult for both public and private sectors—one of the reasons for a strategic framework to aid in the many decisions that lie ahead.