Chapter 3

Superconductivity in Japan and the United States

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SUMMARY

The first 10 weeks of 1988 saw the discovery of two more copper-oxide based superconducting materials—one with bismuth as a critical ingredient, the other thallium. These two compositions—both with critical temperatures in the range of 100 degrees Kelvin—joined those containing rare earth elements (e.g., lanthanum, yttrium) that scientists around the world had been studying for a year. Laboratory resources had been heavily committed to the yttrium-barium-copper-oxide family–the so-called 1-2-3 superconductors —and the scientists had been making good progress in improving current densities and learning to make thin films. Then, all of a sudden, two entirely new compositions—equally complex, five elements in each, partially understood structures and phase diagrams. Two new worlds to explore. Heaven for the scientist (though more sleepless nights). Hell for the businessman.

Business planners and government strategists–at General Electric and Sumitomo, MITI and the Pentagon—now faced still more choices. Superconductors came in at least three varieties:

1. The old, low-temperature superconducting (LTS) materials–metal alloys like niobium-titanium, well understood but calling for cooling to near liquid helium temperatures —might still remain the material of choice for some applications. Very sensitive detectors of enemy submarines or brain waves might have to be operated at liquid helium temperatures in any event, to get noise levels down.
2. The 1-2-3 ceramics—brittle, not very stable, but with properties that people had begun to understand.
3. The latest high-temperature superconducting (HTS) compounds—those containing bismuth or thallium–still a mystery, but potentially easier to work with and perhaps having better combinations of properties than the 1-2-3s.

Then there is the fourth category—everything as yet undiscovered.

With no theory, only enlightened empiricism to guide the search, not even the biggest laboratories can explore all the possibilities. Choices must be made, priorities set, resources allocated. For a company, 50 people working on HTS means 50 people who cannot work on other projects that might, in the long run, be equally important.

This chapter is about those choices, and how they are made, in U.S. and Japanese companies, and in Japan's Government. Chapters 4 and 5 deal with the choices facing the U.S. Government.

Corporate managers in the United States and Japan look at the world differently. In seeking strategies for profits and growth, they make different kinds of choices, set different priorities, because they operate in contrasting economic, political, and social environments. Companies that do business on a global scale—IBM, Du Pont, Nippon Steel, Hitachi–may have much in common in their view of the world, but there are important differences between them as well. It may be a cliché to say that Japanese firms put more weight on growth and market share than on short-term profits, but it is true, and it makes a difference in R&D strategies, business plans—the entire array of competitive choices. The U.S. startups, financed with venture capital, that sprang up during 1987 have no counterparts in Japan. Nor do the small LTS specialists mentioned in the preceding chapter. Japan's joint government-industry R&D projects—a fixture of that country's industrial and technology policies—have no counterparts here.

Business planners must decide how *many* people and how much money to put toward superconductivity. They must decide how to spend that money, and what kind of people to assign. Is it too early to think about applica-

tions? Does it make sense to continue exploring LTS technologies? Managers in the United States and Japan have made diverging choices:

- A few large American companies are pumping substantial resources into HTS. But many other U.S. firms—organizations with the resources to pursue HTS if they wished—have taken a wait-and-see attitude. They may have a few people working on HTS R&D, but mostly just to keep track of the technology.
- Most of the effort in the United States is going toward research. American managers believe HTS should remain in the laboratory until more scientific knowledge is in hand.
- Perhaps a dozen large, integrated Japanese multinationals—manufacturers not only of electrical equipment and electronic systems, but of ceramics, glass, and steel—are pursuing multi-pronged R&D strategies in superconductivity. As in the semiconductor industry, these resource-rich companies could prove potent rivals for smaller American firms hoping to stake out a position.
- Japanese companies are conducting research but also thinking about applications. They are putting more effort than U.S. firms into thinking through what HTS might mean for the company's strategy. In general, managers in Japan believe that HTS is closer to the marketplace than do American managers. They also see HTS as a means of creating new businesses, while American managers are more likely to view it in the context of their existing business. The breadth of the Japanese effort substantially exceeds that of the United States.

Managers in the larger American companies believe that if HTS takes off, they will be able to catchup or buy in. Japanese managers want to move down the HTS learning curve in real time. They believe that advantages established now will last. Scientists, managers, and venture capitalists involved in the HTS startups in the United States believe the same thing, but they are few, small, and weak compared with the Japanese companies.

Taken as a whole, the U.S. approach—driven by the need to show financial paybacks in the short term—could leave American industry behind Japan within a few years. Such an outcome is not assured. HTS could languish in the research laboratories. Or HTS could evolve like the laser industry—never quite matching the expectations of the enthusiasts, driven heavily by military needs, lacking the revolutionary impacts of the computer or the semiconductor chip.

On the other hand, HTS could grow and spread and expand like the digital computer. Computers—especially the microprocessors and single-chip microcomputers found in microwave ovens and TV sets, banking machines and machine tools, Chevrolets and 767s—have penetrated innumerable products and manufacturing processes. The same could eventually happen with HTS technologies.

American companies, by and large, have taken the conservative view; Japanese companies have taken the optimistic view. If technical developments in HTS proceed as swiftly over the next 2 or 3 years as they did during 1987, then Japanese companies that have been laying the groundwork for commercialization will be in a stronger position.

Superconductor fever has swept through Japan's Government too, with ministries vying with one another for the lead in policy. The picture has now stabilized, but 1987 saw many actors seeking center stage—and few signs of the coordinated, monolithic policy machine that some Americans still think of as Japan, Inc.

CORPORATE STRATEGIES

What place does R&D have in the strategies of American firms? How do managers think about HTS? How does the business culture in the United States differ from that in Japan? Effective government policies depend on an understanding of the attitudes and practices of managers, the forces that condition their decisions. As it happens, there is substantial truth to the commonplace observation that Japanese managers take a longer view than Americans. This difference shows up in R&D decisions on HTS.

For years, American firms have been criticized for short-sightedness.[1] Managers are under pressure from Wall Street and institutional investors (pension and mutual funds, insurance companies) to show high and increasing quarterly earnings. Failure to do so can lead to a loss in stock values, and vulnerability to hostile takeovers. Jobs and egos are on the line, so the argument goes; few chief executive officers or division heads can survive many mediocre quarterly reports.

Techniques used by American managers for evaluating investment alternatives—discussed in the next section—reinforce the pressures to sacrifice long-term opportunities for short-term profits. Instead of investing in R&D that will increase their firm's storehouse of proprietary know-how, managers cut R&D to reduce costs. Instead of investing in new plant and equipment to increase productivity and flexibility, they slash payrolls, keep the old equipment running while spending no more than absolutely necessary on maintenance, and move labor-intensive production offshore or to the Sunbelt. Rather than putting money into core businesses, managers diversify (from steel to real estate, from manufacturing to services), buy up other companies rather than build their own, and seek paper profits. The picture may be a caricature, but it has a good deal of truth in it.[2]

How have these pressures affected corporate decisions on HTS? What other factors enter into R&D decisions? How, specifically, do U.S. managers view HTS compared with their Japanese counterparts? The next section of this chapter examines the R&D strategies of American firms. Later sections turn to Japan.[3] The findings in brief:

- American managers have been notably more reluctant to commit resources to HTS —a technology with highly uncertain prospects. They view profits as lying well in the future.
- Japanese executives, in contrast, seem confident that investments now will pay off– some time and in some way. Their view of the future is quite a different one from that of American managers.

These contrasting views reflect the business environments and investment climates in the two countries—indeed, the entire complex of factors that affects management decisions.

1 More than a dozen years ago, an experienced U.S. R&D manager wrote that " . . . the root cause of the present and future decline of U.S. technological prominence is a temporal mismatch between the natural pace of innovation and the time horizon of most U.S. industrial corporations . . . . this root cause is overlooked by the managers of major U.S. industries because they have a warped set of values' '–R.D. Dean, Jr. "The Temporal Mismatch—Innovation's Pace vs Management's Time Horizon," ***Research Management,*** May 1974, p. 12.

A recent survey of nearly 140 U.S. companies found "greater emphasis on near-term lower-risk results-oriented work" in their R& D–''Trends in the Chemical Industry," Results of the March-May, 1987 Survey of ACS Corporate Associates. (ASC is the American Chemical Society. The survey covered corporate members from other industries as well.)

For 1988, the National Science Foundation has forecast the lowest rate of real, inflation-adjusted growth in R&D since 1977. Even the Electric Power Research Institute, financed by regulated utilities, evidently feels many of the same pressures as publicly owned corporations. According to the Institute's president, "We now must clearly demonstrate that there is value in what we are doing and that it falls in an acceptable business time frame, This is a remarkable difference from when we started" [1973]– ''EPRI's New President Looks to the Future," New ***Technology Week,*** Feb. 1, 1988, p. 8.

2 A typical example: Tektronix, a leading manufacturer of instrumentation and computer work stations, will fire 1,000 white-collar employees "in a bid to boost earnings. " When the company announced that it would close down some R&D projects, and scale back its marketing and sales staff, a stock market analyst said, "They're addressing the right issues." See J.P. Miller, " Tektronix Plans To Dismiss 6 percent Of Its Workers, " ***Wall Street Journal,*** Mar. 7, 1988, p. 12.

3 Most of the information on company views of HTS comes from interviews in the United States and Japan during late 1987 and early 1988, and from surveys of U.S. and Japanese firms. The U.S. National Science Foundation, through its Tokyo office, conducted the survey of Japanese companies for OTA.

R&D and Business Planning in the United States

Funding Decisions

American firms approach R&D much like any other investment. With some exceptions, a decision on individual R&D projects or divisional R&D budgets will be viewed in the same light as a decision to invest in new production equipment, acquire another company, or sell the firm's Manhattan headquarters and move to New Jersey. Box E describes the process.

R&D carries higher risks than many other corporate investments, in the sense that outcomes are less certain. Moreover, the projects with the greatest uncertainty tend to be those with longer payback periods. As explained in box E, such projects must promise exceptionally large rewards, or the investment money will go elsewhere.

Research that loses out in private corporations might nonetheless benefit the country as a whole. If no one company can reap the rewards, none may invest. That is why the Reagan Administration has continued relatively liberal funding for basic research, even though cutting back on more applied work. Companies do little basic research because, from their perspectives, it does not pay. But the social returns from a portfolio of such investments can be great.

R&D Management

American companies normally engage in R&D to support existing business activities, or those that have emerged from reasonably careful planning exercises. Even the two remaining giants of U.S. corporate research—IBM and AT&T—seek, in their own quite different ways, to guide and manage R&D in support of overall corporate goals.

Oriented toward results, American executives see corporate R&D as an activity to be guided by the firm's overall objectives. Only rarely do they look to R&D as a means of uncovering wholly new business opportunities. When they do, they tend to seek home runs (like the Xerox copier or Polaroid photography) rather than the incremental advances that have a central place in Japanese corporate strategies.

Du Pont would dearly love another product like Nylon, and Intel another invention with the impact of the microprocessor, but who knows where these might come from? Inventions cannot be planned, and no company will spend much money on an unguided search. Furthermore, in big organizations with ample R&D budgets, projects that might be exciting technically can get lost in the corporation's grand strategy. Even though they might promise high rates of return, if the overall market looks relatively small, a big company may not be tempted. Low-temperature superconductivity provides a number of examples, and HTS will probably bring more.

Most firms give their R&D managers latitude in initiating work on their own, hoping for results that will eventually contribute to the bottom line.[4] Individual managers, moreover, do not always follow corporate policy. Working-level people bootleg research that might not be approved higher up. Top management normally lets project leaders and departmental managers follow their own judgment, so long as not too much money is involved. Star researchers, likewise, may be left alone to pursue their hunches and intuitions (which is how HTS was discovered in IBM's Zurich laboratory). A few companies let people spend some fraction of their time–usually small–following personal research interests.

