Chapter 4

U.S. Technology Policy: Issues for High-Temperature Superconductivity

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SUMMARY

The preceding chapter discussed company strategies toward high-temperature superconductivity (HTS) in the United States and Japan, as well as the policies of the Japanese Government. The question now becomes: How can U.S. Government initiatives help American companies with commercialization? Both this chapter and the next deal with Federal policies and what they mean for HTS. Both also go beyond superconductivity, taking up broader issues that affect commercialization and competitiveness,

Many of these policy issues are matters of ongoing concern to Congress and the executive branch: the Federal R&D budget and its management; the health of university research; technology transfer from national laboratories to industry. Table 7 provides a guide to some 20 policy issues and options discussed in this chapter; tables 9, 13, and 14, which follow later, give more detail. As a glance at table 7 makes clear, many of the issues and options have relevance that goes far beyond HTS. By the same token, many of the policy questions important for HTS can only be understood in the broader context of U.S. technology policy.

Federal agencies will spend some $60 billion on R&D this year (ch. 2). Industry will spend about as much, with private firms also conducting more than half the Government-funded total under contract. All companies that use technology live to some extent off the publicly financed storehouse of technical knowledge. The path to commercialization begins with this technology base.

The overall size of U.S. R&D expenditures—more than twice as much as Japan, and far more than any of the Western European nations—presents something of a paradox. How is it possible, given spending on science and technology exceeding $125 billion, that the United States has a problem in technology? Why doesn't American industry have what it needs to compete? The question has two kinds of answers, both partially true. The first is that technology is not, in fact, the problem—that difficulties in commercialization and competitiveness lie elsewhere. The analysis in chapters 2 and 3 indicated that technology *is* part of the problem—though far from the whole problem. The second answer is that not enough of the R&D money goes toward commercially relevant technology development.

Any analysis of the Federal role in commercialization must begin with a look at how the Government spends its $60 billion:

- Nearly 70 percent goes for defense, up from 57 percent at the beginning of the Reagan Administration. The United States devotes a much larger share of total R&D outlays for military projects than most other countries. Defense gets less than 5 percent of the Government R&D budget in Japan.
- Much of the Federal money—this year, about $20 billion—goes to the 700-plus national laboratories. For the most part, these laboratories do not have a good track record in transferring technology to civilian industry. While recent initiatives by Congress and the Administration have sought to strengthen interactions between the laboratories and industry, the process of change is just beginning.
- Outside of defense, aerospace, and health, Federal agencies spend little on applied research and development. Given the short-term orientation of most of the R&D paid for by private industry, a wide gap often separates basic research and commercial technologies—a gap that neither Government nor industry has been filling.

Table 7.—Summary Guide to Policy Options

Issue area	Option	Relevance
I. Funding Levels and Priorities for Federal R&D (see Table 9 for details)		
A. Funding Levels for HTS		
• New money, agency priorities	1	HTS
B. Continuity of Funding		
• Multi-year benchmark plan	2	HTS, but potentially broader
• Two-year funding trial	3	HTS, could be broader
C. National Science Foundation Budget		
• Overall NSF budget increase	4	general
• Funding for university laboratory equipment	5	general
D. Weaknesses in the Industrial Technology Base		
• Review of U.S. technology base	6	ail commercial technologies
• Basic research tax credit	7	general
E. Setting Priorities for Federal R&D		
• Strengthen the Office of Science and Technology Policy	8	general
II. Strengthening Interactions Among Universities, Industry, and Government (see Table 13 for details)		
A. University-Industry Interactions; Multidisciplinary Research		
• Funding for NSF centers	9	general
• Postdoctoral fellowships	10	general
B. Government-Industry Interactions: Technology Transfer and Joint R&D		
• Oversight on technology transfer from the national laboratories	11	general
• Pilot program for transfers of HTS technology resulting from DoD-sponsored R&D	12	HTS, but potentially broader
• Technology transfer demonstration projects	13	general
• Personnel exchanges	14	HTS could get special attention
• Cooperative R&D with industry	15	HTS, but potentially broader
• Sharing costs with private R&D consortia	16	HTS, but potentially broader
• Support for State Government initiatives	17	general, but HTS could get special attention
III. Technology Interchange with Japan (see Table 14 for details)		
• Seed grant for office in Japan to monitor developments in HTS	18	HTS
• Research participation and language training	19	general
• Japanese technical literature	20	HTS, but potentially broader

SOURCE: Office of Technology Assessment, 1988.

At present, the Federal Government maybe spending as much on HTS as the private sector. The agencies expect to spend $95 million on HTS in fiscal 1988. OTA's industry survey (ch. 3) found that 55 U.S. firms plan to spend about $97 million on superconductivity R&D (LTS as well as HTS) in 1988.

While $95 million sounds like a lot, nearly half will go for military projects. Department of Defense (DoD) objectives shape R&D goals even at the level of basic research. Nonetheless, much of the fundamental understanding of HTS that results from DoD-sponsored research will support the overall technology base for HTS. Moreover, the Defense Advanced Research Projects Agency (DARPA) has emphasized processing in its HTS R&D; this work should yield commercial spinoffs.

In general, however, civilian and military technologies have been diverging, as DoD's needs grow ever more specialized. This pattern is already evident in HTS, where prospective applications include passive shielding for protection from nuclear radiation, or sensors for the Strategic Defense Initiative (app. B). Moreover, in a period of tight budgets, DoD decision-makers—from project and program managers to laboratory directors and Under Secretaries—scrutinize the R&D budget to make sure that immediate military needs get the highest priority. Basic research suffers in such periods, along with other work that might be of use on the civilian side of the economy.

The Department of Energy (DOE) and its laboratories will get the lion's share of the nonmilitary funding—nearly 30 percent of the Federal total. Ten DOE laboratories may have more to spend on HTS in 1988 than NSF will distribute to the Nation's universities. DOE's basic research, like that of DoD, will help support the technology base. As for commercial technology, the laboratories are trying to develop new cooperative ties with U.S. industry. However, it could take years for effective working relationships to develop; in the absence of such relationships, DOE R&D may not make a major contribution to commercial technology development.

The National Science Foundation (NSF) share of the HTS R&D budget, going almost entirely for university research, declined from 25 percent of the Federal total in 1987 to 15 percent in 1988. The universities do get some funding from DOE and DoD (especially through the basic research programs of the Air Force and the Navy). But the allocation of Federal R&D funds seems out of balance, given the great strength of American universities in basic research.

Continuity of funding over the next 5 to 10 years will be just as important as the level and allocation in any one year (Options 1, 2, 3). The Federal budget for HTS is really nothing more than the cumulation of agency decisions and appropriations. Both Congress and the Administration could benefit from a better sense of the overall dimensions of the Federal effort, so that priorities could be weighed rather than simply emerging at the end of the yearly budget process. A benchmark, multi-year funding plan for HTS, which could be adjusted periodically (not at alla rigid blueprint), would help in making good decisions. Congress might also choose to experiment with multi-year authorizations and 2-year budgeting. These steps could help avoid too much duplication in agency R&D (some overlap can be desirable), as well as cuts in other needed R&D to provide money for HTS (little of the Federal total represents new money specifically appropriated for superconductivity).

Many fields of science and technology vital for competitiveness do not get adequate research support; technical knowledge that could help American firms compete is not available when they need it. Often, the underinvestment is most severe in fields that lack glamour and the promise of immediate payback (examples range from materials synthesis to corrosion and wear)—just those likely to suffer when more money must be found for an exciting new opportunity like HTS. Given the constraints on the Federal budget, any decision to begin filling some of these gaps by spending more on civilian R&D must begin with good information and a government-wide perspective, matters addressed in Options 6 and 8.

Commercializing HTS will require multidisciplinary R&D—physicists, chemists, materials scientists, and engineers. NSF can play a vital role in supporting multidisciplinary research in universities, where such work has seldom caught on (Options 9 and 10). While the Reagan Administration proposed doubling the Foundation's budget over a 5-year period, Congress gave NSF very little increase for fiscal 1988. Sustained growth in the NSF budget will be needed if the agency is to increase its support of traditionally underfunded areas, including engineering research—a critical priority for competitiveness.

If the Federal laboratories, in their turn, are to provide much help in commercialization, they will need to make sustained commitments to working with the private sector (Options 11 through 17). Congress, in several recent laws, has stressed the need for closer linkages between the laboratory system and industry. Agency responses have been mixed. With experience limited, it might be prudent for the DOE laboratories to adopt an experimental approach, beginning with pilot projects, rather than plunging into a full-fledged program of cooperative endeavors. Personnel exchange programs could also help shift the culture of the laboratories; scientists and engineers working in the laboratory system need to understand how industry functions and how the marketplace works if they are to help in commercialization.

Chapter 3 outlined Japan's proposals for international cooperation in HTS research. So far, American firms have not responded with much enthusiasm. Options 18, 19, and 20 suggest steps the Federal Government could take to help industry and professional groups test Japan's openness to foreign R&D participation, and to monitor Japanese technical developments. Given the importance of person-to-person contact in technology transfer, early steps should include language training for U.S. engineers and scientists, so they can work inside the Japanese research system.

Although the analysis that follows covers a broad range of issues related to HTS, it does not pretend to be a comprehensive discussion of U.S. technology policy. Nor do the 20 policy options address all the problems identified in earlier chapters—short-term decisionmaking in U.S. industry, for example. This chapter has a more modest aim: examining alternatives for managing the Federal R&D budget to more effectively support the Nation's commercial technology base without detracting from agency missions. Most of these are incremental policy adjustments; chapter 5 looks at more comprehensive alternatives.

GOVERNMENT SUPPORT FOR HTS R&D

Funding Levels

Funding for HTS R&D has grown dramatically since the end of 1986; table 8 gives the best available estimates.[1] It is hard to criticize the totals; indeed, the increases shown in table 8 seem generous in a time of budgetary pain. Although little of the money represents new budget authority, in 1988 the U.S. Government will probably spend more on HTS alone than Japan's Government will spend on HTS and LTS together. The 1988 total approaches the recommendation—$100 million—of a National Academy of Sciences (NAS) panel.[2]

But the totals do not tell the whole story. HTS could remain in the laboratory for many years. During much of this time, the Federal Government will remain a primary source of R&D funds. Effective support for commercialization will require stability in Federal funding, attention to priorities, and good management of agency budgets.

In their fiscal 1988 budgets for HTS, some agencies fared much better than others. DOE and NSF spent roughly equal amounts on HTS in 1987; the Energy Department will have more than twice as much this year, while NSF's in-

[1] Low-temperature superconductivity (LTS) has shared in the expansion. For years, DOE and DoD have funded LTS projects such as energy storage and superconducting machinery (e.g., for ship propulsion–Appendix B). Federal spending for LTS increased from $40 million in fiscal 1987 to $84 million in 1988. Agency requests for LTS in the 1989 budget come to about $83 million. (Both the 1988 and 1989 figures include Strategic Defense Initiative (SDI) contract work on superconducting magnetic energy storage.)

[2] "Research Briefing on High-Temperature Superconductivity," Committee on Science, Engineering, and Public Policy, National Academy of Sciences, Washington, DC, 1987, p. 19. The panel, noting that corporate funding might add a comparable amount, termed this" . . . a good beginning in addressing the challenges and opportunities offered by the new materials. "

Table 8.–Federal Funding for HTS R&D

	Fiscal year budget (millions of dollars)		
	1987 (actual)	1988 (estimated)	1989 (requested)
Department of Defense[a]	$19.0	$46.0	$63.0
Department of Energy	12.5	27.2	38.7
National Science Foundation	11.7	14.5	17.2
National Bureau of Standards	1.1	2.8[b]	9.3
National Aeronautics and Space Administration	0.5	4.2	6.7
Bureau of Mines	0.1	0.1	0.1
	$44.9	$94.8	$135.0

[a]Working figures, subject to change.
[b]Excludes $750,000 correlated work.

SOURCE: Preliminary agency data and budget estimates provided to the Subcommittee on Superconductivity of the Committee on Materials, May 1988

crease is only 25 percent. NSF officials have said they have received many more highly-rated proposals on HTS than they can support in fiscal 1988. Meanwhile, the DOE laboratories—which typically get nearly two-thirds of the Department's basic research funds—may have more money for HTS than NSF will provide the Nation's universities.

The NAS panel emphasized the need for new money for HTS to avoid cuts in other, perhaps comparably important, R&D. When the excitement over HTS reached a peak early in 1987, the fiscal year was well underway. Thus almost all the 1987 funding came through redirecting of dollars originally allocated to other research. In many cases, scientists and engineers with Federal contracts and grants took the lead in this process, seeking approval from agency contract monitors to move into HTS.

Faced with little growth in R&D budgets, most agencies have had little choice but to continue pulling money from other fields to pay for HTS. The National Bureau of Standards (NBS)–with a budget that grew 16 percent from 1987 to 1988— is probably alone in being able to fund its HTS work without sacrifices elsewhere.

In a period of tight budgets, when there may be no way to avoid sacrificing one kind of research to pay for another, good decisions on priorities within and across agencies become more important than ever. Doing a better job of formulating R&D budgets could help identify conflicts earlier, and perhaps ease their resolution. For HTS, stability over time will be as important as next year's R&D totals. a

At present, most of the funds for HTS come from the general R&D authorizations of the agencies. Rather than this piecemeal approach, Congress could take a broader look at the Federal effort in HTS, and provide overall guidance, through such mechanisms as a single piece of legislation that would provide multi-year authorizations of appropriations, defining the responsibilities in HTS for each agency. This approach is discussed in more detail in table 9 (Option 1). It carries dangers: for example, possible micromanagement by Congress. On the ether hand, if implemented in too weak a form, the effort could end up as little more than a paper exercise, with little or no influence on the actual allocation of HTS R&D support across the agencies.

As a further step, Congress could direct the Administration to prepare a multi-year estimate of funding expectations for HTS R&D (see Option 2 in table 9). Some of the proposals on HTS before the 100th Congress–e.g., H.R. 3217, as

[3]In a well publicized episode, a recent NSF effort to reduce uncertainty in university research programs backfired. Managers in the Foundation's Materials Research Division, expecting a substantial funding increase in fiscal 1988, made too many long-term commitments during 1987, When the Federal budget was finally approved, and the money was not there, NSF cut back on ongoing multi-year grants (which are conditional on availability of funds) in order to support some new starts. See "Statement on Funding Levels for the Division of Materials Research, " National Science Foundation, Mar. 3, 1988.

