Critical Technology Assessment of the U.S. Superconductivity Industry

Prepared by

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Background

- The National Defense Authorization Acts 1991 and 1993 require the Departments of Commerce and Defense to prepare assessments for the Senate and House Armed Services Committees on the financial and production status of industries supporting technologies critical to current and next generation defense systems.

- Superconductivity was one of the six such technologies chosen for initial analysis by a consensus of the Department of Commerce (Bureau of Export Administration), Department of Defense and the White House Office of Science and Technology Policy. The other assessments cover Advanced Composites, Advanced Ceramics, Artificial Intelligence, Flexible Computer Integrated Manufacturing, and Optoelectronics. While the Department of Defense has deemed these technologies essential to the development of the next generation of weapon systems, they are also crucial to the nation's ability to compete in the global economy.

- The primary objective of these assessments is to provide industry executives and government policymakers with comprehensive information and analysis on the production and technology status, economic performance, and international competitiveness of private sector firms involved in critical technologies, in light of declining defense budgets.

- The Department of Commerce's Office of Industrial Administration (OIRA), Strategic Analysis Division, is the office within the Bureau of Export Administration responsible for conducting these critical technology assessments. For each technology, OIRA created an advisory team made up of experts from government agencies and the private sector. The team included representatives from Commerce's Technology Administration (including the National Institute of Standards and Technology) and International Trade Administration, and the Department of Defense's Office of the Deputy Assistant Secretary for Production Resources/Manufacturing Technologies. Assistance was also provided by Defense's Advanced Research Project Agency, the U.S. Air Force, and the White House Office of Science and Technology Policy.

- The FY 1991 and FY 1993 National Defense Authorization Acts require that the assessment address a number of factors. These factors include the financial ability of U.S. industries supporting these technologies to conduct R&D, apply the technologies to the production of goods and services, and maintain a viable production base in the wake of reductions or terminations in defense procurement; trends in profitability, investment, and R&D for these critical industries; international competitiveness and market trends; consequences of mergers, acquisitions, and takeovers; effects of dependence on foreign or foreign-owned suppliers; results of DOD spending on these technologies; efforts of DOD

to expand its use of commercial technology and equipment; and the need and effort of industry in the area of defense conversion.

- OIRA sent comprehensive questionnaires to U.S. industry under authority of the Defense Production Act of 1950 (DPA), as amended, and related Executive Order 12656. Information regarding the foreign superconductivity industry was gathered by BXA's Office of Foreign Availability (OFA). In preparing this separate assessment, OFA contacted industry specialists in domestic and foreign firms as well as experts in government and academia.

Technology Overview

- Superconductivity is a state in which a material experiences no resistance to electricity. This lack of resistance means that almost no electricity is lost to heat when a direct current is passed through a superconductor. Superconductors can thus generate very strong magnetic fields without the heat generation and electric current losses to resistance that occur with conventional conductors.

- Two classes of materials are known to be superconducting under the right circumstances: **Low Temperature Superconductors (LTS)**, which are metals or alloys and fullerenes; and **High Temperature Superconductors (HTS)**, which are oxides or ceramics.

- For purposes of the survey, the superconductivity industry was roughly divided into three areas: **Enabling Technologies**, **Components and Devices**, and **Systems and Applications**. Systems and Applications were further divided into **Medical Applications**, **Energy Applications**, **Transportation or Industrial Applications**, and **Electronics Applications**.

Company Identification

- There is much basic research still to be done on superconductivity; it is, however, appropriate to speak of a superconductivity industry in the usual commercial sense. LTS in particular is an established technology, but HTS has also developed enough to make products commercially available. This assessment focuses primarily on these commercial aspects of the industry.

- Most of the 40 respondents were individual companies, and they split for the most part into two groups: small or mid-size companies whose main business is superconductivity or related enabling technologies, and large companies who have the resources to maintain a relatively small superconductivity unit that is not one of their core businesses.

