Chapter 2

Commercialization : Government and Industry

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Chapter 2

Commercialization: Government and Industry

SUMMARY

The United States invents and Japan commercializes. So say some. Is it true? If so, this would suggest not only that American companies fail to capitalize on technologies developed here, but that Japanese firms get a free ride on American R&D. Furthermore, if this has happened in other industries and with other technologies, it could happen with high-temperature superconductivity (HTS).

Has American industry really had that much difficulty in commercialization—in designing, developing, manufacturing, and marketing products based on new technologies? Yes—in *some* industries and with *some* kinds of technologies. In other cases—for example, biotechnology or computer software—American firms continue to do better at commercialization than their overseas rivals. Nonetheless, the competitive difficulties of American semiconductor firms have long since shown that continuing U.S. advantages in high technology cannot be assumed. And sectors like consumer electronics demonstrate that, when it *comes to engineering, if not science, Japan has been a formidable presence since the 1960s.*

Commercialization is the job of the private sector. Government plays a critical role in two respects:

1. R&D *funding.* Federal agencies will spend some $60 billion on R&D in 1988. Government dollars create much of the technology base that companies throughout the economy draw on. In 1988, the U.S. Government will spend some $95 million on HTS R&D. This is about as much as the American firms surveyed by OTA say they will spend on superconductivity R&D (LTS as well as HTS) in 1988. (See ch. 3, box F).
2. *The environment for innovation and technology development.* A host of policies—ranging from regulation of financial markets, to protection for intellectual property, and education and training—affect commercialization by companies large and small.

Private firms use scientific and technical results—more or less freely available, including knowledge originating overseas—in their efforts to establish proprietary advantages. Universities and national laboratories create much of the science base. Some industrial research contributes to the storehouse of scientific knowledge. All three groups—universities, government laboratories, industry—contribute to the larger technology base (which includes science but goes well beyond it).

Much technical knowledge remains closely held–protected by patents, by secrecy (classification for reasons of national security, trade secrets), or simply as proprietary expertise. Much proprietary information resides in peoples' heads, in organizational routines, management styles, as tacit know-how. Companies also write down some of their organizational knowledge: in product drawings and specifications; in process sheets, manuals, and computer programs for running production lines and entire factories. The manufacturing skills that helped Japanese semiconductor manufacturers outstrip their American competitors depend heavily on proprietary know-how, much of it embodied in the skills of their employees—skills that people often cannot fully articulate or explain.

Commercialization of HTS will depend on scientific knowledge, much of this available to anyone who can understand it. It will also depend on know-how, hard-won learning and experience—making good thin films, orienting the grains in superconducting ceramics to increase current-carrying capacity. Knowledge of markets will count too.

Government contributes directly through support for the technology and science base.

Federal agencies may spend their HTS R&D budgets wisely, or not. National laboratories may transfer technologies to the private sectors quickly, or only after long bureaucratic delays.

Government policies also affect commercialization indirectly. Patents and legal protection of trade secrets help firms stake out proprietary technical positions. Education and training policies (and immigration policies) affect the labor pool from which companies hire people who can understand the science of HTS, envision new computer architectures based on superconducting electronics, grasp the market opportunities created by the new materials.

No one anticipated superconductivity at 90 or 125 °K. No one can predict what will come next. More likely than not, 5 to 10 years of R&D—much of it supported by Federal agencies—lie ahead before HTS markets will have much size or begin to grow rapidly. A few niche products could come sooner. So could some military applications. New discoveries could change the picture radically. The ways in which the Federal Government spends its R&D dollars matter right now. Policy makers may have a bit more leisure to review the other channels of policy influence on commercialization of HTS. The stakes are high—for the private sector, and for government decisionmakers.

Potential for dramatic breakthroughs, coupled with great uncertainty, makes for difficult decisions. OTA sees no reason to rule out the possibility of room-temperature superconductivity (next month, next year). Room-temperature superconductivity—in a cheap material, easy to work with—has almost unimaginable implications. Companies with proprietary technical positions could reap huge rewards. The risks of inaction are high; on the other hand, progress could stall. High expectations and media hype could be followed by disillusionment, difficulty in raising capital, inaction on the policy front. Biotechnology has already lived through several such waves. HTS probably will too.

Early applications of new technologies tend to be relatively specialized, of modest economic significance. The public may lose interest, financial markets downgrade the prospects. No one can know, at this point, whether HTS could turn out to be a solution in search of a problem. The laser—invented in 1960—never seemed to live up to expectations. And yet solid-state lasers eventually made fiber-optic communications possible—an innovation with vast impacts on a worldwide scale (including, for example, a new source of competition for satellite communications systems). It was not that the possibilities went unrecognized.[1] Prospective applications of the laser to eye surgery and optical communications got immediate attention; but while ophthalmologists quickly began using lasers, little progress was made in communications for 15 years. It took, not only solid-state lasers, but low-loss glass fibers to make optical communications a reality.

In the early years of laser technology, no one fully anticipated the possibilities for fiber-optic communications networks; they snuck in through the back door. The same could happen with HTS. One of the tasks for public policy is to bring stability to the early years of new technologies, building a base for later commercialization. Industry will not do this alone, absent the potential for near-term profits.

OTA's analysis suggests that commercialization of HTS will proceed somewhat faster than many American companies expect, though not as fast as the Japanese companies that have been making heavy investments seem to anticipate. (Ch. 3 outlines U.S. and Japanese business strategies toward HTS.) As American companies move down the learning curves that mark out accumulated knowledge and experience in HTS, federally funded R&D will provide critical support for the technology base that all firms—but particularly smaller companies—draw from.

[1] "The Maturation of Laser Technology: Social and Technical Factors," prepared for OTA by J.L. Bromberg, The Laser History Project, under contract No. H3-521O, January 1988, pp. 7-9. Theodore Maiman, who built the first laser in 1960, stressed the communications possibilities—multi-channel capability, low cost per channel—at the press briefing announcing his invention.

The analysis in this chapter leads to the following conclusions:

- Small, entrepreneurial firms will be well placed to develop commercial applications of HTS. The conditions are right: a new science-based technology; synergistic links with existing industries, including low-temperature superconductivity (LTS) and electronics; venture capital for good ideas. But while small companies have been a major source of U.S. strength in high technology, few can assemble the financing, the technological breadth, or the production and marketing capabilities to grow as fast as their markets.
- Larger American corporations may find that they are starting out behind some of their Japanese rivals. The new HTS materials are ceramics, Japanese firms have a useful lead in both structural and electronic ceramics. Some of this expertise will transfer to HTS. So will a good deal of know-how developed for fabricating microelectronic devices—another field where Japanese firms have demonstrated themselves to be at least as good and sometimes better than American companies.
- Processing and fabrication techniques will be critical for commercialization. American companies have fallen down in manufacturing skills across the board; the more heavily process-dependent HTS applications turn out to be, the more difficult it will be for U.S. firms to keep up with the Japanese.
- Product as well as process technologies will demand much trial-and-error development. Japanese engineers and Japanese corporations are good at this. American companies are not. To the extent that commercialization of HTS depends on step-by-step, incremental improvements—brute-force engineering–U.S. companies will be in relatively poor positions to compete.
- R&D funded by the U.S. Government will help American companies in commercializing HTS, but the spinoffs from defense-related R&D may not be large or long-lasting if military requirements become highly specialized and diverge from commercial needs.
- Indirect policy measures—intended to remove the roadblocks to commercialization and increase the rewards for innovators and entrepreneurs—can also help. But the indirect approach alone will not be an adequate response to the coming international competition in HTS.

What about U.S. commercialization in general—the backdrop for the statements above?

- Mobility among scientists, engineers, and managers has spurred rapid growth and technological innovation in postwar U.S. high-technology industries ranging from computers and semiconductors (starting in the 1940s and 1950s) to biotechnology (beginning in the late 1970s). Venture capital for small, high-technology firms, likewise, has been a consistent source of competitive strength, one that will continue to work to U.S. advantage in HTS.
- Many larger American companies have pulled back from basic research and riskier technology development projects. Ease in establishing new small firms compensates in part for these relatively conservative investment decisions; indeed, negative decisions on proposed R&D projects sometimes spawn startups that go on to commercialize new technologies. Some of this will probably happen in HTS.
- With few American firms self-sufficient in technology, a lack of long-term R&Din the private sector, and managements that look for home-run opportunities rather than building technologies and markets step-by-step, the Federal Government has, by default, become a primary source of support for technology development. As yet, agency missions do not reflect this new role.
- Despite the onslaughts of foreign firms since the late 1960s, many American companies have not yet made the changes in their own organizations necessary to compete more effectively. Paying little more than lip service to well-known engineering methods such as simultaneous prod-

uct and process design, they fail to give manufacturing high priority. Neither managers nor engineers in the United States have learned to take advantage of technologies originating overseas.
- Industry cannot justifiably blame the U.S. Government for its failures. Compared with most other industrial economies, U.S. policies create a favorable environment for innovation and commercialization.

The indirect policy approach the U.S. Government has traditionally relied on to stimulate innovation and commercialization worked well for many years. Today, with foreign competition stronger than ever before, it seems time to explore new directions. The Federal R&D budget has grown rapidly over the postwar period. Management practices in government agencies, mechanisms for setting priorities, for ensuring an adequate technology base, have not kept pace.

The climate for innovation can always be improved, the barriers reduced. But the barriers are low already, and limited scope remains for policies intended simply to unleash American industry to compete more effectively. Indeed, the short-term perspectives of U.S. corporations, many of which have been unwilling to keep pace with foreign investments in new technologies, stem in part from the removal of another set of barriers—deregulation in U.S. financial markets.

Unless the United States learns to match the kinds of supports for commercialization that have proven effective elsewhere–topics treated in more detail in later chapters—only small improvements can be expected. U.S. industry could fall behind in HTS, and in the uses this new technology will find.

THE GOVERNMENT ROLE

HTS is fresh from scientific laboratories, but many commercial innovations begin with existing knowledge, gleaned from textbooks, design manuals, the schoolhouse of experience. The work of commercialization centers on engineering: development of new products and new manufacturing processes. Companies support their development groups with marketing people, and in some cases with research. Sometimes new science is part of commercialization, but not always.

The process may begin with an idea that is old, but has never been reduced to practice because of gaps in the technology base. The automobile, the airplane, and the liquid-fueled rocket all had to await needed pieces of technical knowledge. The Wright brothers learned to steer and stabilize their flying machine. Despite years of trial and error (and centuries of speculation), they were the first to find a way around these technical barriers.

Superconductivity itself, discovered in 1911, has a long history as a specialized field of physics, and a shorter history—beginning about 1960—as a technology that private firms sought to exploit. Appendix B, at the end of this report, summarizes the science and technology of superconductivity at both low temperatures (e.g., where liquid helium commonly provides cooling) and high (above the boiling point of liquid nitrogen).

Support for Industry: Direct and Indirect

What does this have to do with government? Today, governments finance much of the R&D that provides the starting point for commercialization. Companies everywhere start with this publicly available pool of technical knowledge in their search for proprietary know-how and competitive advantage. Second, public policies influence the choices companies make in financing their own R&D, and in using the knowledge available to them. Tax and regulatory policies encourage or discourage investments in commercial technology development. Patents create incentives, high capital gains taxes disincentives.

Smaller companies depend heavily on externally generated knowledge; many manufacturing firms with hundreds of employees have few if any engineers on their payrolls. But if smaller companies have the greatest needs, science and technology move so fast today that big companies also rely heavily on government R&D. Moreover, pressures for near-term profits have forced many larger U.S. corporations away from basic research. In the United States, a few hundred large companies account for the lion's share of industry-funded R&D—three firms (IBM, AT&T, General Motors) for more than 15 percent.

Half of all U.S. R&D dollars come from the Federal treasury. The fraction is smaller in most other countries, but in all industrial economies public funds pay for a substantial share of national R&D. The reasons begin with health and with national defense, but competitiveness has been one of the rationales: the first government research laboratories, established in the early years of this century in Britain, Germany, and the United States, were intended to help domestic industries meet foreign competition.

Foreign firms have access to many of the results of federally funded R&D, just as U.S. firms can tap some of the technical knowledge generated with foreign government support. Governments seek to use technology policy to help domestic firms compete, while commercial enterprises seek to take advantage of the world store of technical knowledge. Technology policy begins with R&D spending—setting broad priorities, making funding decisions at the project level, agency management. Other tools include intellectual property protection, which can help domestic firms establish and protect a technological edge. Of course, many countries also provide direct funding for commercially oriented R&D.