Table 9.–issue Area 1: Funding Levels and Priorities for Federal R&D

Issue	Options for Congress	Advantages	Disadvantages
A. Funding Levels for HTS **On the surface, Federal funding for HTS R&D seems generous–$95 million for fiscal 1988.** The difficulties lie beneath the surface: • Little of the total is new money. Few agencies got the increases in their R&D budgets they had planned on for fiscal 1988. They have taken money for HTS from other research. . Universities have had difficulty in lining up funds. Ten DOE laboratories may well get more for HTS during fiscal 1988 than NSF will have for all the Nation's universities. . The Administration is requesting a hefty increase for HTS–to $135 million in 1989–and is calling for a substantial rise in non-defense R&D. If Congress pares back the R&D budget to accommodate other needs, the new money issue, along with allocations of R&D funds among the agencies, could be central issues, not just for HTS, but for R&D generally.	**OPTION 1.** Provide a legislative framework defining the overall Federal commitment to HTS–for example, a single bill providing specific multi-year authorizations for HTS R&D by agency. The authorizations would signal the congressional appropriations and budgeting committees, as well as the agencies, concerning the relative shares of funds for HTS R&D to be given to each agency.	A single framework for funding decisions could help keep Congress aware of potential imbalances among the R&D agencies. Multi-year authorizations, along with the multi-year planning exercise discussed in Option 2, and the experiment in multi-year funding discussed in Option 3, could help make the point to universities, the laboratories, and to industry that Congress intends to sustain the Government's commitment to HTS over time.	Congressional guidance could turn into micromanagement of Federal R&D, or pork-barreling.
B. Continuity of Funding HTS could easily require a decade or more of steady R&D support before a technology base adequate to support commercialization emerges, with a continuing need for Congress and the executive branch to assess funding levels, as well as allocations across agencies–e.g., support for processing R&D, and whether it is adequate to support commercialization.	OPTION 2. Direct the Administration to prepare a multi-year estimate of Federal funding expectations for HTS R&D. This might be a rolling 5- to 10-year plan, directed at commercial (rather than military) applications, and intended to be revised periodically (not a rigid, inflexible set of research targets). Private sector input could be built into the process.	As a mechanism for helping policymakers gain perspective on annual budget proposals, multi-year estimates should be useful both to Congress and the agencies. The effort could improve agency coordination, limit overlap in R&D funding, improve the quality of scientific and technical advice to Federal agencies, and reduce the likelihood that money for superconductivity will come at the expense of other needed R&D. If successful for HTS, the approach might become a model for other fields.	Without proper oversight from upper levels in the Administration, such an exercise could turn into an agency wish list, with little utility for making tough budget decisions. Moreover, any effort to develop a government-wide perspective would probably be seen by some as top-down planning–threatening agency autonomy and flexibility. Multi-year budget estimates, finally, would probably have limited utility unless the agencies supported the concept–which few do now.
Stop-and-go funding has been a common problem for U.S. science and technology policy–and a serious one–in part because of year-by-year budgeting for Federal R&D. A period without newsworthy research results could lead to a dry spell in HTS R&D budgets.	OPTION 3. Direct the Administration to experiment with a 2-year funding cycle for HTS–possibly beginning with a pilot program at NSF. (Section 201 of Public Law 100-119 encourages congressional committees to experiment with multi-year authorizations and 2-year appropriations.)	Uncertainty over funding for HTS during 1987 and early 1988, and particularly over the prospects for new money, made it hard for research groups in government, universities, and industry to plan, and delayed some projects. Such problems cannot be totally avoided in a fast-moving field like HTS. But a 2-year budget cycle would help keep R&Don a steady course.	In the absence of improvements in mechanisms for establishing R&D priorities, a 2-year budget cycle would do little to overcome the fundamental budgeting problems posed by competition for limited funds, To some extent, a 2-year cycle might reduce the flexibility of the system, with potentially serious consequences in periods of rapid technological advance.
C. National Science Foundation Budget Despite the Administration's announced objective of a doubling in the NSF budget between 1988 and 1992, the Foundation's fiscal 1988 appropriation grew by only 6 percent (compared with a request of 17 percent). NSF has had to postpone increases in funding for multidisciplinary R&D centers and for research in engineering, traditionally underfunded.	**OPTION 4.** Consider substantial increases in the NSF budget over the next few years. Budget increases along the lines of President Reagan's proposal for a doubling of the Foundation's budget over 5 years would permit NSF to double or triple its funding for engineering research –to the $400 million to $500 million level–without sacrifices elsewhere.	More money for engineering would be a major step, not only in commercializing HTS, but in supporting U.S. industrial competitiveness across the board. NSF will spend $171 million on engineering research in fiscal 1988, only 10 percent of the agency's research budget.	Given the size of the Federal budget deficit, a significant increase for one agency could well come at the expense of others. The increases in civilian R&D included in the President's fiscal 1989 budget request–$300 million for NSF, $400 million for DOE, $2.5 billion for NASA–cannot be accommodated within the framework agreement worked out between Congress and the Administration in late 1987 unless Congress adjusts other budget items downward.
Laboratory equipment in many American universities is inadequate for either research or teaching.	OPTION 5. Appropriate substantially more money to NSF–an added $100 million or more per year–for equipment grants to the Nation's universities for both research and teaching.	Gifts from the private sector can help, but the problem is far too big to be solved in this way alone. Government action would help improve the Nation's technological capabilities,	Unless accompanied by an overall increase in NSF's budget (see Option 4), more funds for equipment could cut into the Foundation's research budget.

Table 9.—Issue Area 1: Funding Levels and Priorities for Federal R&D—Continued

Issue	Options for Congress	Advantages	Disadvantages
D. Weaknesses in the Industrial Technology Base			
Despite the size of the U.S. R&D budget, gaps open in the technology base where neither industry nor government provide support. Prior OTA assessments have pointed to some of the problems; many more certainly exist. The first step toward a solution is to characterize the weaknesses more fully	OPTION 6. Request a detailed review of the U.S. technology base by the National Academies of Science and Engineering. Such a review might encompass: • funding levels for both basic and applied research across the broad range of scientific and technical disciplines **important for industrial competitiveness, with particular attention to actual and potential bottlenecks and to technical fields (like manufacturing) that historically have been underfunded;** • **processes for setting research priori**ties and determining funding levels within and across Federal agencies.	Given the budget deficit, it is more important than ever that R&D decisions be based on sound analysis, Less glamorous. less visible fields tend to suffer most in such periods, with harmful impacts that show up only in later years, when the damage has been **done.**	Studying the problem without taking steps to solve it would accomplish little,
American companies conduct relatively little basic research. Under the Tax Reform Act of 1986 (Public Law 99-514) companies get a more favorable tax credit for basic research they fund in universities than for work performed internally. Both the general R&D tax credit and the basic tax credit for work sponsored at universities expire at the end of 1988.	OPTION 7. Permit a separate tax credit for basic research conducted within the firm. To have much impact, an in-house research credit would have to be as favorable as current rules applying to basic research paid for by industry but conducted at universities, and more favorable than tax credits for internal R&D under the 1986 tax act, A basic research credit could supplement the overall R&D tax credit if Congress decides to make it permanent for 1989 and beyond. If Congress lets the existing credit expire, a special provision might be crafted-perhaps on a trial basis–for basic research within industry.	A basic research credit for work within the firm would create stronger incentives for attacking technical problems that fail to excite much interest in universities.	Creating new tax credits runs counter to the spirit of tax reform, while enforceable guidelines for basic research could be difficult to define,
E. Setting Priorities for Federal R&D			
Competition for Federal R&D dollars seems bound to grow more intense, with conflicting demands between big science and small, defense and civilian R&D, and basic research and more applied work. Establishing priorities and sticking to them–e g , weighing the pros and cons of expenditures such as required for a Superconducting Super Collider, or the National Aerospace Plane–requires a government-wide perspective. This is the job, in principle, of the Office of Science and Technology Policy (in the Executive Office of the President).	OPTION 8. Give the Office of Science and Technology Policy access to the staff resources and advisory processes needed, not only to monitor science and technology issues in the agencies, but to assume an effective decisionmaking role within the executive branch.	A strengthened OSTP would permit the Executive Office of the President to develop and articulate priorities for science and technology–backed up with analytical depth and detail that have not been possible, given the Office's current staff (about 30) and budget (about $1.9 million).	OSTP will have little influence unless the President wants it to, Lacking this, congressional action to strengthen the Office would make little difference,

SOURCE: Office of Technology Assessment, 1988.

introduced—would direct the executive branch to provide, on a one-time basis, a Federal program plan for superconductivity, including estimated funding levels by agency for a five-year period. H.R. 3217 would assign the overall responsibility to the Executive Office of the President, with roles for the Office of Science and Technology Policy and the National Critical Materials Council. It provides for consultation with the mission agencies, as well as universities and industry. The proposal would also create a more formal structure for coordination among agencies, (Box M discusses interagency coordination of HTS R& D.) Any effort to develop Government-wide estimates risks being seen as top-down planning—threatening agency autonomy, professionalism, and flexibility. Nonetheless, viewed as a mechanism for helping policymakers gain perspective on annual R&D budget proposals, multi-year estimates could be useful both to Congress and to the agencies.

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Box M.—Coordinating the Federal Effort

Given the U.S. Government's highly decentralized approach to R&D, coordination has been a perennial issue. HTS promises to be no exception. With a wide-open scientific and technical agenda—and potential applications that range from a space-based strategic defense system to high-performance computing to electric power (Appendix B)—many agencies have good reasons for supporting R&D, and many organizations and research groups good reasons for seeking funds from Government. Decisions made in industry will determine when HTS reaches the marketplace. But government decisions—on R&D funding (for universities, for the national laboratories, for industry), procurement plans by the mission agencies (principally DoD), and a host of other matters—will affect the timing of commercialization.

Issues of coordination have technical dimensions and policy dimensions. Soon after discovery of the new materials, the Administration established a subgroup of its Committee on Materials (COMAT) to deal with superconductivity. COMAT itself is a committee of the Federal Coordinating Council on Science, Engineering and Technology, an interagency group chaired by the White House Office of Science and Technology Policy (OSTP). The new subgroup provides a forum for interchange among research administrators of major Federal R&D agencies. A number of the agencies, in turn, have established internal coordinating bodies, such as the working group within DoD which prepared the Department's 5-year R&D options paper (discussed later in the chapter). Within DOE, the Energy Materials Coordinating Committee has created a subcommittee on superconductivity. DOE, NBS, and NSF have joined with the Electric Power Research Institute and a number of utilities in a committee on electric power applications of HTS. And of course, in a relatively small and specialized field like superconductivity, program managers and contract monitors in the agencies normally know one another, and talk frequently. Informal exchanges of information, however, have little to do with the hard choices of setting priorities and making budgetary decisions.

Up to this point, coordination at high policymaking levels—of the sort that might help sustain the Federal commitment to HTS over the longer term—has been *ad hoc*. The Economic Policy Council (EPC) set up a working group to develop the President's 11-point initiative, but the EPC itself is an informal body, with no statutory basis. Chaired by the Secretary of Treasury, and lacking full representation from such major R&D agencies as DoD, the EPC has not played much of a role since the release of the initiative. OSTP itself, with a staff of about 30 people and a very broad range of responsibilities, finds itself continually pressed to keep up with issues that emerge on a day-to-day basis. The Administration's Wise Men's Advisory Group on superconductivity—announced in the President's initiative but not appointed until February 1988—will probably go out of business after delivering its report.

Given the circumstances—hardly unfamiliar ones in U.S. science and technology policy—several members of Congress have introduced proposed pieces of legislation calling for a national program on superconductivity. Advocates of some such program point to the many Federal agencies that are already funding HTS R&D, and cite the need for coordination to avoid the dangers, on the one hand, of duplication, and, on the other, of neglecting critical technical needs. They also argue the need for an overall plan, with benchmarks for Federal R&D spending over the longer term. On the other side are those worried about new layers of bureaucracy, who contend that the R&D agencies do a good job of coordinating their activities—because, after all, it is in their interests—and that HTS will be no different.

Perhaps the first question is this: Who could do the planning and coordinating? Is it realistic, for example, to expect the National Critical Materials Council (NCMC) to take this on (as proposed in several bills)? Created by an Act of Congress in 1984, thus far the Council has not been very visible. The Reagan Administration opposed its creation, and did not name the first members for more than a year. Only rarely has the NCMC enjoyed a professional staff of more than one. The Administration's 1989 budget would cut the Council's funding in half, from $350,000 to $175,000. Assigned in 1984 the task of developing a Federal program plan for advanced materials, the Council has yet to do so, although plans have been announced for a submission to Congress in the summer of 1988; as currently envisioned, the submission will be little more than a report reviewing Federal activities in materials (including superconductivity)—not a program plan.

Without major changes, the NCMC would plainly have difficulty in serving as a coordinating body for HTS. This could all change, of course, given an Administration committed to the idea of a National Critical Materials Council—willing to give it a staff, and listen to its advice.

How about private sector input to government planning processes? President Reagan's initiative created the Wise Men's Advisory Group (all five members are in fact men) to provide high-level policy guidance. Several private organizations hope to serve similar functions on a less formal basis (e.g., the Council on Superconductivity for American Competitiveness, headed by George Keyworth, former director of OSTP). A number of bills before Congress have proposed temporary commissions with representatives from government, industry, and universities. Others propose a body that would report periodically to Congress on policies for accelerating commercialization of HTS.

The decentralized U.S. approach to R&D implies ongoing coordination. Lacking this for HTS, there are real risks of a Federal effort adding up to less than the sum of its parts. Perhaps the primary point is that *coordination in the sense of information exchange has little to do with priorities*. The Federal Government has few mechanisms for sorting out R&D funding across agencies. Multi-year authorizations and a 2-year trial for HTS, as suggested in Options 2 and 3, could help Congress and the Administration establish and maintain priorities.

With Congress appropriating money annually for research programs that may go on for years, the ups and downs in R&D funding have also stimulated frequent proposals for multiyear authorizations and/or appropriations.[4] Although Congress has been reluctant to move in this direction, growing concern over the budget process as a whole has led to discussion of a two-year budget cycle. As a more modest step toward a longer-term perspective on R&D decisions, Congress could experiment with multiyear funding in a single agency—perhaps NSF (Option 3). The experiment might be undertaken by programs in, say, the engineering directorate or the materials research division—both of which support HTS.

Neglect by Government and industry of commercial R&D has slowed the passage of technology from laboratory to marketplace, harming U.S. productivity and competitiveness. Less glamorous fields, particularly in engineering, seldom attract funding commensurate with their potential economic significance. Chapter 2 stressed U.S. underinvestment in processing R&D; other examples include materials synthesis (box C, ch. 2).[5] For such reasons, and despite the huge U.S. investment in R&D, the technology base no longer seems adequate to support a competitive set of industries.

In government, lack of mechanisms for setting priorities, coupled with stop-and-go funding for some kinds of R&D, have contributed to the problems. Gaps and holes in the technology base emerge particularly in fields that Federal agencies—DoD, DOE, NASA (the Na-

[4]For discussion of some of the possible mechanisms, see U.S. *Science and Engineering Base: A Synthesis of Concerns about Budget and Policy Development,* GAO/Reed-87-65 (Washington, DC: U.S. General Accounting Office, March 1987), pp. 22-34.

*On the lack of R&D in construction technologies, see *International Competition in Services* (Office of Technology Assessment, July *1987),* pp. 138-144. Other examples include:

- Direct reduction of iron to steel.
- Railway technology. (Given the importances of rail transportation for the Nation's economy, support has been woefully inadequate compared to, say, aeronautical engineering.)
- Process control models for the fabrication of microelectronic devices.
- Theoretical foundations for software engineering. (Better understanding could lead to greater productivity in programming, helping break a major bottleneck in U.S. industry.)
- Fundamental understanding of combustion processes. (Environmental pollution from stationary powerplants, burning of solid wastes, and automotive engines costs the United States billions of dollars each year. Lack of a research base in combustion—in terms of thermodynamics, chemical kinetics, fluid mechanics, heat transfer—makes it difficult to develop inherently clean combustion processes.)
- Corrosion and wear. (These processes, so familiar and pervasive as to seem inevitable, have economic costs measured in billions of dollars annually; wear, in particular, has never attracted much scientific attention or research support.)

Also see *Directions in Engineering Research: An Assessment of opportunities and Needs* (Washington, DC: National Academy Press, 1987].