Such policies tend to be pursued for reasons of morale. They help create a more comfortable environment for industrial scientists, a more academic setting. If the results bring in money for the company, this will normally be viewed as a lucky accident; in most U.S. firms, most R&D scientists and engineers work within carefully managed groups, on projects that corporate management first approves and then monitors.

[4] This latitude seems increasingly circumscribed. For instance, many U.S. research managers must take such decisions as whether to spend, say, $250,000 to join an R&D consortium, all the way to the top of the management hierarchy. See "Roundtable: Physics Research In Industry," *Physics Today*, February 1988, p. 54.

Box E.—R&D in U.S. Corporations

Many large American firms have turned away from corporate research. Some—U.S. Steel in the 1970s—have closed their laboratories. Others—Exxon comes to mind—have scaled them back dramatically. GE has shed the Sarnoff Laboratory inherited from RCA.[1] The staff of AT&T Bell Laboratories has shrunk by 5,000 people since divestiture. Even those laboratories that have continued to expand—for example, IBM's research arm—find themselves under renewed pressure to support development projects for the operating divisions. None of this is necessarily bad. Linking research with engineering and production is a perennial problem. Much of the success of Japanese corporations in world markets can be traced back to effective management of product and process development.

But things have, in fact, changed in the United States. R&D of a sort that companies funded during the 1960s or 1970s might not go forward today. It may even be possible that American managers have lost sight of their company's long-term interests—misled by oversimplified techniques for investment analysis, the short-term myopia alluded to earlier in this chapter.

Present-Value Methods

Most American companies make most decisions on R&D spending in accordance with straightforward financial criteria: they compare proposed R&D investments with other possible uses of their funds. If the R&D promises a high enough payback, they will pursue it. If not, they will do something else with the money.

This means that in many if not most American corporations, R&D managers must justify their budgets in much the same way as operating managers. All use standard methods of financial decision making, normally based on the present value of cash flows anticipated from the investment. Companies estimate expenses and revenues over time, then "discount" them based on a factor that depends on the firm's cost of capital. For an R&D project, the expenses correspond to those listed in table 2 (in ch. 2): they begin with the R&D itself, and continue on through commercialization. Revenues begin when the product reaches the marketplace. The discount rate used in these estimates depends on prevailing interest rates in capital markets, along with many firm-specific factors.[2]

The basic decision rule is simple: accept projects that show a positive present value, reject those with negative present values. Put another way, the company would invest in projects with predicted rates of return greater than the company's cost of capital. Of course, the future is always uncertain—and when it comes to R&D, it can be highly uncertain. But the method permits firms to compare uncertain alternatives.

Two conclusions follow directly:

1. Investments that show positive cash flows in early years appear more desirable than those with cash flows equal in magnitude but later in time. Projects with late payouts—common in R&D—will be more difficult to justify. The longer sales revenues are delayed, the greater those revenues must be.
2. The higher a firm's cost of capital, the more difficult it is to justify any project. Managers typically handle the uncertainty associated with longer-term projects by increasing the discount rate they apply. This puts a double hurdle in front of long-term R&D projects.

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[1]GE has a long tradition of excellence in research, but even so has achieved many of its greatest successes over the years through turning other people's inventions into commercial realities. One example: improvements to Parsons and Curtis steam turbines so that they became practical for driving electrical generators. See G. Wise, "R&D in General Electric," R&D Pioneers Conference, Hagley Museum and Library, Wilmington, DE, Oct. 7, 1985. Wise, GE's corporate historian, emphasizes the longstanding ties between product development and research in the company, illustrated by the early works laboratories with their extensive evaluation and testing of insulating materials. He views GE's research style as emerging from a conflict between two schools of thought, represented by Thomas Edison and Elihu Thomson. Thomson emphasized teamwork and evolutionary development, an approach that quickly became dominant. Nonetheless, the visionary Edison continued to have followers at GE. According to Wise, GE's post-World War II turn toward basic research—a swing which seems to have reversed in the last 5 to 10 years—can be seen as Edisonian.

[2]On costs of capital, including differences between the United States and Japan, see *International Competitiveness in Electronics* (Washington, D.C.: Office of Technology Assessment, November 1983), ch. 7.

Return on investment as a decision criterion and measure of corporate performance originated within Du Pont early in the 20th century, and quickly replaced such ratios as return on sales as the primary financial measure in use. See R.S. Kaplan, "Accounting Lag: The Obsolescence of Cost Accounting Systems," *The Uneasy Alliance: Managing the Productivity-Technology Dilemma*, K.B. Clark, R.H. Hayes, and C. Lorenz (eds.) (Boston, MA: Harvard Business School Press, 1985), pp. 196-197.

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These practices follow quite naturally from accepted business practices in the United States. They are part of the received wisdom—wisdom that says the rare inventive genius will in any case strike out on his or her own, founding a new company to exploit whatever is really new.

U.S. Strategies in High-Temperature Superconductivity

As the survey results in box F indicate, at least 28 American companies are spending at the level of $1 million or more on superconductivity R&D. On the average, they have nearly 20 professionals at work. Many of the companies working in HTS have LTS experience. During 1987, most of HTS R&D went toward understanding the 1-2-3 ceramics, and toward processing-related work. The high proportion of scientists compared to engineers reflects the basic character of the research.

A number of American companies, big and small, have been conducting R&D on superconductivity—and perhaps producing LTS wire or magnets—for two decades or more. Some attempted to commercialize LTS products, later to scale back or abandon their work. In the 1970s, LTS-based Josephson junctions (JJs) excited considerable interest in U.S. electronics and computer companies. The enthusiasm faded, and much of the U.S. work was eventually dropped. (The Japanese persevered with JJs, as discussed in box J, later in chapter.) In other cases, companies like GE—with its line of medical imaging equipment incorporating LTS magnets (ch. 2)—have gone onto become major forces in the marketplace. Still, some of the Americans with experience in LTS view the new ceramic superconductors with considerable skepticism. Earlier disillusionment may have affected the current strategic posture of some American firms.

Indeed, many U.S. R&D managers feel it is too early even to think about applications of HTS. They think much more research will be needed to characterize the new materials. Moreover, they believe that commercial payoffs are likely to be in the distant future. Media hype has had little influence on them, These views affect funding for HTS R&D.

But if research in HTS is called for, who, on the American side, will do it? With few exceptions, U.S. industrial R&D laboratories avoid science. Their job is to support the operating units. U.S. industrial research grew rapidly during the early 20th century—led by companies like GE (which established a corporate R&D facility in 1900), Du Pont (which followed in 1902), AT&T (1911), and Eastman Kodak (1912), But decline has set in, for reasons that range from corporate decentralization to the shortening of time horizons. Today, few American corporations pursue much basic research with their own funds. Thus, when American managers state that HTS belongs in the laboratory, they often mean someone else's laboratory.

Two strategic scenarios, then, encompass most American firms:

1. The first includes the companies that have taken a careful look at how HTS might affect their businesses, assuming continuing advances in the technology. Such assessments often entail a complete review of the firm's product lines—a process some firms have begun by revisiting earlier evaluations of LTS.

   At this stage, such an assessment is no easy task, given the uncertainties. No one can predict which of the new families of

Photo credit" Westinghouse

Rotor for prototype LTS generator

Box F.—Superconductivity R&D in U.S. Companies

Between January and June, 1988, OTA surveyed 55 U.S.-based companies with significant R&D efforts underway in HTS (i.e., more than a handful of people tracking the technology). The survey was not exhaustive; the results should be viewed with caution, as a lower bound on U.S. activities. Nonetheless, it probably captures most of the R&D in HTS in startups and large firms.

Level of Commitment

- The 55 firms had approximately 625 scientists and technicians at work on superconductivity R&D (both LTS and HTS), either part-time or full-time.
- In total, the 55 firms expected to spend $97 million on superconductivity R&D in 1988.
- Twenty-eight of the firms have a current annual commitment of $1 million or more for superconductivity R&D. Of those, 16 are spending in the $1 million to $2 million range; 9 from $2 million to $5 million; and 3 firms are spending $10 million or more (none fall between $5 million and $10 million).

Types of Firms

- The 55 companies fall into the following broad categories: firms whose main business has been LTS materials and/or applications, or other advanced materials (including ceramics) (19); recent startups (5); defense and aerospace firms (12); and others—many of them large manufacturers with diversified product lines, and firms in industries including electronics, telecommunications, and chemcials (19).
- The 1987 revenues of the companies surveyed range from zero (for a new startup) to $100 billion.
- Average 1988 R&D spending on superconductivity in the four categories is as follows:

LTS and advanced materials	$1.1
startups	$1.7
aerospace/defense	$1.1
other	$2.9

R&D Activities

- Of the 625 people engaged in superconductivity R&D, three-quarters are scientists/engineers, the rest technicians. The scientists/engineers divide as follows:

physicists	43 percent
materials scientists	30 percent
chemists	15 percent
electrical engineers	12 percent

- Most firms have some work on materials characterization underway, but the bulk of the basic research is going on in a half-dozen large corporations.
- HTS is receiving much more R&D effort than LTS. Among the 28 firms spending $1 million or more, only 7 are directing more than 30 percent of their R&D efforts to LTS materials and applications, and these are mostly companies with extensive experience in LTS (including defense contractors).

Other Observations

- Less than half of the 55 firms are involved in some sort of domestic cooperative R&D activity in superconductivity; others expect to get involved in the next 2 years. For a number of firms, this activity is limited to cooperation with a single university or federal laboratory.
- Perceptions of where "the most significant HTS R&D is currently being done" centered heavily on IBM and AT&T. Also mentioned frequently were Stanford University, Berkeley, the University of Houston, Argonne National Laboratory, and Du Pont. When asked "which country is ahead in HTS R&D today," 22 of the 55 firms surveyed indicated Japan, and 7 indicated the United States; 14 companies said they viewed it as a tie or else gave the United States the lead in science and Japan the lead in applications. (The other 12 firms did not answer this question.)
- About half of the 28 companies spending at the $1 million and above level are getting some Federal R&D funds, as are a handful of the firms spending below that level. Many other companies expect to get some of their superconductivity funding from the Federal Government in the future (the survey predated most fiscal 1988 Federal contract awards).

materials might prove most useful, what kinds of problems the design of practical magnets or Josephson junctions might bring, whether three-terminal devices will emerge (ch. 2)—much less the costs.

There is a second problem, one creating even more uncertainty. Will somebody discover superconductivity at room temperature this year? Next year? In 2050? This makes all the difference for any economic evaluation. In fact, most U.S. companies have based their assessments on liquid nitrogen operating temperatures—an assumption leading to relatively pessimistic evaluations except for quite specialized applications. The typical view goes something like this:

- The primary need is for materials characterization, work that can be carried out (and is) at literally hundreds of academic, government, and corporate laboratories around the world.
- Our company could spend a lot of money on HTS without much chance of a breakthrough. Even then, the research would probably not result in proprietary advantage.
- In any case, the first applications are likely to be in defense systems, where cost constraints are less severe.
- Under these circumstances, the best strategy is to hedge the company's bets by tracking the science and technology worldwide, without investing heavily.

Such a strategy implies willingness to alter course if someone else makes a major breakthrough (not necessarily in operating temperatures—a big increase in critical current densities might be enough for at least some U.S. firms). These companies —many of them currently spending at the $1 million to $5 million level (box F), and with perhaps a dozen people assigned to HTS—will keep a core group at work. But they are not ready to jump into the HTS R&D race.

2. The second strategic scenario includes those companies, most of them large, with strength in research and the ability to pursue HTS R&D on a significant scale. The list is short: AT&T, IBM, Du Pont. Bellcore, Westinghouse, GE, and a few others might be added, along with several major defense contractors.