The U.S. Position in Technology

Past OTA assessments have examined U.S. competitiveness in a number of industries, and linked technological position with competitiveness; the most recent found signs of slowdown in U.S. R&D productivity, as well as evidence that newly industrializing countries have made surprising gains in technology.[2] Principal findings from these earlier assessments include:

- Technology is vital for competitive success in some industries (including services like banking). In others, it may be secondary. But in all or nearly all sectors, the technological advantages of American firms have been shrinking for years. The United States may be able to retain narrow margins in some technologies. Parity will be the goal in others. Regaining the advantages of the 1960s will, in the ordinary course of events, be impossible.
- In newer technologies, those that have developed since the 1960s, the Japanese have been able to enter on a par with American firms, and to keep up or move ahead. Examples include optical communications, and both structural and electronic ceramics. European firms, in contrast with the Japanese, have had trouble turning technical knowledge into competitive advantage.
- Today, U.S. military and space expenditures yield fewer and less dramatic spinoffs than two decades ago. The U.S. economy is vast and diverse. Defense R&D—increasingly specialized when not truly exotic—cannot provide the breadth and depth of support needed for a competitive set of industries.
- Japan and several European countries place higher priorities on commercial technology development than does the United States. R&D spending by Japanese industry reached 2.1 percent of gross domestic product in 1986, compared with 1.4 percent here.

Productivity, Innovation, Competitiveness, Commercialization

Import penetration in steel and consumer electronics, going back two decades, marks the beginnings of the wave of concern over lagging

[2] *International Competition in Services* (Washington, DC: Office of Technology Assessment, July 1987), ch. 6. Also see "Development and Diffusion of Commercial Technologies: Should the Federal Government Redefine Its Role?" staff memorandum, Office of Technology Assessment, Washington, DC, March 1984.

U.S. productivity growth and competitiveness. Commercialization is simply the latest catch phrase for problems that are all of a piece. The ongoing policy debate has centered on the proper mix of policies in the United States, where government has been reluctant to intervene as directly or as deeply in the affairs of industry as, say, in Japan or France.

During the Carter Administration, an interagency task force, supported by a panoply of private-sector advisory committees, labored for 18 months to produce a Domestic Policy Review of Industrial Innovation (DPR). The recommendations included:[3]

- easier licensing of federally owned patents;
- stronger ties between universities and industry;
- help for small, entrepreneurial firms through small business innovation research grants;
- removal of unnecessary regulatory barriers;
- signals to industry that antitrust policy did not bar cooperative R&D;
- tax incentives for R&D and innovation.

Plainly, the focus was on indirect policies. In one form or another, most of these steps have been taken.

Other recommendations of the Carter DPR, dealing with direct support for technology development, were not implemented. After Congress passed the Stevenson-Wydler Technology Innovation Act in 1980, the Reagan Administration declined to act on the central provisions of the legislation, which called for a network of Centers for Industrial Technology charged with supporting commercial technology development.[4]

The Reagan White House began its own study of the problems in mid-1983, creating a Commission on Industrial Competitiveness headed by John Young, president of Hewlett-Packard. When the Commission delivered its findings a year and a half later, many of the recommendations were familiar: "balance" in regulations; better labor-management cooperation; stronger protection for intellectual property.[5] Although its leadoff recommendation called for a new Department of Science and Technology (which got a frosty reception from an Administration committed to scaling back the Federal bureaucracy), the Young Commission, like the Carter DPR, stressed the indirect influences of Federal policies on technology development. The Commission helped turn the spotlight on technology transfer from the national laboratories, and urged use of the tax system to encourage private-sector R&D.

During the 1980s, then, the environment for technology development continued to evolve along the lines mapped out by the Carter DPR. Congress included an R&D tax credit in the 1981 tax bill, and extended it—although at a lower level—in 1986. In 1982, Congress passed the Small Business Innovation Development Act, requiring Federal agencies to set aside 1.25 percent of extramural R&D budgets exceeding $100 million for awards to smaller companies. With the executive branch adopting a much-relaxed enforcement policy for antitrust, the National Cooperative Research Act of 1984 explicitly permitted certain forms of joint private-sector R&D, while limiting private antitrust suits to actual (rather than treble) damages. The Administration also began negotiations with the governments of several foreign countries

[3]For a brief summary, see J. Walsh, "What Can Government Do for Innovation?" *Science*, July 27,1979, p. 378, together with N. Wade, "Carter Plan to Spur Industrial Innovation," *Science*, Nov. 16, 1979, p. 800.

In addition to agency participants, several hundred people from outside government took part in the Carter DPR; for the reports of the private sector committees and subcommittees, see *Advisory Committee on Industrial Innovation: Final Report* (Washington, DC: Department of Commerce, September 1979).

[4]Section 6 of the Stevenson-Wydler Technology Innovation Act of 1980 (Public Law 96-480) directed the Secretary of Commerce to "provide assistance for the establishment of Centers for Industrial Technology." Section 8 extended this authority to the National Science Foundation, The centers were envisioned as supporting generic technologies at the pre-competitive stage—those that could benefit many companies and industries. Commonly cited examples included R&D on welding processes, or on steelmaking. See *Implementation of P.L. 96-480, Stevenson-Wydler Technology Innovation Act of 1980*, hearings, Subcommittee on Science, Research, and Technology, Committee on Science and Technology, U.S. House of Representatives, July 14, 15, 16, 1981 (Washington, DC: U.S. Government Printing Office); also *International] Competition in Services*, op. cit., pp. 364-365.

[5]*Global Competition: The New Reality*, vols. I and 11 (Washington, DC: U.S. Government Printing Office, January 1985). Most of the 30 members of the Young Commission were businessmen.

where pirating of U.S. intellectual property has been at its worst.

At the same time, Federal laboratories—particularly those funded by the Department of Energy (DOE)—were seeking tighter linkages and better working relationships with private industry. During the early 1980s, the Federal laboratory system had come in for some rather harsh scrutiny.[6] An outside review panel (headed by David Packard, one of Hewlett-Packard's founders and a former Pentagon official) called for closer interactions with the private sector, setting the stage for efforts still underway to open up the laboratories and place their relationships with industry on a new footing (ch. 4). Meanwhile, State Governments began taking more active roles in technology policy.

President Reagan's proposed Superconductivity Competitiveness Act (box B) continues the stress on indirect policies. The draft legislation—which would further relax U.S. antitrust policy, while extending the reach of patent protection—would apply quite generally to U.S. industry: there is little that is specific to HTS.

R&D Funding and Objectives

If the weight of explicit shifts in U.S. technology policy during the 1980s has been on the indirect side, the direct role of the Federal Government has also changed—though not in the direction of support for commercial technology development. Government R&D has grown under the Reagan Administration, but much of the expansion has been for defense. Support for commercially oriented R&D has lagged, and in many cases been cut back.

Department of Defense (DoD) R&D went from $20.1 billion in fiscal 1982 to $37.9 billion in 1988 (table 1). DoD R&D, plus the defense-related portion of DOE spending (about half the Department's R&D), account for nearly 70 percent of all Federal R&D (figure *1);* the great majority consists of applied research and the engineering of weapons systems.

As figure 1 suggests, the U.S. Government has not paid much attention, relatively speaking, to R&D of interest to companies outside the defense, aerospace, and health sectors. And in the 1980s, Federal agencies have backed away even further (e.g., from energy R&D). The Reagan Administration has held that government has no business supporting commercial technology development. Fundamental research, yes, but anything more would be a subsidy—unjustified and likely to create harmful economic distortions.

The basic research portion of the DoD budget does contribute quite directly to the Nation's store of commercially relevant technical knowledge. The Pentagon, for example, provides nearly 40 percent of Federal support for university research in engineering.[7] In constant dollars, however, DoD basic research (budgeted at $892 million for fiscal 1988) remains at roughly the same level as in 1967, while the total DoD R&D budget has been steadily expanding in real terms.

Based on 1987 obligations, the Federal R&D budget breaks down as follows into the three broad categories of basic research, applied research, and development:

Basic research	$ 8.8 billion
Applied research	9.0 billion
Development	38.7 billion
	$56.5 billion

[6] See, for example, P.M. Boffey, "National Labs Reel Under Criticism and Investigation," New *York Times,* Aug. 24, 1982, p. cl.
The Packard report, below, appeared as ***Report of the White House Science Council Federal Laboratory Review Panel*** (Washington, DC: Office of Science and Technology Policy, May 1983). For more recent perspectives, see F.V. Guterl, "Technology Transfer Isn't Working," ***Business Month,*** September 1987, p. 44; and E. Lachica, "Federal Labs Give Out Fruit of More Research For Commercial Uses," ***Wall Street Journal***, Feb. 1, 1988, p. 1.

[7] The National Science Foundation follows, at about 30 percent. Universities carry out half of all DoD-sponsored basic research. See ***Directions in Engineering*** Research: ***An Assessment of Opportunities and Needs*** (Washington, DC: National Academy Press, 1987), pp. 46 and 63. Recently, the military has spent a little more than 2 percent of its R&D budget on fundamental research; 5 percent of private industry's R&D total goes for basic work.

Box A.—The Reagan Administration's Superconductivity Initiative

[illegible]

… covered by U.S. process patents.

Many agencies subdivide these categories further.[8]

Basic research itself covers a wide range of activities. Some of this really is "untargeted" science—work that could be called pure research, Nobody expects that astrophysics or the

[8] No figures for 1988 were available as this report was being completed. Distinctions between these categories are necessarily arbitrary; for the Federal Government definitions, see *Science Indicators: The 1985 Report* (Washington, DC: National Science Board, 1985), p. 221. DoD subdivides its R&D budget into six subcategories, designated as follows:

6.1 Research
6.2 Exploratory Development
6.3 Advanced Development
6.4 Engineering Development
6.5 Management Support
6.6 Operational Systems Development

Several of these are further subdivided,

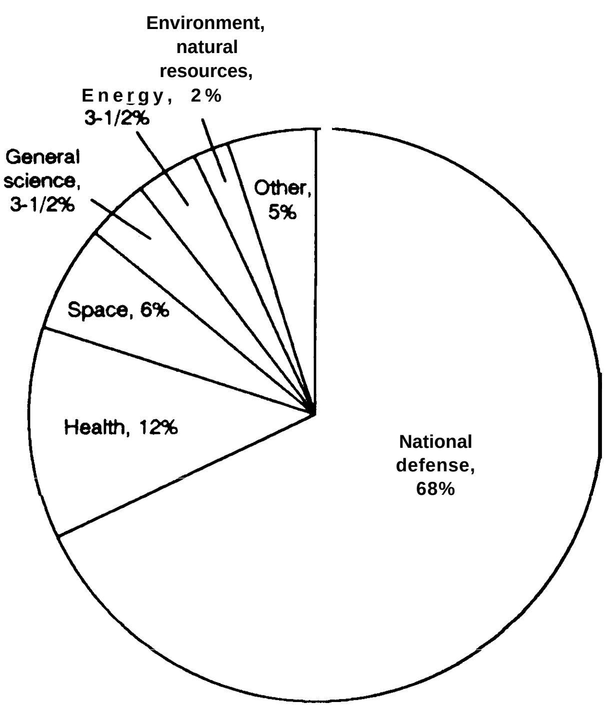
Table 1.—R&D Budget by U.S. Government Agency, 1988"

	Obligational authority (billions of dollars)	Percentage of total Federal R&D budget
Department of Defense (military functions only) . .	$37.9[b]	63.20/o
Department of Health and Human Services	7.2	12.0
Department of Energy	5.1	8.5
National Aeronautics and Space Administration . . .	4.8	8.0
National Science Foundation	1.5	2.5
All others.	3.5	5.8
	$60.0	100 "/0

[a]Excludes $2 billion in obligations for R&D facilities.
[b]The three services expect to commit a total of $29.4 billion in fiscal 1988-$15.2 billion for the Air Force, $9.5 billion for the Navy, and $4.7 billion for the Army. Adding in the rest of the DoD R&D budget (e.g., spending by agencies such as the Defense Advanced Research Projects Agency) brings the total to $37.9 billion.

SOURCE: *Special Analyses: Budget of the United States Government, Fiscal Year 1989* (Washington, DC: U.S. Government Printing Office, 1988), pp. J-3, J-5.

Figure 1.—U.S. Government R&D by Mission, 1988



SOURCE: Federal *R&D Funding by Budget Function, Fiscal Years 1987-1989, NSF-813-315* (Washington, DC: National Science Foundation, 1988), p

Superconducting Super Collider will lead to results of much practical use in the foreseeable future. Understanding is the motive.

Other projects, likewise defined as basic research for budgetary purposes, nonetheless bear quite directly on agency missions. Almost all the R&D funded by the National Institutes of Health (NIH, part of the Department of Health and Human Services) could be termed directed research. NIH supports much fundamental science—e.g., in molecular biology—but it does so with a view toward eventual improvements in health care; many NIH-sponsored projects have quite specific objectives such as a cure for AIDS, or better understanding of the growth of cancerous cells.

Likewise, DoD and DOE R&D serve agency missions. Research in physics laid the foundations for nuclear weapons, with DOE inheriting much of the ongoing support for physics from the Atomic Energy Commission. When the armed services or the Defense Advanced Research Projects Agency (DARPA) sponsor work in the behavioral sciences, they seek insights into the responses of fighter pilots to sensory overloads, or knowledge that will help make artificial intelligence a practical tool for battle management.