- Most firms combined manufacturing and R&D functions in the same establishment. California had 12 establishments, the highest concentration, followed closely by New York with ten. Eighteen companies stated that they had plans to expand their superconductivity operations by building new facilities within the next five years.

Employment

- Total employment shows a slow but steady gain of 6.6 percent from 1989-1992. Taking estimated 1993 numbers into account, totals would show an 11.8 percent increase over the five-year period. The high ratio of scientists to marketers reflects the developing nature of the technology.

- Labor concerns most frequently mentioned by respondents were related to the technical skills and educational qualifications of current or prospective employees. However, the slow economy of recent years seems to have eased this problem: as other firms have downsized, there are qualified technical people available.

Production

- Respondents' government sales grew by 286 percent from 1989-1992, but they were still dwarfed by commercial sales. Exports accounted for a healthy percentage of total sales, growing from 29 percent of sales in 1989 to 36 percent in 1992.

Research & Development

- Total reported R&D funding from all sources rose 19.4 percent over the period from 1989-1992. In-house funding exceeded government funding each year from 1989 to 1992

- Respondents' receipt of Federal funding rose 14.6 percent from 1989-1992. The Departments of Energy and Defense are responsible for the major share of government R&D funding captured by the survey.

- Total R&D outlays by responding companies showed a 20.3 percent increase over 1989-1992. While spending supporting R&D on enabling technologies rose every year from 1989-1992, respondents projected a significant drop in their estimate for 1993. Components and devices, as a category of R&D expenditures, almost doubled from 1989-1992 and was projected to continue rising in 1993. Systems and applications outlays fluctuated from year to year, without showing a clear trend.

Financial

- All forty study participants provided financial information for some or all of the period covering 1989 to 1991. Of these firms, 28 firms provided information for each of these years.

- While aggregate sales of all respondents show an increase each year, increasing 87.9 percent between 1989 and 1991, about half the companies reporting had a net loss in each year, with the most respondents (19 of 34 or 56 percent) reporting losses in 1991.

- In 1991, over half of the firms reporting data for all three years (15 of 28, or 54 percent) were operating at a loss, while in 1989 and 1990 slightly less than half experienced losses (46 percent and 43 percent, respectively).

- In spite of financial difficulties, one company's response seems to sum up the industry's tenacious attitude: "We are going to hang in there, come hell or high water, and eventually we hope that persistence and fortitude will win the day."

<u>Impact of Defense Cuts</u>

- Two-thirds of respondents indicated that they would be adversely affected by cuts in the defense budget over the next five years. Companies could be affected by the cuts in two ways: directly, since over 50 percent of reported Federal R&D funding came from DOD; and indirectly, by restricting defense-oriented customers of superconductivity-related products, restricting these products' sales and thus producers' money for R&D.

- The importance of DOD as a customer (direct or indirect) was stressed in respondents' comments: "Government funding keeps R&D in superconductivity afloat. No R&D, production suffers." Military systems are traditionally the initial endusers of highly advanced technology that is financially risky to develop. If DOD as the customer is not as strong, the technical development will proceed more slowly.

<u>Government Programs</u>

- Twenty-eight respondents indicated that they have participated in one or more government programs. The most frequently mentioned was the Small Business Innovative Research (SBIR) program. Other programs mentioned included the National Labs' Pilot Centers, the Advanced Technology Program (ATP), and the Strategic Partnership Initiative.

- The respondents ranked both the SBIR and the ATP highly, in terms of suitability to their funding needs. Both programs are scheduled for large budget increases in the coming years.

<u>Obstacles to Competitiveness</u>

- According to survey respondents, technological obstacles to competitiveness include the need for further development of HTS wire and related devices, and, for those companies in LTS, contending with maturing technologies and competition from HTS.

- The recession was a financial obstacle to competitiveness, according to respondents; also, there is a need for capital, particularly to help firms through the commercialization process.

- Legal/regulatory obstacles listed included environmental, export, workers' compensation, and other regulations which have proven burdensome for firms in the industry.