Here, the presumption that HTS should remain in the laboratory is not a bar. Of course, not even IBM or AT&T can do everything; these companies too face the choice of investing money and manpower in HTS or in alternative R&D projects. But HTS exerts a powerful attraction, not only on working scientists, but on those who manage research. Finally, for some of these companies, success in HTS R&D could have pervasive impacts on their businesses. In a company like IBM, which already maintains a portfolio of equally uncertain R&D—most with far less potential impact —HTS quite naturally gets a high priority. A few American firms, then, have 50 or 60 people assigned to HTS, and some work underway that verges on development.

There is also a third group, not large, consisting of startups with venture financing (see box G), plus other small firms.

Government money for R&D could pull a few more American firms into HTS R&D. But much of this money will go for defense projects. Even in companies that include military or space divisions along with other operations—as IBM, AT&T, and many other large corporations do—the two sides of the company normally operate largely separated from one another (ch. 4).

In summary, most U.S. companies have adopted a wait-and-see attitude toward HTS. They may have assigned a group of people to monitor developments. Perhaps they conduct research on a small scale. But few major U.S. firms have placed superconductivity among their top R&D priorities. The others see good reasons for their decisions, of course. Risks and uncertainties are high; judgments differ. But if HTS develops more rapidly than they anticipate, few U.S. companies will be able to respond as quickly as the aggressive Japanese firms that have already begun laying groundwork for commercialization.

Box G.—Venture Startups in HTS[1]

Through the end of 1987, private venture capital funds in the United States had invested about $20 million in four startup companies aiming to exploit HTS. Several other startups were looking for venture funding. At least at first, the startups expect to work on proprietary HTS technologies that other companies can bring to market.

Interest in the possibilities of HTS has been widespread within the venture capital community; OTA estimates that an additional $50 to $60 million would potentially be available during 1988 if the right opportunities came along (i.e., significant new discoveries).[2] Most of the activity has centered around 10 or so venture capital firms that have succeeded in the past with long-term, seed capital investments—e.g., in semiconductor and biotechnology startups, including a number that today are cornerstones of their respective industries. The pattern in HTS resembles that in the early days of biotechnology: startups have been brainchildren of the venture capital community, rather than of capital-hungry scientist/entrepreneurs.

Investors have sought out university faculty with past accomplishments in superconductivity at schools like Stanford, MIT, and Berkeley. Startups like American Superconductor Corp. and Conductus Inc. are managed by members of the supporting venture-capital firms. The startups have gradually added staff, but so far have mostly worked with university patenting/technology licensing offices in lining up consultants and advisory boards, while searching for corporate partners to share the investments, aid in technology development, and stand ready to help with marketing. Each of the new firms has been funded by pooling money from several venture capital sources. None had a business plan at the time of initial capitalization.

Most of the venture capitalists interviewed felt that commercialization of HTS would take 5 to 10 years, with some specialized defense applications (e.g., sensors) perhaps coming sooner. Those who have plunged in state that they are in for the long term. They generally agreed that the large, integrated Japanese manufacturers will be at a substantial advantage when the time comes to move into production and marketing. This is the reason they have searched for partners among bigger companies here. None had taken on a European or Japanese partner, although all have been approached.

[1] "Early Investments in High-Temperature Superconductivity," prepared for OTA by D. Sheddon under contract No. J3-2685, December 1987.

[2] In a recent survey, venture capital firms put superconductivity at the top of the list of potential investments that would excite the most interest during 1988—well above biotechnology, computer software, fiber optics, and robotics. See *High Technology Business*, March 1988.

Japanese R&D

As in the United States, the R&D strategies of Japan's corporations flow from more general managerial attitudes. In important respects, Japanese executives exhibit decisionmaking behavior that differs from that here. As noted in the preceding chapter, U.S. and Japanese management styles also show many similarities, particularly in high-performing companies, but some strategic choices that make sense in an American context may be incompatible with Japanese views.

Corporate Research in Japan

Patterns of industrial R&D have been changing rapidly in Japan. American firms, accustomed to advantages in technology, must also adapt—perhaps to being first among equals. Japanese firms have a tougher job. They are trying to catch up and take the lead—and trying to do so with people and organizations that, until recently, started by licensing and adapting foreign technologies. s This takes money, and Japanese industry has been willing to spend it.

Table 5—showing the rapid rise in business-funded R&D in Japan–demonstrates the strength of that commitment. Japanese firms see technology development as a key ingredient in com-

[5] *See International Competition in Services* (Washington, DC: Office of Technology Assessment, July 1987), ch. 6.

Table 5.—R&D Funded by Business and Industry

	Business-funded R&D expenditures		
	1981	1983	1986[a]
United States:			
Billions of dollars	$35.9	$43.2	$58.2
As percentage of all U.S. R&D	50.0 %	50.0%	49.8%
Japan:			
Billions of yen	¥ 4364	¥ 5451	¥ *7000*
Billions of dollars	$19.8	$22.9	$41.6
As percentage of all Japanese R&D.	72.9%	75.9%	77.8%

[a]Estimated.

SOURCE: *International Competition in Services* (Washington, DC: Office of Technology Assessment, July 1987), p 205

petitive strategies. While business-funded R&D in the United States has been going up almost as fast in real terms, the overall lead of the United States in private sector R&D stems simply from the greater size of the American economy; on the average, Japanese firms spend substantially more on R&D as a percentage of sales.

In earlier years, major Japanese corporations began by scanning the world for technology, often with the aid of Japan's large trading companies, as well as the government. When possible, they set one potential source for technology against another to minimize licensing costs. Japanese companies followed with engineering excellence, highly developed manufacturing systems, and carefully targeted marketing strategies—often competing aggressively at home before launching their export drives.

But the world has changed for Japanese companies. In many technical fields, they have reached parity with the West. American and European firms, in any case, are much more wary of licensing than even 10 years ago. There is little more for Japan to assimilate. Japanese firms must either wait for new ideas to appear elsewhere or step up their own research. Even for companies not pressed by increasing competition from newly industrializing countries like South Korea, the first choice is a recipe for disaster at home. Thus Japan's major corporations are working hard to generate new technical knowledge.

This search for proprietary technologies means more basic research.[6] As American companies turn away from relatively fundamental work, Japanese firms are turning toward it. Many American R&D managers give the Japanese little chance of accomplishing much, at least over the next 5 or 10 years. They view Japan's culture–and the organizational environment in Japanese firms—as hostile to creative research. Many Japanese would agree. Their engineers may be superb at painstaking product development efforts, but, at least according to the stereotype, research demands individuality and creativity—qualities discouraged in Japan.

This stereotype is greatly exaggerated: a closer look suggests that creativity in engineering—something the Japanese have amply demonstrated—differs little from creativity in research and in science. In fact, U.S. scientists and R&D managers directly involved in HTS research give their Japanese counterparts high marks for their work. Moreover, in related fields like ceramics, the Japanese already have the lead in commercialization.[7] While Americans still see Japan as lagging generally in science,

Wee, for instance, S.K. Yoder, "Japanese Launch Bid to Lead the World in Pure Science," ***Wall Street Journal***, June 3, 1987, p. 26, Also P. Marsh, "The search for some home-grown heroes," ***Financial Times,*** July 6, 1987, p. 15, which quotes Tokyo University's Professor Shoji Tanaka, Japan's best-known superconductivity expert, as follows: "For a long time the Japanese people had the feeling they were behind in science. But now the inferiority complex is starting to vanish. We do have a relatively inflexible university system. But . . . young people are changing and will force their professors to adopt different ideas. " In searching for creative scientists and engineers to staff their research laboratories, Japanese companies are hiring more women and foreigners—M. Kanabayashi, "An Acute Shortage of Engineers Threatens Japan's Research Goals," ***Wall Street Journal***, Oct. 15, 1985, p. 32; "Poor lab facilities hamper plan to attract foreign researchers," ***Japan Economic Journal,*** Apr. 16, 1988, p. 5.

Industry and government in Japan have put considerable emphasis on the life sciences in their overall drive for research excellence. See ***Commercial Biotechnology: An International Analysis*** (Washington, DC: Office of Technology Assessment, January 1984), pp. 505-510. Later sections of this chapter discuss government policies in support of basic research in Japan.

'***High-Technology Ceramics in Japan,*** NMAB-418 (Washington, DC: National Academy Press, 1984); ***Ceramic and Semiconductor Sciences in Japan, 1987,*** PB 88-122478 (Washington, DC: Department of Commerce, 1987); ***Advanced Materials by Design: New Structural Materials Technologies*** (Washington, DC: Office of Technology Assessment, June 1988).

there is no basis for complacency—and certainly not when it comes to superconductivity.

Time Horizons

How about the longer term view that Japanese managers reputedly take? This stereotype holds up–as can already be seen in HTS. The reasons begin with notions of success and failure that differ substantially between the business cultures of the United States and Japan.

In the United States, management perceptions of the factors that determine the value of a firm's stock heavily influence decisions. When surveyed, U.S. managers rank profits (as measured by return on investment), and increase in share price, as their primary objectives. Japanese executives also view return on investment as important, but put it below another goal—market share—which appears no better than third in rankings by American managers.[8]

Furthermore, Japanese companies need not worry too much about the price their stock commands, given the way Japan's financial markets work. Equity remains less important than debt in corporate financing, and new stock issues are the exception in raising funds. The now-standard—and often oversimplified—arguments concerning costs of capital also come into play here; plainly, on a present value basis, or indeed almost any reasonable criterion, lower costs of capital in Japan make long-term projects more attractive.[9]

Japanese companies, then, typically use different decision rules in evaluating investment alternatives. Managers in Japan see R&D as a means for maintaining or increasing market share, both at home and abroad, with market share a necessity for holding on to a competitive position in dynamic markets. Japan's rapid postwar economic growth, and success in exporting, has made market share the top priority; when sales are expanding rapidly, grabbing as big a share as possible, and holding on to it, become the key to profits.

The emphasis on growth reflects a belief among Japanese executives that only large companies can remain financially viable in international competition. Japanese industry has spawned few of the entrepreneurial startups so much a part of the scene in U.S. high-technology industries—although many policymakers in Japan would like to create a place for them.

Other factors and practices reinforce the view that growth is all-important. Larger Japanese companies historically have attempted to provide "lifetime" employment for a portion of their work force. Managers continue to view this as an obligation, and growth makes it easier to sustain employment. Layoffs tend to be seen as evidence of management failure, rather than—as in the United States—a consequence or symptom of economic downturn. This sense of obligation helps shape corporate goals and managerial behavior. Where American executives would slash payrolls, Japanese companies will often accept lower profits.

What does this mean for R&D? A continuous search for new products and new markets, including those that might not fit very comfortably into ongoing operations. Where American companies look to R&D to support existing businesses, Japanese companies are just as likely to see it as a means of creating new businesses. Where American firms look for home-run opportunities, their Japanese counterparts have been more willing to start small and grow new businesses gradually.

Government-Industry Relations

The antagonism with which so many U.S. corporate managers view government also contrasts with typical Japanese attitudes. American managers feel, by and large, that the Federal Government's role should be tightly circum-

[8] J.C. Abegglen and G. Stalk, Jr., ***Kaisha: The Japanese Corporation*** (Tokyo: Charles E. Tuttle, 1987), pp. 176ff.

While decision criteria in Japan certainly differ from those here, there is little consensus in the Weston the extent to which Japanese firms rely on financial measures—or, more precisely, on what kind of measures they use, and for what purposes. See, for example, "Part Two Discussion Summary," ***The Uneasy Alliance: Managing the Productivity-Technology Dilemma,*** op. cit., p. 283.

[9] *International Competitiveness in Electronics* (Washington, DC: Office of Technology Assessment, November 1983), ch. 7.

scribed. Wherever possible, economic matters should be left to the private sector.

Later sections of the chapter describe how government and business in Japan have worked together to promote HTS. Here, the point is simply that Japanese executives have relatively comfortable working relationships with government. Japanese managers tend to feel that employees of their government are competent and deserving of respect, even when they disagree vehemently on matters of policy.