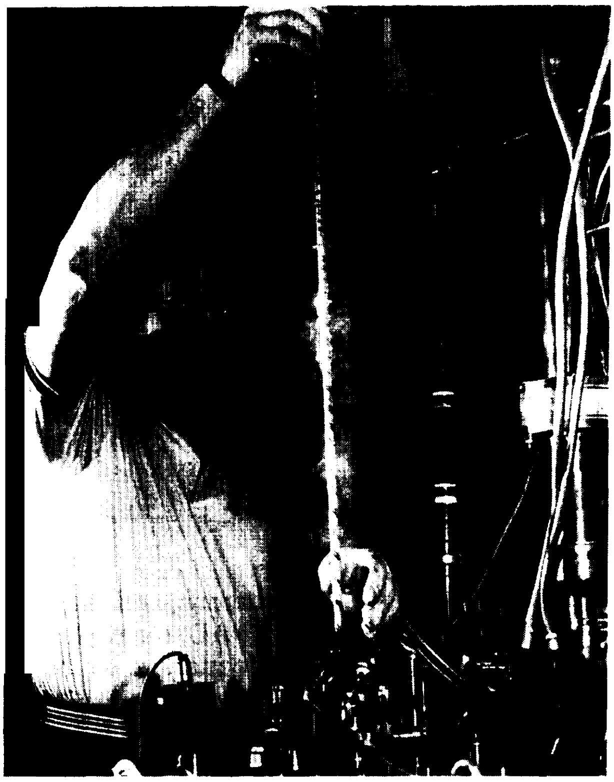

Photo credit: Argonne National Laboratory

HTS superconducting wire, ready for testing.

tional Aeronautics and Space Administration)—view as too far from their missions, and that, in the view of corporate managers, will not yield financial returns in the short or medium term. Among the other causes: relatively low levels of support for engineering research, and Federal R&D programs that have often gone astray when not tightly linked to agency missions.

Congress could begin to enlarge the pool of commercially-relevant technology by appropriating additional funds to NSF, allowing the Foundation to expand its support for engineering research without taking money from other areas (Option 4). NSF's mission embraces the strengthening of the Nation's science and engineering base; yet its current spending on engineering research ($171 million) does not amount to three-tenths of a percent of the overall Federal R&D budget.

Congress might also provide additional money to NSF specifically for laboratory equipment. Equipment in the Nation's engineering schools averages 20-30 years old; a quarter of it cannot even be used.[6] An additional $100 million annually, to supplement NSF's current spending of $250 million a year—would help (Option 5).

NSF ranks no better than fifth in R&D spending among Federal agencies. Any search for a broad solution to the problems in commercial technology will have to look beyond NSF and the university research it sponsors. Given the pressures on the Federal budget, a realistic first step might be to identify the weaknesses in the existing technology base, and begin establishing priorities for allocating the limited funds available. Congress could ask the National Academies of Sciences and Engineering to begin this task (Option 6).

As a complementary measure, aimed at encouraging American firms to undertake more fundamental research, Congress might consider changes to the Research and Experimentation Tax Credit.[7] At present, industry finances only a fifth of all U.S. basic research. Federal agencies—which pay for two-thirds (universities fund the remainder)—do not set priorities based on commercial relevance. Giving companies greater incentives to conduct work inhouse would help focus basic research on industrial needs.

Congress could institute a special basic research tax credit for work conducted within

[6] P. Doigan and M. Gilkeson, "Engineering Faculty Demographics: ASEE Faculty & Graduate Student Survey, Part II," *Engineering Education*, January 1987, p. 212. The National Research Council suggests that an increase of $3o million or more for engineering equipment alone would be appropriate—*Directions in Engineering Research: An Assessment of Opportunities and Needs*, op. cit., pp. 50-51. Also see "Scientific Equipment for Undergraduates: Is It Adequate?" staff paper, Science, Education, and Transportation Program, Office of Technology Assessment, Washington, DC, September 1986.

[7] Introduced in 1981, the credit was reduced from 25 percent of qualifying R&D expenditures to 20 percent in the 1986 Tax Reform Act. On its effectiveness, see *International Competition in Services*, op. cit., p. 364. Current law allows companies more favorable tax treatment for support of basic research at universities or other qualified R&D organizations than for work carried out at their own facilities,

industry (Option 7). Assuming that Congress extends the existing R&D tax credit, now set to expire at the end of 1988, or makes it permanent, basic research conducted internally could be given more favorable treatment than other qualifying R&D.

Finally, Congress could ask the Academies for recommendations on an R&D strategy aimed specifically at strengthening the Nation's commercial technology base (as noted in Option 6). Such an exercise might help OSTP carry out its policy and planning functions—including legislative mandates that the office has had limited success in fulfilling. As discussed under Option 8 in table 9, OSTP may need strengthening if it is to be an effective arbitrator among agencies and interest groups seeking Federal R&D funds. In a period of intense competition for scarce dollars, a Government-wide perspective is needed more than ever in setting and enforcing priorities.

Defense-Related R&D

Funding Patterns

DoD has been supporting superconductivity R&D for more than three decades because of the potential applications in military systems. In this light, the dominance of DoD in Federal support for I-ITS (shown earlier in table *8)* should be no surprise; much of the work is a natural follow-on to earlier sponsorship of LTS R&D.

The three services, together with DARPA and the Strategic Defense Initiative Organization (SDIO), maintain their own programs–with the DARPA and SDIO efforts the biggest by far (table 10). Three-fourths of DARPA funds, and a high proportion from SDIO, go to industry. DARPA states that as much as *60* percent of the processing R&D contracts currently in negotiation could go to firms that are not traditionally part of the defense industry. As for the services, about two-thirds of their HTS R&D funding is currently going to universities; if HTS follows the typical pattern for basic research in the services, this fraction may eventually decline somewhat (universities perform about half the *6.1* (basic) research paid for by the services, with government laboratories and industry sharing the remainder).

DARPA's widely publicized processing initiative accounts for nearly all that agency's *1988* total of *$18* million. With no R&D facilities of its own, DARPA will support processing-related work in industry, universities, and laboratories overseen by other agencies. The primary objective: speeding development of fabrication techniques for HTS coatings, thin and thick films, wires and other conductors. DARPA officials view the effort as a natural extension of the agency's ongoing program in manufacturing technology for advanced ceramics. After receiving about *zoo* proposals during the summer of 1987—responses to a solicitation that assumed funding of up to $50 million for 1988 —the agency announced in January that some 16 companies and 4 universities had been selected to enter into contract negotiations. When DoD placed a temporary freeze on some of its outside R&D (including DARPA's) in May 1988, nearly all of the contracts remained to be awarded. The freeze was in effect when this report went to press in June 1988.

SDIO's HTS R&D—second to DARPA's in funding–focuses on relatively near-term applications. The organization works closely with the services and other agencies, looking to "technology insertion working groups" for advice on where to direct its R&D dollars. Like other parts of DoD, SDIO contracts extensively with industry. In addition to HTS, the organization funds considerable work on LTS—for instance, a design competition on magnetic energy storage for powering large lasers, budgeted at $11 million currently and $13 million for fiscal 1989.

R&D sponsored by the services reflects their missions. Much of the Air Force effort goes toward possible applications in electronics, funded (principally through the Air Force Office of Scientific Research) in universities and the Air Force's own laboratories. The Office of Naval Research is likewise putting most of its current HTS money into basic research (6.1). While the Army also has a program underway, the level is low (as expected, given that the

Table 10.-Department of Defense Funding for HTS R&D[a]

	Fiscal year budget (millions of dollars)		
	1987 (actual)	1988 (estimated)	1989 (requested)
Army	$1.0	$2.0	$3.0
Navy	5.0	7.0	9.0
Air Force	4.0	7.0	8.0
Defense Advanced Research Projects Agency (DARPA)	4.0[b]	18.0	20.0
Strategic Defense Initiative Organization (SDIO)	5.0	12.0	23.0
	$19.0	$46.0	$63.0

[a]Working figures, subject to change. DoD also spends substantial sums on low-temperature superconductivity.
[b]Includes $2 million from the Balanced Technology Initiative.

SOURCE: U.S. Department of Defense, April 1988.

Army traditionally funds relatively little R&D compared to the other two services). Each of the services has formed internal working groups to coordinate its effort.

Implications for HTS

With DoD paying for nearly half the government's HTS R&D, the obvious question follows: What does this mean for commercial development, and for the civilian side of the economy? In the past, Federal dollars for both R&D and procurement provided much of the impetus for vibrant commercial industries—aircraft, computers, microelectronics.

At the same time, as summarized in box M, DoD's very success in driving technology forward has led to a split between military and civilian applications, with defense systems growing steadily more specialized. Some would claim that military spending has undermined U.S. industry—distorting the technological enterprise by diverting the best and brightest engineers and scientists from civilian industries, skewing university research (and, through the research interests of faculty, university curricula), and turning companies aside from the cost-driven discipline of the marketplace. In this view, rather than providing fertile ground for spinoffs, DoD support for HTS might divert resources from commercialization.

Indeed, there seems little reason to expect that spinoffs from DoD funding for HTS will have impacts as significant as those that spurred earlier high-technology industries. Since the *1950s* and *1960s,* technology transfer from the military to the civilian side of the economy has slowed, for reasons that include the expanding curtain of secrecy surrounding DoD and its contractors. With military systems growing steadily more esoteric, it would be unwise to rely on DoD support for HTS as a *substitute* for civilian R&D. This does not mean that DoD R&D cannot be a valuable *complement.*

Two broad questions will determine the effects of DoD spending on the commercial prospects for HTS: 1) What are DoD's objectives with respect to HTS, and how do they compare with commercial needs? and 2) How much money will go to generic R&D, and thus offer potential for commercial spillover regardless of ultimate system requirements?

In mid-1987, a DoD working group examined the R&D that would be needed to exploit HTS in military systems. The working group, in an options paper described as a "map of the territory" rather than a "predetermined itinerary," concluded that an aggressive program to bring HTS to the point of military-specific applications would cost about $500 million over a 5-year period.[8] The working group's options paper, which assumes that technology, not money,

[8]"Superconductivity Research and Development Options: A Study of Possible Directions for Exploitation of Superconductivity in Military Applications," U.S. Department of Defense, July *1987.* Summary figures for the 5-year program plan, totalling $506 million, appear on pp. 122 and 123. In the first 3 years (fiscal 1988 to 1990], the working group called for $293 million—twice the $150 million DoD expenditure mentioned in the President's July 1987 superconductivity initiative, and far more than defense agencies are likely to spend over this period, judging from preliminary budget figures.

would be the limiting factor, discusses R&D in several broad categories:

- materials characterization, including efforts to find HTS compositions with higher transition temperatures;
- processing R&D;
- small and large scale applications and demonstrations.

While there are no signs that the 5-year spending plan will go forward as outlined in the working group's report, the budget estimates provide a baseline for considering DoD's view of prospects and priorities in HTS. Sixty percent of the 5-year total would go for applications—$306 million. processing–which holds more potential for commercially relevant R&D results—would get $129 million, or 25 percent; the options paper allocates $71 million for materials characterization, equally generic. The breakdown by budget category paints a similar picture: basic research (6.1) accounts for 29 percent of the total, compared to 38 percent for exploratory development (6.2), and 33 percent for advanced development (6.3A). Viewed either way, basic research and generic R&D would get a substantial share of the resources, as befits a new technology.

Most but not all of the applications work would be of interest primarily to the military. Examples include infrared sensors, detectors for submarines, and electromagnetic coil/rail guns. Some applications projects might generate commercial spinoffs: electronic devices for digital systems; motors, generators, and other electrical power equipment. (As discussed in app. B, these applications could, in principle, be implemented with LTS technology; indeed, even were HTS reduced to practice, LTS might provide superior performance.)

Still, superconducting motors and generators for military applications, to take one example, will differ fundamentally from those for civilian applications. DoD's interest stems largely from the advantages that superconducting motor-generator sets could have for ship propulsion and on board aircraft. Such propulsion systems would offer new freedom in packaging the major systems within a ship's hull; for submarines, in particular, there would be more room for weapons. Compact design becomes a primary design criteria. For civilian power generation, in contrast, greater efficiency is the objective, with size (and weight) of little import. From a design standpoint, superconducting generators for the military and for electric utilities would have relatively little in common. Only in the most general sense would know-how from one transfer to the other.

Processing technology will be particularly important for HTS. Wire manufacture and fabrication received little emphasis in LTS R&D until becoming a bottleneck to applications. Years were then spent learning to produce niobium-titanium wires and windings with the needed properties. A similar experience in HTS could put U.S. firms behind, given that processing is an area in which Japanese firms will undoubtedly excel. Here, DARPA's processing program should help. Many of the processing and fabrication methods ultimately developed will be similar regardless of end-application, and DoD officials have frequently stated that results will remain unclassified to the extent possible. (In part for such reasons, H.R. 3024, the proposed National Superconductor Manufacturing and processing Technology initiative, would give DARPA a lead role in the Federal Government for processing-related work. The 100th Congress had taken no action on this bill, which assigns subsidiary roles to DOE, NSF, and NBS, as OTA's report went to press.)

DoD work aimed at high-performance computers, where applications will depend in part on thin-film fabrication capabilities—e.g., for Josephson junctions–could likewise have positive impacts on the civilian economy. Not only DARPA, but the National Security Agency has traditionally supported work aimed at high-performance computing (box N).

If DoD were to follow a spending plan something like that outlined by the working group—i.e., roughly half a billion dollars over five or six years—civilian industry would surely benefit from some of the technology developed. Despite the stress on applications—noteworthy, given the relative pessimism of U.S. industry

Box N.—DoD and Postwar High-Technology Development

R&D and Procurement

The decades between the end of World War II and the Vietnam War represented a kind of golden age for U.S. military R&D. Defense planners needed jet engines for high-performance fighters and bombers, computers for plotting missile trajectories, semiconductors for the guidance systems in those missiles. When these technologies were young, with almost no infrastructure of trained people or knowledge, the Federal Government picked up most of the tab for creating an industrial base. Defense and space agencies funded basic research, along with generic technology development. Within DoD, much of the responsibility fell to the Advanced Research Projects Agency, established in 1958 (the prefix changing the name to DARPA came in 1972). Box O, later in the chapter, describes some of ARPA's activities in support of university research during the 1960s.

(D)ARPA was not alone in supporting generic technologies. During the 1950s, the Air Force spent more than $60 million developing numerical control (NC) systems for machine tools—badly needed for carving out aircraft structural members. Work carried out at MIT's Servomechanism Laboratory and elsewhere led to both hardware and software technologies for NC that have since spread worldwide. To take another example, the SAGE air defense system, also developed for the Air Force during the 1950s, required the coordination of multiple computers in real time. Teams from MIT, IBM, Burroughs, and Bell Telephone Laboratories laid many of the foundations for timesharing, digital communications, and computer graphics.[2] Although NASA (and its predecessor, the National Advisory Committee on Aeronautics, NACA) focused primarily on system-oriented development, during the Apollo years the space agency took care to spend money with the Nation's universities.

The Pentagon not only paid for mission-oriented R&D directly, American companies pursued related work on their own in hopes of future contracts. As the customer, DoD guided and stimulated technological advance. Agencies knew what they wanted. They could evaluate alternatives, provide feedback to R&D groups and manufacturers.[4] For industry, the follow-on procurements meant profits and stability. Even in the middle 1950s, IBM got nearly half its revenues from sales to the U.S. Government—far more than any of the firm's rivals, and a major factor in IBM's emergence as by far the biggest computer manufacturer in the world.[5] In the semiconductor industry, learning economies resulting from rapidly expanding production volumes drove down the average price of an integrated circuit from $50 in 1962 to $1.62 by the end of the decade. Missile systems accounted for most of the demand.