International

- The United States and Japan have the largest share of the market for superconducting materials and systems. These countries have the largest application markets, and they also have the most sophisticated academic and industrial research bases to support insertion of superconducting materials and devices into commercial systems.

CRITICAL TECHNOLOGY ASSESSMENT OF THE U.S. SUPERCONDUCTIVITY INDUSTRY

I. BACKGROUND

This critical technology assessment of the U.S. superconductivity industry was initiated under Section 825 of the Defense Authorization Act for Fiscal Year 1991. This section of the law requires the Secretary of Defense (acting through the Under Secretary for Acquisition) and the Secretary of Commerce (acting through the Under Secretary for Export Administration) to submit annual reports to the Armed Services Committees of the Senate and the House of Representatives on the financial and production status of industries supporting technologies deemed by the Department of Defense (DOD) as critical to the performance of current and next generation weapon systems. The National Defense Authorization Act of Fiscal Year 1993, Section 4215, further expands the scope and requirement for technology and defense industrial base capability assessments under the auspices of an interagency National Defense Technology and Industrial Base Council.

The primary objective of these assessments is to provide industry executives and government policymakers with comprehensive information and analysis on the production and technology status, economic performance, and international competitiveness of private sector firms involved in critical technologies, in light of declining defense budgets. While DOD has deemed these technologies essential to the development of the next generation of weapon systems, they are also crucial to the nation's ability to compete in the global economy. Not surprisingly, almost all of the DOD critical technologies are also found on the Department of Commerce's 1990 list of Emerging Technologies and the Office of the Science and Technology Policy's 1991 list of National Critical Technologies.

Six of the DOD critical technologies were selected for review and submission to the Congress during FY92-93. Superconductivity is one of the six chosen; the other assessments cover Advanced Ceramics, Advanced Composites, Artificial Intelligence, Flexible Computer Integrated Manufacturing, and Optoelectronics.

The Department of Commerce's Office of Industrial Resource Administration (OIRA), Strategic Analysis Division, is the office within the Bureau of Export Administration that is responsible for conducting these critical technology assessments. For each technology OIRA created an assessment team whose members were drawn from the Department of Commerce's Technology Administration (including the National Institute of Standards and Technology - NIST) and International Trade Administration, and the Department of Defense's Office of the Deputy Assistant Secretary for Production Resources/Manufacturing Technologies. Assistance was also provided by the Advanced Research Project Agency, the U.S. Air Force, and the White House Office of Science and Technology Policy.

OIRA also sought out private sector associations, consortia, and businesses which specialize in the six critical technologies selected for review. Associations and consortia participating provided support in the area of industry survey design and field testing, technical advice, mailing lists, on-site visits, and in establishing company contacts. The Council on Superconductivity for American Competitiveness (CSAC) was particularly instrumental in this superconductivity assessment.

In accordance with the requirements of the FY91 and FY93 National Defense Authorization Acts, the following factors were addressed in each of the critical technology assessments:

A. The financial ability of U.S. industries supporting these critical technologies:

1) to conduct research and development relating to critical defense technologies;

2) to apply those technologies to the production of goods and services;

3) to maintain a viable production base in critical areas of defense production and technology in the wake of reductions or terminations in defense procurement; and

4) to expand the defense production base in national security emergencies.

B. Additional analysis was undertaken on such factors as:

1) trends in profitability, investment, research and development, and debt burden of businesses involved in research on, development of, and application of critical defense technologies;

2) international competitiveness and market trends;

3) consequences of mergers, acquisitions and takeovers of such businesses;

4) effects of dependence on foreign or foreign-owned suppliers;

5) results of Defense spending for critical technologies in the current fiscal year, as well as the likely future levels;

6) efforts of Defense to expand the use of commercial technology and equipment; and

(7) the need and efforts of industry in the area of defense conversion.