Managers in Japan pay attention to goals and objectives announced by the Ministry of International Trade and Industry (MITI), or the Ministry of Finance. This does not mean they will necessarily follow the paths that MITI or other ministries attempt to lay down. Contrary behavior is common. On the whole, Japanese executives would prefer to go along with government, while working to mold policy in ways they regard as desirable.

R&D Management

Traditionally, Japanese R&D has focused on engineering—product/process development, rapid transfers to manufacturing. Despite the engineering perspective, managers put less weight on short-term outcomes, and show more willingness to invest in projects that will not yield positive cash flows until well into the future. Japan's national goal of technological independence pushes companies in the same direction.

Personal opinions by managers carry great weight—especially when the advocates of particular projects enjoy high standing as researchers or managers. One man's recommendation can lead to a major new R&D project in Japan—something that would be highly unusual in an American company.

Competition among Japanese firms combines with cultural characteristics to yield another contrast with the United States. Japanese companies tend to emulate one another; when one begins research in a field like HTS, others follow. Few executives will risk letting a direct competitor engage in R&D without investigating the subject themselves. Similarly, companies are uncomfortable at the thought of closing down a research program that others are continuing. For such reasons, Japanese firms spend a good deal of effort tracking their competitors' day-to-day R&D efforts. American companies, which tend to look to R&D for means of differentiating themselves, show more interest in products soon to hit the market.

Finally, given the way Japanese firms make decisions, it should be no surprise to learn that they stick with R&D efforts once begun. One executive commented in an OTA interview, "In Japan, we continue research projects unless persuasive reasons are mustered against them. In the United States, I get the feeling that projects are cancelled in the absence of good arguments supporting continuation. The difference is subtle, but important. We tend to be optimistic on research results; you tend to be pessimistic." Such attitudes may be remnants of an earlier time, when success came easier. Still, they contribute to the persistence that has been so important to Japan's accomplishments in commercialization.

The typical Japanese approach to R&D carries disadvantages as well as advantages. With little systematic guidance for comparing one project to others, and subject to the influence of strong personalities, Japanese firms risk bad decisions. This weakness could become more important in the future; given their lack of experience in managing fundamental research—particularly if companies follow one another down blind alleys. But for now, the freer hand that Japanese managers have in allocating resources to long-term, high-risk projects is a notable strength.

Japanese Strategies in High-Temperature Superconductivity

Japanese R&D managers, almost unanimously, see HTS as a revolutionary technology, one that promises radical change. Skepticism, common in the United States, has been rare in Japan. Implicit in some Japanese views, explicit elsewhere, has been the assumption that room temperature superconductivity is not far away. (Otherwise, even the more optimistic Japanese scientists and engineers see the potential as relatively limited.)

A corollary follows: Japanese executives believe that HTS will be a major battleground for international competition over the next two or three decades.[10] All those interviewed by OTA believed that Japan would have to depend on home-grown technologies in the future. It follows that early exploitation of HTS holds a rare opportunity. Japanese managers—in sharp contrast to their U.S. counterparts—have little doubt that HTS will be a central element in competitive strategies.

Not surprisingly, then, commitments in Japan —as indicated by industrial employees assigned to superconductivity R&D—substantially exceed those here. Box H, based on a survey of Japanese firms conducted for OTA by the U.S. National Science Foundation (NSF), reveals the following contrasts with the United States:

- Although reported budgetary outlays by U.S. industry exceed those in Japan (at $97 million compared with $90 million), Japanese firms reported 900 people working on superconductivity (versus 625 here).
- Total Japanese R&D spending on superconductivity for 1988—industry plus government—should exceed $160 million, U.S. spending $250 million. Such comparisons must be treated with caution, however. The company surveys are incomplete, the fiscal years for the two governments are 6 months out of phase, and the exclusion of some salaries from the Japanese Government budget figures makes the estimate for Japan low by some unknown amount. Finally, spending levels say nothing about the outputs of R&D. Given all these uncertainties, the contrast in numbers of industrial employees takes on the greatest weight.
- Japanese firms are emphasizing prospective applications more heavily. Many companies in Japan are continuing to invest in LTS projects, most of them heavily developmental. They have more engineers assigned to superconductivity R&D than the American firms.

The strength of the Japanese commitment is visible not only in numbers of people, but in the range of businesses represented among the companies that have begun to invest. HTS R&D spans glass and ceramics, shipbuilding and steel, in addition to microelectronics, computers, consumer electronics, and electrical equipment.

The Japanese firms can nonetheless be grouped into two classes:

1. Some have relatively extensive experience in LTS. This group includes manufacturers of superconducting magnets (e.g., for medical imaging systems). A number have been involved in Japan's magnetically levitated train project (see box K later in this chapter). Toshiba, Mitsubishi Electric, and Hitachi have all built and tested prototype LTS generators. Sumitomo Electric, Japan's leading producer of wire and cable, supplied superconducting wire for many of these projects. Sumitomo is also Japan's (and the world's) leader in small synchrotrons—which may emerge as a critical technology for production of next-generation integrated circuits. Finally, a number of Japanese firms have continued to pursue R&D on LTS Josephson devices, with high-performance computers in mind (see box J, later in the chapter).
2. Others, new to superconductivity, began their research programs only after the discoveries in Zurich, Houston, and Tokyo. Some view HTS as important for existing businesses; others seek diversification. The first group includes electrical equipment manufacturers and other suppliers of cap-

[10] Sixty percent of 167 Japanese companies responding to a mid-1987 survey expected a $2o billion world superconductivity market by 2000—"Superconductor Industry Survey Conducted," *JPRS Report–Science & Technology, Japan,* JPRS-JST-87-068-L, Foreign Broadcast Information Service, Oct. 29, 1987, p. 1 [translated from *Nikkei Sangyo Shimbun*, July 28, 1987]. Electronics applications were ranked most promising, followed by energy storage, and then by a variety of other electric power applications. Nearly 85 percent of those responding to a different survey foresaw applications of room temperature superconductors in industrial equipment by 2010—"Waga kuni ni okeru Gijutsu Kaihatsu no Hoko ni kansuru Chosa" [Survey of Trends in Technology Development in Japan], no. 4, Kagaku Gijutsucho [Science and Technology Agency], 1987, p, 12.

Box H.—Superconductivity R&D in Japanese Companies

NSF's Tokyo Office conducted a mail survey of 43 Japanese companies for OTA in early 1988, receiving responses from 38 firms with significant HTS R&D activities. As with the U.S. survey, the sample was intended to cover Japanese firms with substantial activity in HTS, but it was not exhaustive. Indeed, undercounting of people and R&D funding in the Japanese survey almost certainly exceeds that for the U.S. survey. Not only did the U.S. survey cover more companies, but the list of Japanese firms that have joined MITI's International Superconductivity Technology Center (ISTEC) shows many participants that the Japan survey did not reach.[1]

Level of Commitment

- As of early 1988, the 38 firms surveyed had approximately 900 scientists and technicians at work on superconductivity R&D (both LTS and HTS), either part-time or full-time.
- In total, the 38 firms expected to spend about $90 million on superconductivity R&D in 1988.
- Seventeen of the firms reported a current annual commitment of $1 million or more for superconductivity R&D, with 3 spending in the $1 million to $2 million range, 8 at $2 million to $5 million, and 5 putting between $5 million and $10 million into superconductivity R&D; one firm is investing more than $10 million.

Types of Firms

- The 38 firms fall into the following broad categories: primary metals, and wire and cable (8); glass, chemicals, and specialty materials (12); electrical machinery and equipment, and electronics, including telecommunications (15); and other (3).
- The 1987 revenues of the companies ranged from $72 million to $46 billion, with a median of $3.2 billion. R&D spending ranged from 1 percent of sales to 12 percent; the median is 3.2 percent.
- Average 1988 R&D spending on superconductivity in the four categories is as follows:

primary metals, wire & cable	$4.0 million
electrical machinery and electronics	$3.3 million
glass, chemicals, specialty materials	$0.8 million
other	$0.3 million

R&D Activities

- Of the 900 people engaged in superconductivity R&D, three-quarters, as in the United States, are scientists/engineers and one-quarter are technicians. The scientists/engineers divided roughly as follows:

materials scientists	34 percent
physicists	28 percent
electrical engineers	20 percent
chemists	18 percent

- All 38 firms reported some work underway on materials characterization and processing. Fifteen of the 17 firms spending at $1 million and up have projects directed at electronics applications of HTS, and half are working on high-current, high-field applications. Most of the companies with smaller HTS efforts are focusing more on materials R&D and processing than on applications.
- Ongoing LTS work seems markedly greater than among the U.S. firms. Among the companies spending $1 million or more on superconductivity R&D, 11 have LTS projects underway, and many expect to direct roughly equal resources to LTS and HTS.

[1] By May 19SS, 45 Japanese companies had joined ISTEC as full members—Report Memorandum #155, Tokyo Office of the U.S. National Science Foundation, May $3,1-. The survey reached only 25 of these, and an even smaller fraction (5 of 45) of associate members. For some of these companies, of course, superconductivity may be a new area of R&D, with little internal activity.

All currency conversions in this hex, as elsewhere in the chapter, have been made at 130 yen to the dollar.

Other Observations

- About two-thirds of the Japanese firms reported some form of cooperative R&D in HTS. One-third expect to engage in cooperative R&D internationally in the future; two firms are currently working with American companies.
- Perceptions of where "the most significant HTS R&D is currently being done" centered on Sumitomo Electric, Japan's National Research Institute for Metals, Tokyo University, IBM, and AT&T. When asked which country was ahead, 13 responded that the United States had the lead in HTS R&D, 7 indicated Japan, and another 10 rated the two countries even (the remaining 8 did not answer this question).
- Ten of the seventeen companies spending $1 million or more have received government funding for HTS R&D.

ital goods. It also includes steelmaker, who have begun speculating, for instance, that magnetic levitation of strand-cast products could lead to better surface quality and higher yields (box I). The steelmaker are also trying to diversify, along with glass companies and shipbuilders. All these industries are in decline; opportunities for diversification and continued growth hold great attractions in Japan.

Regardless of industry, many Japanese firms are pursuing research and applications development in parallel fashion.[11] They have basic work underway, mostly in characterization, and people searching for materials with better properties. Development projects include work on thin films and efforts to fabricate wires. In these activities, the Japanese are proceeding much like their counterparts at the leading U.S. industrial laboratories.

Japanese efforts differ in one major respect from those in the United States. Many firms in Japan have groups at work on feasibility studies and exploratory "what if" exercises. (Government programs, treated later in the chapter, show the same thrust.) These groups have a specific task: to think about possible commercial applications. In some cases, the efforts have already been carried to the stage of preliminary designs and marketing analyses. The work is highly speculative, of course, but the Japanese believe it will help prepare for commercialization. Only a few U.S. companies have begun similar efforts.

U.S. and Japanese Strategies Compared

The Japanese see applications coming relatively quickly. When queried in the spring of 1987, scientists and research managers in Japan called for more basic research in their country, and efforts to develop applications based on patents filed in the United States.[12] Like Americans, they viewed superconductivity as largely a research enterprise for now—with the research laying groundwork for commercial competition that would come soon, perhaps as soon as one to three years. In essence, Japanese companies are pursuing a three-pronged R&D strategy: 1) basic research; 2) development, aimed mostly at processing; and 3) product planning and market evaluation. The last of these carries the gravest potential consequences for U.S.-Japan competition. *If technical developments in HTS proceed as rapidly over the next two or three years as during* 1987, *Japanese firms will be in better positions to move toward commercial applications than American companies.*

If U.S. firms wait to think about product and process developments until the research results

[11] As Sumitomo Electric Vice President Nakahara explains it, Japanese companies and other research organizations should pursue basic research and applications on "parallel tracks" to ensure cross-fertilization of efforts—*Chodendo to wa Nanka* [What is Superconductivity], Nihon Keizai Shimbunsha, 1987, p. 91.