Indirect government support—e.g., purchases of computers by aerospace firms—also contributed to industrial expansion and technological advance. Companies like Boeing and Lockheed pioneered many of the emerging applications of computing. They bought machines, and learned to use them—generally writing their own software. The know-how spread quickly through the engineering profession and to U.S. industry as a whole. In essence, government and industry shared the risks of pushing the technology forward.

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[1] Much of the information on computers in this box comes from "Government's Role in Computers and Superconductors," prepared for OTA by K. Flamm under contract No. [illegible], February 1988. Also see K. Flamm, *Targeting the Computer* (Washington, DC: Brookings, 1987) and *Creating the Computer* (Washington, DC: Brookings, 1988).

[2] Although the SAGE project proved an expensive white elephant from a strictly military standpoint, DoD came to regard it as a great success because of the technological [illegible].

[3] On NASA and the universities, below, see "Case Studies of 'Flagship' Technology," prepared for OTA by W.H. Lambright and M. Fellows, Syracuse Research Corp., under contract No. [illegible], Dec. 31, 1987, p. II-8.

[4] While goal-oriented military R&D often led to successes like the Minuteman missile guidance and control system, in other cases DoD has followed [illegible] technological blind alleys. From the invention of the laser in 1960, for example, the military pursued high-power solid-state lasers for applications such as ballistic missile defense. When the gas-dynamic laser appeared on the scene in [illegible], the services were already heavily committed to the solid-state alternative. Although gas-dynamic lasers held much more promise technically, it was several years before the services changed direction. See R.W. Seidel, "From glow to flow: A history of military laser research and development," *Historical Studies in the Physical and Biological Sciences*, vol. 18, 1987, p. 111.

[5] *International Competitiveness in Electronics* (Office of Technology Assessment, November 1983), p. 147.

[6] On integrated circuits, below, see N.J. Asher and L.D. Strom, "The Role of the Department of Defense in the Development of Integrated Circuits," IDA Paper P-1271, Institute for Defense Analyses, May 1977.

Finally, DoD also funded a considerable amount of visionary research-one of (D)ARPA's jobs. Here, the military mission did not always dictate R&D objectives, or even provide much guidance: (D)ARPA supported work in artificial intelligence and the behaviorial sciences inthe absence of near-term military applications.

Military and Civilian Technologies: Diverging Objectives

During the Vietnam years, defense R&D growth slowed; DoD has never built its support for generic technology development back to pre-Mansfield Amendment levels. (The Mansfield Amendment, part of the military authorization bill for fiscal years 1970 and 1971, sought to tie DoD R&D more closely to defense needs.) Meanwhile, military high technology moved steadily away from civilian high technology. In the face of pressures from the Pentagon, DARPA too has turned toward projects for which it can more easily demonstrate military relevance, and steered a greater fraction of its funding to traditional defense contractors.[4]

As computers, for example, proliferated on the civilian side of the economy, prices dropped and the government role as primary customer declined. Computer firms took more of the R&D burden on themselves, adapting their products to the needs of banks, insurance companies, and manufacturing firms. Even so, defense agencies have continued to support both basic research and high-risk, high-cost development projects—work that could have major impacts in the future; as noted in chapter 3 (box J), the National Security Agency provided partial support for IBM's research on superconducting computer components. Military demand also continues to provide substantial support for supercomputer manufacturers.[5]

In semiconductors, the story is similar. Military procurements accounted for about half of all U.S. production in 1960. By the middle 1970s, the military had become no more than a minor customer for all except the most highly specialized chips; today, military sales run at less than 10 percent of the U.S. market, In 1979, the Pentagon found itself forced to create the VHSIC (Very High-Speed Integrated Circuit) program, an effort to take advantage of advances on the commercial side of the industry, where applications had long since outrun those in military systems.

The Pentagon likewise provided much of the early R&D support for lasers—in the early 1960s, twice the industry's own spending—and today continues to pay for most of the work on high-power lasers.[6] Military R&D, including fundamental research, has been conducted primarily in DoD's own laboratories, or those of its contractors, not at universities. As customers, the services have sought laser rangefinders for tanks—the first significant application on the defense side-and beam weapons. Civilian applications, meanwhile, began with eye surgery.

Today, the growing divergence between military and commercial technologies is visible in at least three ways:

- *System Design Requirements.*—In the 19th century, military needs contributed to the technology of interchangeable parts and the American system of manufactures, in the 20th, to the 707—but also to the Space Shuttle, and potentially to the recently proposed National Aerospace Plane (NASP).[7] Mission-specific operating requirements, and growing system complexity, mean less overlap between military and civilian designs. DoD's performance targets for the NASP go well beyond the point of diminishing returns for commercial carriers, who have shown little interest. Specifications and testing procedures for military chips (temperature cycling, radiation hardness) provide another example of the ways in which defense requirements may run counter

[4] DARPA has weathered a number of these cycles—tolerance for visionary research, followed by a turn back toward applications, engineering, and hardware. See *Targeting the Computer*, op. cit., p. 190; also "The Advanced Research Projects Agency, 1S88-1974," Richard J. Barber Associates, Washington, DC, December 1975.

[5] G. Kozmetsky, "Supercomputers and National Policy: Maintaining U.S. Preeminence in an Emerging Industry," *Supercomputers: A Key to U.S. Scientific, Technological, and Industrial Preeminence*, J.R. Kirkland and J.H. Poore, (eds.) (New York: Praeger, 1987), P. 10.

[6] "The Maturation of Laser Technology; Social and Technical Factors," prepared for OTA by J.L. Bromberg, The Laser History Project, under contract No. H2-521O, January 1988; R.W. Seidel, "From glow to flow: A history of military laser research and development,*' op. cit.

[7] *Advanced Materials by Design: New Structural Materials Technologies* (Washington, DC: Office of Technology Assessment, June 1988). Those on the commercial side of the aircraft industry envision an airplane that could fly halfway around the globe in 2 hours, reaching speeds of Mach 5 (i.e., 5 times the speed of sound). DoD aces the NASP as a possible launch vehicle for SDL among other things, and the military version would have to reach Mach 25.

to commercial needs; for years, the industry has argued that DoD requirements are unrealistic, but to little avail.

- *Manufacturing Processes.*—Much of what DoD buys, it buys in small quantities—a few ships, a few hundred planes, a few thousand missiles. Production costs may not be irrelevant, but mass production manufacturing technologies are seldom called for. Moreover, much of DoD's support for advanced manufacturing methods has gone toward specialized techniques such as diffusion bonding of titanium, or filament winding for graphite-epoxy rocket motor casings. Subsonic aircraft do not need titanium structural members, and much of the graphite-epoxy consumed by commercial industry goes into tennis rackets, fishing rods, and golf clubs (where the quality control requirements, for example, need not be as stringent).

  Despite a good deal of military R&D on automated manufacturing technologies—much of it following from earlier support of NC machining—the more recent benefits on the civilian side have been small. The Air Force program on Integrated Computer-Aided Manufacturing—launched in 1979—has yet to have much impact. All three services operate ManTech (Manufacturing Technology) programs. However, these do not seem to have had much effect, even in defense production.[8] DoD's emphasis on system designs that stretch the outside limits of performance encourages labor-intensive manufacturing methods, while cost-plus contracts do little to encourage efficiency.
- *Markets.*—Before the Cold War era, military planners viewed industrial mobilization much as they did manpower mobilization. Industry would convert from producing shoes and cars to boots and tanks. Nuclear weapons, fire-and-forget missiles, and airplanes packed with computers have changed all that. Today, it takes years—sometimes decades—to design and develop weapons systems. The result? A permanent defense industry, one that goes its own way, insulated from commercial markets.

  Even in the many large firms with a foot in both markets—Boeing, IBM, General Motors (especially since its purchase of Hughes)—the two sides of the organization normally function as separate entities; scientists and engineers, who once moved freely between military and commercial projects—taking new technology with them—now tend to stay on one side of the house or the other. In the 1980s, few defense contractors, shielded from the pressures of the marketplace, have the organizational skills or motivation to succeed at commercialization for civilian markets.

The Cold War also brought restrictions on exports of defense-related technologies and the diffusion of technical knowledge. Conflict between secrecy and technology transfer is not new: in 1947, when scientists at Bell Laboratories invented the transistor, they feared their discovery might be classified. Today, the conflict has become more severe. DoD's black programs consumed an estimated $22 billion in 1987, compared to $5.5 billion in 1981.[9] Defense agencies can and sometimes do forbid publication of results based on R&D they fund, even if unclassified. The effects of restrictions on the flow of scientific and technical information have been widely debated in the United States. The impacts on commercialization, while getting less attention than those on the research enterprise itself, could be just as serious.

[8] *Manufacturing Technology: Cornerstone of a Renewed Defense Industrial Base* (Washington, DC: National Academy Press, 1987), p. 16.
[9] J. Stowsky, "Competing With the Pentagon," *World Policy Journal*, vol. 3, 1986, p. 701.

—the options paper calls for a lot of money in total, and a hefty infusion of funds for the more generic work.

But DoD will almost certainly not have this much money for HTS, as table 10 indicates. The fiscal 1988 total--$46 million--is well under the $68 million called for in the options paper, and the gap will grow: DoD has requested $63 million for HTS in fiscal 1989, much less than the working group's recommendation. With funds tight, defense agencies normally preserve their applications programs as best they can; they will have to continue with materials characterization and processing to support downstream development in HTS developments, but the temptation will be to go no further into basic work than absolutely necessary.[9]

The final point is this. R&D management in any mission agency entails a continuous series of large and small decisions. These deal with such matters as funding levels and priorities, research targets, intramural versus extramural projects, contract and program managers constantly weigh alternatives for expenditures ranging from a few thousand dollars to many millions. Broad objectives are set at upper levels; people lower down make their choices guided by these objectives (though often with considerable autonomy). But at all levels, *DoD decisionmakers— from program managers to laboratory directors and the Under Secretary for Acquisition (who has overall responsibility for DoD R&D)—have their eyes on military needs, not those of the civilian economy.* This is their job. Directives from outside the Pentagon may influence these day-to-day decisions, but not by much.

HTS R&D in the Energy Department Laboratories

DOE laboratories have actively sought major roles in HTS, typically for reasons including diversification beyond their primary missions. As table 8 indicated, DOE's budget for HTS R&D exceeds that of NASA, NSF, and NBS combined; table 11 gives the allocation within the Department. If usual patterns prevail, two-thirds or more of DOE's basic research dollars will be shared among DOE's nine multiprogram laboratories (the "National laboratories") and a number of more specialized research facilities,

The Energy Department and its predecessors have been the patron of big science in the Federal Government since the days of the Manhattan Project. While the Federal Government owns the DOE laboratories, most are operated under contract—some by universities, some by private corporations.[10] The laboratories have a collective budget well into the billions, and employ about 15,000 scientists and engineers, Several have strong foundations in superconductivity, stemming from years of work on LTS magnets for high-energy physics and fusion research, along with projects such as Brookhaven's 10-year effort on superconducting power transmission. By one estimate, DOE has spent $100 million on LTS R&D over the last two decades, in addition to $200 million for purchases of materials and equipment. Given this history, and the Department's responsibilities for energy R&D, it is no surprise that the laboratories have garnered the majority of non-DoD Federal dollars for HTS.

A number of the laboratories have excellent equipment for synthesizing and characterizing the new HTS materials. They have physicists, chemists, and engineers with the skills and experience to contribute to the science and technology base for HTS. But while many of these laboratories produce excellent science (as well as mission-oriented weapons development), they have little experience in helping industry

'The technical objectives of DoD 6.1 basic research are commonly shaped to considerable extent by military needs. DoD's own options paper notes:

> While DOD will surely benefit significantly from efforts of other organizations (DOE, NSF, DoC, NASA) in areas of materials characterization, theory, and séarch for high-transition-temperature materials, it is essential that DSRD [Defense Superconductivity Research and Development] itself include substantive activity in these areas. Much of the remainder of DSRD activity is so highly applications driven that DSRD characterization, theory, and search activities are essential as a means to provide focus in directions of greatest perceived impact on DoD applications. Weight considerations are paramount in many DoD applications (as in those of NASA), and DoD has other stressing requirements related to mechanical and thermal shock, as well as to radiation hardness, all of which dictate that DoD-specific characterization investigations be pursued.

"Superconductivity Research and Development Options: A Study of Possible Directions for Exploitation of Superconductivity in Military Applications," op. cit., pp. 19-20.

[10] Eight multiprogram national laboratories have gotten most of the DOE funds for HTS. These laboratories. and contractors as of *1988,* are:

Laboratory	*Contractor*
Argonne	University of Chicago
Brookhaven	Associated Universities, Inc.
Lawrence Berkeley	University of California
Oak Ridge	Martin Marietta Energy Systems, Inc.
Pacific Northwest	Battelle Memorial Institute
Lawrence Livermore	University of California
Los Alamos	University of California
Sandia	Sandia Corp. (a subsidiary of AT&T Technologies)

Livermore, Los Alamos, and Sandia are weapons laboratories. Single-program DOE laboratories active in HTS include Ames Laboratory [operated by Iowa State University) and the Solar Energy Research Institute (operated by the Midwest Research Institute).

Table 11.–Energy Department Funding for HTS R&D[a]

	Fiscal year budget (millions of dollars)		
	1987 (actual)	1988 (estimated)	1989 (requested)
Office of Energy Research			
Basic Energy Sciences	$10.2	$15.1	$16.7
High Energy&Nuclear Physics	0.2	0.2	0.3
Defense Programs	1.6	6.7	6.7
Office of Conservation & Renewable Energy			
Energy Storage & Distribution	0.2	4.4	12.9
Energy Utilization Research	0.1	0.4	2.0
Office of Fossil Energy Advanced Research &			
Technology Development	0.2	0.3	0.2
	$12.5	$27,2	$38.7

[a]Excluding the Department's Small Business Innovation Research Program. DOE currently spends more on LTS R&D than on HTS—$28.5 million on LTS in fiscal 1987, $39.5 million in 1988. In fiscal 1989, the Department isseeking $52 million fo LTS R&D (a figure that excludes $34 million for procurement of materials and components).

NOTE: Totals may not add because of rounding.

SOURCE: U.S. Department of Energy, 1988.