With industry and interagency assistance, OIRA devised a comprehensive questionnaire to collect information to respond to the assessment factors listed above. The questionnaire was field tested with regard to availability of data, technical accuracy, clarity of instructions, disclosure and reporting format. As part of this effort, OIRA co-sponsored a Critical Technologies Workshop with NIST on February 6, 1992, to gather and incorporate industry input into our draft survey instruments and assessment outlines for each of the six studies. Approximately 500 experts from academia, industry, and government attended the workshop with many providing comments on our six draft survey forms.

OIRA disseminated the six separate questionnaires to U.S. industry, and selected U.S. Government laboratories and universities under authority of the Defense Production Act of 1950 (DPA), as amended, and related Executive Order 12656. Section 705 of the DPA authorizes the Department of Commerce to collect information when necessary or appropriate to the administration of the DPA.

To enhance Commerce's effort to assess the industry's international competitiveness and the effects of dependence on foreign or foreign-owned suppliers, BXA's Office of Foreign Availability (OFA) conducted separate reviews of the efforts of leading foreign companies, governments, and research institutions in the six technologies. To conduct this review OFA contacted industry specialists in leading domestic and foreign firms, as well as in government agencies and universities. Department of Commerce foreign commercial service officers in U.S. embassies and consulates in Europe and Asia also collected and forwarded information to OFA

to supplement the data collected from industry. Excerpts from the OFA Foreign Industry Assessment of Superconductivity are included in the international portion of this report.

Technology Overview

Superconductivity is a state in which a material experiences no resistance to electricity. This lack of resistance means that almost no electricity is lost to heat when a direct current is passed through a superconductor. Superconductors can thus generate very strong magnetic fields without the heat generation and electric current losses to resistance that occur with conventional conductors. This type of magnetic field is fundamental to such applications as fusion reactors and medical diagnostic equipment. Another superconductor characteristic is the Josephson effect of electron tunnelling. In a Josephson junction, a device that exhibits this effect, electrons tunnel through a thin insulating barrier between two superconducting layers. With their very fast switching capabilities, Josephson junctions are key to superconducting electronics.

Two classes of materials are known to be superconducting under the right circumstances: **Low Temperature Superconductors (LTS)**, which are metals or alloys; and **High Temperature Superconductors (HTS)**, which are oxides or ceramics. A third type of material, organic superconductors such as the doped C_{60} buckminsterfullerene or "buckyball," has recently been shown to superconduct, but it will not be dealt with in this assessment as no survey respondents provided information regarding it.

Three parameters determine the ability of a particular material to superconduct: critical temperature (T_c), critical current (J_c), and critical magnetic field (H_c). T_c is the temperature at which a material makes the transition to a superconductor. J_c is the maximum current density a superconductor will carry, measured in amperes per square centimeter (A/cm^2). H_c is the maximum applied magnetic field, measured in Tesla (T). These values vary with the material, but if any of them is exceeded, the material will "go normal," or cease to superconduct. Superconductivity was first discovered in 1911, appearing in mercury cooled to the boiling point of helium, at 4.2K, close absolute zero. Absolute zero, or 0K, is the point at which all molecular motion stops; it is equal to -460° F. In 1957, scientists Bardeen, Cooper, and Schrieffer came up

with the theory that superconductivity is a result of linked pairs of electrons traveling through a material; this theory, known as BCS, won them a Nobel Prize. In 1986, two Swiss researchers, Bednorz and Muller, discovered the property in a ceramic above 30K, a temperature that, while still quite cold, was considerably higher than had been previously found. Subsequent materials discoveries raised the transition temperature even more, to above 100K. An ideal or room temperature (294K) superconductor, however, is still far away. Experimentation with materials is complicated by the fact that high temperature superconductors do not yet have the firm theoretical underpinning that BCS has given low temperature superconductors, so prediction of properties is rendered more difficult.