Research carried on in industrial laboratories, almost by definition, has a practical orientation. So does engineering research in universities and nonprofit laboratories. Plainly, distinctions such as that between untargeted and directed research will always be arbitrary. Nonetheless, such distinctions help in thinking about R&D and how it supports commercialization.

Within directed research, further distinctions can be made. Incremental work, for example, takes a step-by-step approach toward reasonably well-defined goals. The problems may be technically difficult, but the territory has been at least partially explored. Much of the work on synthesis of new materials that laid the groundwork for the discovery of HTS (box C) falls in this category, as does the many years of R&D aimed at improving the properties of LTS materials.

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becomes available, it will be posted
within the copy of this report
found on one of the OTA websites.

Most research serves the needs of government or industry. Military needs, social objectives such as health care, and industrial competition have driven the scientific enterprise at least since the end of the 19th century.

COMMERCIALIZATION

Both industry and government support directed research. Promising results lead naturally into development. Research and development then go on in parallel, with research outcomes suggesting new avenues for development, and problems encountered in development defining new research problems.

While the U.S. Government has a long tradition of support for basic research and mission-oriented R&D, it usually leaves pursuit of commercial technologies to the private sector. This policy worked well for many years. For instance, continued development of fiber-reinforced composite materials–lighter and with greater stiffness, strength, and toughness than many metals—builds on a technology base that has been expanding at a rapid rate since the 1950s.[9] The primary stimulus came from the military, where composites found their first applications in missiles, later in manned aircraft. penetration into commercial aircraft followed.

When it comes to technologies where Federal agencies have been less active, U.S. firms have often fallen behind. Although the U.S. Government has spent several hundred million dollars for R&D on structural ceramics since the early 1970s (app. 2A, at the end of the chapter), the effort has been a small one compared with fiber composites. Japan, meanwhile, has established a useful lead in structural (as well as electronic) ceramics. In semiconductors, American firms established a commanding lead during the 1950s and 1960s, when military procurement provided much of the demand (ch. 4). In later years, as production swung towards civilian markets, Japanese firms closed the gap.

Four Examples

In addition to summarizing Federal programs on ceramics, appendix 2A outlines the evolution of the video-cassette recorder (VCR)—a quite different case from any of those mentioned so far. The appendix also reviews the development of magnetic resonance imaging (MRI) systems, a relatively new product of the medical equipment industry, and LTS magnets. Magnets wound with niobium-titanium alloy—the most widely used LTS conductor—find uses not only in MRI, but in scientific research.

The examples in appendix 2A illustrate something of the range and complexity of commercialization. Sometimes government R&D support is critical (LTS magnets), sometimes nearly irrelevant (the VCR—although much of the underlying technology of magnetic recording did benefit from ongoing government-sponsored R&D). Sometimes governments try to push a technology, to little avail (ceramics for gas turbine engines). For MRI, the major policy impacts had little to do with R&D: commercialization depended on regulatory approvals, as well as Medicare and Medicaid payment policies.

The starting point may be new science, creating new opportunities (MRI, LTS magnets), or it may be the prospect of a huge market if development problems can be solved (VCRs). Inter-firm competition may be intense and international (MRI, VCRs), or it may be largely irrelevant (LTS magnets, where much of the work was undertaken within Federal laboratories).

Government agencies supported R&D on LTS magnets as part of larger, ongoing programs: high-energy physics research, nuclear fusion. Development of niobium-titanium wire for these magnets has been mostly a matter of painstak-

[9] *Advanced Materials by Design: New Structural Materials Technologies* (Washington, DC: Office of Technology Assessment, June 1988).

Photo credit: University of Kansas Medical Center

Magnetic resonance image of human face.

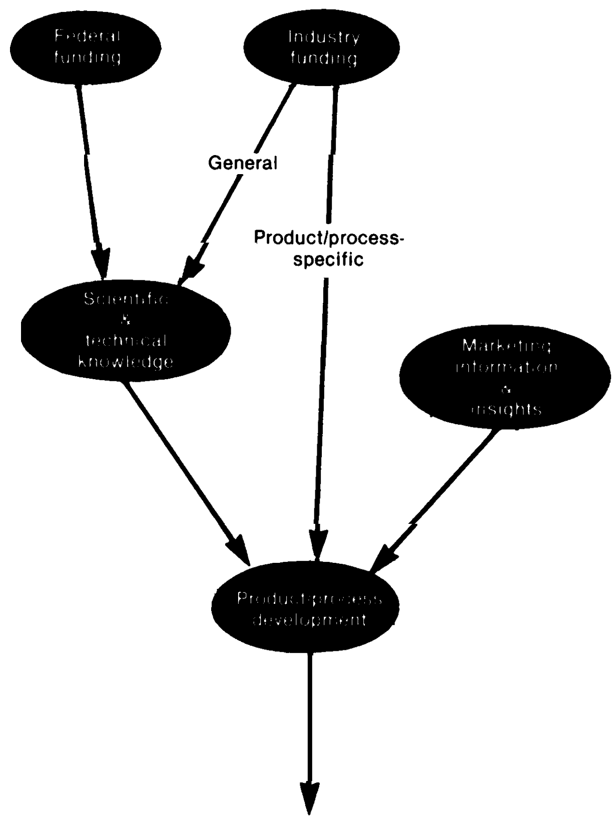
ing engineering. Federal funds paid for much of the work.[10]

The U.S. Government pushed structural ceramics technologies for different reasons. Most recently, DOE has supported work on ceramics for gas turbine engines, hoping to overcome their efficiency limitations; with greater fuel economy (and low enough manufacturing costs), the hope was that turbines could compete with gasoline and diesel engines for automotive applications. While these objectives are consistent with DOE's mission, there has been little pull from the marketplace.

Inputs to Commercialization: Technology and the Marketplace

Product or process development—whether adapting LTS magnet technology for medical imaging systems, or generic techniques for computerized process control to steelmaking—depends on at least two inputs from outside the development group itself. The first of these is knowledge drawn from the technology base, including science, engineering, and shopfloor know-how (figure 2). The second input is knowledge of markets—what potential customers want and need. Steelmaker may improve their process control systems because their customers want better formability, which requires more precise control of melt chemistry. The purchasers of steel maybe seeking to provide

Figure 2.—The Process of Commercialization



SOURCE: Office of **Technology Assessment, 19SS.**

[10] "Superconductive Energy Storage," vol. IV, DOE/ET/26602-35, Final Technical Report, January 1976 to October 1981, prepared by the Applied Superconductivity Center, University of Wisconsin-Madison, for the U.S. Department of Energy, July 1983, ch. III.

their own customers with products (automobile fenders, dishwashers) that have better-looking painted surfaces.

R&D and Marketing

Innovations follow their own paths. Figure 3 summarizes the later stages for MRI—those after initial research and feasibility demonstration. Science came first, the complete chronology beginning in 1936 with theoretical predictions of the underlying phenomenon of nuclear magnetic resonance. Experimental demonstrations followed a decade later, with the first two-dimensional images (e.g., of a wrist) in 1973.

Heavy continuing involvement by physicians and scientists made MRI something of an exception. Normally, commercialization is a job for engineers, supported on the one side by knowledge flowing from the technology and science base, and on the other by information on customer, wants, needs, and perceptions.

Much of the early work in HTS will be undertaken by multidisciplinary groups including physicists, chemists, materials scientists, and ceramists, along with electrical, chemical, and mechanical engineers. The known HTS materials are oxide ceramics—brittle and difficult to work with. Learning to use them means drawing where possible on past R&D—work undertaken earlier and for other purposes on structural and electronic ceramics, as well as processing, fabrication, and design techniques from microelectronics.

As applications come into view, companies will call on marketing tools ranging from feasibility studies (which may include detailed projections of manufacturing costs) to consumer surveys. Technical objectives shift as prospective markets emerge; some firms use "technology gatekeepers" to help match research results and market needs. This is an area where U.S. and Japanese strategies in HTS contrast markedly, with Japanese companies much quicker to begin thinking about applications and the marketplace (see ch. 3).

Judging market prospects can be harder than judging prospects for technical progress. Furthermore, market prospects often depend on technological capabilities. Early efforts by Matsushita and Toshiba to design VCRs for household use failed: production costs were high; recording times were short. Not many people would pay upwards of $1000 for a machine limited to 30 minutes per cassette. But improvement was steady. RCA's VideoDisc died in the marketplace in part because the company miscalculated the speed with which VCR manufacturers could reduce their costs to match RCA's target price (initially, *$500* at retail). RCA also underestimated the weight consumers would place on off-the-air recording capability, and, failing to grasp the implications of rapidly growing rentals of videotapes, prohibited rentals of its discs.

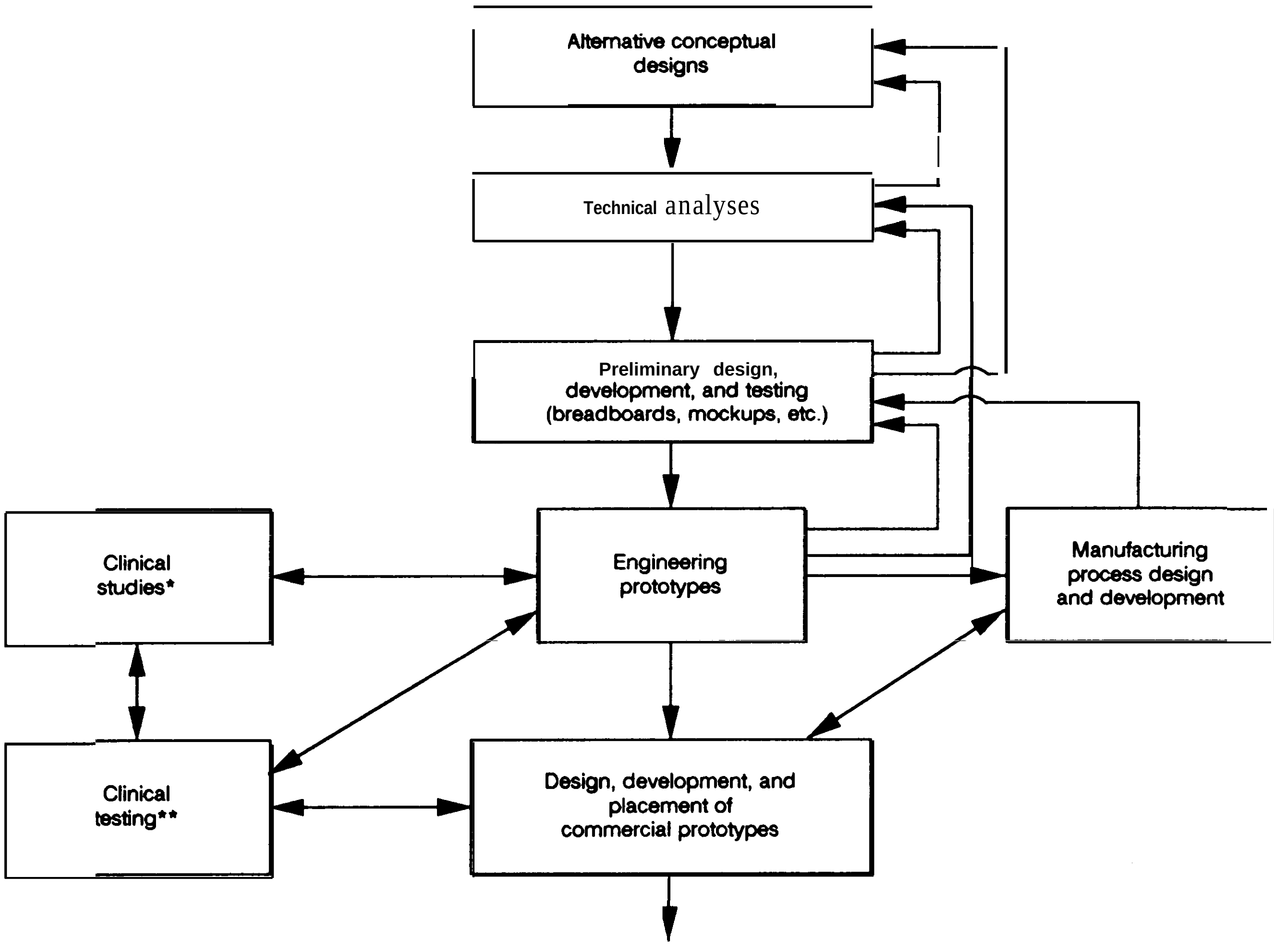
HTS Markets

It is too early to reach many conclusions about markets for HTS. The more obvious high-current, high-field applications—magnets, electric generators, coil and rail guns for the military—have all been analyzed for feasibil-

Photo credit: Argonne National Laboratory

HTS wire, flexible before firing,

Figure 3.—Development Stages for Magnetic Resonance Imaging (MRI) Systems



* Primarily aimed at developing the technology of MRI and, learning to use it (establishing efficacy, subject safety, etc)
**Primarily aimed at tearing prototype MRI system.