[12] "Chodendo Busshitsu: Nichibei Gokaku no Kaihatsu Kyoso" [Superconducting Materials: Japan and the U.S. on a Par in Competition for Development], *Nikkei Sangyo Shimbun*, May 12,1987.

Box I.—HTS R&D at Nippon Steal

Why did the largest steel producer in the world put 40 people to work on HTS in February ***1987?*** Nippon Steel may be the leader in market share, but its sales have been declining—partly the result of structural changes in the Japanese economy, leading to declining demand for steel, and partly a consequence of greater competition in international markets. Company strategists have two major tasks: 1) finding ways to make steel more cheaply, thereby helping the company compete in its primary if shrinking businesses; and 2) identifying new opportunities. Superconductivity fits both objectives.

Planners see Nippon Steel as bringing three primary technical strengths to HTS. First, the company has always designed much of its own production equipment. It has process engineering skills, not only for making steel, but for titanium and other metals as well. Second, the firm has expertise in wire manufacture-a technology that could turnout to be important as HTS matures. Finally—and most important-Nippon Steel has worked hard over the years to develop technical capabilities in ceramics. Originally, most of this work was in refractories for furnaces. More recently, the company has sought to diversify into high-technology ceramics, and also into silicon production for the semiconductor industry. To the extent that the new superconducting materials will demand expertise in ceramics and other advanced materials, Nippon Steel believes it will be well-placed.

None of these perceived strengths may turn out to be sufficient to place the firm in the forefront of HTS. Nippon Steel's executives might be grasping at straws. Nonetheless, the company has looked with some care at ***50*** or more potential applications of HTS. Some of these analyses have been taken to the point of comprehensive feasibility studies. For example, company engineers have evaluated the prospects for continuous strand casting using superconducting magnets to confine and float molten steel, followed by in-plant materials handling also based on magnetic levitation.

are in, they may lose out competitively. Japanese companies will already have thought through those steps, weighed the potential problems, considered alternatives—perhaps anticipated some of the follow-on technical work and even begun to pursue it. The Japanese approach probably costs more—some R&D groups will pursue false trails, companies may be paying the salaries of too many people working on overlapping projects—but the eventual rewards could more than make up for this. Japanese managers find it strange that American companies believe they can track a technology's development, waiting for the right time to begin product development, without actively and aggressively pursuing that technology in their own laboratories. (Of course, many Japanese firms did just this not so many years ago.)

JAPAN'S HTS INITIATIVES

Many countries are pursuing HTS research, but talk of a superconductivity race has focused on the United States and Japan.[13] Sumitomo's many hundreds of patent applications, for example, have drawn widespread attention. The race is certainly a real one in terms of science. Laboratories around the world confirmed superconducting behavior in the thalium-based materials in a matter of hours.

[13]See, for example, "Two Different Cadences in the Superconductor Race," ***Washington Post,*** May ***20,1987,*** p. Al; "U.S. 'Leading Slightly' in Superconductor Race, " ***Japan Economic Journal,*** June ***13, 1987,*** p. ***15.***

This section is based in part on interviews with government officials in Japan during the fall of ***1987.*** For background on Japanese industrial policy, see ***International Competitiveness in Electronics*** (Washington, DC: Office of Technology Assessment, November ***1983),*** pp. 413-422.

On patenting, below, see S.K. Yoder, "Rush to Exploit New Superconductors Makes Japan Even More Patent-Crazy," ***Wall Street Journal,*** Aug. ***27, 1987,*** p. ***18.***

Preoccupation with Japanese efforts is hardly a surprise, given Japan's huge trade surplus with the United States, and the longstanding view by some that Japanese companies have been getting a free ride from American research.[14] Press reports have suggested that Japan is taking off in superconductivity, with government agencies in the lead.[15]

MITI asked for 3.5 billion yen (about $27 million at 130 yen to the dollar) for superconductivity in fiscal 1988, well above the previous year's level (550 million yen, $4.2 million). (Japanese budget figures do not include breakdowns for high- and low-temperature superconductivity.) But the image of a government-coordinated, crash program in HTS is false. The policy environment for superconductivity remained in flux in Japan during 1987. The difference is this. After the middle of the year, the outlines of Japanese Government policies began to solidify. By early 1988, they had taken shape. U.S. policies, in contrast, remain in a state of considerable disarray.

Government Resources for Superconductivity

In Japan, four principal agencies have competed with one another for resources to support HTS (table 6): the Science and Technology Agency (STA); MITI; the Ministry of Education (Monbusho); and the Ministry of Transport. Key players in government, industry, and universities have been seeking to get into the superconductivity game, looking for money and the authority to expand their programs.

Much of the substance of Japanese industrial and technology policies emerges from behind the scenes, the product of long-standing ties among government officials, corporate executives, and, in a case like HTS, senior professors in the leading universities. A host of advisory committees, reports, and budget proposals also contributed to the rise of superconductivity on Japan's policy agenda. The statements of the Council for Science and Technology—an advisory group chaired by the Prime Minister and including the directors of MITI, STA, and other major ministries—are typical. In August 1987 the Council issued a report on superconductivity calling for "hybrid" basic research, involving experts from many fields. Japan's national laboratories should promote cooperation with industry and universities, and reward in-

Table 6.—Major Japanese Government Programs and Activities in Superconductivity

Science and Technology Agency (STA):
- *Multicore Project*
  Nine laboratories and other government organizations participating in work on theory and database development, materials characterization, processing, and technology transfer. The lead laboratories are the National Research Institute for Metals (NRIM, with work on theory, databases, thin films, and a superconducting generator) and the National Institute for Research on Inorganic Materials (materials synthesis and new material development, crystal structure determination, microstructure control).
- *Japan Atomic Energy Research Institute*
  R&D on superconducting magnets and applications.
- *Japan Research Development Corporation*
  Primarily measurement work.
- New *Superconductivity Materials Research Association (Forum)*
  Primarily information exchange.

Ministry of International Trade and Industry (MITI):
- *Electrotechnical Laboratory (ETL), plus other MITI facilities*
  R&D on superconducting electronics (e.g., Josephson devices), as well as new materials (including superconducting polymers).
- *Moonlight Project*
  Superconducting generator.
- *Support for Technologies Needed for Research and Processing*
  Thin film fabrication techniques; low temperature processing of bulk materials.
- *Research Associations*
  (*See* text.)
- *International Superconductivity Technology Center (ISTEC)*

Ministry of Education (Monbusho):
- *University research support*
  Examples: Professor Tanaka's group at Tokyo University, working particularly on new materials; Professor Muto's work on theory at Tohoku University; support for the Ceramics Center at Tokyo Kogyo University.

Ministry of Transportation:
- *Support for the Magnetically Levitated Train project at the Railway Technical Institute*

SOURCE: Office of Technology Assessment, 1988.

[14] This perception is an exaggeration. See *International Competition in Services,* op. cit., pp. 202-203.
[15] For example, "On one hand, companies vie to beat each other to the patent office and marketplace. But at the same time, archrivals join forces on certain tasks when speed is essential and the research is risky. And the MITI orchestrates it all." See S.K. Yoder, "Superconductivity Race Shows How Japan Inc. Works," *Wall Street Journal,* Aug. 12, 1987, p. 6. The same article calls superconductivity a Japanese "obsession."

dividual excellence, the Council urged, envisioning HTS R&D as a major step in improving Japan's creative research capabilities.

STA and the Multicore Project

Each agency is independently pursuing these broad goals. In the summer of 1987, when HTS became the focus of attention worldwide, STA set up a Committee for the Promotion of Research and Development of Superconducting Materials. The nine members represent the major STA laboratories, the Japan Research Development Corporation, and the Interministerial R&D Division of the STA Research and Development Bureau. The Committee's report stressed the many unknowns concerning superconductivity, and recommended a high priority for basic research–not surprising, given the STA mission.[16]

Highlighting the role of government, particularly STA, the Committee urged that Japan's national laboratories, already credited with significant contributions in HTS, accelerate their efforts even more. While emphasizing the need for research, the members also advocated preparations for commercialization of new products. Their report touches on opportunities for international cooperation, recommending that Japan's joint government-industry R&D programs be opened to foreign participation, and that Japan seek to make a global contribution to HTS. At the same time, the Committee underscored the importance of making research results from STA laboratories—of which there are five—widely available.

The STA Committee sees these laboratories, and the agency's new Multicore Project, as the bridge between university science and corporate applications. Companies and universities participate through the New Superconductivity Materials Research Association, which had about 130 members at the end of 1987. The Multicore Project, with a budget of more than 2 billion yen (about *$16* million) for fiscal 1988, aims to strengthen the capabilities of STA laboratories in HTS, and to speed transfer of research results to industry.[17]

A number of STA laboratories will get more money for HTS—notably the National Research Institute for Metals (NRIM), which plans a major thrust in materials characterization. NRIM scientists discovered the bismuth oxide HTS composition in January 1988. The National Institute for Research on Inorganic Materials and the Atomic Energy Research Institute will get most of the rest of the STA money. Nine laboratories in total will participate in the Multicore Project, with "core" research work going on in each.

Given this decentralized approach (no physical relocations are planned), STA will rely on a steering committee with representatives from industry and universities, as well as government, for coordination. The steering committee's job will be a difficult one, the more so if—as STA officials hope—MITI laboratories can also be pulled into the Multicore Project. At present, however, MITI has its own quite independent plans.

MITI Programs

A recent report by the Advisory Committee on Superconductivity Industrial Technology Development, made up of representatives from industry and universities, reflects the perspective of MITI—to Western eyes, the most visible agent of Japanese industrial policy.[18] Like STA, the MITI committee sees the government role as one of helping industry make use of research results from the national laboratories and universities. But MITI goes further in ad-

[16] "New Developments in Superconducting Materials R& D," Science and Technology Agency, Tokyo, Sept. 21, 1987.

[17] *Chodendo Zairyo Kenkyu Muruchikoa Projekuto 63 nendo Kisan Yokyu Sokatsuhyo* [Budget Request for Multicore Project for FY1988]; also "Superconductor R&D to Industrial Application," *JPRS Report-Science& Technology, Japan,* JPRS-JST-88-007-L, Foreign Broadcast Information Service, Mar. 11, 1988, p. 100 [translated from *Nikkan Kogyo Shimbun*, Jan. 1, 1988]. The Multicore name signifies that multiple organizations form the core of the project, emphasizing the thrust toward coordination and reorientation rather than an all-new initiative. The project accounts for about two-thirds of STA's fiscal 1988 budget request for superconductivity, which totals 3.1 billion yen. (Japan's fiscal year begins in April.) STA has also sought funding for a superconducting generator project.

[18] *Chodendo Sangyo Gijutsu Kaihatsu Kondankai (1988).*

vocating national projects, not only for R&D on the new materials, but for applications in electronics and electrical machinery. Box J notes the Ministry's support for Josephson computing technologies—a field where Japan began by following the path laid down by IBM and other U.S. companies, then persisted after American firms cut back their efforts.

A good portion of MITI's 1988 superconductivity budget will go toward applications. Examples include a new project on thin films and Josephson devices, part of the "Technologies for Next Generation Industries" program of the Agency for Industrial Science and Technology (AIST is part of MITI). The Ministry's 70 megawatt (MW) generator project, based on LTS technology and also scheduled for more than $10 million—a hefty slice of the 1988 MITI superconductivity budget—follows several years of feasibility studies. Motivated in part by the search for energy savings, goals for the 8-year project range from improvements in methods for processing superconducting wire to construction of a complete prototype.[19] Officials say that HTS technologies will be utilized if available.

Late 1987 saw a major step for the 70 MW generator project, the formation of a research association (kenkyu *kumiai).* As is typical of these research associations—central mechanisms of Japanese technology policy—MITI not only helped with the planning, but will assist with administration and furnish ongoing financial support. Likewise typical of MITI projects, the research association brings together participants with a range of technical strengths, and companies from different industries: the members include two cryogenic engineering firms, the Fine Ceramics Center, the Central Electric Power Research Institute, and a number of major electric power and electronics firms. MITI sees its role as supporting industry not only by creating incentives for applications-related R&D, but by spurring productive interactions among firms and industries that might not otherwise collaborate.