Low Temperature Superconductivity is a relatively mature technology. By the 1960's and '70's medical and high-energy physics applications for LTS had become successfully commercialized. The subsequent discovery of HTS galvanized wide-spread interest in all types of superconducting applications. International cooperation to further superconductivity is now being promoted by the International Superconductivity Industry Summit (ISIS), made up of CSAC, the International Superconductivity Technology Center (ISTEC) of Japan and the Consortium of European Companies Determined to Use Superconductivity (CONECTUS). At its second annual meeting in May 1993, ISIS put the 1993 global market for products incorporating superconductors at $1.5 billion annually and estimated that the global market will grow rapidly, to $8-12 billion by the year 2000.

Survey Methodology

The primary basis for this assessment is the information provided by industry in response to questionnaires. Superconductivity is an emerging technology in the literal sense, and much basic research remains to be done. Many universities and national laboratories have strong programs in this field. Because commercialization is a central hurdle facing this technology, the questionnaires were targeted primarily at actual corporations rather than universities or national labs. A total of 40 entities responded to the survey. Most respondents were individual companies, although non-corporate entities also responded.

The survey was divided into five sections. **Firm Identification** included the number of manufacturing or research establishments maintained by each firm, the focus of its superconductivity operations (i.e., HTS or LTS), domestic and foreign relationships, and employment trends. **Production** responses detailed shipments of superconductivity-related products and services and their markets. **Research and Development** dealt with sources of research and development (R&D) funding and areas of expenditure in addition to levels of both. **Financial Information** solicited was similar to that which might be published in an annual report, and many companies chose to include such a report rather than complete that section. **Competitive Considerations and the Role of Government** consisted mainly of open ended questions, allowing respondents to express their views as well as provide information on their operations.

For purposes of the survey, the superconductivity industry was roughly divided into three areas: **Enabling Technologies**, **Components and Devices**, and **Systems and Applications**. Systems and Applications were further divided into **Medical Applications**, **Energy Applications**, **Transportation or Industrial Applications**, and **Electronics Applications**. A copy of the questionnaire is included in Appendix 1.

Enabling Technologies

Development of superconducting applications depends on a solid foundation of enabling technologies: cryogenic refrigeration, materials and materials processing. While enough progress has been made in these areas to support development of more complex applications, work on enabling technologies continues to be important.

Because even "high temperature" superconductors must operate at extremely low temperatures, cryogenic refrigeration is a key enabling technology. The need for refrigeration can act as a barrier to demand for superconducting products when alternative products that can operate at ambient temperatures exist. Cryocoolers must be reliable, compact and relatively inexpensive in order to be broadly accepted. One of the most profound implications of the discovery of oxide superconductors is their potential to be cooled by liquid nitrogen, at 77K (-320°F), rather than

liquid helium. Liquid nitrogen is less expensive and easier to handle than liquid helium, broadening the range of attractive prospects for commercialization.

The properties of low temperature metal superconducting materials such as niobium-titanium (NbTi) and niobium tin (Nb_3Sn) are fairly well established, while the properties of the newer high temperature oxide superconductors are still being explored. The most successful HTS materials have been oxides of copper and rare earth elements such as yttrium-barium-copper oxide, or YBCO. Bismuth and thallium compounds have also shown promise.

Materials processing includes thin and thick film processing, including sputtering and chemical vapor deposition, as well as wire and tape drawing. Here again, it is the high temperature superconductors that require greater development; wire-based applications to which ductile LTS metals are well-suited are not as immediately applicable to brittle HTS ceramics. Bulk superconducting powder is packed into a tube, which is then drawn into wire or tape. Problems with this process include aligning the grains of the powder to carry sufficient current density, particularly over the lengths that would be necessary for most practical applications.

Components and Devices

Components and devices may be split -- even more than into HTS and LTS -- into bulk or wire-based and film-based devices. Wire-based devices include magnets, motors and generators. Magnetically levitated superconducting bearings, another bulk application, could operate virtually without friction.

Film-based devices include analog and digital devices and SQUIDs, or superconducting quantum interference devices. SQUIDs can detect very small changes in magnetic fields.

Microwave and millimeter-wave components, detectors, analog-to-digital (a/d) converters, and semiconductor hybrids are other components and devices that offer possibilities of insertion into larger systems.