SOURCE: Based on *Health Technology Caaa Study 27: Nuclear Magnetic Resonance Imaging Technology* (Washington, DC: Office of Technology Assessment, September 19S4), ch 4

ity, but no one knows much about making practical wire, cables, or current-carrying tapes from the new materials (app. B). These will need higher current densities than yet in view.

Good thin film fabrication methods, the precondition for applications to sensors and electronics, will probably be easier to achieve. Even so, as of mid-1988, there had been no public announcements of reproducible HTS Josephson junctions (JJs). Many of the technical questions on which practical applications depend will not be answered until R&D groups learn to fabricate JJs easily.

Later sections of the report discuss these technical matters in more detail. Here the point is simply that, until the technological prospects come into sharper focus, it will be impossible to do more than speculate about markets. And even then, uncertainty will remain high. No one—scientists, engineers, marketing specialists, science fiction writers—can predict with much accuracy how a new technology like this will eventually be applied. Nor can potential customers say what they might want, or be willing to pay, if they cannot imagine the possibilities. It is the unexpected that will probably have the greatest impact.

Success and Failure

What makes for success or failure in the marketplace? Product and process engineering, marketing skills, luck, sometimes research results. No one has a recipe, any more than a recipe for room-temperature superconductivity.

Costs are central for some products, but for others — MRI is one — competition revolves around non-price features. Many hospitals will readily pay a premium of several hundred thousand dollars for an MRI system with superior imaging performance. At the same time, small private clinics or rural hospitals make up a niche market for which a number of manufacturers have designed low-cost systems.

Products may come out too late or too early. A company may fall behind its competitors and never get much market penetration. Early innovators in the semiconductor industry have sometimes failed and sometimes succeeded.[11] The pioneer minicomputer manufacturer, Digital Equipment Corp., whose PDP-8 established this part of the market, went onto become the second largest computer firm in the world, On the other hand, the microcomputer pioneers—Altair, Imsai, polymorphic Systems—disappeared. Toshiba invented helical scan recording but the company ended up licensing Sony's Betamax technology (which itself has lost much ground to VHS).

Cost and Risk

As firms move further along the development path, mistakes become more costly. Only one often projects launched at the R&D stage ever brings in profits. Before reaching the marketplace, half of all R&D projects fail for technical reasons; poor management or financial stringencies kill two or three more. Of those that do enter production, some never earn enough to cover development costs.

The vast majority of project budgets go for product engineering, process design and development, tooling and production start-up, and test marketing. Introducing an MRI system means investments of $15 million and up for R&D alone; pilot production and field trials require much larger financial commitments. Seldom does research account for more than 10 percent of total project outlays, although the distribution of costs varies a good deal from project to project and industry to industry. The distribution also varies between the United States and Japan.

As table 2 shows, Japanese companies (for the industries and time period examined) spent a bit less on R&D than the average American firm, and much less on manufacturing startup and product introduction. They budgeted more in gearing up for production—on facilities, tooling, and special manufacturing equipment (a difference that may also reflect higher projected volumes). Japanese firms no doubt have lower startup costs because they invest more in front-end process development. Yet a substantial difference remains. Adding the percentages for tooling and equipment to those for manufacturing startup gives a total of 40 percent for the U.S. companies, 54 percent for the Japanese. The greater proportion of total project expenses for tooling and equipment reflects the higher priorities Japanese managers place on manufacturing as an element in competitive strategy.

Such priorities will make a difference in commercialization of HTS, which will depend critically on process know-how. U.S. firms have underinvested in process technology for years—one reason for competitive slippage in industries ranging from steel to automobiles to electronics.

[11] See, for example, *International Competitiveness in Electronics* (Washington, DC: Office of Technology Assessment, November 1983), "Appendix C: Case Studies in the Development and Marketing of Electronics Products, Semiconductors: The 4K Dynamic MOS RAM," pp. 524-531.

Table 2.—Distribution of Costs for Development and Introduction of New Products and Processes[a]

	Percentage of total project cost				
	Research, development and design	Prototypeor pilot plant[b]	Tooling and equipment	Manufacturing startup	Marketing startup
U.S. companies	26940	17%	23%	17%	17%
Japanese companies	21	16	44	10	8

[a]Survey figures from 1985 for 50 matched pairs of U.S. and Japanese firms, The total of 100 included 36 chemical companies, 30 machinery, 20 electrical and electronics, and 14 from the rubber and metals industries.
[b]For cases of product development, the costs are for prototyping; for process development, they include investments in pilot plants.
NOTE: Totals may not add because of rounding.

SOURCE: E. Mansfield, "The Process of Industrial Innovation in the United States and Japan: An Empirical Study," unpublished seminar paper presented Mar. 1, 1988 in Washington, DC.

Competitive Advantage

What does it take to use technology effectively? The examples mentioned above, and others, point to the following common factors:

- *Appropriate use of technology and science,* new and old—whether a company generates the knowledge internally, or gets it elsewhere. Much of the science base for HTS will be available to everyone. To establish a competitive advantage, companies will have to develop proprietary know-how, and do it ahead of their competitors.
- *Effective linkages between engineering and marketing.* Customers for many of the early applications of HTS—in military systems, electronics, or perhaps energy storage—will be technically astute. Marketing will count, but not so heavily as for consumer products.
- *Effective linkages between product development groups and manufacturing—a* point already stressed for HTS.
- *Managerial commitment to risky and uncertain R&D projects*. The next chapter explores this dimension more fully for HTS.

What are the conditions under which American firms have trouble in commercialization—in the *effective utilization of technical knowledge,* new or old? Under what circumstances do American firms perform best? Effective policies depend on the answers to such questions.

Generally speaking, OTA assessments have found the problems to be most acute when it comes to applications of *existing technology* by firms in *older industries—and* particularly when it comes to shopfloor *manufacturing technologies*. In the earlier years of high technology, the United States had potent competitive advantages: entrepreneurship and venture capital; a decentralized science infrastructure with many centers of excellence both inside and outside the Nation's universities; flexible labor markets, with high mobility among engineers, scientists, and managers. These strengths have begun to wane. In many industries, Japanese companies are out-engineering American firms. Even in high technology, the Japanese have been able to move quickly from the laboratory to the marketplace. The days when U.S. companies could take their time in commercializing R&D are past.

STRENGTHS, WEAKNESSES, AND STRATEGY

What does the discussion above (and in app. 2A) imply for U.S. abilities in commercialization? The first point is simply that taking a new product into the marketplace is always difficult. In their efforts to penetrate the U.S. market, Japanese automakers suffered from many problems they failed to anticipate. Powertrains wore out quickly in long-distance driving. Companics like Honda found themselves trying to sell cars with fenders that would rust through after one or two northern winters. Federally mandated recalls were frequent.

Product/Process Strategies

Japan's automakers overcame these difficulties. They redesigned their products to suit U.S. needs and tastes, establishing deserved reputations for quality and reliability. They built strong dealer organizations that helped them understand American consumers. In contrast to European manufacturers, the Japanese began developing vehicles specially tailored to the U.S. market—small pickup trucks, four-wheel drive vehicles, sports and luxury models. Most were variants on products sold in Japan and other foreign markets, but a few—such as Nissan's Pulsar—were designed primarily in the United States to appeal to Americans.[12]

Japan's automakers learned many lessons from their American rivals, and learned them well. The credit goes to the industry, which benefited from government policies, but not nearly so directly as, say, Japanese computer manufacturers. In the past several years, with their upmarket moves and new brand names, Japan's automakers have taken another leaf from Alfred Sloan: in turning their automobiles into high-fashion products, they have introduced new models much more quickly than American or European firms—a necessary capability for implementing such a strategy.

Design / development / tooling cycles for Japanese automakers have shrunk to little more than half those in the United States; Honda's model cycle is down to 40 months, while American firms take 5 or 6 years.[13] U.S. automakers have looked to computer-aided engineering to narrow the gap. The Japanese, however, appear to succeed through quite conventional approaches to engineering development, carefully managed. Certainly they do not have the lead in such computer-intensive techniques as numerical analysis of vehicle structures, aerodynamic modeling and simulation, or analytical predictions of vehicle ride, vibration, and handling.

The high-fashion, product differentiation strategy is new for Japanese companies only in the automobile industry. It is one the Japanese have used in the past in cases like consumer electronics and motorcycles. Successful targeting of markets—whether for consumer goods, for capital equipment (machine tools), or for intermediate products (semiconductor chips)—has been a hallmark of Japan's competitive success.[14]

As discussed in the next chapter, Japanese companies have already put a good deal of effort into thinking about new applications of superconductivity; they may well locate some of the possible market niches before American firms. The Japanese have often carved out substantial markets by starting from small niches; large, integrated Japanese firms have been more

[12] J. Yamaguchi, "Quick-change open-top car matches closed coupe in body rigidity, " *Automotive Engineering,* February 1987, p, 167.

When Toyota models got poor ratings on U.S. crash tests, the company quickly made design changes that upped their scores—L. McGinley, "Car Crash Rankings: Safety Guide Or Numbers That Don't Add Up?" *Wall Street Journal,* Dec. 1, 1987, p. 39.

la'' Honda's R&D Mastermind," *Automotive Industries,* November 1987, p. 52, More generally, see H. Takeuchi and I. Nonaka, "The new new product development game," *Harvard Business Review,* January-February 1986, P. 137; J. Bussey and D.R. Sease, "Manufacturers Strive To Slice Time Needed To Develop Products, " *Wall Street Journal,* Feb. 23, 1988, p. 1; R. Poe "American Automobile Makers Bet On CIM To Defend Against Japanese Inroads," *Datamation,* Mar. 1, 1988, p, 43; K.B. Clark and T. Fujimoto, "Overlapping Problem Solving in Product Development," working paper, Harvard Business School, April 1988, Part of the Japanese advantage may come simply from putting more engineers to work: GM, Ford, and Chrysler employ a total of 30,000 engineers, Toyota, Honda, and Nissan more than 40,000—J, McElroy, "Outsourcing: The Double-Edged Sword, " *Automotive Industries,* March 1988, p. 46.

While it takes much longer for American firms to introduce new products in some industries, according to a recent survey, the U.S.-Japan difference in design and development times does not hold across the board—E. Mansfield, "The Process of Industrial Innovation in the United States and Japan: An Empirical Study, " unpublished seminar paper presented Mar. I, 1988 in Washington, DC. Professor Mansfield's survey does show that Japanese companies were generally much quicker than American firms when product development efforts began with licensed technologies. Moreover, Japanese firms willingly absorb substantially higher costs to shorten their development cycles.

[14] On the Japanese approach to product planning and marketing, see J.K. Johansson and I. Nonaka, "Market research the Japanese way," *Harvard Business Review,* May-June 1987, p. 16; P. Marsh, "The ideas engine which drives Japan, " *Financial Times,* May 29, 1987, p. 14; P. Marsh, "Why research is in the driving seat," *Financial* Times, June 2, 1987, p. 12; C. Lorenz, " 'Serum and Scramble'—the Japanese Style, " *Financial Times,* June 19, 1987, p. 19; P.S. Leven, "Repatriate product Design," *Across the Board,* December 1987, p. 39; C. Rapoport, "How Honda research runs free and easy, " *Financial Times,* Feb. 16, 1988, p. 10.

aggressive than their American counterparts in pursuing specialized products, including advanced materials. *Japanese companies are willing to start with small-volume production and grow with their markets—a strategy likely to prove successful in HTS, indeed one that may prove necessary.*

How do companies based in Japan do so well at defining and attacking market segments, particularly in countries foreign to them? Most Japanese companies do use market research techniques, although table 2 showed they spend less on this than American companies. As some U.S. firms also realize, the best marketing research often remains as informal today as it was 50 years ago—a matter of good judgment from within the company more than consulting firms, focus groups, and consumer surveys.

Japanese firms in many industries have also capitalized on the quality of their goods. Lagging quality not only leaves customers unhappy, it raises manufacturing costs. Quality and reliability problems have plagued American industries ranging from automobiles to semiconductors. Careful control of the production process will be necessary for fabricating the new HTS materials, as it is for high-technology electronic and structural ceramics, or for integrated circuits.

The primary point is this: by the 1960s, American firms had come to think of their skills in engineering and marketing as far and away the best in the world. If this was true then, it is true no longer. Many U.S. companies have not yet faced up to the need to do better. Others periodically rediscover such well-known management and engineering practices as simultaneous engineering, design for production, or quality engineering, but fail to follow through with actions that institutionalize them. Some still look to techniques like quality circles for miracle cures.

Research, Development, and Engineering: Parallel or Sequential?

Simultaneous engineering means nothing more than tackling product and process development in parallel, with overlapping responsibilities in design and manufacturing groups, if not a fully integrated approach. Simultaneous engineering may be hard to achieve in a modern American corporation, but in principle is nothing but common sense. A hundred years ago, technology was simpler and no one had discovered any need to separate design and manufacturing.