[19] *Chodendo Hatsuden Kanren Kiki-Zairyo Gijutsu no Fizabirite Chosa Kenkyu,* March 1987. The original proposal, advanced in 1985, was much more ambitious, calling for a 200 MW generator to be built in 5 years.

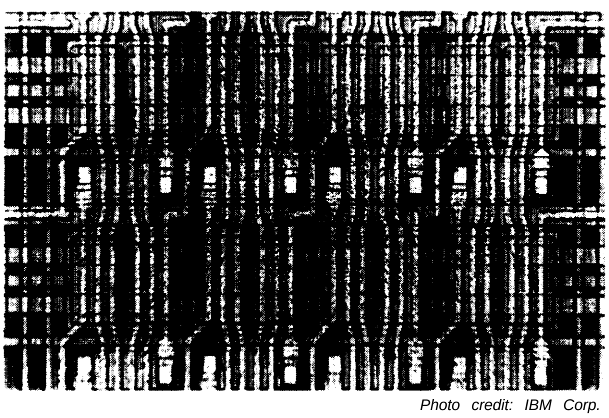

Photo credit: IBM Corp.

Memory cells in experimental Josephson junction integrated circuit chip

MITI, like STA, also runs its own laboratories. The Electrotechnical Laboratory—which has won worldwide respect for its research—has been involved in superconductivity since the middle 1960s, when the laboratory began R&D on LTS magnets for MHD (magnetohydrodynamic) power generation under the Moonlight Project. More recently, ETL has attracted particular notice for its work on niobium-based Josephson devices (box J). ETL's overall 1987 budget came to $57 million; like many organizations in the United States, the laboratory was able to reprogram funds internally for HTS during 1987; MITI will get $2.5 million for ETL research on the new superconductors in 1988. The laboratory has several groups, and about 40 people in total, working on superconductivity (the ETL research staff numbers 560).

The Ministry seeks to involve private corporations in its efforts through mechanisms ranging from research associations to advisory boards and symposia. Industry is MITI's major constituent, and the Ministry's HTS programs will follow patterns laid down over the years for supporting other industries and other technologies-e. g., semiconductors, computers, biotechnology.

The Ministry of Education

The Monbusho, which supports university research, has a larger R&D budget than any other arm of the Japanese Government. Sup-

Box J.-Josephson Junction Computer R&D: From the United States to Japan[1]

The pursuit of a Josephson-based computer has taken quite different paths in the United States and Japan since the early 1970s. Josephson devices provide the fastest electronic switches known, hence—in principle-the fastest digital computers. Because they are Superconducting devices, with very little power dissipation, JJs can be packed tightly together. Theoretically, therefore, a computer built with JJs could be very compact, as well as extraordinarily fast and powerful.

U.S. Efforts

Three U.S. corporations pursued JJ R&D for computer applications: AT&T, IBM, and Sperry Univac (which later merged with Burroughs to form Unisys). Each made significant contributions to the JJ technology base. Beginning in the 1960s, more than 10 years of research at AT&T's Bell Laboratories produced a much better understanding of the physics of JJs. IBM went much farther, building a prototype of the circuitry for a complete computer, as well as exploring fabrication methods for JJ logic and memory chips. Sperry concentrated on JJs made from refractory materials such as niobium and niobium nitride (instead of the lead alloy used by IBM), and developed processing methods for high-performance, all-niobium circuits.

All three companies had scaled back or abandoned their JJ projects by the early 1980s–each for its own reasons. AT&T terminated the Bell Laboratories program in 1979 after deciding that the technical hurdles to practical applications were formidable. Sperry abandoned its effort to develop a JJ computer in 1983, after closing its Sudbury, Massachusetts, research center, the focus of the work. (JJ research by Sperry's Defense Systems Division, aimed at sensors, continued.)

IBM, with the most ambitious program, was spending about $20 million annually by the early 1980s, with the National Security Agency (NSA) providing about $5 million of this. Although NSA urged continuation, IBM drastically scaled back its effort in 1983, ending pursuit of a working computer, after its Yorktown Heights Laboratory was reorganized and the JJ work came under new management. Logic chips based on IBM's experimental production technology performed adequately, but the memory did not; the new management team estimated that improving the memory chips would add another 2 years to the schedule. By that time, management reasoned, continuing progress with more conventional silicon and/or gallium arsenide chips would make it hard for a JJ-based machine to offer compelling advantages in speed or processing power.

Before ending its JJ program, IBM came close to an agreement with Sperry for joint development of Josephson technologies. IBM had the most advanced. designs but was struggling to fabricate them, while Sperry had proven processing technologies. The agreement was almost 18 months in the making, and had apparently cleared the antitrust hurdle after the NSA proposed taking the project under its wing. But the agreement was never consummated because Sperry's management decided to decentralize its R&D among its operating divisions, and reassigned its JJ computer group to the Defense Systems Division--a reassignment that key technical employees declined.

[redacted]

ing a 10-gigaflop machine by 1990. ETL's ongoing effort was absorbed into this new initiative, and expanded, with MITI supporting JJ work at Fujitsu, NEC, and Hitachi.

*Much of the information in this box is based on interviews. Also see A.L. Robinson, "New Superconductors for a Supercomputer," *Science,* Jan. 1, 1982, p. 40; A.L. Robinson, "IBM Drops Superconducting Computer Project," *Science,* Nov. 4, 1983, p. 492; "JTech Panel Report on Opto- & Microelectronics," Japanese Technology Evaluation Program, Science Applications International Corp. under contract No. TA-83-SAC-02294 from tbe U.S. Department of Commerce, May 1985, Section 11; "Government's Role in Computers and Superconductors," prepared for OTA by K. Flamm under contract No. H3-6470, March 1988, pp. 47-52.

The Japanese clearly benefited from U.S. R&D on Josephson devices. Bell Laboratories scientists published their findings widely and exchanged information on a regular basis with colleagues in the United States and Japan. During the 8 years of Sperry's active involvement in research on JJ-based computers, the company's leading researchers visited Japan several times—at MITI's expense.

Sperry and IBM technology laid the groundwork for nearly all the Japanese developments in JJ computing. Fujitsu's technology, for example, has been based almost entirely on Sperry's original designs and fabrication methods. More recently, U.S. visitors to Japan have been impressed with the advances in JJ logic and memory circuits emerging from Japanese laboratories, especially with the work on manufacturing techniques.

Lessons

American firms made a good deal of technical progress on JJ-based computers before largely abandoning the field. The Japanese continued, in part because of MITI's push, and they too have advanced the technology. It is too early to say whether the Japanese work will eventually yield a practical computer based on Josephson electronics. But it has become clear that, technologically, the Japanese have made considerable headway.

Fujitsu and NEC have demonstrated LSI (large-scale integration) chips containing thousands of JJs. Both firms are within reach of a simple computer based on a 16-bit JJ microprocessor, and seem likely to reach this goal by their 1990 target dates. Like IBM earlier, the Japanese may find that the margin of improvement will not be enough to compete with silicon (or gallium arsenide). In other words, the Japanese could find themselves with a technical success but a commercial failure.

And certainly it is too early to tell whether Japan will have an edge over the United States in developing HTS JJ electronic devices as a result of its persistence with LTS JJs. Indeed, some believe that HTS JJ devices will never prove technologically useful. Four points with potential relevance for HTS nonetheless emerge from the JJ computer experience:

1. Long-term R&D becomes hard to justify when viewed only in terms of costs: Sperry's research center became "too expensive," contributing to the loss of the U.S. lead in a potentially significant technology.
2. Diverse approaches to R&D, as in the three U.S. companies, increase the likelihood of eventual technical success.
3. Complex and demanding technical goals call for a parallel (rather than serial) approach to R&D, with feedback and cross-fertilization among complementary streams of research. In Japan, for example, the Monbusho supported research on materials problems, supplementing MITI's efforts on device physics and the architecture and system design aspects of a Josephson computer.
4. Concrete goals—as in MITI's supercomputer effort—can be an important motivating force for R&D, as well as helping to define intermediate research objectives.

port for superconductivity is relatively new, however, going back only to 1984. In 1987, Monbusho funded 41 mostly small projects on superconductivity at Japanese universities, with spending totaling $4.3 million.[20] For fiscal 1988, Monbusho spending on superconductivity will reach about $14 million. Although the Education Ministry has placed superconductivity at the top of its list for greater support, it ranks third behind MITI and STA in its 1988 budget for direct support of superconductivity.

In addition to the many small projects it funds, Monbusho provides much of the support for a few large programs headed by internationally known scientists. For instance, Professor Shoji Tanaka's group at Tokyo University will receive more than $700,000 during 1988. Professor Tanaka (who recently retired

[20] *Daigaku Kankei ni okeru Chodendo Kenkyu no Tsuishin ni tsuite* [Concerning Support for Superconductivity Research in Universities], Monbusho. The Ministry of Education's figures for support of university R&D normally exclude salaries, which are paid out of other accounts. (Other Japanese Government agencies typically include salaries in their published R&D budget figures, just as in the United States.)

from the university to direct research at MITI's International Superconductivity Technology Center, ISTEC), has also been awarded a 3-year grant of $1.6 million for "Specially promoted Distinguished Research." Professor Yoshio Muto, at Tohoku University, whose group has been designated one of 30 priority research projects, will get more than $2 million over the 3-year period 1988-1990. These large university-based efforts generally include participants from a number of universities, selected by the lead professor.

Taking university research as a whole, the scope in Japan is narrower than in the United States, and the quality substantially lower. Japan has fewer centers of excellence, and a more rapid drop-off in quality as one moves down the scale. The best institutions in Japan are very good. There simply are not that many of them.

Superconductivity, however, has been an exception. Before the discoveries in HTS, the field had been something of a backwater. Interest had been declining in the United States, more so than in Japanese universities. Recently, American scientists have given the Japanese high marks for research in superconductivity.

Tokyo, Tohoku, and Kyoto Universities have been getting about three-quarters of Monbusho superconductivity funding. Some of the research groups at these schools—e.g., Tokyo University's in superconductivity—are on a par with the best in the world. And even in their less known schools, the Japanese excel at some kinds of work—notably painstaking empirical research. Most important, R&D in Japan's universities is improving rapidly, in part because of the efforts of the younger faculty members trained in the United States.

The Ministry of Transport and the Maglev Train

Japan's magnetically levitated (maglev) train project—box K—which has been underway for two decades, is scheduled to get more than $4 million during 1988 from the Ministry of Transport, which oversees the effort. While current prototypes use LTS magnet systems for both suspension and propulsion—and a relatively small fraction of the program's funds go toward superconductivity R&D—the engineers leading the project hope that HTS materials can eventually be incorporated.

The maglev program typifies the kind of long-term, continuing effort—in this case beginning in the 1960s—that Japanese decisionmakers expect will pay off in eventual commercialization. Although maglev R&D supported by the U.S. Government ended in 1975, the Japanese have persevered. To Japan, the linear motor car has become a symbol of indigenous technology development.

Summarizing the Government Role

As the many different programs mentioned above suggest, the scene has changed rapidly in Japan. Major ministries involved in superconductivity R&D steered more money to HTS during 1987, and have substantially higher budgets for 1988. A superconductivity city has even been proposed, where research would be centralized and applications tested.[21] Increases in government spending send unmistakable signals to industry, as well as to the universities and national laboratories.

Japanese industrial policy works primarily through incentives. Ministries seek advice from

[21] No agency has linked itself with the proposal, which seems to be a trial balloon—"Superconductivity City Project," *Science and Technology in Japan*, November-December, 1987, p. 43.