Systems and Applications

Medical Applications

Magnetic Resonance Imaging (MRI), a medical diagnostic tool that produces images of soft tissues, has been the most impressive commercial success story for superconductivity. The Department of Defense refers to MRI as "a billion-dollar-per-year industry."[1] The Department of Commerce's International Trade Administration (ITA) estimates that the superconducting component is worth ten to fifteen per cent of the total value of the MRI system, making the installed base of superconducting magnets worth $500 million. Providing a strong, stable magnetic field, LTS magnets have no viable non-superconducting substitute in this application.

Biomagnetometers use SQUIDs very sensitive to tiny changes in magnetic fields. These instruments can detect the changes caused by electrical currents in the body, such as those in the brain or heart, and have considerable potential as diagnostic tools. Magnetic Source Imaging (MSI) uses this technology to trace electrical signals moving through the brain by picking up the magnetic fields they create, thereby mapping the brain's sensory and motor functions. When the MSI electrical map is used in conjunction with an MRI structural picture, the resulting scan shows which areas of the brain perform which functions, knowledge that can be vital -- to neurosurgeons who need to perform surgery while dodging speech and motor centers, for example.[2]

Energy and Power Applications

High-energy physics particle accelerometers are another well-established application for LTS magnets. The 54-mile in diameter Superconducting SuperCollider (SSC), its construction now halted, was to be the largest market for superconductors; ITA had estimated $1 billion of LTS magnets and wire would be procured for the project. At this writing, the SSC's funding has been discontinued by Congress. Despite the SSC's widely acknowledged potential scientific value to

[1] 1991 Critical Technologies Plan, U.S. Department of Defense.

[2] See Larry Armstrong with Jonathan B. Levine and Neil Gross, "Watching the Brain at Work," Business Week, July 19, 1993.

particle physics, which examines the basic components of all matter, Congress declined to pay its escalating costs, estimated to reach a total of approximately $11 billion.

The function of a Superconducting Magnetic Energy Storage (SMES) unit is roughly analogous to that of a battery. Current stored in an LTS coil circulates without dissipating. These systems have considerable commercial potential, especially as load-levelers. Utilities could use SMES to store energy generated during off-peak hours, then tap into it during peak hours. SMES can also store energy generated from renewable resources, such as solar power. Further, the units have defense applications as sources of high-energy pulse power.

Underground cables for power transmission which can operate practically without resistive losses are under development. Lower losses would produce cost savings while reducing energy generation requirements.

Nuclear fusion generates energy with a reaction similar to what takes place in the sun: a plasma ignites at an extremely high temperature. Fusion reactors require superconducting magnets to create a strong "magnetic bottle" to hold the igniting plasma and contain the reaction. The Joint European Torus, the Princeton Tokamak Fusion Test Reactor and the International Thermonuclear Experimental Reactor (ITER) are fusion reactors currently under development. These require very high-field magnets and radiation-resistant materials.

Transportation Applications

High-speed, magnetically-levitated trains (MAGLEVs) could reach speeds over 250 mph. There are two different types of MAGLEV, the attractive force or electromagnetic MAGLEV developed by the Germans, and the repulsive force or electrodynamic MAGLEV favored by the Japanese. Only the repulsive force MAGLEV uses superconductors. This application has significant defense conversion possibilities, as many aerospace skills are directly applicable to

MAGLEV. For instance, Grumman Corp.'s model MAGLEV drew on the company's existing aerospace expertise for aerodynamic design and digital control systems.[3]

Ships can be propelled by magnetohydrodynamic (MHD) propulsion, when a field applied by a superconducting magnet interacts with current passed through seawater, thrusting the vessel along. In June 1992, a Japanese consortium tested an MHD ship, the *Yamato 1*. Because MHD propulsion eliminates the need for propellers, it also eliminates cavitation, or the turbulence propellers cause, giving an MHD-propelled vessel the possibility of reaching higher speeds, as well as removing the vibrations that make a propeller-driven ship detectable by sonar.[4]

Industrial Applications

Superconducting magnets can efficiently separate magnetic ores from other materials or remove magnetic impurities from substances such as kaolin clay. Such separators have been sold commercially. Superconducting sensors can be integrated into manufacturing processes.