The chain can be extended back to research. But given the uncertainties that accompany the search for new knowledge, and the high costs of downstream development, many U.S. executives have come to view research, development, and product planning as sequential processes. Only when consistent, verifiable, and potentially useful results begin to emerge from the laboratory do American companies think about incorporating engineers into the effort. Even at this point, research may remain separated from development: the scientists pass along their findings, but the two groups continue to work independently. Under these circumstances, the entire process can become almost purely sequential—running from applied research to product planning and development to manufacturing engineering, with little overlap.

Technology-based Japanese companies, in contrast, have developed simultaneous or parallel processes to a high level. Many are now busy integrating backward into research–a task they see as necessary for commercializing high technologies like HTS. Already, they do a better job of responding to design and marketing requirements through incremental, applied research.

Japanese managers, moreover, tend to be optimistic about research in general and about HTS specifically (ch. 3). Perhaps because they mix development and engineering personnel into project groups at an early stage, the belief seems pervasive that useful results of one sort or another will inevitably emerge from HTS R&D. Japanese managers have strong convictions on these matters. They believe it wrong to think about technical developments as proceeding more-or-less linearly from basic research to applied research, then to development and product design, and finally to process engineering. More to the point, they are acting on these beliefs in HTS.

American managers know just as well that many of the steps should take place in parallel. But for reasons ranging from trouble in learning to manage parallel processes effectively (one reason for longer product development cycles), to the characteristics of U.S. financial markets, they do not always act on this knowledge, When it comes to HTS, American managers have been relatively cautious; they want to see results from the laboratory before taking the next step.

COMMERCIALIZING HTS

There is a bright side. The United States retains major sources of strength in commercializing new technologies. Table 3—which draws heavily on past OTA assessments of competitiveness—summarizes advantages and disadvantages of U.S. firms. Table 4 outlines the implications for HTS. Later chapters expand on many of the points in these two tables, particularly where the Federal Government has policy leverage.

Table 3 has a simple message: the United States has a number of areas of advantage, coupled with several serious handicaps. Those handicaps—emphasis on short-term financial paybacks, low priorities for commercial technology development and for manufacturing—have put U.S. firms at a severe disadvantage in competing with Japan. Some of the consequences can already be seen in HTS.

On the other hand, American firms have often been successful—at least in the past—when new science has led to new products and new industries, especially where fast-growing and volatile markets promise rich rewards (table 3, factor 1). American companies perform less well, and often poorly, at incremental innovation—more-or-less routine improvements to existing products and processes. These kinds of problems have been much more prevalent in steel than in chemicals, in machine tools than in computer software, in automobiles than in commercial aircraft.

Most of the success stories came in the years before U.S. industry had much to worry about from international competition. Table 4 summarizes the lessons that past performance and events thus far hold for HTS, and compares the strengths and weaknesses of American companies with those in Japan. Some of the U.S. entrants will be new companies, started specifically to exploit HTS and staffed by people with strong credentials in related fields of science and technology. Other firms will move in from a base in LTS. Both kinds of companies should be able to respond effectively to the problems and opportunities that emerge in the early years of HTS—with good ideas and a strong science base, together with venture capital and entrepreneurial drive, leading to success in specialized products and niche markets.

The picture could change as the technology stabilizes and financial strength becomes more important. When production volumes increase, manufacturing capabilities will grow more important. Companies will have to carefully tailor products to emerging markets, and find capital for expansion. U.S. industries that flourished as infants have run into difficulty as competitors—primarily the Japanese—caught up and pulled ahead in the race to capitalize on new approaches to factory production or new knowledge concerning electron devices; in the years ahead, the biotechnology industry could stumble, just like the semiconductor industry.[15]

Microelectronics, and Other Precedents

A decade ago the semiconductor industry still seemed a bastion of U.S. strength. The Japanese were nibbling at the margins, no more. Today, the Federal Government finds itself putting money into the new consortium Sematech, trying to help American firms regain a technological lead lost seemingly overnight.

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[15]So far, however, there has been little sign of such slippage. *See New Developments in Biotechnology: U.S. Investment in Biotechnology* (Washington, DC: Office of Technology Assessment, July 1988).

Table 3.—U.S. Strengths and Weaknesses in Commercialization

U.S. strengths	U.S. weaknesses	Comments
Factor 1. Industry and market structure: market dynamics.		
In the past, U.S. firms performed well in rapidly growing industries and markets, especially during the early stages in R&D-intensive industries.	American companies have had trouble coping with slow growth or contraction. Although new technologies promising greater productivity might improve competitive Performance in industries like steel, 'corporate executives frequently choose to invest in unrelated businesses. Where foreign firms might take a more active approach to managing contraction, American companies sometimes let troubled divisions struggle along, without new invest. ment, until profits disappear. Then they shut the doors.	Other countries frequently look to public policies to help companies and their employees adjust to decline.
Factor 2. Blue and gray collar labor force.		
High labor mobility helps American companies attract the people they need.	Many development projects depend on craftsmen who can fabricate prototypes and modify them quickly based on test results and field experience. In some U.S. industries, shortages of skilled labor—e.g., technicians, modelmakers —have begun to slow commercialization. U.S. apprenticeship programs have been in decline. Vocational training reaches greater fractions of the labor force in nations like West Germany; large Japanese companies invest more heavily in job-related training for blue- and gray. collar employees than do American firms.	In the past, U.S. wage rates worked to the disadvantage of American firms, while creating incentives for investments in R&D and new manufacturing technologies that could raise productivity. Today, international differences in labor costs are less of a factor than in the 1970s.
Factor 3. Professional and managerial work force.		
Mobility among managers and technical professionals has stimulated early commercialization in high-technology industries. New products have reached the marketplace more quickly because people have left one company and started another to pursue their own ideas. Deep and well-integrated financial markets—e.g., for venture capital—have helped.	American companies underinvest in process (as opposed to product) technologies. This is part of a bigger problem: too many managers and engineers in the United States avoid the factory floor: • for managers, marketing or finance has been the road to the top. • engineers—schooled according to an applied science model—have been insensitive, not only to role of manufacturing, but to the significance of design and marketing. Put simply, the engineering profession has divorced itself from the marketplace, and the needs and desires of potential customers (particularly when it comes to consumer products). Compounding these problems, many American companies underutilize their engineers. Finally, many U.S. firms provide little support for continuing education of their technical employees. Managers and professionals in the United States sometimes place individual ambition over company goals. Competition among individuals may make cooperation within the organization more difficult (e.g., between product engineering and manufacturing).	More upper level managers in Japanese and West German firms have technical backgrounds than in the United States; they appear more sensitive to the strategic significance of manufacturing, and in at least some cases to new technological opportunities.
Factor 4. Industrial Infrastructure (also see Factor 6 below).		
American companies can call on a vast array of vendors, suppliers, subcontractors, and service firms for needs ranging from fabrication of prototypes to financing, legal services, and marketing research. Few other countries have a comparable range Of capabilities so easily available.[a]	U.S. competitiveness in capital goods like machine tools has slipped, compounding the problems in manufacturing technology. Arms-length relationships between American firms and their vendors and suppliers may not be as conducive to commercialization as the relationships found in Japan (relations which might be classified as close and cooperative, or perhaps with equal accuracy as coercive and dependent).	At present, the independent computer software and services industry is perhaps the preeminent illustration of U.S. infrastructural strength.

[a]On the importance of specialty firms for the U.S. microelectronics industry, particularly those supplying semiconductor manufacturing equipment, see *International Competitiveness in Electrons* (Washington, DC: November 19S3), pp. 144-145. On service inPuts, see *International Competition in Services* (Washington, DC: July 1987), pp. 32-34 and 55-57.

Table 3.—U.S. Strengths and Weaknesses in Commercialization—Continued

U.S. strengths	U.S. weaknesses	Comments
Factor 5. Technology and science base (also see Factor 7 below).		
U.S. strength in basic research—both science and engineering—has been a cornerstone of commercialization. The national laboratory system is a major resource, although one that has not been turned to the needs of industry. Multidisciplinary R&D—essential in industrial (and government) laboratories–has been the exception rather than the rule in American universities. Foreign university systems, however, have probably been even worse at multidisciplinary research.	U.S. strength in basic research has not always been matched by strength in applied research, nor in the application of technical knowledge. The Nation depends heavily on a relatively small number of large corporations for industrial R&D and the development of new commercial technologies. When R&D is not close enough to anyone's interests, gaps open in the technology base. Moreover, U.S. firms seem to be falling behind in their ability to move swiftly from the R&D laboratory to the marketplace. Diffusion of technology within the U.S. economy has been a persistent and serious problem. American engineers and their employers have often remained unfamiliar with technologies developed elsewhere, reluctant to adopt them. This reluctance is evident, for instance, when it comes to rules of thumb and informal procedures—sanctioned by experience if not by scientific knowledge. Examples include shop-floor practices for job scheduling and quality control.	The science base and technology base are not identical. The latter spreads much more broadly, encompassing, for instance, the intuitive rules and methods—many of them tacit rather than formally codified—that lie at the heart of technological practice. The semiconductor and biotechnology industries have both sprung from scientific advances. But the theoretical foundations for each remain relatively weak. As a result, progress depends heavily on experience and empirical know-how—again, part of the technology base but not the science base. Japanese and German firms give commercial technology development higher priorities. Governments in these countries also give more consistent support to generic, pre-competitive R&D.
Factor 6. The business environment for innovation and technology diffusion (also see Factor 7 below).		
Clusters-of-knowledge and skills such as found in the Boston area, or Silicon Valley, help speed commercialization. While some of this entrepreneurial vitality can be linked to major research universities, other regions have become centers of high-technology development even though lacking well-known schools like MIT or Stanford. The size and wealth of the U.S. market, and the sophistication of customers—especially business customers—work to the advantage of innovators; indeed, foreign companies sometimes come to the United States simply to try out new ideas.	Many American firms seem preoccupied with home runs—major breakthroughs in the marketplace—unwilling to begin with niche products and grow gradually. Poor labor relations sometimes slow adoption of new technology. Reluctance among American engineers and managers to learn from shop-floor employees hurts productivity and competitiveness. Companies in other parts of the world may be somewhat more willing to cooperate in R&D.	Linkages between universities and industry could be stronger, but nonetheless probably function better in the United States than elsewhere. Business and consumer confidence encourage innovation and rapid commercialization. Over the past few years, business confidence appears to have ebbed somewhat–a casualty of Federal budget deficits, trade imbalances, rapid exchange rate swings, and the evident inability of the Government to address these issues. At the same time, the political stability of the United States remains a major strength.
Factor 7. ***The policy environment for innovation and technology development.***		
The United States h-as a deeply rooted commitment to open markets and vigorous competition. (So does Japan, when it comes to domestic markets and domestic competition.) With widespread economic deregulation since the early 1970s—plus a tax system and financial markets that reward entrepreneurs—startups and smaller companies have often been leaders in commercializing new technologies. Purchases by the Federal Government have stimulated some industries, particularly in their early years. Examples range from aircraft and computers to lasers and semiconductors. A broad range of other U.S. policies—e.g., strong legal protections for intellectual property-helps companies stake out and exploit proprietary technological positions.	Deregulated U.S. financial markets bear some of the blame for the risk aversion and short-term decisions common in American business. Sometimes U.S. regulatory policies delay commercialization. Examples include approvals for drugs and pharmaceutical products.	Many government policies act on commercial i-zation indirectly. Industries have evolved in different ways in different countries, in part because of these influences: • Along with antitrust, financial market regulations—e.g., rules covering holdings of stock in one company by others—affect the extent of vertical "and horizontal integration. • Tax policies—treatment of capital gains, R&D and investment tax credits—influence corporate decisions on investments in new products and processes. • Antitrust enforcement helps set the environment for inter-firm cooperation in R&D. • Trade protection can reduce the risks of new investment, thereby stimulating commercialization. On the other hand, protected firms may grow complacent and decline to invest in new technologies. • Technical standards sometimes act to speed the adoption of new technologies. If premature or poorly conceived, however, they can impede commercialization. • Education and training have enormous long run impacts on commercialization and competitiveness.

SOURCE: Office of Technology Assessment, 1988.

As yet, no one knows very much about the technical problems that will have to be overcome in commercializing the new superconductors. Still, parallels have begun to emerge. In microelectronics, product and process know-how are closely tied.[16] This will also be the case in HTS, where the companies that move down learning curves the fastest will reap competitive advantages.

Semiconductor firms must grapple with difficult technical problems in the heat of fierce competitive struggles: understanding the effects of purity and defect population in the silicon crystals with which production begins; process variables for the steps in diffusion or formation of oxide layers. Costs depend on yield—the fraction of functional chips produced. Both yield and quality depend on the design of the chip as well as control of the manufacturing process. With the technology of semiconductor devices ahead of the underlying science, chip designers and process engineers must proceed on a largely empirical basis as they work toward ever denser and more powerful circuits. New applications of HTS will likewise require tailoring of material properties on a microscopic scale, probably without much theoretical guidance.

Companies in the semiconductor industry must solve problems today so they can compete in the marketplace tomorrow. HTS is not

[16] *International Competitiveness in Electronics*, op. cit., ch. 6. As the example of Trilogy Systems illustrates, firms must be able, not only to design, but to build new types of devices; Trilogy had to abandon its planned line of computers after finding it could not fabricate the wafer-scale integrated circuits required.