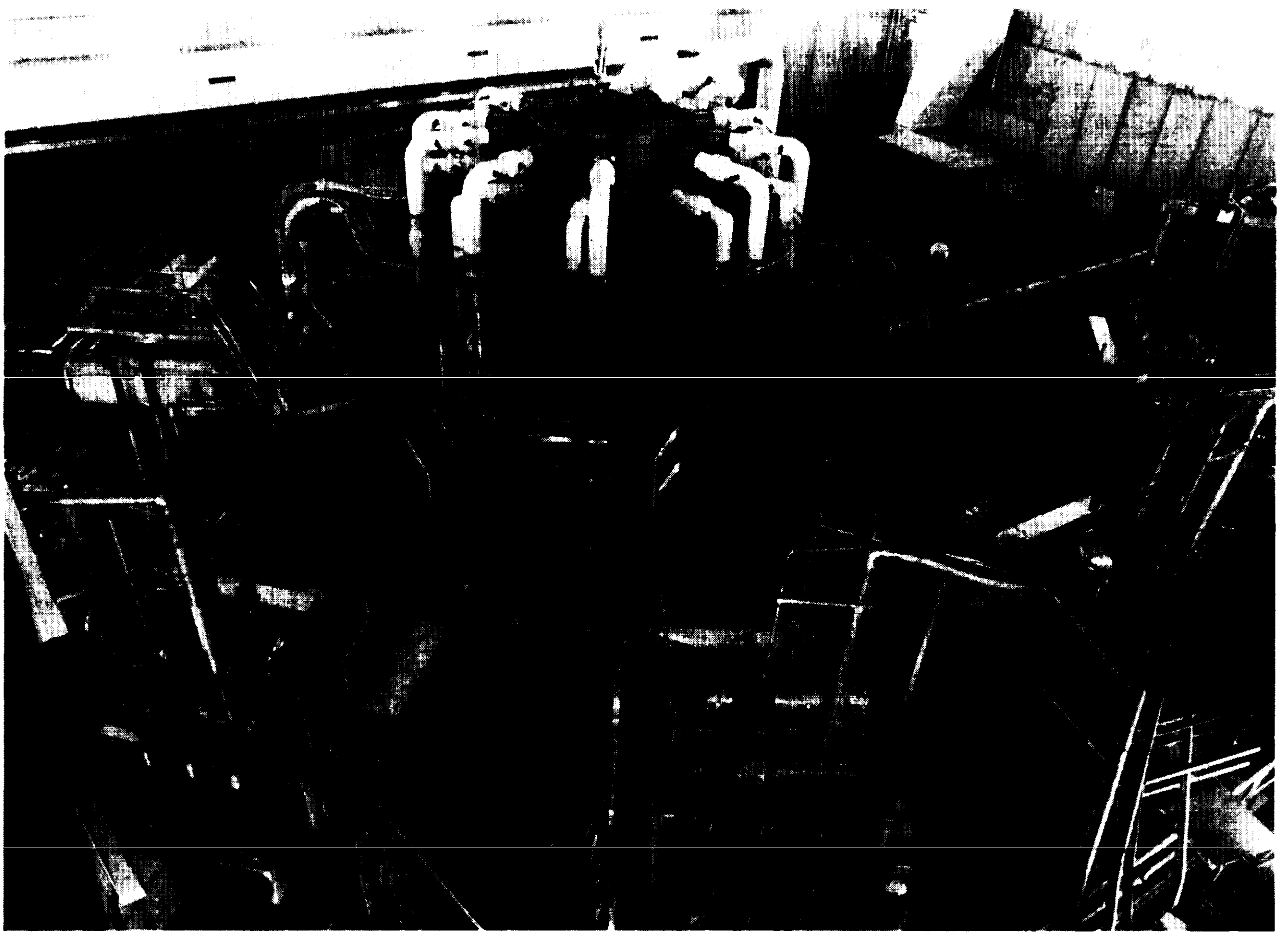


Photo credit: Princeton University Plasma Physics Laboratory

Tokamak Fusion Test Reactor, employing superconducting magnets.

commercialize new technologies. *DOE plans to require the laboratories to involve industry and the universities in their HTS work to a greater extent than usual; for DOE's R&D to have impacts on commercialization commensurate with the Department's budget allocations, these efforts will have to succeed.*

In 1988, more than half of DOE's HTS budget—$15 million of $27 million total—will be channeled through the Basic Energy Sciences program (B ES, table 11). While some BES funds go to universities and to industry, most of the program's HTS work during 1987 was undertaken within the laboratory system—a pattern that will probably continue.[11] BES has established two joint programs in HTS, each involving three laboratories. Under an arrangement worked out in 1987, Argonne, Ames, and Brookhaven will concentrate on processing R&D for bulk materials, while Oak Ridge, Los Alamos, and Lawrence Berkeley will work primarily on materials synthesis, thin films, and electronic devices. The Administration's 1989 budget request would give BES a 10 percent increase for HTS.

Another DOE office—conservation and renewable energy—will spend nearly $5 million in fiscal 1988 for R&D related to possible electric power applications. Initial activities included a number of feasibility studies, including a jointly funded effort with the Electric Power Research Institute examining possible end uses. If the president's 1989 budget is adopted, conservation and renewable energy could find its HTS budget tripling. Most of this would go to the office's energy storage and distribution group. In April 1988, DOE announced that it would provide relatively small sums to 10 DOE laboratories (eight of the multiprogram facilities, Ames Laboratory and the Solar Energy Research Institute) for work related to electric energy storage and distribution. Future funding under this program will depend in part on the ability of the laboratories to involve industry and universities.

As table 11 shows, the only other DOE program with significant funding for HTS engages in defense R&D. Most of this work—budgeted at $6.7 million for 1988, with next year's request at about the same level—takes place at the three weapons facilities.

The sections of this chapter dealing with technology transfer consider DOE's prospective contributions to commercialization of HTS—for instance, the likelihood of productive collaborative efforts between the Department's laboratories and private industry. If cooperative arrangements and rapid technology transfers to industry are to flourish, the laboratories will have to change in style and culture. Table 13, later in the chapter, includes a number of specific policy options for accelerating this shift.

Other Mission Agencies: NBS and NASA

For more than three decades, the National Bureau of Standards, part of the Commerce Department, has been engaged in research on LTS materials. President Reagan's superconductivity initiative gave NBS the responsibility for establishing a superconductivity center focusing on electronic applications. While NBS's technical achievements have been impressive —e.g., a precision voltage standard incorporating 19,000 Josephson junctions—the Bureau is small compared to many other Federal laboratories, and superconductivity a minor part of its work. The NBS appropriation for 1988 included $2.8 million for HTS projects (table 8) on measurement methods, standard reference materials, and devices for measuring weak magnetic fields. The Administration seeks a major increase for NBS—to $9.3 million—for fiscal 1989.

The National Aeronautics and Space Administration's HTS R&D will aim at eventual applications such as remote sensing, power and

[11] The Division of Materials Sciences, which controls most of the money for HTS within BES, spent 63 percent of research funds totaling $155 million within DOE's own laboratories during fiscal 1987. About 35 percent went to universities (including support for graduate student research at national laboratories), and 1.8 percent to industry. See ***Materials Sciences Programs: Fiscal Year 1987***, DOE/ER-0348 (Springfield, VA: National Technical Information Service, September 1987), p. F-3. These figures do not include $15.5 million in equipment funds.

propulsion, and space communications.[12] In space, simple passive cooling systems could keep the new materials below their transition temperatures. As a result, HTS holds considerable interest for NASA. At the same time, space missions demand very high reliability, thus painstaking development and testing; deployment on an actual mission is probably many years in the future. In some contrast to the other major R&D agencies, NASA has not rushed into HTS; the agency's R&D is still in the planning stages.

NASA reprogrammed some $4.2 million for HTS during fiscal 1988—mostly for feasibility studies (table 8), and is seeking twice as much for 1989. The preliminary program plan cited above calls for spending $48 million on HTS over the period 1988-94. Even at this level, however, it seems unlikely that NASA R&D would have much impact on commercialization of HTS: mission requirements are apt to be too specialized.

[12] *NASA Technology Program Plan: High Temperature Superconductivity Technology, Preliminary Program Plan,* Vol. 1, National Aeronautics and Space Administration, Feb. 3, 1988.

NSF AND THE UNIVERSITY ROLE

The National Science Foundation is a mission agency too, but its responsibilities differ greatly from those of DoD, NASA, or DOE. The NSF mission: to support research because this is in the public interest (for reasons including economic growth and competitiveness). Almost all NSF's research dollars go to the university system, which the United States depends on far more than other industrialized economies.

NSF expects to spend $14.5 million in fiscal 1988 on HTS—table 12. With only a few U.S. companies putting much effort into basic research, many of the preliminaries to commercialization of HTS will take place on the Nation's campuses.

Are the universities up to the job? In the short run, the answer is plainly yes. But the work of commercialization will go on for years, and as it shifts from research toward applications, a set of perennial problems in engineering research, and in university/industry relationships, could hinder the process. These problems stem from the inhospitality of universities to multidisciplinary research, and the differing goals of university and industry R&D.

Disciplinary Boundaries

Many of the Nation's universities have strong if often small HTS research efforts. As HTS technology moves ahead, multidisciplinary R&D will be essential. Progress will depend on the physics community—e.g., for theoretical guidance and an understanding of the ways in which structure, particularly at the atomic level (crystallography, flux pinning sites) determines properties (critical current densities). Chemists will add their skills, particularly in materials synthesis and characterization, as well as in processing. Materials scientists will have the job of understanding microstructural and substructural effects (grain boundaries, twins, dislocation structures), and of linking these with processing (e.g., thermal-mechanical sequences). Materials engineers will develop processing techniques that yield the needed structures (hence properties) at reasonable costs. Design of electronic devices will fall mostly to electrical engineers and physicists. Electrical and mechanical engineers will develop high-power/high-field applications—e.g., for energy storage systems. Each group has its own language, its own assumptions and preconceptions, its own world view.

To the lay person, science and technology may seem all of a piece. They are not. In private firms, multidisciplinary groups function effectively because they must—otherwise the company would not be able to compete. Over the past decade, American companies have worked hard at this, as they have faced up to the loss of technological advantages in world competition. Firms like IBM and AT&T—leaders in HTS R&D—have been seeking better ways

Table 12.–National Science Foundation Funding for HTS R&D

	Fiscal year budget (millions of dollars)		
	1987 (actual)	1988 (estimated)	1989 (requested)
Directorate for Mathematical and Physical Sciences:			
Materials Research	$8.0	$10.0	$12.0
Chemistry	0.3	0.4	0.6
Physics	2.2	2.3	2.4
Engineering Directorate:	1.3	1.9	2.2
	$11,7	$14.5	$17.2

NOTE: Totals may not add because of rounding
SOURCE: National Science Foundation, 1988.

of moving new technology from the research laboratory, through development, and into production. The steady advance of technical knowledge—which inevitably entails greater specialization and fragmentation—only makes this more difficult. The job is one for management, and a continual struggle.

Universities find it even more difficult to accommodate such work, lacking the imperatives of the corporation. Specialization and fragmentation begin on campus. Indeed, disciplinary boundaries account for some of the technology gaps noted earlier in this chapter. No one undertakes needed R&D because no group of engineers or scientists looks on the problems as part of its territory (welding, wear, ceramic processing). HTS will probably face some of these kinds of problems.

NSF Centers

Federal agencies have tried to encourage interdisciplinary research in the universities, using the carrot of R&D money, but funds for programs like NSF's Engineering Research Centers (ERCs) remain small compared to those for single-investigator projects. Figure 4 shows the trends over three decades at NSF. Individual project support remains at about 70 percent of the NSF total—well above the level of the mid-1960s.[13] Still, NSF-sponsored research centers could number 80 or more by the middle 1990s, if the Foundation gets the budget increases it has been seeking.

Currently, about one-fifth of the NSF engineering budget goes for the ERCs, the first of which were established in 1985. In the Foundation's 1988 spending plan, the ERCs account for $33 million ($15 million less than NSF originally sought) of the $171 million allocated to engineering.[14]

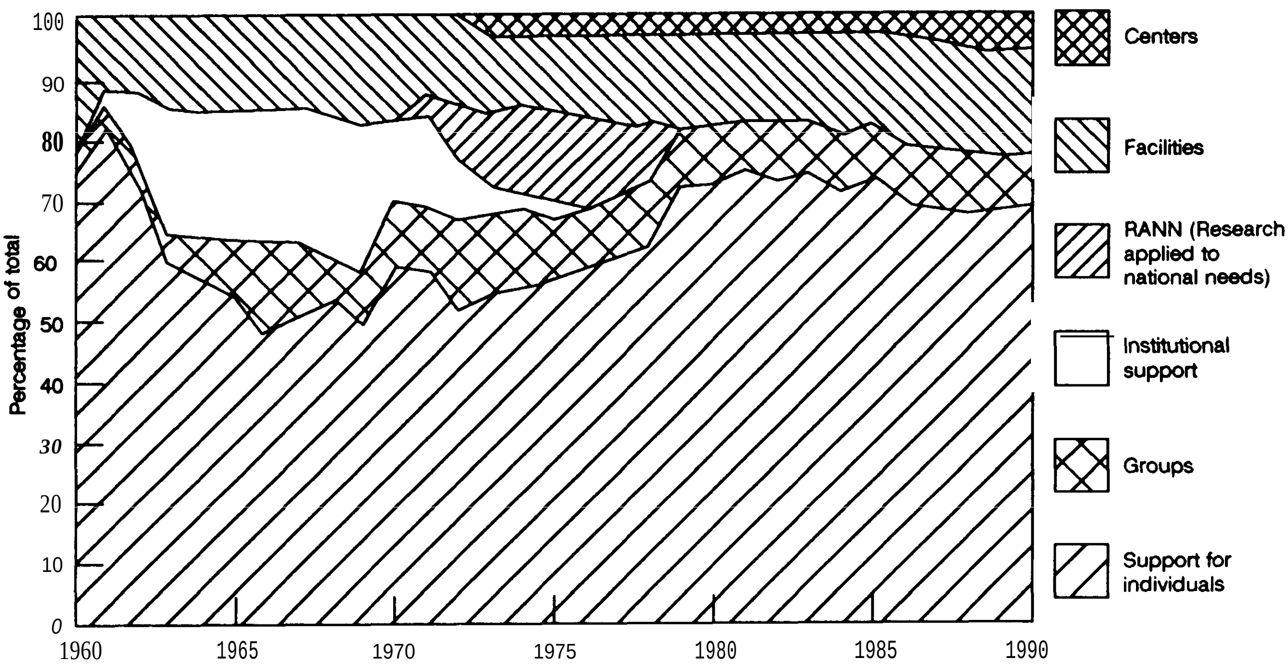
The ERC's are relatively small and focused—e.g., on Optoelectronic Computing (University of Colorado). Annual funding levels have ranged from $1.5 million to $3.5 million. While NSF expects many proposals for HTS centers in the future, superconductivity does not fall within the purview of any of the 14 ERCs approved through the end of 1987. Indeed, this group of 14 includes only one center in the area of materials (and it is scheduled to lose its NSF support)--perhaps because the Foundation also funds about a dozen interdisciplinary Materi-

[13] About 13 percent of NSF's fiscal 1987 budget went for multidisciplinary research centers—Department *of Housing and Urban Development–Independent Agencies Appropriations for 1988,* Part 4, hearings, Subcommittee on HUD-Independent Agencies, Committee on Appropriations, U.S. House of Representatives (Washington, DC: U.S. Government Printing Office, 1987), p. 74.

[14] In the first 2 years of the program, the Foundation approved 11 ERCs (expending $27.7 million, with industry, States, and localities more than doubling the NSF contribution). Current plans call for up to 18 ERCs by the end of 1989. Under the program, NSF agrees to support centers for up to 11 years, with evaluations after 3 and 6 years. The Foundation recently announced it will discontinue support for two of the initial centers, following their 3-year reviews. For further background, see ***The New Engineering Research Centers: Purposes, Goals, and Expectations*** (Washington, DC: National Academy Press, 1986), and ***Educating Scientists and Engineers: Grade School to Grad School*** (Washington, DC: Office of Technology Assessment, June 1988), ch. 3.

On NSF's proposed S&T centers, below, see ***Science and Technology Centers: Principles and Guidelines*** (Washington, DC: National Academy of Sciences, 1987); also C. Norman, "NSF Centers: Yes, But . . . " ***Science,*** July 3, 1987, p. 21.