Electronics Applications

Computers could be made to run much faster and with less power dissipation by using superconducting chips. In this instance, cryogenics would be less of an obstacle than they are to some other applications; silicon-based supercomputers require cryogenic cooling already anyway. High performance and low power consumption are two reasons that HTS electronics are being incorporated into satellites and analog signal processors. ISIS projects strong growth in the electronics sector of the market for products incorporating superconductors over the next twenty years.

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[3] Anthony L. Velocci, "Grumman Nears MAGLEV Milestone," Aviation Week & Space Technology, December 13/20, 1993.

[4] T.R. Reid, "Japanese Ship's Magnetic Attraction." The Washington Post, June 22, 1992.

Defense Concerns

Superconductivity is, at this point in its development, a strongly "dual use" technology; its defense and commercial applications have much in common. This commonality can be clearly seen in the applications that are of particular interest for defense purposes. In its 1991 Critical Technologies Plan, the Department of Defense details the impact of superconductivity on future weapons systems, as well as its effect on the U.S. industrial base.

Development plans for LTS aim for "widespread military utilization of niobium-based analog and digital electronics systems for ultrafast, real-time sensing and signal processing on military platforms" and "the routine use of low temperature superconductor magnets in a variety of propulsion and energy storage applications." The long-term objectives for HTS are "the achievement of complete communications and surveillance receivers using low radio-frequency-loss film passive electronics technology; ... the development of HTS weak link and Josephson Junction (JJ) electronics technology as the basis for a variety of advanced sensors and electronic processors; and ... the development of HTS supermagnets for new applications and retrofit of LTS supermagnets."

The plan emphasizes that "the performance advantages of such systems must be adequate to more than compensate for the necessary refrigeration requirements." Despite the natural focus on weapons systems, the plan asserts, "DoD efforts in superconductivity offer substantial potential for beneficial effect on the industrial base."

II. FIRM IDENTIFICATION

There is much basic research still to be done on superconductivity, and much of it is being done in universities or National Labs, as one might expect. It is, however, appropriate to speak of a superconductivity industry in the usual commercial sense. LTS in particular is an established technology, but HTS has also developed enough to make products commercially available. This assessment focuses primarily on these commercial aspects of the industry.

Most of the 40 respondents were individual companies, and they split for the most part into two groups: small or mid-size companies whose main business is superconductivity or related enabling technologies, and large companies who have the resources to maintain a relatively small superconductivity unit that is not one of their core businesses.

Take, for instance, the 33 companies that reported their total sales for 1991. At that time, the average number of employees working full-time on superconductivity in all 33 companies was 54. Nine companies had sales of over $1 billion that year, but of these nine large firms, six had fewer than 20 employees working full-time on superconductivity in 1991. Only two had more than 100.

One of the nine large companies that responded to the survey discontinued its superconductivity efforts as of late 1992. One smaller company noted a trend of "decreasing support of R&D (in superconductivity and other fields) by almost all large U.S. corporations" that it thinks will ultimately be "very detrimental. Small companies can not carry the field alone."

Two respondents to the survey cannot be described as companies, but rather as consortia or research organizations. Because the survey was oriented primarily toward commercial activity, some questions were not applicable to other operations. "Company" and "firm" are often used interchangeably with "respondent" throughout this assessment. Although these names may apply imperfectly at times in absolute terms, they do apply in the context of the information solicited in the survey; therefore, where they are used, they include consortia.

Few companies had more than one establishment dedicated to superconductivity; forty respondents named 49 different establishments where superconductivity-related work was performed, even if the facility was not exclusively dedicated to superconductivity. Most firms combined manufacturing and R&D functions in the same establishment, although seven respondents maintained separate research and manufacturing facilities. About half of all establishments were founded by 1987, the year HTS was discovered, and half were founded in 1987 or afterwards. California had 12 establishments, the highest concentration, followed closely by New York with ten. Eighteen companies stated that they had plans to expand their superconductivity operations by building new facilities within the next five years.