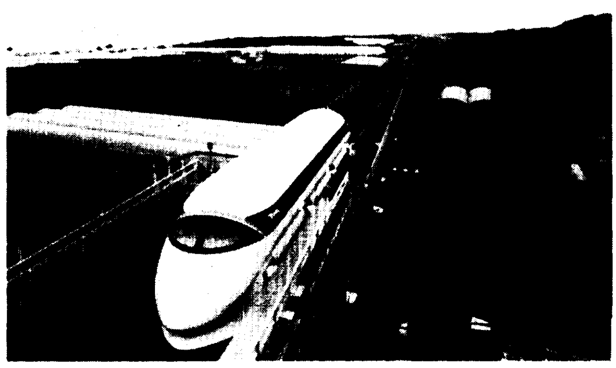

Photo credit: Japan External Trade Organization

Japan's prototype linear motor car, a magnetically levitated train.

Box K.—Japan's Magnetically Levitated Train Program[1]

In 1979, a prototype Japanese train without any people aboard set a (then) world record speed of 321 mph. In the spring of 1987, a later version—able to carry 44 passengers—began demonstration runs. This well-known high-speed train project (sometimes called the linear motor car) can be traced back to studies of linear induction motors for high-speed propulsion at Japan National Railways (JNR) during the 1960s. The maglev concept itself—the use of superconducting magnets to float a train—apparently originated in the United States, and first got heavy publicity during the late 1960s. A few years later, JNR began operational tests on a superconducting maglev motor car at its facilities on the southern island of Kyushu. The prototypes use onboard magnets, wound with niobium-titanium alloy and cooled with liquid helium. Participating companies—including Toshiba, Mitsubishi Electric, and Sumitomo Heavy Industries—have gained a good deal of valuable experience in LTS engineering from their design and fabrication of these systems.

The program demonstrates the continuity that characterizes both public and private technology development efforts in Japan. The Japanese have spent roughly $100 million in bringing the technology to its current stage. Since the privatization of JNR in 1987, work has continued at the Railway Technical Institute, now jointly owned by seven newly private railroads. To policymakers in Japan, application of HTS to the linear motor car seems a potentially attractive vehicle for pushing the technology forward and demonstrating its usefulness.

Like the bullet train before it, the intent of the maglev project has been to keep Japan in the forefront of railroad technology while finding practical solutions to transportation problems in a crowded and cramped country. The bullet train can reach 150 mph; the linear motor car aims to double that. Only a West German project, using normal magnets in a different configuration, comes close in terms of its potential to radically alter rail transportation. The aim in both countries is to break through the limitations of wheel-on-rail technology in terms of speed, noise and vibration, and maintenance costs (which go up rapidly with speed because of high dynamic forces and the need for very precise track alignment). Maglev offers potential for moving people over distances of several hundred miles with travel times comparable to air service, and lower energy consumption. The 310-mile trip from Tokyo to Osaka—the most heavily traveled route in Japan—currently takes about 2½ hours on the bullet train. The Japanese hope to cut this to a bit over an hour.

When the maglev effort began, Japan had no guarantees that a levitated train would be technically or economically feasible. JNR had identified a major future problem—very heavy traffic on existing rail routes, with the need for faster trains and greater carrying capacity—and sought solutions. The corporation, then publicly owned, gained approval for a long-term research effort—a project of a scale and duration that would be highly unusual in the United States (outside of defense and space).

The project also illustrates the way in which applications drive technical development at more fundamental levels. Superconducting magnets had never before been designed and built for such a purpose—levitation of a train. Choosing superconducting (rather than normal) magnets, in turn, forced solutions to problems of magnet design and fabrication, as well as handling liquid helium in a rather difficult environment. Because Japan imports all its helium, the designers chose a closed-cycle refrigeration system (based on Western technology), so that no gas would be lost. This led ultimately to new cryogenic (very low temperature) refrigeration technology. Successful development of the refrigeration equipment—not an easy task—provided an experience base that has already proved useful in other low-temperature technologies, and could well help with some HTS applications. About 20 of these refrigeration systems have been manufactured for sale.

The Railway Technical Institute—showing more than a touch of optimism—hopes to have levitated trains running on scheduled routes before the turn of the century, and claims costs will be lower than those of the bullet train. With Diet members expressing support for construction and advocating alternative routes, debate has become intense on issues ranging from cost to environmental impacts. The Minister of Transportation has announced plans for a 2-year feasibility study to begin in 1988, followed by construction of two maglev routes starting in 1990. Japan would like to sell this technology to the United States.

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[1]This box is based in part on interviews. Also see Y. Kyotani, "Jiki Fujo Kinsoku Kaihatsu no Omoide," [Remembrances Concerning the Development of Maglev], [illegible] beginning in January 1987; "[illegible] Kangaeru beki" [What We Ought to Think about Before Commercializing Maglev], editorial, *Nihon Keizai Shimbun*, Sept. 8, 1987, p. 2; W. Sullivan, "Race for the Fastest Train: Japan Builds a New Prototype," *New York Times*, Sept. 15, 1987, p. C1; "Floating Trains: Linear-Motor Cars Ready to Beat the Bullet Train," *Nikkei High Tech Report*, Nov. 9, 1987, p. 1; "Status of Magnetically Levitated Vehicle (Maglev) Development," *JPRS Report—Science & Technology, Japan*, JPRS-JST-87-0[illegible], Foreign Broadcast Information Service, Dec. 2, 1987, p. 61 [translated from *Kikaku Gijutsu*]; "Unyosho ga Iko Hyomei" [Ministry of Transport Demonstrates Intent], *Nihon Keizai Shimbun*, Jan. [illegible], 1988.

On the technology, see *U.S. Passenger Rail Technologies* (Washington, DC: Office of Technology Assessment, December 1983), ch. 6; also *Maglev Transport: Now and for the Future* (London: Institution of Mechanical Engineers, 1984). On the origins of the maglev concept, see J.R. Powell and G.R. Danby, "A 300-mph magnetically suspended train," *Mechanical Engineering*, November 1967, p. 30.

business leaders in the early stages of policy development. The processes through which officials in government and the private sector interact, and informal encouragement of industry efforts by government, arguably play a role at least as important as direct financial support. Government funding for R&D projects tends to be modest; consistently, private industry has paid for three-quarters or more of all Japanese R&D, compared with about half in the United States (table 5).

At the same time, public funds for the maglev train provided a stimulus for companies like Sumitomo Heavy Industries to build their experience base in superconductivity and related problems in cryogenic engineering. Japanese companies participate as members of consortia formed by MITI to undertake projects such as the 70 MW generator. In the Japanese view, such projects leverage public investment, helping break technological bottlenecks and diffuse results to industry. Companies participating in Japan's government-sponsored R&D efforts normally contribute about half of the project funding.

When it comes to basic research, the government share is about 50 percent in Japan, versus two-thirds here. As pointed out earlier in the chapter, many leaders in business, government, and universities in Japan are pushing for improvements in basic research, seeking greater creativity and originality. Because of budget pressures, Government support for basic science has been growing at an annual rate of only 3 percent, slower than the overall rate of R&D growth in Japan. Thus the government share of basic research funding has been declining.

As the yen rises relative to the dollar, Japanese spending, when translated into dollars, appears more impressive. Calculated at exchange rates current at the end of 1987, direct Japanese Government support for superconductivity—exclusive of salaries—seems likely to be about $70 million during 1988. Budget figures in Japan do not break out LTS and HTS, but a good portion of the total will no doubt support ongoing work with low-temperature materials. Funding increases have been sharp, coming after a period of relatively low spending on superconductivity (leaving aside such projects as the linear motor car, where superconductivity is a means to an end). In fiscal 1986, for example, MITI spent about $2 million on LTS technologies. And set against overall Japanese Government R&D support—itself relatively small compared to corporate R&D—superconductivity remains a minor item.[22]

MITI's 1988 HTS budget exceeds that of the other agencies, but it would be a mistake to conclude that MITI is tightly coordinating Japan's superconductivity policies. In OTA's interviews, MITI officials argued that, at this stage in the development of HTS, competition among ministries and research groups should be seen as healthy. STA staff, meanwhile, hopes that MITI laboratories will eventually join the Multicore Project—while conceding that this is unlikely in the near term.

Who Has the Lead Role, Government or Industry?

Westerners often misconstrue relationships between government and industry in Japan. MITI and other ministries may try to influence corporate decisions, but Japan's Government does not issue directives to industry. A more accurate picture of Japanese policymaking sees government-industry interactions based on processes of "reciprocal consent"—continuing discussion and negotiation.[23] Corporate leaders are heavily involved in building consensus and helping shape government programs. HTS will be no exception.

In superconductivity, industry has influenced government policies through frequent meetings with ministry officials. At least a third of the members of MITI's Advisory Committee on Superconductivity Industrial Technology Development come from the private sector. More than a hundred Japanese corporations belong to the STA's newly formed *Shin Chodendo*

[22] The Japanese Government budget for all science and technology activities totals 1,700 billion yen for fiscal 1988—about $13 billion. See Report Memorandum #147, Tokyo Office of the U.S. National Science Foundation, Feb. 5, 1988.

[23] R.J. Samuels, *The Business of the Japanese State* (Ithaca, NY: Cornell University Press, 1987).

Zairyo Kenkyukai [New Superconductivity Materials Research Association], best known as the superconductivity forum.

The forum, chaired by Dr. Shinroku Saito, serves as a "window" between corporate members (who pay an annual fee of about $1,000) and the universities and national laboratories involved in the Multicore Project. According to the director of STA's Research and Development Bureau, the forum will hold workshops and symposia, undertake "brainstorming" in support of the Multicore Project, and encourage cooperation in research, both domestically and internationally. Many participants, including Dr. Saito, also advise other ministries; thus the forum helps build linkages within the Japanese Government.

The Fine Ceramics Center (FCC) illustrates a different mechanism. Government and industry have both provided money for an extraordinarily well-equipped laboratory in Nagoya, with participating companies sending scientists and engineers. In contrast to some other MITI-sponsored R&D efforts, many of which have had staffs viewed as second rate, the FCC appears to have attracted highly qualified people. The companies continue to pay their salaries, and they help transfer technology from the Nagoya laboratory back to their employer.

When it comes to Japan's national laboratories, opinions differ as to whether corporations give more than they receive. For instance, at the National Research Institute for Metals, which normally hosts a half-dozen people from industry who work alongside NRIM scientists, laboratory officials contend that they have been ahead of industry in at least some areas of superconductivity. Organizations like NRIM also let contracts to companies, including large corporations (New Japan Steel, Toshiba). While laboratory managers view contract research as a mechanism for helping industry, the companies —which make little profit on such work—tend to see it as part of their contribution to the larger national effort.

In the future, government scientists may have a chance to spend time working in corporate laboratories—some of them much better equipped than government facilities—but so far this has been rare. Legal provisions, only recently relaxed through new legislation, have limited such arrangements.

Direct cooperation in research between companies and universities has likewise been limited. This is also changing, however. Professor Tanaka recently had 10 scientists from a group of private companies working in his Tokyo University laboratories. The Monbusho reports a total of 300 cooperative projects linking universities and companies during 1987, 11 of them (all with Monbusho sponsorship) in superconductivity.[24] In some contrast to efforts in the United States, many of which seek to push universities into doing industrially relevant work (see the next chapter), rhetoric in Japan stresses cooperation in projects of interest to both sides.

Japanese leaders, like those in many countries, view ties among universities, industry, and government as weak. Statements on science and technology policy continually highlight the need for more effective working relationships. Industry tries to help by donating equipment to the universities, but professors worry aloud that industry will steal their best research workers. At the same time, senior professors typically help steer their graduates to particular companies, helping build long-lasting informal communications networks. Professional societies and study groups also bring people together, providing opportunities for working-level scientists and engineers from industry, government, and the universities to share information. In this respect, they replicate the function of high-level advisory committees involving senior professors, corporate executives, and ministry officials.