Figure 4.—National Science Foundation Research Support



SOURCE: National Science Foundation, 1988

als Research Laboratories (MRLs) under a separate program (see box O).

As discussed in box O, ARPA (later DARPA) —which, over the years, has financed a good deal of work in superconductivity–originally sponsored the MRLs. Five of the MRLs have moved into HTS research, with $3.5 million of NSF's 1988 support for HTS going toward these activities.

The MRLs represent an early attempt by the Federal Government to change the ground rules for university research; the ERCs, along with NSF's proposed Science and Technology (S&T) centers represent the latest. Announced by President Reagan in his 1987 State of the Union Message, the S&T centers could eventually become the largest NSF program for interdisciplinary research support. Universities submitted more than 300 proposals after this program was announced (plus a comparable number of planning proposals), a third of them in the general area of materials (and some of these on superconductivity). Given the slow growth in its budget, discussed above (table 9, Option 4), the Foundation has not yet found money for the S&T centers. In February, the Administration announced that none would be funded during the 1988 fiscal year. Instead, the Administration will seek a one-time appropriation of $150 million in fiscal 1989 to fund 10 to 15 S&T centers for 5-year periods. If Congress provides the money for these centers, it is possible that one or two of those approved by NSF might have a focus on superconductivity.

Funding for the Industry/University Cooperative Research Center program—well on the way to proving its worth—has been flat in recent years. Nor has the ERC budget grown as NSF had hoped. As discussed under Option 9 in table 13, additional funds will be needed to expand the center programs. Growth in these programs will not have much impact on HTS unless one or more of the proposals that would focus on superconductivity wins the competition for funds. While Congress could direct NSF to launch a center specifically for HTS, this would bean unfortunate precedent, given that the Foundation has traditionally avoided tar-

Box O.—Multidisciplinary Research in American Universities

The boom in Federal R&D since the first Soviet Sputnik, launched in 1957, changed the face of American science and engineering, and the face of American universities. In 1960, the Federal Government spent about $600 million for university research; for 1988, the total will come to $6.7 billion. Yet some things have not changed. Departmental and disciplinary boundaries—separating physics from chemistry, science from engineering—remain as high as ever. Multidisciplinary research has never caught on. Although the university system has changed a great deal over the postwar period, the schools continue to train new people in old ways.

NSF's ERCs and proposed S&T centers represent a renewal of efforts to alter the patterns. Better linkages with industry have also been a goal, as with NSF funding for Industry/University Cooperative Research Centers—a long-standing interdisciplinary program in some respects more directly targeted than the other center programs, and one that has proven successful in attracting industry support.

Engineering and Science in the Universities

Since the latter part of the 19th century, engineering has moved steadily toward applied science. After World War II, American engineering schools embraced a scientific model for the profession—largely in consequence of the dominant role played by scientists in wartime developments such as radar, computing, and the atomic bomb. Few engineers had the understanding of physics, and the analytical tools of applied mathematics, needed for major contributions. Engineers were at home in factories, but not in research laboratories.

During the 1960s, Sputnik and the space race spurred further revisions of engineering courses and curricula. Added work in the engineering sciences—electrical dynamics, solid and fluid mechanics, thermodynamics—replaced design and manufacturing. Paper and pencil exercises (and computers) replaced hands-on laboratory courses. American engineers became more comfortable doing research. But many lost sight of the marketplace, and came to disdain the factory floor.

Just as important, the profession—always fragmented—remained locked into a set of disciplinary boundaries defined by 19th century technology (civil, mechanical, electrical, chemical). Each has grown steadily more specialized. Civil, mechanical, and aeronautical engineers, for instance, all deal with problems in structural analysis and design. But each has its own textbooks, and its own ways, sanctioned by tradition, of approaching similar problems. With the advent of computing and solid state electronics, electrical engineering departments dropped much of their research and teaching on electrical machinery (motors, generators)—a major point of contact with mechanical systems and mechanical engineering. New fields like control systems grew up more or less independently in departments of electrical engineering, mechanical engineering, and aerospace. Today, specialists in control system problems from electrical and mechanical engineering can hardly communicate with one another. Attempts to establish interdisciplinary departments such as engineering mechanics that could bridge the gaps often led to new entities which in turn sought to differentiate themselves. Fragmentation increased rather than diminishing.

The Government Role

Federal R&D policies contributed. As figure 4 indicated, most of the Government money goes for grants to individual investigators and small groups (usually from a single department)—a pattern that holds equally for science and engineering. This approach to research is sanctioned, not only by tradition, but by the practices of agencies such as DoD and NASA. In these agencies, mission-related technical problems are broken down and defined [illegible] and engineers. Those parts of the problem suited for university research are [illegible] ers and their graduate students. Other parts of the problem go to industri[illegible] the Federal laboratories. From the point of view of the agency, this may be nothing more than good management; R&D must be tightly defined if it is to contribute. But the cumulative effect is to help shape university curricula around narrow research topics, and to maintain existing disciplinary boundaries.

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To the universities, the rolling block grants seemed heaven-sent. Each MRL had almost complete autonomy in distributing funds—and still does under NSF. Typically, faculty members apply to the MRL for support rather than to external agencies, conducting research within their home departments of physics, chemistry, or engineering. Originally dominated by physicists, in recent years, only about a third of MRL funds have gone to faculty associated with physics departments, another third to materials faculty, and the remainder to chemists and engineers. Evaluations have shown that MRL-sponsored research differs little from other academic research, either in quality or in multidisciplinary collaboration.

Other Precedents

NSF's ERCs and S&T centers have other predecessors. Industry/University Cooperative Research Centers (IUCRs), intended to foster long-term collaboration with the private sector, go back to 1973. IUCRs must be co-funded by industry to qualify for initial financing; they are expected to become independent of NSF in 5 years. The Foundation estimates that a fourth of the centers (11 of 44) will have successfully negotiated this transition by the end of 1988. A measure of their success: during 1987, industry and State Governments provided an estimated $22 million, far more than the $3 million NSF contribution.[3]

To encourage individual faculty members to work more closely with industry, NSF established an Industry/University Cooperative Projects Program in 1978. The program provided partial funding for projects—often running for 2 years or so—to be conducted jointly by university and industry scientists. Funding ceased in 1986.[4]

In an effort during the 1970s—much more ambitious than any of those mentioned above—, the Nixon Administration established the Research Applied to National Needs (RANN) program in an attempt to turn university scientists and engineers toward practical problems.[5] Multidisciplinary research was an explicit objective. RANN reflected the belief that applied research could help solve pressing U.S. economic and social problems. Its budget grew from $50 million in 1971 to $143 million in 1975 (Figure 4), then declined just as swiftly until the program was abolished in 1978.

The Defense Department's University Research Initiative

First funded in 1986, DoD's University Research Initiative (URI) program aims to strengthen university capabilities—teaching as well as research—needed for future defense technologies. The three services and DARPA all participate. Funding totaled $90 million in fiscal 1986, dropped to $35 million the next year, and rebounded to $110 million for 1988. Most of the URI money goes for multidisciplinary programs. DoD has solicited proposals in technical fields judged critical for defense, some of which have commercial spinoff potential. The selection process is merit-based, largely determined through DoD reviews. The Department has encouraged collaboration between universities and military laboratories, as well as with industry.

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[3]Most of the centers have been at major research universities, with large companies accounting for much of the sponsorship. While industry has provided financing, there is little evidence of close working relationships with the centers. For instance, industry and university scientists communicate only infrequently. See D.O. Gray, et al., "NSF's Industry-University Cooperative Research Centers Program and the Innovation Process: Evaluation-Based Lessons," D.O. Gray, T. Solomon, W. Hetzner, eds., *Technological Innovation: Strategies for a New Partnership* (Amsterdam: North-Holland, 1986), pp. 187-189.

[4]A survey of industry participants covering 118 completed projects found that companies had undertaken 91 follow-on projects on their own, with budgets averaging $98,000. D. Gray, E.C. Johnson, and T.R. Gildey, "Industry-University Projects and Centers: An Empirical Comparison of Two Federally Funded Models of Cooperative Science," *Evaluation Review*, vol. 10, December 1986, p. 788.

[5]*Science Policy Study Background Report No. 1: A History of Science Policy in the United States, 1940-1985*, prepared for the Task Force on Science Policy, Committee on Science and Technology, U.S. House of Representatives (Washington, DC: U.S. Government Printing Office, September 1986).

geted R&D. (Chapter 5 discusses a number of alternative approaches.)

Some academics have feared that increases in funding for centers and other multidisciplinary programs would come at the expense of single-investigator and small-group research. While a legitimate concern, figure 4 shows that the relative shift has been small. Without growth in the NSF budget, competition for limited funds will intensify. Independent research must be preserved. Even so, it would seem prudent to risk erring on the side of support for the new multidisciplinary centers, rather than on the side of a continuation of traditional funding patterns.

There are other ways as well to foster a multidisciplinary environment in the university system: for example, federally funded postdoctoral fellowships could be designed to encourage scientists and engineers planning academic careers to to move laterally into related fields—e.g., from chemistry to materials, from electrical engineering to solid state physics (Option 10).

Table 13.—Issue Area II: Strengthening Interactions Among Universities, Industry, and Government

Issue	Options for Congress	Advantages	Disadvantages
A. University-industry interactions; Multidisciplinary Research			
Commercialization of HTS requires multidisciplinary R&D, To **do a better job of training** people who can help American firms compete, universities will need to encourage multidisciplinary research and teaching. Federal agencies, notably NSF, have been increasing support for multidisciplinary research, but have had limited funds to accomplish this,	**OPTION 9. Congress** could: **. Provide full funding for NSF to launch its proposed interdisciplinary Science and Technology centers. The Foundation seeks a one-time appropriation for fiscal 1989 of $150 million to support 10 to 15 centers** for 5 years. • Appropriate funds at the $5 million or above level for NSF's Industry/University Cooperative Research centers over each of the next several years, ensuring that the newer centers do not overshadow this program. Congress might also consider renewed support for the industry/University Cooperative Projects Program. Ample continuing support for NSF's Engineering Research Centers, provided evacuations indicate they are effective, also seems appropriate.	More support for multidisciplinary research and teaching could help train engineers and scientists to do a better job of bridging the gaps between research and design, development and production, R&D and marketing. Not only will this be vital for competitiveness in HTS, it is vital throughout the U.S. economy.	Without a corresponding increase in NSF's overall budget (see Option 4 in Table 9), money for centers could come at the expense of individual and small group research–one of the outstanding strengths of the American university system.
Most of the incentives in American universities reward those who pursue conventional research careers; few encourage faculty members to cross disciplinary boundaries.	**OPTION 10.** Direct NSF, along with other agencies that fund postdoctoral fellowships, to establish programs specifically for scientists and engineers who chose to move to **a** related field for a year or more of research.	According to the National Research Council, such fellowships "would facilitate communication among disciplines and 'seed' the faculty with individuals who are experienced in the cross-disciplinary approach. "[a]	Without complementary changes in the university environment, such moves might hurt the career prospects of those accepting fellowships.
B. Government-industry interactions: Technology Transfer and Joint R&D			
Over the past few **years, Congress has enacted several pieces of legislation intended to encourage transfer of technology from Federal laboratories to industry.** These provide a framework for reform, with decentralized decision-making at the laboratory level. While some of the laboratories have responded enthusiastically to the new laws, it is not clear that the agencies–especially at higher levels—have embraced this mandate,	**OPTION 11. Conduct early oversight on the responses of major R&D agencies—particularly the Departments of Defense and** Energy–to recent laws and executive branch actions aimed at speeding technology transfer and commercialization of federally funded R&D.	The oversight process could help Congress determine whether further changes in the legislative framework are needed. Matters that might be examined include: • Whether to require that Federal agencies issue regulations for implementing the provisions of the Federal Technology Transfer Act of 1986, The law does not require agencies to issue implementing regulations; indeed, it specifies that they shall not delay implementation until rules are issued. But the situation is a new one for industry too, and lack of guidelines may discourage them from approaching the laboratories,	Reforms take time to implement, It may be too early to get an accurate reading of agency responses to the new rules for technology transfer, The oversight process itself could mean that responsible officials spend time answering inquiries that otherwise would go into improving transfer processes.

[a] *Directions in Engineering Research: A Assessment of Opportunities and Needs* (Washington, DC: National Academy press, 1987), p. 67.

Table 13.—Issue Area II: Strengthening Interactions Among Universities, industry, and Government-Continued

Issue	Options for Congress	Advantages	Disadvantages
		• Actions taken by the laboratories to improve institutional support for technology transfer through personnel policies and provisions for royalty sharing with inventors, . Effects of agency mission on the course of technology transfer. Congress might also ask DoD and DOE how, specifically, their procedures will apply to HTS. • The success of the Federal Laboratory Consortium in living up to its mandate under the 1986 Act.	
Technology transfer may get few resources and little attention when it is not viewed as part of the agency's own mission, For HTS, effective transfer mechanisms could be especially important, DoD, with more money to spend on this technology than other agencies, has fewer reasons for working hard to transfer R&D results to commercial (non-defense) industry	**OPTION 12.** Direct DoD, working with DOE and the Federal Laboratory Consortium for Technology Transfer, to use on a trial basis an intermediary or adjunct organization for transfer of HTS technology to non-defense firms. The intermediary would need to have well-established working relationships with the private sector, and strong motives for making the transfer process function effectively.	Given DoD's funding levels for HTS R&D, transfers to the civilian side of the economy could have substantial impacts on commercialization. Once R&D results were approved for transfer by DoD, the intermediary could take on the job of working with industry, minimizing interference with the primary missions of DARPA, SDIO, and the services. Regardless of the mechanism chosen, an HTS technology transfer program could be viewed as a demonstration—with high visibility **and potential relevance for other technologies.**	Transfers from DoD might come to be viewed as substitutes for R&D funding by civilian agencies, to the possible detriment of commercial technology development,
Demonstration projects could help Identify better methods for transferring technologies to industry, but little funding has been available. The same is true of demonstration projects involving R&D cooperation between the national laboratories and industry.	**OPTION 13. Appropriate or allow more money to be set aside for the Federal Laboratory Consortium for Technology Transfer to undertake three** or more demonstration projects on technology transfer and/or R&D cooperation over the next year or two. Projects with outcomes relevant to several agencies would be most useful. Possibilities include: . pilot programs at the State level (see Option 17 below); • development of guidelines, and trials, involving intermediary organisations (see Option 12 above), • preparation and testing of a technology transfer training program for laboratory (and industry) employees.	The FLC received about $700,000 during 1987 under a set-aside specified in Public Law 99-502, with only 5 percent available for demonstration projects, Additional funds for demonstrations–perhaps $300,000 per year–would begin to address the need.	Each technology transfer situation is unique, putting limits on the lessons to be learned, Nor can a cookbook approach to technology transfer function effectively.
If the national laboratories are to transfer technologies to industry effectively, many more laboratory employees will need to understand industrial needs and marketplace realities While industrial (or university) scientists can arrange to work in a Federal laboratory with little difficulty, the primary need is for movement in the other direction–from the laboratories to industry.	OPTION 14. Authorize and encourage temporary exchanges of technical personnel (and sharing of personnel), as well as cooperative R&D projects between industry and the national laboratories. HTS could get special attention. Alternatively, Congress could create a broader exchange program to send engineers and scientists from national laboratories to private corporations for periods of 6 months to 2 years. One hundred fellowships per year would begin reaching enough laboratory employees to make a difference. Laboratory engineers and scientists could be required to work on problems of mutual interest, with the Government paying half their salaries and maintaining pension eligibility benefits.	Such a program would serve a need largely unmet–giving laboratory employees hands-on industrial experience, thereby speeding commercialization. Fellowships could be made available to laboratory personnel on a competitive basis. Temporary assignments in universities would not serve the same purpose, nor would programs that focus only on bringing industry people into the laboratories. Cost sharing by companies would help ensure that the laboratory fellows worked on commercially relevant problems.	Such a program carries risks of conflict of interest, as well as the appearance of subsidy, Moreover, the laboratories might find industry hiring away some of their more valuable people. Some firms might fear they could lose control over proprietary technology.
DOE's national laboratories are seeking a major role in helping U.S. industry commercialize HTS, but as yet have limited experience in cooperative R&D with the private sector, Working out R&D arrangements that suit industry's needs without detracting	OPTION 15. Direct DOE to encourage an experimental approach to cooperation with industry, As the Department's laboratories establish pilot centers for HTS R&D, and engage in other collaborative efforts with industry and universities, each center could	An experimental approach would help the laboratories learn to work with industry without consuming a disproportionate share of HTS research dollars, Trying a number of different approaches implies learning from the results, hence provision for evaluation;	Relying too heavily on cooperation between the laboratories and industry, particularly to the exclusion of other policies for speeding commercialization, would be a mistake. There is a second dan-