Table 4.–U.S. Advantages and Disadvantages in Commercializing HTS

U.S. advantages	U.S. disadvantages	Comments
Factor 1. Industry and market structure; market dynamics.		
New science and technology make for conditions under which American firms should be it able to commercialize quickly and compete effectively.	At some point, financing constraints may make difficult for startups and smaller U.S. companies to continue in HTS on an independent basis. Mergers may be necessary for growth.	Past U.S. successes in high technology came when international competition was a minor factor. Foreign firms have now proven they can move quickly from the R&D stage to the market place. Mergers or other arrangements driven by financing needs sometimes help, sometimes hurt. Ties with larger companies may stifle innovation. In biotechnology, linkages between small firms and larger companies have helped with regulatory approvals and process scale-ups. American semiconductor firms, however, have seldom been willing to sacrifice their independence for new capital—one reason they have fallen behind large, integrated Japanese competitors.
Factor 2. Blue and gray collar labor force.		
Some American companies start with a core of employees having experience in low-temperature superconductivity (LTS). A portion of these skills will translate to HTS. At the same time, given that the new HTS superconductors are fundamentally different materials—ceramics rather than metals—a wide array of quite different skills will be needed. Some of the skilled employees may come from related industries, including electronics.	Japanese companies with ceramics businesses can draw on larger numbers of people with relevant skills. These employees will help give Japan a head start in certain kinds of HTS R&D–e.g., mechanical behavior, processing and fabrication. Japanese firms also have many workers with extensive and transferable experience in microelectronics.	So far, few American ceramics firms have been prominent in HTS R&D.
Factor 3. Professional and managerial work force.		
Managers, engineers, and scientists moving into U.S. HTS companies from industries like microelectronics will bring new insights and new ideas.	Decisionmakers in American companies, large and small, may not be willing or able to make long-term commitments to HTS-related R&D, particularly more basic work.	At least initially, HTS startups will have managerial staffs with strong technical backgrounds. Some larger U.S. firms with the resources to compete in HTS-related markets

Table 4.—U.S. Advantages and Disadvantages in Commercializing HTS—Continued

U.S. advantages	U.S. disadvantages	Comments
	Processing and fabrication will pose difficult technical problems, of a sort that American companies have not been very good at solving. Much of the R&D needed to develop HTS will be empirically-based engineering, with heavy doses of trial and error. Japanese companies do very well at this kind of development, often better than their American counterparts.	may chose other investments because managers fail to understand the technology or recognize the opportunities. Managers with previous experience in LTS may tend to err on the side of conservatism. On the other hand, HTS has had more than its share of exaggerated publicity already. A cautious view of HTS, born of past experience in LTS, could prove realistic.
Factor 4. Industrial infrastructure **(also see** Factor 6 below).		
The generally strong U.S. infrastructure for high technology should be an advantage **in** HTS.	When it comes to the science and technology of ceramics, specifically, the U.S. infrastructure is weak. American HTS companies with ceramics-related technical problems may have trouble finding help.	Japan's HTS infrastructure exists mostly inside large, integrated companies. In the United States, startups will have to rely heavily on help from outside. The US. approach has advantages in flexibility and creative problem-solving, while Japan's reliance on internal resources creates reservoirs of skills and expertise that will be very effective over the longer term.
Factor 5. Technology ***and science base*** **(also see** Factor 7 **below).**		
Despite lack of attention to ceramics compared with Japan, the United States has a relatively strong base in materials R&D. In the early years of HTS development, the defense emphasis of federally supported R&D will work in some ways to the U.S. advantage. Funding from the Department of Defense (DoD) will help train engineers and scientists, and may support the development of some dual-use HTS technologies (e.g., powerful magnets). DoD support for processing R&D could be especially important. A number of national laboratories have the resources, including specialized equipment, to help with the technical problems of HTS.	Military and civilian applications of HTS will diverge rapidly, limiting the spillover effects from DoD R&D spending.	In 1966, U.S. engineering schools granted 3700 PhDs—but only 14 in ceramics. Without major policy shifts, Federal agencies will fund little R&D that directly supports commercialization. Nonetheless, the United States is beginning to address the problems of transferring federally funded R&D to industry. American companies will probably be at a disadvantage for years to come in solving the manufacturing-related problems of HTS. To make progress here, American scientists and engineers—including those engaged in university research—must be willing to spend more of their time working on industrial problems (even if the scientific and university communities continue to view practical work as less than fully respectable). Without substantial efforts in manufacturing R&D, some American companies could be forced into partnerships with Japanese firms simply to get access to processing know-how.
Factor 6. The *business environment for innovation and technology diffusion* (also see Factor 7 below).		
U.S. markets should prove receptive to new products based on HTS. Some foreign companies could find they need an R&D presence here simply to keep up.	With Japanese firms starting on a par with American companies, know-how from abroad may prove essential for keeping pace. Many American companies have been unable or unwilling to reach useful technology transfer agreements with Japanese firms. Lack of experience in doing business with the Japanese could become a significant handicap in HTS.	University-industry relations in the United States seem to be following patterns similar to those in biotechnology, with strong and productive linkages developing. Small U.S. firms have begun devising strategies for commercializing HTS. Many larger American firms with the resources to compete in HTS, however, seem to be adopting a wait-and-see attitude.
Factor 7. The policy environment for innovation and technology development.		
So far, the U.S. policy approach seems conducive to entrepreneurial startups in HTS. There is little indication that the 1966 changes in U.S. tax law—which increased rates on capital gains—have choked off funds for HTS startups.	After the initial announcement of the Administration's 1 l-point superconductivity initiative, little was heard for 7 months—a long time in such a fast-moving field. Budgetary uncertainties, moreover, delayed decisions on Federal R&D funding well into the 1966 fiscal year, hampering progress in universities, industry, and the national laboratories.	While Federal procurements helped the U.S. semiconductor industry get off the ground in the 1960s, poor experience with demonstration projects in energy and transportation has soured prospects for some kinds of policy options that otherwise might provide stability and support for HTS during a long period of gestation. Some companies continue to express concern that U.S. antitrust policies will limit opportunities for consortia and other forms of joint R&D. However, OTA has not learned of any case in which U.S. antitrust enforcement has in fact stopped firms from cooperating in R&D.

SOURCE: Office of Technology Assessment, 1988.

yet at this stage. There is no market. The race is still a scientific race. But if HTS lives up to expectations, some of the history of microelectronics may be replayed.

Commercialization, indeed, may begin with specialized electronic devices—perhaps very sensitive detectors of electromagnetic signals, or high-speed digital circuits (app. B). HTS-based devices maybe used in conjunction with semiconductors. Other parallels are non-technical—matters of industrial structure, corporate decisionmaking, and public policy. Relatively small U.S.-based semiconductor firms find themselves competing with vertically integrated Japanese multinationals, enterprises with far more money and manpower. These same Japanese firms have made heavy commitments to HTS R&D. Government policies for HTS in Japan, while far removed from the (false) stereotype of industrial targeting, show many familiar features: notably, pragmatic attention to bottlenecks that might slow commercialization by Japan's very aggressive private sector.

The Japanese firms that have made so much progress with electronic and structural ceramics will be well placed when it comes to fabricating wires, cables, tapes, and other forms of conductors made from the new HTS materials. Learning to make practical conductors from the new materials—for the circuitry inside computers, or for electrical windings in generators or energy storage systems—will require a great deal of trial-and-error development. Japanese companies do well at this kind of engineering. Some of the specific skills in ceramics processing they have developed will transfer, just as will some of their skills in semiconductor processing. American firms, in contrast, have fallen down badly in processing and manufacturing skills over the past two decades.

HTS Technologies

Appendix B outlines prospective applications of HTS (table B-l), including estimated time frames for commercialization (table B-3). Early applications of HTS will be highly specialized—military equipment, niche markets on the commercial side (perhaps in scientific apparatus, or for nondestructive inspection). Japanese firms will provide strong competition from the beginning.

High-Current, High-Field Applications; Electrical Machinery and Equipment

Japan's lack of energy resources means strong motives for commercializing HTS in order to conserve electrical power. Even though superconductivity offers relatively small efficiency increments (because large-scale conventional equipment is highly efficient already), Japanese companies may make more rapid progress than American firms in superconducting motors and generators, as well as transformers and energy storage systems. Similar forces are at work for magnetically levitated trains, where the motivation comes from a heavy existing commitment to fixed-rail passenger transportation—natural in a small and crowded nation like Japan. Summarizing:

- Both the United States and Japan start from a roughly equivalent experience base in LTS motors and generators, but the Japanese have more work underway at present, and will probably pull ahead when and if suitable HTS conductors become available.
- Each country has one or more active LTS energy storage projects (large superconducting rings in which electrical current circulates indefinitely, to be withdrawn when needed). With SDI funding, two U.S. firms are designing a prototype ring that would quickly dump the stored energy into powerful lasers. Japan's R&D has been directed at storage for electric utilities, where discharge rates will be much lower. While the U.S. effort will yield some lessons for utilities, design trade-offs will bias the prototype—and the knowledge gained from it–towards the quick-discharge military application.
- DoD R&D aimed at coil and rail guns and other high-power, high-field applications (e.g., ship propulsion) could strengthen the generic technology base in HTS, helping commercial industries indirectly.
- When it comes to possible applications such as magnetically levitated trains, the

United States starts out behind, having halted R&D in 1975 (see box K, ch. 3). However, it is not yet clear that HTS would offer much advantage here.

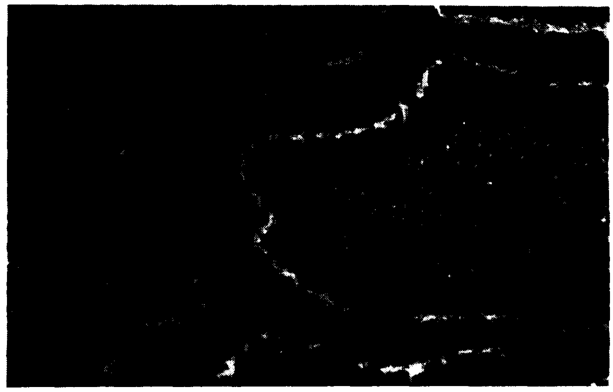
- In medical electronics—e.g., MRI—the United States has a substantial lead in know-how and experience, one that should persist (although LTS might again continue to be the technology of choice for some time).

Pursuing most of these applications will demand technical resources and experience, as well as financing, on a scale beyond that of the small, entrepreneurial firms that emerged in the early years of LTS, and those being started today to exploit specialized HTS applications. If big U.S. companies prove reluctant to move into markets for electric power equipment—and smaller entrants cannot—integrated foreign producers will probably take the lead, internationally and perhaps in the U.S. market.

Superconducting Electronics

Progress in thin films for electronics should be more rapid than for the conductors needed in high-power applications. When it comes to electronics, the Japanese will probably benefit to some extent from R&D on Josephson-based computers; government and industry in Japan continued work on JJs for computing after U.S. companies dropped most of their own activity (see box J in the next chapter).

Josephson junctions, however, function only as two-terminal devices, weak amplifiers at best. No one knows how to make useful three-terminal devices like transistors from superconducting materials. A practical three-terminal superconducting device, even one restricted to liquid helium temperatures, could open up a broad range of opportunities. Whether this will be possible is an open question. JJs also make for highly sensitive detectors of infrared and other electromagnetic radiation. LTS sensors—and in the future perhaps HTS sensors (e.g., for satellites, where passive cooling should keep operating temperatures below the transition temperatures of the new materials)—have potentially important military applications. As a



Hg mg mg g m

result, DoD has funded a good deal of R&D over the years on these devices, as well on superconducting components for very powerful computers. As DoD R&D increasingly focuses on HTS, some of its work—perhaps in sensors—will contribute to commercial spin-offs.

Japanese companies will prove able competitors over the long run in both devices and systems applications of HTS. In their efforts to catch up with IBM and other U.S. computer firms, Japan's integrated manufacturers—several of which make chips, computers, and telecommunications hardware—have been spending heavily on R&D for years. They are seeking a technological window that would help them overtake the United States in high-technology electronics, and particularly in computers—a field where American firms remain broadly superior. The Japanese see HTS as a possible window.

Smaller American firms will probably find electronics markets attractive. Hypres, for example, founded by an ex-IBM physicist after the computer manufacturer scaled back its LTS JJ computer project in 1983, introduced a very high-speed LTS-based data-sampler in 1987. The company hopes its experience base will give it advantages in HTS. Other small LTS specialists also plan to move into HTS by building on their past work with the older materials.

CONCLUDING REMARKS

The next chapter looks in some detail at corporate strategies toward HTS in the United States and Japan. European countries, too, have excellent science and engineering capabilities in both private and public sectors. But longstanding problems in capitalizing on these strengths suggest that European firms will not be able to keep up in the race to commercialize HTS. Box D summarizes the reasons.