Recent changes in the law—for instance, making it easier for faculty members to consult— encourage interactions with industry, but many Japanese officials think further steps will be needed. Broad success in basic research would seem to demand such cooperation. Given the

[24] "Sangaku Ittai e Hirogaru Koryu" [Expanding Exchange Between Industry and Universities], *Nihon Keizai Shimbun*, Jan. 20, 1988, p. 1.

slow growth in the government R&D budget, the industry role is a critical one; superconductivity promises to be a prime test case.

As noted earlier in the chapter, many Japanese companies–Sumitomo Electric is a good example—have been expanding their basic research efforts, while also pursuing parallel programs of applied R&Din HTS. The new opportunities have pushed many firms toward more basic work—which they see as the necessary preliminary to commercialization—and sensitized them to the importance of university science. Even so, a major reorientation of Japanese R&D toward fundamental research will require institutional, cultural, and political shifts. The university system is widely viewed as hierarchical and stifling, offering inadequate incentives to bright young researchers. Change has begun, but it is not clear how far it will go or how deeply it will penetrate.

Rivalry or Cooperation? The Internationalization of Japanese Superconductivity R&D

International cooperation in HTS has been a central theme in pronouncements by government officials in Japan. MITI has opened its HTS programs to foreign companies. The STA states that it will promote international collaboration under the Multicore Project. In addition, the Key Technology Center–sponsored by MITI and the Ministry of Posts and Telecommunications—has provided financial support for foreign engineers and scientists who wish to work in Japan. Finally, the Ministries of Foreign Affairs and Education have announced a postdoctoral fellowship program that will bring recent graduates of overseas universities to Japan for research. Possibilities for U.S.-Japan cooperation in HTS also exist on an agency-to-agency basis. The U.S. National Bureau of Standards and ETL have been exchanging scientists for a number of years. Both have informally expressed interest in cooperation on HTS-related standards.

Why the stress on “internationalization”? There are two major reasons:

- The United States, along with other nations, has been pressing Japan to make a greater contribution to global welfare—one commensurate with the size of the Japanese economy and Japan’s technological capabilities (box L). Among other things, this implies a greater commitment to science—the fruits of which should benefit all—and to the transfer of technologies to other parts of the world. Opening Japanese research institutions to greater foreign participation would be a first step. In many official policy statements—including those on HTS—Japan has pledged to take such actions.
- More than just altruism, internationalization would-serve Japan’s interests as well. Foreign scientists and engineers will help invigorate Japanese laboratories, encouraging new approaches to research, and breaking down some of the traditions which—particularly in the universities—seem roadblocks to creativity. Japanese leaders also realize that they may have to open their own doors to retain access to R&D from other countries. With science and technology holding the keys to continuing economic growth in the 21st century—a firm belief in Japan—internationalization can be viewed as a strategic and economic imperative.

The stress on international cooperation does not signify any slackening in Japan’s efforts to develop indigenous technologies. The Japanese view it as a complement to these efforts—far more than a matter of image, it is an intrinsic element in Japan’s strategy for competing in a world of intensifying global rivalries.

So far, as box L indicates, rhetoric has overshadowed results. MITI’s pitch for international collaboration focuses on the International Superconductivity Technology Center, established in January 1988. ISTEC, which gets financial support from MITI, will be located near Tokyo on a site formerly owned by Tokyo Gas. More than 85 Japanese companies have signed on as founding members. Although the initial fee for full members is about $800,000, with annual charges of about $100,000, the costs are considered donations and earn the companies tax benefits. Associate members, who pay

Box L.—Prospects for U.S.-Japan Cooperation in Superconductivity R&D

President Reagan has called for bilateral cooperation in superconductivity with Japan. But despite apparent interest by the Japanese Government, concrete steps have yet to follow. There is a broader context: prolonged negotiations over the non-energy bilateral science and technology agreement between the two countries.

During these negotiations, the United States raised questions concerning Japan's willingness to carry more of the worldwide burden of basic science research.[1] U.S. officials pressed Japan to open its research laboratories to foreigners, expand fellowship programs, even pay for translations of technical articles into English—while also trying to tie the agreement to concerns over export controls and intellectual property protection. Part of the background: repeated assertions that Japan always comes out ahead in scientific cooperation—that these arrangements become one-way streets in which Japan gets more than it gives.

Unless the Japanese take genuine steps towards cooperation, they run the risk of the United States closing off its own research, to the extent this could be accomplished. However, the advocates of international cooperation in Japan could be discredited if they are seen as caving in to unreasonable demands—an outcome that could have deep repercussions for U.S.-Japan relations.

From a U.S. perspective, it would be ironic if science and technology exchanges were curtailed just as Japan begins to demonstrate parity in research. In principle, two-way flow offers substantial benefits to the United States, although it would take hundreds of American engineers and scientists, able to communicate in Japanese, to take advantage of the opportunities. For Japan, cooperative projects could, under the proper circumstances, bring fresh ideas into the research establishment, while also helping to maintain access to work overseas.

Nonetheless, the significance of the invitations for foreign participation in STA and MITI undertakings on HTS has yet to unfold. Although the STA has invited foreign organizations to participate in the New Superconductivity Materials Research Association, only the Delegation of the European Community has joined. STA officials are weighing amendments to existing legislation that would make it easier for foreign scientists to work in the agency's laboratories. So far, only a few foreign firms have joined MITI's ISTEC program. If foreigners find themselves unable to participate fully, resentment will grow. If, on the other hand, cooperative projects bring tangible benefits to the foreign concerns, they could have symbolic importance well beyond HTS.

For the United States, participation in Japanese research may be the only way to gain full access to results. Certainly, it will help Americans gain a more sophisticated appreciation of Japan's approach to R&D—with potential benefit for U.S. companies seeking to improve their own performance in product development and manufacturing. Learning from Japan's technology means direct and deep involvement in Japanese R&D.

To take advantage of new programs designed to bring foreign researchers into Japanese laboratories, Americans will need considerable support from their employers at home and their hosts in Japan. For cooperation to be meaningful, the Japanese will have to structure projects so that Americans can function as full participants. On the U.S. side, effective participation demands capable scientists and engineers who have learned to speak their host's language.

Cooperation in HTS could become a bellwether for the future. The United States needs greater access to Japanese science and technology in many fields. But there is a potential downside to cooperation with Japan in HTS. The best Japanese HTS R&D is likely to take place in corporate laboratories, rather than the government and university facilities in which visiting Americans would probably be working. Universities and national laboratories are generally stronger in the United States than in Japan. The Japanese, in short, could learn more from exchanges in HTS. U.S. policymakers will have to weigh this risk against the overall benefits of gaining access to the Japanese system, particularly laboratories like ETL and NRIM—benefits that include the informal contacts so important in R&D.

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[1] M. Sun, "Strains in U.S.-Japan Exchanges," *Science*, July 31, 1987, p. 476; M. Sun, "Japan's Inscrutable Research Budget," *Science*, Oct. 2, 1987, p. 22; E. Lachica, "U.S., Japanese Negotiators Deadlocked on Tapping Each Other's Technology," *Wall Street Journal*, Jan. 22, 1988; C. Rapoport, "Japan goes public with apparatus for basic experiments," *Financial Times*, Mar. 11, 1988, p. 10; "U.S., Japan Hammer Out Science Agreement," *Science*, Apr. 8, 1988, p. 140.

According to a survey by STA, 600-plus Japanese firms hosted 360 foreign scientists and engineers during 1986. The survey provides no information on nationalities, nor is there information on American or other foreign researchers temporarily working in Japanese universities or national laboratories. See Report Memorandum #141 (Revised), Tokyo Office of the U.S. National Science Foundation, Jan. 25, 1988.

much less, will not be able to participate in research or have immediate access to R&D results, but simply to ISTEC publications and symposia.

ISTEC plans not only to conduct research in its own facilities, but to support R&D in other institutions, review and evaluate research for its members, and carry out feasibility studies on applications of HTS. To benefit from full membership, foreign companies would need Japanese-speaking employees, skilled in relevant technologies, on site in the ISTEC laboratory. As of May 1988, no foreign companies had joined as full members, although several had signed on with associate status.

Are American companies missing a bet by not joining ISTEC? For smaller firms, the costs pose a major barrier. But a number of U.S. companies with R&D operations in Japan could certainly afford them. Some form of jointly sponsored membership—e.g., through an industry association, or a joint venture such as Microelectronics & Computer Technology Corp.–might also be possible. If ISTEC yields impacts comparable to past MITI-promoted R&D efforts —e.g., the very large-scale integrated circuit project of the late 1970s—then participation could pay off. Even if the results in terms of research outcomes prove meager, active participation helps keep tabs on the competition. This, after all, has been a primary motive for Japanese firms to join in such group efforts.

CONCLUDING REMARKS

The U.S. business culture differs from that in Japan, R&D strategies in American companies tend to be driven by hard-headed calculation of risks and rewards—which does not encourage aggressive commitments to HTS. Most U.S. firms hope that someone else will do the fundamental research. Many American executives feel uncomfortable with this short-term approach, sometimes defensive. But they see little choice, given the way U.S. financial markets operate.

Japanese executives work in a society and an economy with a different set of traditions and rules. They too must worry about profit levels, but these are not the most important influence on their behavior, Japanese managers think first about growth and market position. Furthermore, they are acutely aware that they can no longer depend on technologies from the United States and Europe. Managers in Japan are attempting, often with some fumbling, to increase their firms' research capabilities, seeing this as one road to continued expansion.

Given the differences in attitudes and in approach to R&D, HTS has stimulated contrasting responses. As a generalization, large Japanese companies have more people at work on HTS, doing a greater variety of things. Japanese managers see HTS as a technology of paramount importance for global competition in the 1990s and beyond. U.S. executives might agree, but they also see the risks and uncertainties more starkly. They believe commercial products are farther off—that HTS will remain in the laboratory for some years to come.

Thus, most U.S. R&D efforts could be described as selective and probing. In contrast, most of the Japanese efforts are relatively broad, with people already assigned to think about applications. In pursuing their strategies, Japanese companies are studying superconductivity now as a potential commercial technology. American companies are not. The Japanese companies could be wasting their time and money. At this point, no one knows. But if the pace of discovery in the future matches that of the past year, Japanese companies will be better positioned.

In the United States, some of the first HTS applications may well come from small, *startup* firms–financially weak, and likely to face difficulties in growing. The pattern is clear in biotechnology, where startups have had to link with larger companies to proceed with commercialization. Thus far, of course, the startups are outnumbered by big American companies like Du Pont and IBM. In Japan, the large, diversified, and financially strong companies have the field largely to themselves.

These Japanese firms are poised to move quickly into production and marketing, on a worldwide scale if they choose. In the past, this asymmetry in industrial structure has had powerful impacts—e.g., on competition in microelectronics, where American firms have fallen behind for reasons that include lack of financial muscle. It remains to be seen how the story will unfold in biotechnology—or in HTS.

In the United States, cooperation between Government, industry, and the universities tends to be *ad hoc,* motivated by particular circumstances. There is no indication that HTS will be an exception. Japanese companies compete intensely with one another, but are nonetheless quite capable of cooperating on projects judged to be in their interests, especially when MITI or government agencies seek to foster these projects.

Japanese Government funding for R&D in superconductivity will not match spending by the U.S. Government (although the exclusion of salaries from some of the Japanese budget figures makes comparisons difficult). Including both LTS and HTS, the U.S. Government will spend more than twice as much in fiscal 1988. More important, however, Japanese firms have many more people at work on HTS than American firms. Companies commercialize, and companies in Japan have stronger commitments to superconductivity.

Neither country has a coordinated national initiative. Both seek to promote cooperation among universities, industry, and national laboratories. While business and government in Japan do not always find it easy to cooperate, they do exchange views and work toward consensus. And, if Japan's policy cannot be described as a coordinated plan, policy directions have been debated much more thoroughly than here. By the beginning of 1988, policy objectives in Japan had been reasonably clearly defined. They show a clear recognition of specific needs and specific problems impeding commercialization, and the Japanese Government aims to help solve them.