Table 13.—Issue Area II: Strengthening Interactions Among Universities, Industry, and Government—Continued

Issue	Options for Congress	Advantages	Disadvantages
from broader laboratory missions could require considerable experimentation	be designed somewhat differently, even though all were charged with aiding in commercialization	to succeed, the laboratories will have to be self-critical Approaches that worked for HTS could be adopted elsewhere.	ger as well: DOE and the laboratories might find it difficult to shut down cooperative projects that proved ineffective, or were no longer needed
Under the right circumstances, collaborative R&D–involving several private firms in pre-competitive projects–could be an efficient mechanism for building the HTS technology base. Yet the time horizons of industry consortia are unlikely to be that much longer than those of individual firms	**OPTION 16.** The Federal Government could make funds for HTS R&D available on a cost-sharing basis to industry consortia, provided the funding agency determines that public money will serve to extend the R&D time horizons.	Cost-sharing of longer-term R&D would address a critical problem for U.S. competitiveness. The Federal contribution could involve provision of facilities (e.g., at a national laboratory) and/or temporary assignments of personnel to a consortium, in addition to financing,	Any project involving Federal funding would be subject to the vagaries of the budget process. Unless Government, as well as industry, lengthened its time horizons, money could be wasted. On the other hand, cost-sharing, once started, might be difficult to stop–even if, in time, the justification vanished.
State Governments have a broad range of economic development tools at their disposal. In addition to the direct funding for R&D that some have provided, States could help commercialize HTS through programs that accelerate the diffusion of research results to industry. At present, however, linkages between State Governments and national laboratories within their borders tend to bead *hoc* and not very well established.	**OPTION 17.** Congress could: • Provide small planning grants to the States for strengthening R&D-based economic development initiatives, including grants for the evaluation of existing programs, H may take 5 years or more for States to put new programs in place; planning grants available now could mean better capabilities at the State level when HTS technologies begin moving out of the laboratory, • Fund several State Government pilot projects embodying different approaches to the transfer and commercialization of federally-funded HTS R&D (conducted in universities as well as national laboratories). . Direct Federal agencies to give greater weight to support from State Governments in evaluating proposals for university-based R&D centers, and other proposals where commercialization is a major objective.	Strengthened capacities in the States to assist smaller businesses in commercializing innovative technologies would complement Federal SBIR (Small Business Innovation Research) programs, particularly Phase Ill efforts, Planning grants could also help the States find ways of bridging the gap between Phase I and Phase II awards.	Few State programs have been evaluated by independent parties; little is known about the approaches that work best Federal assistance could end up favoring States that might need help the least–e g , those that already have well-developed programs

SOURCE: Office of Technology Assessment, 1988

TECHNOLOGY TRANSFER: THE FEDERAL LABORATORIES

Much of the Federal funding for HTS R&D is going to government laboratories—mostly facilities run by DoD and DOE, but also to NBS and NASA research centers. These laboratories differ in missions, in their historical ties with industry, and in operating arrangements. While NBS has long had good relations with industry, and DoD laboratories often work closely with military contractors, few Federal laboratories have accomplished much in commercialization. This has not, after all, been one of their tasks. *Whether the laboratory system will be able to contribute much beyond a general strengthening of the HTS technology base remains an open question.* Certainly it would be a mistake to rely heavily on the laboratories for commercialization until they have proven themselves.

New Rules for the Laboratories

For many years—as congressional hearings and an accumulation of studies pointed to the large fraction (said to be 90 percent) of federally owned patents never licensed or otherwise commercialized—the U.S. Government has sought to stimulate commercial use of publicly funded R&D. Since 1980, Congress has enacted a series of laws intended to give industry greater access to the laboratory system, and to speed transfers of technology to the private sector.

As a result of patent law changes in 1980, small businesses, non-profit organizations, and universities can gain title with relative ease to inventions they make in the course of R&D paid for by Government. In 1984, Congress extended this statutory policy to contractor-operated laboratories, including several DOE facilities. (The statutory policy does not extend to weapons laboratories, or DOE laboratories operated by large, for-profit businesses, although the Administration has initiated changes here as well.) The most recent step, the 1986 Federal Technology Transfer Act, seeks tighter links between government-operated laboratories and industry. This law:

- provides clear authorization for government-owned and -operated laboratories to enter into cooperative R&D with private firms.
- Gives the Federal Laboratory Consortium on Technology Transfer (FLC) a statutory charter. About 400 laboratories, representing 11 agencies, belong to the FLC, which was organized to facilitate use of federally developed technologies.[15]
- provides for agencies to return licensing income to the originating laboratory, and requires that at least 15 percent of royalties or other income go to the employees responsible.
- Directs laboratory directors to consider technology transfer activities in performance evaluations and promotions, and to include it in job descriptions.

The 1986 Act decentralizes many administrative responsibilities, giving substantial discretion to the laboratory directors. Beyond these statutory changes, President Reagan's April 1987 Executive Order 12591, on facilitating access to science and technology, establishes guidelines for all the laboratories.

While many of the laboratories have expanded their technology transfer activities over the past several years, the pace of change at the agency level has often been slow. Moreover, the discretionary authority given to laboratory directors in the 1986 Act applies only to government-operated laboratories, not to contractor-operated facilities like DOE's. To help determine whether further policy modifications might be needed, Congress could conduct oversight on the responses of the mission agencies to the 1986 Technology Transfer Act, other recent changes in the law, and to Executive Order 12591 (Option 11, table 13).

Transferring HTS R&D

While a new framework for technology transfer exists, it is far from clear that industry and the laboratories will be able to forge effective partnerships for commercializing technologies like HTS. Many of the formal barriers have come partway down, but the culture of these 700-plus institutions insulates them from industry and marketplace. The laboratories also differ greatly in style and tradition. Some stress engineering, others research for the sake of research. Policies with much to recommend for a DOE facility maybe irrelevant for NIH, while conflicting with DoD security requirements.

Technology Transfer from DoD

Much of the Federal funding for superconductivity passes through DoD, which operates more than 70 laboratories, a pattern that will probably continue. While defense agencies work hard at transferring technologies to military contractors, diffusion to the civilian side of the economy poses special problems. These begin with the frequent requirements for secrecy, and end with the likely reluctance of the Pentagon to accept such a burden as a major ongoing responsibility.

In authorizing an HTS program for fiscal years 1988 and 1989, Congress instructed DoD (and DOE, when its laboratories receive DoD funds) to give special attention to transfers of technology to the private sector.[16] Apparently,

15 "' Strategic Plan: 1988-1992," Federal Laboratory Consortium for Technology Transfer Administrator, Fresno, CA, October 1987.

16 Section 218 of the National Defense Authorization Act for 1988 and 1989 (Public Law 100-180) earmarked $60.56 million annually for 2 years for a DoD program on HTS. Congress appropriated only $15 million for fiscal 1988 under this provision, which went to DARPA for initial funding of its processing R&D effort, described earlier in the chapter.

DoD intends to use existing mechanisms to implement the requirements of the Defense Authorization Act, rather than establish procedures specifically for HTS. While current practices may suffice for transferring HTS technologies to defense industries, they will probably be less effective for transfers to firms on the civilian side of the economy. Instead, it might make sense to assign the task of working with non-defense firms to an intermediary organization (Option 12).

A number of arrangements seem feasible. Several DOE laboratories—including Argonne, Oak Ridge, and Ames—have set up adjunct organizations to handle technology transfer. DoD could contract directly with an existing organization—e.g., a not-for-profit R&D laboratory like Battelle. An intermediary charged exclusively with transferring technical knowledge to commercial enterprises could play a useful role during the stages of technology development and commercialization processes that are not germane to DoD's mission.

Demonstration and Evaluation

Technology transfer has significance going beyond HTS. So does cooperation in R&D between industry and the national laboratories. But both in the laboratories and at middle and upper ranks in the agencies, commitment to meaningful change has not always been visible. Information about what works would help; successful demonstration projects could have considerable impact (Option 13). The FLC has the authority to conduct demonstrations, but its set-aside funds from the agencies paid for only one such project during 1987.

Making technology transfer function effectively and efficiently will demand systematic, empirically-based analysis of transfer processes (including cooperative R&D), and of subsequent impacts on innovation and commercialization. Demonstration projects without critical evaluation of results may not accomplish much.

Laboratory Personnel

People transfer technology much more effectively in person than through reports, and they do so best when they work together (rather than in meetings). Transferring HTS technologies from the national laboratories means: 1) bringing people from industry into the laboratories to work on HTS, perhaps through cooperative R&D projects; and 2) sending people from the laboratories to industry so they can learn what commercialization is all about. In the short run, the first of these steps has much to offer for HTS. The second step is necessary for lasting changes in the culture of the laboratories, and for long-run success in better integrating the laboratories into the Nation's R&D infrastructure. Because of possible conflicts with DoD missions, personnel exchanges have greater potential attraction at DOE (non-weapons) laboratories.

The laboratory system attracts many highly competent people with more interest in research than in the practical problems of industry—no surprise, given that commercialization has not been a mission of the laboratories. Some people join a laboratory precisely because they have no wish to work on industrial problems. They may be highly capable professionals, dedicated to research, but even if motivated to work with industry, laboratory employees may not know how—through lack of exposure to corporate life and the realities of the marketplace.

Agency policies have been broadened in recent years, so that many Federal employees can do consulting (on their own time), or take leaves of absence to work in industry. Both these steps will make a difference. So could a program of temporary appointments sending laboratory personnel to the private sector (Option 14). Although industry employees can come to the laboratories quite easily, flow in the other direction will have more impact in changing the laboratory culture. Congress could explicitly authorize and encourage fellowships and/or exchanges. Several of the HTS bills introduced in the 100th Congress authorize industrial fellowships at Federal laboratories, but not fellowships that would send laboratory employees to industry. Others have tied personnel exchanges to cooperative R&D programs. The need is a broad one: there seems no necessary reason to tie personnel exchanges either to cooperative R&D or to HTS.[17]

Cooperative R&D

Cooperative research bringing together laboratory employees with those from industry—and perhaps from universities—offers another way to integrate the laboratories more effectively into the Nation's technological infrastructure. The possible arrangements serve needs ranging from efficiency—avoiding too much duplication —to lengthening industry's time horizons, as discussed in the next chapter (see box R on collaborative R&D). The discussion below focuses on HTS–e.g., approaches such as the proposed National Laboratory Cooperative Research Initiative Act, S. 1480 in the 100th Congress.[18]

DOE has itself moved toward closer cooperation with industry. In April 1988, the Secretary of Energy designated three national laboratories—Los Alamos, Argonne, and Oak Ridge—as superconductivity pilot centers. The pilot center approach, including expedited procedures for contracting and project approval, and transfer of intellectual property rights, had been initially proposed by Los Alamos, which had been asked by the Secretary to explore mechanisms for cooperative ventures.

DOE user facilities have begun attracting the attention of private firms: the Department's figures show 1600 industrial visits in 1987, compared with 260 in 1981.[19] But collaborative projects with industry, though on the rise, involved just 57 companies and R&D valued at about $110 million during 1987 (for the multiprogram laboratories). Given this so-far modest showing, Congress might direct DOE to take an explicitly experimental approach to cooperation with industry (Option 15). Rather than a full-scale effort, structured trials could help industry and the laboratories find ways of working together while avoiding unrealistic expectations and the danger of steering too many HTS R&D dollars to untested programs. Pilot projects could take a variety of forms: firms might work with the laboratories singly or in groups; potential rivals could choose to pursue pre-competitive projects jointly; firms with similar R&D objectives, though in different businesses, could cooperate, along with those having supplier-customer relationships.

Industry will have to take much of the initiative if the DOE laboratories are to aid in commercialization of HTS. Companies must be willing to search out areas of expertise in the laboratory system, and seek to take advantage of them—contributing a substantial share of project funds. If Federal dollars cover too high a fraction, the company may no longer feel it has a stake in outcomes; projects can stray from the needs of commercial technology development. The laboratories might also find that the only companies working with them were those with few prospects for commercial success, and little choice but to take whatever help DOE might offer.

At the same time, while few firms are likely to make substantial financial commitments without guarantees of influence over research goals, industry cannot have too much control, else planning horizons will shorten: unless cooperative projects have riskier and/or more generic R&D objectives than companies would pursue on their own, there is little justification for Government participation. These consider-

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[17] The president's Commission on Executive Exchange, in response to the April 1987 Executive Order, has been working on a small-scale plan for exchanges of technical personnel between industry and Federal laboratories. Industrial participants will probably be limited to relatively large companies that can afford to share the administrative expenses, as well as picking up part of the costs of the exchange. Contractor-operated laboratories may not be covered—thus excluding most DOE facilities.

[18] Introduced in 1987, S. 1480 also includes provisions for cooperative R&D on mapping the human genome and semiconductor manufacturing. The bill, in its original and modified versions (Senate Amendment 1627, introduced in March 1988) would direct the Secretary of Energy to establish cooperative centers at DOE national laboratories for HTS R&D, and give the laboratories greater autonomy in negotiating agreements with private companies and universities.

[19] The 1987 estimate comes from DOE's Laboratory Management Division, that for 1981 from the statement of Dr. James Decker at the Joint Hearing on Technology Transfer before the House Committee on Science and Technology and the Subcommittee on Energy Research and Development of the Senate Energy and Natural Resources Committee, Sept. 4, 1986 (Washington, DC: U.S. Government Printing Office, 1987), p. 22.

ations suggest projects that last 3 to 5 years or more, with industry cost sharing in the range of 40 to 60 percent.

It might also be appropriate for Federal agencies to share costs with industry-based collaborative R&D ventures (Option 16—also see ch. 5). The justification? Longer time horizons. While national laboratory participation might sometimes be desirable, there seems no reason to make this a precondition.

Regardless of final policy decisions on cooperative R&D, mechanisms for evaluating differing approaches, and disseminating the results —and not just the success stories—will be needed. The approaches emerging could have relevance going well beyond superconductivity.

State Programs and Approaches

Over the past decade, many States, in the name of economic development, have established programs for supporting high-technology businesses. Some already support HTS.