Companies everywhere look for proprietary advantages from R&D—patentable inventions, expertise they can protect through trade secrets. Semiconductor companies, for example, each have their own process technology. Much of the information is closely held; some of it is embodied in the skills of their employees. In LTS as well, proprietary know-how helped small companies stake out positions in the manufacture of wire and in specialized electronics.

The Japanese developed a great deal of proprietary technology in commercializing the VCR. The story is one of Japanese success in innovation—engineering design and development, market research, mass production manufacturing. But in related markets like personal computers there is little evidence of slippage, despite many past predictions of a Japanese takeover. Nor have the Japanese been able, for instance, to move from success in high-density memory chips to microprocessors. U.S. leads in computer software, or biotechnology, may have narrowed in the last 5 years, but not by much. Japan's bet on structural ceramics may not pay off; the technical problems of achieving reliability in very brittle materials could prove too difficult.

Scientific knowledge and technological understanding–not the same–interact throughout such development efforts. Sometimes new science leads to new technology. This has been the case in superconductivity, beginning with its discovery in 1911, but especially since the 1960s. In other cases, demand for new technology spurs scientific advance. Much military R&D works this way.

Corporations are more likely to invest their own money in R&D, and take the risks of commercialization, if they expect rapid market growth. Government policies can reduce these risks. Trade protection does so, along with financial subsidies, and government purchases of a company's products. Strong legal protections for proprietary technology make R&D more attractive. Some governments go so far as to give financial help to customers for new technologies (computers and industrial robots in Japan). But with new knowledge eventually becoming available everywhere and to everyone, those who use it fastest and most effectively will come out ahead in international competition.

U.S. industry has been falling behind in the use of new technical knowledge, in part because of slow product development cycles. In many fields, the Japanese are not only doing a better job of engineering than their American rivals, they are doing it faster. Speed in moving from research to production and the marketplace will be a major factor in competitive success in HTS, just as in industries like automobiles or semiconductors. American firms have also had trouble as production volumes rise, and been poor at incremental product/process improvements. Their production capabilities enabled Japan's semiconductor manufacturers to establish themselves in world markets and compete successfully with American firms that had the lead in many of the functional aspects of circuit design. Many of the manufacturing techniques needed for HTS electronics will be similar to those for semiconductor devices (and ceramics).

Still, at the level of R&D and product development teams, Japanese firms do not seem to operate in greatly different fashion from successful American companies. The differences that do exist are important, however:[17]

[17] K. Imai, I. Nonaka, and H. Takeuchi, "Managing the New Product Development Process: How Japanese Companies Learn and Unlearn," *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. 372-373. Also see the "Commentary" by J.L. Doyle, p. 377.

Box D.—Commercialization in Europe

Excitement over HTS has been high not only in the United States and Japan. After all, the Nobel Prize for the initial discoveries went to two Europeans. Governments in Europe have begun putting together programs intended to support commercialization by domestic companies. But given the trouble that Europe has had in other high-technology industries, it seems unlikely that commercialization of HTS will proceed as rapidly as in the United States and Japan.

Direct government support for commercial R&D has been a tradition in much of Western Europe. France began funding technology development in computing and microelectronics during the 1960s, one of many policy tools brought to bear in search of an independent capability in electronics. Germany pumped a billion dollars into its computer industry during the 1970s in a largely futile attempt to help Siemens compete with IBM in European markets.

Since the early 1980s, renewed efforts to create a truly common market within the European Community (EC) have led to programs like ESPRIT (European Strategic Program of Research in Information Technology). The purpose is to stimulate cooperation in precompetitive R&D across national borders, and tighten linkages between universities and industry—objectives seen as comparable in importance to the technologies generated.

ESPRIT itself resulted in part from a widespread feeling that national programs had been unsuccessful. Periodic proposals for a joint EC industrial policy culminated, by 1980, in an attempt to put together a European strategy in electronics. The plan—never implemented—nonetheless marked the beginning of the current wave of inter-European cooperative R&D ventures, including such later developments as RACE (R&D in Advanced Communication-technology for Europe), BRITE (Basic Research on Industrial Technologies for Europe), and Eureka. The latter is intended to be closer to commercial technology development than earlier efforts focusing on pre-competitive R&D (and often sticking mostly to basic research).

Advocates of these programs claim that European governments, and European corporate executives, have finally begun putting aside their differences, that they are now on their way to working together in meeting American and Japanese competition. Whether or not this is so, the current struggles of Siemens and Philips to keep up with Japan in large-scale memory chips demonstrate that it may not be enough. The two companies, together with the West German and Dutch governments, have committed a billion dollars to a cooperative effort involving [illegible] product development. At this point, the Megachip project, the latest in a long series of attempts by European firms and governments to keep pace in microelectronics technology, seems in danger of running another set of changes on past failures.

Many of the large European companies have long performed high-quality research, but have had difficulty commercializing the results. [illegible] will be different with HTS. So far, the only sign pointing [illegible] the German firm Hoechst patented thallium-containing [illegible] HTS compositions 3 months before the public announcement by scientists in Japan.[31]

[31] "Hoechst AG Filed Bismuth Patent Last November," [illegible]

- American firms tend to proceed through a more analytical and sequential approach, one of narrowing down the alternatives. Japanese firms operate in a looser style, with more room for trial-and-error.
- product development groups in the United States rely more heavily on engineers with narrow technical expertise; Japanese companics staff their development groups with greater numbers of generalists, including people from sales and marketing. They may also involve the firm's suppliers.
- Japanese companies use product development groups as a device to break down

> some of the rigidities in their corporate cultures—e.g., the seniority system—and to create a place where creativity can flourish. Many American firms would like to think they don't suffer from such problems, but probably do.

At the same time, all of the attributes of Japanese product development efforts can be found in some American firms. It is the more successful Japanese firms that are visible in the United States: we seldom hear about the failures.

HTS poses difficult technical challenges. Japanese companies will, no doubt, solve some of the purely technical problems before American firms. Japanese companies will also do well at scaling up HTS manufacturing processes. Some will succeed in defining profitable markets. In short, they will prove highly capable and competitive in HTS. And while many large U.S. corporations have been turning away from long-term, high-risk R&D—the kind of work that will be called for in commercializing HTS–-the Japanese are making a major effort to show the world they can be as creative and innovative in science as they are in technology. It would be a grave mistake to assume that American firms will have a head start in HTS because of U.S. skills in research. The suddenness of the turnaround in microelectronics should have pounded home the message that both industry and Government will need to do things differently in the future.

APPENDIX 2A: R&D AND COMMERCIALIZATION: FOUR EXAMPLES

Ceramics for Heat Engines[1]

The U.S. Government has spent perhaps $300 million since the early 1970s pursuing ceramic engines. Much of the money has gone for applied research and development on components, and for demonstrations. Success has been elusive.

Over the past two decades, advanced ceramics have come into widespread use in electronics, as well as for specialty applications such as wear parts and cutting tools. Ceramics hold their strength at high temperatures much better than metals, but are brittle. If reliable ceramic combustors and rotor blades could be made for gas turbines, operating temperatures could be raised, making possible smaller, lighter, and more efficient powerplants. possible defense applications include stationary power units and engines for tanks, trucks, and cruise missiles (ceramic components may never be reliable enough for manned aircraft).

In 1971, DoD's (Defense) Advanced Research Projects Agency embarked on a ceramics R&D program, funding mission-oriented work of interest to the Army and the Navy on ceramic gas turbines, as well as research into design methodologies for brittle materials. The DARPA program continued into 1977, with funding that averaged slightly over $10 million annually. The Army continued some ceramic engine work thereafter, but DOE (then the Energy Research and Development Administration, ERDA) soon emerged as the primary source of support for applications-oriented ceramics R&D.

The ERDA program, in which NASA also participated, aimed at a gas turbine engine for trucks, seeking better fuel economy. Gas turbines make more sense for trucks than for passenger cars, which operate most of the time at light loads, where turbines give poor fuel economy. However, the focus on truck engines did not last. In *1980,* responding to a high-level political call for the "reinvention of the automobile," DOE created a new program—one that would demonstrate small gas turbines for passenger vehicles. Initially funded at $20 million annually, the incoming Reagan Administration sought to scale the effort back (along with other energy R&D); lobbying by industry contractors helped keep things going.

Increased Automobile Fuel Efficiency and Synthetic Fuels (Washington, DC: Office of Technology Assessment, September 1982), pp. 144-145; T. Whalen, "Development Programmes–USA," ***Proceedings of the First European Symposium on Engineering Ceramics,*** Feb. 25-26, 1985 (London: Oyez Scientific and Technical Services Ltd., 1985), p. 177; K.H. Jack, "Silicon Nitride, Sialons, and Related Ceramics," ***High-Technology Ceramics: Past, Present, and Future,*** W.D. Kingery (ad.) (Westerville, OH: American Ceramic Society, 1986], p. 259; ***Ceramic Technology for Advanced Heat Engines,*** Publication NMAB-431 (Washington, DC: National Academy Press, 1987); J. Zweig, "Deja vu–yet again," ***Forbes,*** Nov. 16, 1987, p. 282; "Case Studies of 'Flagship' Technology," prepared for OTA by W.H. Lambright and M. Fellows, Syracuse Research Corp., under contract No. H3-5565, Dec. 31,1987, ch. IV; R.P. Larsen and A.D. Vyas, "The Outlook for Ceramics in Heat Engines, 1990-2010: Results of a World-wide Delphi Survey," Paper No. 880514, prepared for the 1988 International Congress, Society of Automotive Engineers, Detroit, Feb. 29-Mar. 4, 1988; ***Advanced Materials by Design: New Structural Materials Technologies,*** op. cit., ch. 2.

Recent Federal spending (for all structural ceramics R&D) has averaged about ***$50*** million per year (figure 2A-1), but the turbine programs appear to have moved prematurely into development and demonstration, before establishing an adequate technology base, Industry cost sharing has been relatively low; companies that saw more value in the work presumably would be willing to kick in money at a higher level.

Rather than turbines, Japanese firms have put much of their effort into piston engines, both gasoline and diesel. While brittleness is a serious problem in ceramics for piston engines, it is easier to deal with than in highly stressed rotating blades. Moreover, ceramics can be introduced incrementally, substituted for a few parts in an otherwise conventional design.

Some of the technical problems of structural ceramics overlap those that will be encountered in commercializing HTS ceramics. A stronger basic research effort in ceramics, rather than the demonstration projects of recent years, might have put the United States in a better position to commercialize the new superconductors.

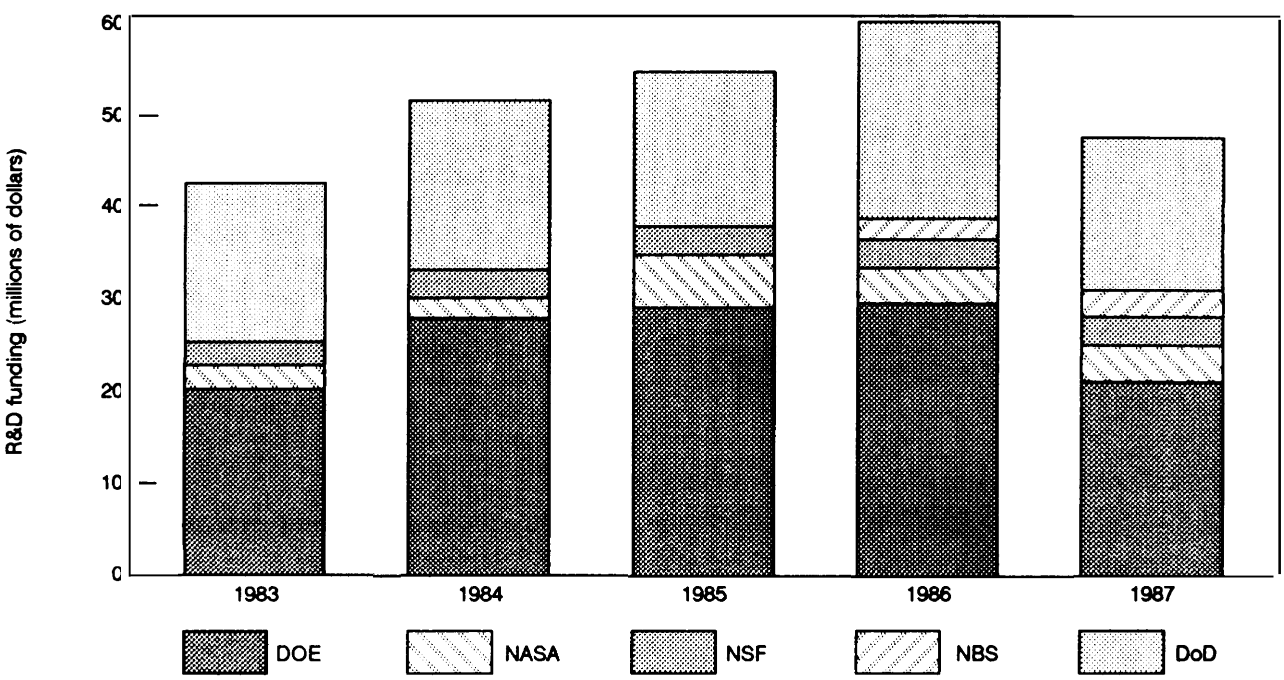
Video-Cassette Recorders*

Beginning in the 1950s, and through the following decade, half a dozen and more Japanese companies raced to develop low-cost VCRs. Commercialization meant solving a long chain of tough engineering problems, so that VCRs could be produced cheaply with the features consumers wanted.