Among the more visible initiatives:

- advanced technology centers intended to attract and work with high-technology industry;
- centers of excellence at state-supported universities (several—e.g., at the University of Houston and the State University of New York at Buffalo—have been established in superconductivity);
- small business innovation research programs, patterned after those at the Federal level (adopted quite recently by half a dozen States);
- technology extension services, intended to help companies attack technical problems and diffuse know-how to industry;
- financial assistance for start-up firms and small businesses.

Many State governments have also established advisory commissions and councils on science and technology.

The variety and innovative nature of State programs also mean that some of the undertakings have been fragmentary. Few States have comprehensive efforts. The New York State Science and Technology Foundation, and Pennsylvania's Ben Franklin Partnership, have been among the more extensive. Still, State governments have some tools to call upon for aiding HTS technology transfer and commercialization that are not available to the Federal Government. They also have compelling motivations—jobs and income.

OTA has previously suggested that Federal matching funds for State programs such as technology extension services could be appropriate.[20] Additional possibilities (Option 17) include small planning grants to the States for strengthening R&D-based economic development initiatives. Pilot projects might include a demonstration program for State technology extension services, as provided for in S. 907 (incorporated in the omnibus trade bill passed by Congress but vetoed by President Reagan in May *1988).*

This option could complement existing Federal Small Business Innovation Research (SBIR) programs. Under the Small Business Innovation Development Act of *1982,* Federal agencies must allocate *1.25* percent of extramural R&D budgets exceeding $100 million for SBIR awards:

- Phase *1* contracts provide up to $50,000 for demonstrating the merit of an idea.
- Under Phase II, agencies may award up to $500,000 for taking Phase I concepts to the pre-prototype stage.
- In Phase III, companies can proceed with development using non-federal funds, or seek non-SBIR money from Federal agencies.

[20] Development and Diffusion of Commercial Technologies: Should the Federal Government Redefine Its Role?" staff memorandum, Office of Technology Assessment, Washington, DC, March 1984, pp. 10 and 48.

Precedents for assistance to the States include Federal funding during the 1960s and early 1970s for strengthening State and local capacities in dealing with issues of technology and science. At the time, these efforts were primarily focused on "public technology" —e.g., the direct needs of State and local governments, rather than economic development and business needs.

SBIR money has gone in the past for LTS research; Federal agencies, including DoD and DOE, are currently evacuating well over 100 SBIR proposals for HTS awards.

So far, half a dozen States have established small business innovation research programs of their own. Many States operate small business advisory services, some of which offer assistance in applying for Federal SBIR grants. planning grants could help the States go further in complementing the Federal effort. Congress might also consider raising the Phase I ceiling from $50,000—which buys relatively little today—to, say, $100,000.

TECHNOLOGY INTERCHANGE WITH JAPAN

President Reagan's superconductivity initiative speaks of reciprocal opportunities for the United States and Japan to cooperate in R&D. The Japanese Government's pronouncements on HTS also stress international cooperation—e.g., foreign participation in government-sponsored superconductivity projects such as the New Superconductivity Materials Research Association, and the International superconductivity Technology Center (ISTEC, ch. 3).

If nothing else, Japan has sought to respond to criticism that its research system has been closed to foreigners. But agencies of the Japanese Government also have quite concrete benefits in view—notably, new perspectives and new ideas that could strengthen Japan's capabilities in basic science. More than symbolism, international cooperation could help the Japanese reach their own objective—a more creative R&D system. The Japanese also realize that they risk loss of access to research from the United States and other countries if they do not open up their own laboratories.

New developments in HTS will continue to come from Japanese laboratories. American companies —as well as individual scientists and engineers—stand to gain from participating in cooperative projects, but only in full partnership with Japanese companies and Japanese scientists. More than direct benefits are at stake. Hands-on involvement in Japanese R&D will help Americans–as organizations and individuals—understand how the Japanese compete so effectively.

Participation and Monitoring

As this report was being completed, no U.S. firm had agreed to join one of Japan's cooperative projects as a full member, although a few had become affiliates. American companies, at this point, feel that the costs are too high—and not only the fees (full membership in ISTEC runs about $800,000). To benefit from full membership, a company would have to assign one or more highly competent professionals—fluent in Japanese—to the cooperative project. Scientists with relevant skills and experience are rare in both countries. American firms would be reluctant to send one of their best people to Japan, even if they had someone who spoke the language. (Evidently, few U.S. subsidiaries in Japan have not had much success in hiring top-rank engineers and scientists.)

For smaller U.S. firms, especially those without Japanese affiliates, any form of participation may be difficult to justify. If U.S.-based professional societies or trade associations were permitted to join Japan's government-sponsored projects, spreading the costs, American industry could gain better access to Japanese HTS R&D. Alternatively, a number of American firms might form a joint venture for such purposes as monitoring HTS R&D in Japan, keeping members aware of opportunities for individuals as well as companies, and helping transfer technology to the United States. The U.S. Government could support such an effort, perhaps by helping finance an office in Japan, or as part of a larger program such as NSF's Japan Initiative (see Option 18 in table 14). Federal support for such an office would build on precedents including aid provided by the Commerce Department in 1984 to the American Electronics Association for a trade office in Tokyo.

Some American companies already operate Japanese affiliates primarily as listening posts,

Table 14.—Issue Area III: Technology Interchange with Japan

Issue	Options for Congress	Advantages	Disadvantages
Smaller U.S. companies may not have the resources to keep up with fast-breaking developments in Japan. While the Japanese have offered foreign firms opportunities to participate in government-sponsored cooperative projects, the response to date has been tepid. A joint venture or an organization such as a professional society or trade association might be able to spread the costs and help American industry gain access to Japanese HTS R&D.	OPTION 18. Provide a seed grant to a professional society or trade association for an office in Japan to monitor developments in HTS, with funds sufficient to operate the office for perhaps 5 years. A non-profit organization such as the American Institute of Physics, the American Chemical Society, or the Federation of Materials Societies should bean acceptable vehicle in Japanese eyes.	One way or another, the United States should take the Japanese up on their offers to cooperate in HTS research. In addition to serving as liaison to forums like the New Superconductivity Materials Research Association, a professional society or trade organization could help screen the latest scientific and technical information in Japanese, identifying HTS research reports for translation and distribution. This function could complement the current effort, quite small, by the Commerce Department under the Japanese Technical Literature Act (see Option 20 below).	Japan might gain more than the United States from cooperation in HTS. Much of the U.S. work will take place in universities, where it will be relatively open; much of Japan's work will take place in industrial laboratories.
Few **technical professionals in the United States have the language skills or inclination to take temporary appointments in Japanese laboratories—the most direct means for transferring technology and know-how from Japan to the United States, and a necessary step** in improving American understanding of Japan's research system.	**OPTION 19. Monitor progress in implementing NSF's Japan Initiative, appropriating additional** money if U.S. funds–together with contributions from Japan–cannot sustain all components of the program.	To take advantage of R&D opportunities, and Japanese technical know-how, more Americans need, not only language training, but experience working In Japan.	Sending more engineers and scientists to Japan, and funding language training for professionals, will be only small steps forward, Longer-term needs begin with language training in U.S. primary and secondary schools.
No more than a tiny fraction of U.S. scientists and engineers will learn Japanese in the near future, leaving an ongoing need for prompt translations of Japanese scientific, technical, and business publications–including informally circulated "gray literature."	***OPTION 20.*** Direct the Department of Commerce, as part of its responsibilities under the Japanese Technical Literature Act of 1986 (Public Law 99-382), to establish a program specifically for gathering, evaluating, and disseminating information on Japanese science/technology and business activities as they relate to HTS. The effort might be viewed as a model for improving the effectiveness of Commerce's programs on Japanese information. For insightful evaluations of technical efforts in Japan, Commerce will probably need help from Federal agencies with greater expertise in engineering and science.	Access to **foreign scientific and technical information has** become increasingly important as U.S. technological advantages have diminished. In the past, technical translations from German and Russian have been more common than from Japanese.	Translations and technical evaluations will need substantially higher funding levels to accomplish much. During fiscal 1987, Commerce reprogrammed $300,000 to implement the Japanese Technical Literature Act; in 1988, the Department plans to reprogram $500,000 for this purpose. An aggressive effort on HTS alone could well consume most or all of this. Screening and evaluation of technical information is particularly important, but expensive. To this point, U.S. companies have shown little interest in Japanese technical and scientific literature.

SOURCE: Office of Technology Assessment, 1988.

just as the Japanese maintain technology centers in the United States. The Japanese should be willing to allow group participation by American firms in information-exchange activities such as the New Superconductivity Materials Research Association. Moreover, there is no reason why a corporation setup as a joint venture should not qualify to join ISTEC.

Language Training; Fellowships in Japanese Laboratories

If the United States is to make better use of R&D conducted in other countries, more Americans will have to seek and take temporary assignments in foreign laboratories. At present, few U.S. engineers or scientists have the right combination of technical qualifications, language skills, and motivation to work in Japan (in part because they may feel that their employer—and the U.S. labor market as a whole—will not reward them for learning Japanese and spending time there). As many as 7,000 Japanese engineers and scientists are currently at work in the United States—in government facilities, as well as universities; perhaps 500 Americans work in Japanese laboratories.[21]

Japan offers research fellowships for foreigners under the sponsorship of its Key Technol-

[21] E. Lachica, "U. S., Japanese Negotiators Deadlocked on Tapping Each Other's Technology," *Wall Street Journal,* Jan. 22,1988.

ogy Center, as well as the Ministries of Foreign Affairs and Education. Given the paucity of language skills within the U.S. technical community—and such less tangible but no less substantial barriers as difficulty in finding employment for husbands or wives—not many Americans have sought out these opportunities. Cultural differences and high living costs create obstacles particularly for more senior American engineers and scientists, including those in R&D management positions.

NSF's Japan Initiative, launched in 1988 with an allocation of $800,000 from the Foundation's budget for bilateral programs, is designed to encourage more Americans to take advantage of research opportunities in Japan. The program offers fellowships for language training, as well as financial support while in Japan. Japan's Prime Minister Takeshita, moreover, has announced that that his government will give NSF $4.8 million to finance work in Japan by U.S. researchers, With this offer, near-term funding for the Japan Initiative seems adequate. NSF is seeking $1.6 million for the program in fiscal year 1989; Congress might monitor progress in implementing the program, and appropriate additional money if U.S. funds (together with contributions from Japan) cannot sustain all its elements (Option 19). Congress might also wish to consider greater Federal assistance to American schools and universities for language training.

Technical Information

Most U.S. scientists and engineers necessarily will continue to rely upon translations for technical information from Japan. Congress could direct the Commerce Department to expand its small program for translations of Japanese technical literature under the Japanese Technical Literature Act, perhaps appropriating funds specifically for information on HTS (Option 20). A professional society or trade organization (as discussed under Option 18), in addition to serving as liaison to organizations like the New Superconducting Materials Forum, could help screen the latest scientific and technical information on HTS.

While major scientific findings from Japanese laboratories normally see publication in English or another Western language, less of the Japanese engineering literature is translated. Moreover, Japan produces a large volume of "gray literature"—company, university, and government reports, as well as other informal documents not widely circulated. The gray literature, hard to acquire outside Japan, often includes important technical and business information.

Foreign Access to U.S. Technology

The U.S. Government has signaled Japan and other nations that it may restrict outflows of information from Federal HTS research. The July 1987 Federal conference, at which President Reagan announced his superconductivity initiative, was itself off-limits to representatives of foreign governments. In the private sector, the Council on Superconductivity for American Competitiveness limits its membership to U.S. corporations and citizens. One title of the Administration's proposed Superconductivity Competitiveness Act, sent to Congress in February 1988, would permit agencies to withold scientific and technical information requested under the Freedom of Information Act under some circumstances.

The scientific community has long argued that restrictions on information exchange harm its enterprise, and can only be justified on strict grounds of national security. But the question for HTS is rather different. Proposals such as the Administration's seem to assume that the United States is far enough ahead in HTS to have something to protect. OTA has found no evidence supporting such an assumption. *Lacking a decisive* ***lead in the*** *R&D race, measures seeking an equitable two-way flow with countries such as Japan have much more to recommend them.* Of course, the threat of embargoes on scientific and technical information helps keep the pressure on other nations to provide access to their own research systems (box P).

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CONCLUDING REMARKS

In the months following the initial breakthroughs in superconductivity, the U.S. Government moved quickly to redirect R&D support. The growth in funding–from virtually nothing in fiscal 1986, to $45 million in 1987, and $95 million in fiscal 1988—demonstrates the responsiveness of the system. Yet there are real reasons for concern: lack of new money for HTS; the possibility of a reaction against continuing high levels of R&D spending unless exciting new results keep coming in; heavy de *facto* reliance on DoD and DOE to generate technology that industry can commercialize. Budget uncertainties in the R&D agencies, which lasted well into the current fiscal year, put many federally funded projects on hold, slowing U.S. progress.

Defense-related spending—centerpiece of the Federal R&D budget since World War II—leads to major new commercial products or processes less frequently than in earlier years. The reasons include a drop in support for both generic and high-risk, long-term R&D relative to the overall DoD R&D budget, as well as growing isolation of the defense sector of the economy. Meanwhile, funds for applied research that would fill the gap between basic science and the short-term projects conducted by industry have been cut back: the U.S. Government spends little money on work that would strengthen the foundations for commercial industries.

At present, DoD has roughly half the Federal money for HTS. The field is new, still in the research stages. Much DoD-sponsored R&D over the next few years should yield broadly useful results. Thus DoD's ample resources could become a major asset in commercializing HTS. But the Pentagon will begin steering dollars to support mission-specific applications as soon as these are in view—indeed, may already be doing so.

When it comes to the Department of Energy, which is getting 30 percent of the Federal funds, the primary questions concern the ability of the national laboratories to forge new cooperative relations with industry. The laboratories are changing. But the system is a big one, burdened with inertia; commercialization has not been a significant mission. It will take a major departure from business as usual for the laboratories to have much impact on commercialization of

HTS (which is not to say that when the next set of opportunities comes along, the DOE laboratory system may not be in a better position to respond).

The Federal Government pays for about two-thirds of the R&D carried out on the Nation's campuses, chiefly through awards to individual faculty members, Given the short-term orientation of most business-funded R&D, the NSF budget for HTS is particularly critical. Policies aimed at breaking down some of the disciplinary barriers in American universities, and creating environments where truly interdisciplinary research could flourish, would help broadly in the commercialization of this and other technologies.

The R&D budget is not the whole of technology policy. Nor is technology the only ingredient in successful commercialization. All of the policy options covered in this chapter, taken together, would be no more than a first step in addressing the competitive difficulties of American industry. Still, the money Federal agencies spend on R&D, the ways they spend it, their efforts to transfer technologies to industry—actions taken every day by more than a dozen agencies—have enormous long-run impacts. When companies search for competitive advantages through proprietary technology, they draw continually on this publicly funded, publicly available technology base. More effective interactions among the major players in the R&D system—industry, the national laboratories, universities—would speed the generation of technical knowledge, and, perhaps more importantly, its use.

In a time of budgetary stringencies, mechanisms for establishing R&D priorities across the agencies become more critical than ever. This is perhaps the single most important point raised in this chapter. To maintain its competitiveness, the United States must generate today the technical knowledge that industry will depend on tomorrow, For HTS, this means, not only effective mechanisms for setting R&D priorities, but stability and continuity in funding. These needs imply another: a strategic view of the ways in which federally funded R&D can spur economic growth and competitiveness—the subject of the next chapter.