Helical scan video-tape recording technology–first patented by Toshiba (table 2A-1)—became a critical feature in VCRs, although Toshiba itself never capitalized on its early lead in helical scanning. Matsushita entered pilot production first, in 1973, but shortly withdrew, deciding its technology was not good enough. Two years later, nearly 20 years after the U.S. firm Ampex built the first

International Competitiveness in Electronics, op. cit., pp. 70, 119-123, and 186-187; R.S. Rosenbloom, "Managing Technology for the Longer Term: A Managerial Perspective," ***The Uneasy Alliance: Managing the Productivity-Technology Dilemma,*** op. cit., p. 297; R.S. Rosenbloom and M.A. Cusumano, "Technological Pioneering and Competitive Advantage: The Birth of the VCR Industry," ***California Management Review, vol.*** XXIX, summer 1987, p. 51.

Figure 2A-1.-- Federal Funds for Structural Ceramics R&D



SOURCE: *Advanced Materials by Design: New Structural Materials Technologies* (Washington, DC: Office of Technology Assessment, June 1988), p. 67.

Table 2A-1.—Chronology of Video-Tape Recorder Developments

1951	R&D begins at RCA.
1953	RCA demonstrates fixed head scanner.
1954	Toshiba files patent applications for helical scanning; prototype follows in 1959. (Earlier U.S. and European patents were never reduced to practice.)
1956	Ampex introduces broadcast model videotape recorder (VTR) with rotating scanning heads. (VTRs use reel-to-reel tape, rather than cassettes.)
1958	Several Japanese firms, including Sony and Matsushita, embark on R&D directed at VTRs for consumer markets; RCA drops its work on consumer model VTRs.
1962	Sony introduces its first helical-scanning VTR, intended for institutional markets (business and industry, schools); JVC follows in 1983.
1969	Sony announces first video-cassette recorder (VCR), replacing reel-to-reel tape with a cartridge.
1970-71	Ampex Instavideo camera/recorder system shown in prototype form—never marketed because of production problems.
1971	Sony U-Matic marketed for institutional use at $1000.
1971	RCA resumes VTR R&D, drops out again in 1974.
1972	JVC develops prototype of its VHS system.
1973	Matsushita enters pilot production with a consumer VCR, but withdraws after a few months.
1975	Sony introduces Betamax for home use.
1976	JVC brings VHS recorders to market.
1988	Sony to begin selling VHS machines alongside its lagging Betamax system.

SOURCES: W.J. Abernathy and R.S. Rosenbloom, "The Institutional Climate for Innovation in Industry: The Role of Management Attitudea and Practices," *The 5-Year Outlook for Science and Technology 1981: Source Mater/a/s, Volume 2,* NSF 81-42 (Washington, DC: National Science Foundation, 1981), p. 407; R.S. Rosenbloom, "Managing Technology for the Longer Term: A Managerial Perspective," *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. 317-327; R.S. Rosenbloom and M.A. Cusumano, "Technological Pioneering and Competitive Advantage: The Birth of the VCR Industry," *California Management Review,* vol. XXIX, summer 1987, p. 51.

broadcast recorders (the size of a closet and selling for $50,000), Sony's Betamax opened the consumer market.

That an American firm produced the first videotape recorders for broadcast applications was close to irrelevant. The Betamax represented the fourth generation of Sony's engineering development—the seventh generation if the company's earlier industrial and institutional models (e.g., the U-Matic, which appeared in 1971) are included. Japanese companies, competing fiercely with one another, persisted with the VCR for years, in the face of many disappointments.

It may be true in a narrow sense to say that the United States invented the videotape recorder and the Japanese commercialized it. But in fact, some *15* companies — American, Japanese, European—demonstrated 9 different technical approaches to home video in the early 1970s. It took many years of money and manpower commitments by Japanese companies to win the race, and a great deal of highly creative engineering—focusing on manufacturing, as well as product design. Once the VCR became a commercial reality, competition centered on cost reduction, better image quality (where manufacturers of magnetic tape made major contributions), and longer recording and playing times.

Firms like Zenith and RCA—which now put their labels on foreign-made machines—never pursued consumer VCRs with the doggedness of the Japanese. After about 1980, no American company could have entered without some sort of breakthrough—a product that would have opened a new round of competition. The Japanese were simply too far down the learning curve. South Korean firms were in a different position: with wage rates well below those in Japan, they had potential cost advantages. When the Japanese refused them licenses, Korean firms developed their own VCRs.

The essential ingredients in Japanese success? First, willingness to make long-term investments in risky and expensive product development efforts. Second, the manufacturing capability to mass-produce precision electro-mechanical components such as the helical read-write heads that proved a key in turning the video-tape recorder into a household product. Commercialization of the VCR exemplifies the kind of incremental improvement and market-oriented engineering that the Japanese have been so good at.

Is the VCR story exceptional? Not really, and certainly not in the context of consumer electronics, an industry that had stagnated in the United States by the mid-1970s. Price competition in traditional products like color TVs was fierce, imports were flooding the marketplace, and the stronger U.S. firms like RCA and GE were diversifying into other lines of business.

Still, the risks did not stop RCA from investing in the VideoDisc.[3] Indeed, the VideoDisc was a bold

[3] M.B.W. Graham, ***RCA and the VideoDisc: the business of research*** (Cambridge, UK: Cambridge University Press, 1986]. The company ultimately lost more than half a billion dollars.

choice. If successful, it would have given RCA a unique product—something that none of its Japanese rivals had. In contrast, pursuit of VCR technology would have meant competing in a class of products that the Japanese plainly would be able to build cheaply and well. RCA managers knew from experience in color TV production how difficult this would be, particularly given the Japanese strategy of attacking consumer electronics markets worldwide (whereas RCA's consumer sales had been confined to the U.S. market).

MRI Systems[4]

Magnetic resonance imaging has been the biggest market for conventional superconducting technologies over the past few years. In 1987, two dozen companies worldwide sold a total of 500-plus MRI systems to hospitals and clinics. At roughly $2 million each, industry sales came to perhaps $1 billion. Both production and sales are concentrated in the United States. Commercialization took many years, following research showing that nuclear magnetic resonance (NMR)—a discovery made by physicists —could be a powerful tool for medical diagnosis.

To construct an MRI image, the patient must be placed within a strong magnetic field—commonly produced by an LTS magnet. A computer processes the resulting NMR signals, creating an image the physician can examine (like an X-ray). MRI provides better contrast and resolution, particularly for the brain and spinal cord, than competing diagnostic imaging techniques, including ultrasound and CT scanning.

During the middle 1970s, more than a dozen companies in the United States, Europe, and Japan began working to commercialize MRI. Some dropped out along the way. Others were bought by stronger firms, or merged with competitors. Japanese companies entered late, and have not been very active outside their home market.

European firms led the way in engineering development. The British company EMI built the first prototype in 1978, and Bruker, a West German manufacturer, followed the next year. Both these companies had prototype systems operating in clinical settings by 1981. Shortly thereafter, EMI decided to leave the medical equipment business, and sold its technology to a competitor. By the end of 1983, eight firms had commercial prototypes available—three American companies, four European, and one based in Israel,

Early in design and development—e.g., during the stage labeled alternative conceptual design in figure 3 (earlier in the chapter)—each firm faced decisions on its magnet system. The alternatives—permanent magnet, resistive (non-superconducting), superconducting—carried advantages and disadvantages in terms of factors such as initial and operating costs, as well as field characteristics like strength and stability. Most companies chose LTS magnets, with several pursuing conventional magnet designs in parallel. Because the design of the magnet affects image quality—a central concern in purchasing decisions by hospitals–feedback from the clinical studies and clinical testing stages (figure 3 played a vital role in refining prototype designs.)

This brief description illustrates, first, the ways in which research may enter the commercialization process. In this case, the R&D ranged from nuclear physics (the NMR phenomenon itself), to the medical studies demonstrating that MRI could be a valuable diagnostic tool, to computerized signal processing and superconducting magnet design,

MRI systems emerged as viable commercial products in 1984. It was only then that designs stabilized and production became relatively routine, at least in the leading companies. It took 38 years to go from scientific discovery (experimental verification of NMR) to marketplace success. Commercialization in the sense of engineering development spanned the years 1977 to 1984.

Regulatory approvals were an early hurdle. The U.S. Food and Drug Administration spent several years evaluating the new technology. Manufacturers had to estimate the effects of third-party payment policies on market growth: Would Government agencies responsible for Medicare and Medicaid give a quick okay to the new technology? Or would they delay? How about the big insurance plans like Blue Cross/Blue Shield? In fact, hospitals were not generally reimbursed for MRI services until late in 1985. Furthermore, with MRI systems costing several million dollars, State government certificate-of-need approvals became a precondition for many sales.

U.S. firms did not have the initial lead. Nonetheless, they quickly emerged in the forefront as the technology moved out of the laboratory and became a practical tool for medical diagnosis. A major reason for U.S. success was simply that this country is the biggest market in the world by far for medical equipment. That the U.S. economy is the world's

[4]*Health Technology Case Study 27: Nuclear Magnetic Resonance Imaging Technology* (Washington, DC: Office of Technology Assessment, September 1984]; "Superconductive Materials and Devices, " Business Technology Research, Wellesley Hills, MA, September 1987, pp. 38-50.

largest and most diverse is both an advantage and a disadvantage for American firms. They are at home here, but their domestic markets are a magnet for foreign firms—who may be willing to lose money in the United States for the sake of learning and experience.

Designing and developing a new product from scratch, as in the case of the first MRI systems, represents a major corporate commitment. An all-new product takes much more time and money than the incremental redesigns, improvements, and new models that come later and constitute most of the routine work of product/process development. The all-new product (or manufacturing process) will also, in the ordinary course of events, depend more heavily on new knowledge—e.g., research results. Feedback from the R&D laboratory and the marketplace remain important even for routine development work, however. Once the medical community accepted MRI, competing firms quickly began differentiating their products through stress on image quality, good service, and reliability.

LTS Magnets[5]

Federal R&D, much of it for high-energy physics experiments and research into nuclear fusion, underlies development of the LTS magnets found in MRI systems. Wound with cable made from niobium-titanium alloy filaments embedded in a copper matrix, and cooled with liquid helium, the magnet accounts for up to a quarter of the cost of an MRI system.

[5]D. Larbalestier, et al., "High-field Superconductivity," ***Physics Today***, March 1986, p, 24; L. Hoddeson, "The first large-scale application of superconductivity: The Fermilab energy doubler, 1972 -1983," ***Historical Studies in the Physical and Biological Sciences,*** vol. 18, 1987, p. 25; "Superconductive Materials and Devices," op. cit., pp. 33-61; "Technology of High Temperature Superconductivity," prepared for OTA by G.J. Smith II under contract No. J3-21OO, January 1988; "Government's Role in Computers and Superconductors," prepared for OTA by K. Flamm under contract No, H3-6470, March 1988, pp. 56ff. Also see app. B.

Until MRI markets began to grow, most superconducting magnets were custom-designed for scientific equipment. The late 1960s saw the first major application of niobium-titanium, a bubble chamber built at Argonne National Laboratory. A much larger federally supported project—the Tevatron particle accelerator, completed in 1983 at the Fermi National Accelerator Laboratory—consumed more than 30,000 miles of niobium-titanium wire for its nearly 1000 magnets. Most of the wire came from Intermagnetics General Corp. (IGC), established by several former General Electric employees in 1971.

IGC and other small, specialized firms had begun moving into LTS as major corporations—Westinghouse as well as GE—withdrew, finding that market growth did not live up to their expectations. Development of the processing techniques for LTS magnet wire was a lengthy and complex task, one that would have taken much more time without the demand provided by the Tevatron. Private firms drew on the publicly supported technology base, and also helped to extend it, as they developed the know-how needed for manufacturing LTS wire and cable (the Fermi Laboratory designed and built the magnets internally).

It took many years to raise the critical current densities of niobium-titanium wire to the levels needed for the Tevatron and for MRI. The task hinged on the relationship between fluxoids (each of which contains a magnetic flux quantum)—a matter of physics—and the microstructure of the wire. Through careful microstructural control–specially tailored sequences of wire drawing and heat treatment—metallurgists and materials specialists were able to create fine dispersions of second-phase particles. These particles pin the fluxoids, keeping them from moving, The pinning can raise the critical current density—hence current carrying capacity—by 10 times or more. R&D aimed at optimizing the processing technology began in the late 1960s, and still continues, with engineering development guided by theoretical understanding.