Companies were asked to broadly characterize their superconductivity operations. Thirty-four companies responded when asked whether their focus was high- or low-temperature superconductivity; the majority, 15 firms, elected both, while 13 were involved only in HTS and six only in LTS. When asked whether they were manufacturing or developing products containing superconductors; superconducting components; or superconductivity-related enabling technologies, most of the 40 companies opted for more than one area. Twenty-one companies are working on products containing superconductors, but only four of these concentrate exclusively on such products. Similarly, only five of 18 respondents manufacturing or developing superconducting components focus solely on that activity. Of the three areas, enabling technologies was the one most likely to be practiced exclusively, as 13 of 26 companies did.

It is important to keep in mind that HTS and LTS are not rigidly demarcated categories, either technologically or institutionally. For instance, HTS oxide compounds, if cooled to liquid helium temperatures, may generate a greater magnetic field than LTS metals.[5] The fact that the majority of survey respondents are pursuing both LTS and HTS indicates significant overlap between the two within one corporate structure.

Table 1 below shows the area respondents picked from a list to broadly characterize their superconductivity operations. In the "Other" category, firms specified such items as bearings,

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[5] Lee Carlson, "Editor's Page," Superconductor Industry, Fall 1991.

thick films and test equipment. Thirty-eight companies responded, most selecting more than one focus area.

Table 1
Focus (by number of mentions)

Area	# Mentions	Area	# Mentions
Contract Research	27	Elec/Power Systems	10
Cryogenics	18	Energy	10
Industrial Mfg	15	Fabrication Equip	10
Research Consortium	13	Metals	9
Thin Film Mfg	13	Wire/Tape Mfg	7
Electronic Components	12	High-Energy Physics	6
MAGLEV	11	MHD Propulsion	6
Ceramics	11	Computers	5
Medicine	10	Other	7

Source: OIRA Questionnaire

Product Acceptance

Of 23 companies responding, not all had difficulties marketing their superconducting or related products as alternatives to other, more established products. In two cases, firms were still developing products and had not yet attempted to market them. One company made an important distinction between types of applications. "In areas where superconductivity is an enabling technology (such as MRI), product acceptance has been relatively routine. In areas where alternative technologies exist or where substantial R&D is required to reduce costs, product acceptance is more difficult -- sometimes impossible -- to achieve." Suppliers of some enabling technologies, such as sputtering targets used in the production of thin films, are not trying to substitute their products for established rival alternatives. Those trying to market superconductivity-related products to replace "conventional" technologies can have a harder time. Cryo-cooling, for instance, was mentioned by six companies as a unique hurdle products containing superconductors face.

Additionally, many HTS products are still at an early enough stage of development that the ratio of price to performance is as yet unattractive to potential customers. Finally, superconductors have been hampered to some degree by public perceptions. On the one hand, the avalanche of publicity and hype that greeted the 1987 announcement of the discovery of HTS generated unrealistic expectations. On the other hand, efforts to deflate this hype have led to an overcorrection of the technology's image, obscuring the real and solid progress made in the ensuing years.

Domestic and Foreign Relationships

Twenty-eight firms reported a total of 46 relationships with other domestic entities. A long-term customer/supplier relationship was the type most often cited (13 times), followed by consortia and licensing agreements (eight mentions each). Twenty companies listed a total of 24 arrangements with foreign entities, just over half the number of domestic relationships mentioned. Foreign relationships were most likely to be marketing agreements (six mentions), joint ventures (five mentions) or long-term customer/suppliers (four mentions). Two firms reported significant foreign ownership, one British and one Japanese.

Mergers, Acquisitions and Takeovers

Based on the survey responses, mergers, acquisitions and takeovers seem to have had little adverse effect on the superconductivity industry. Only four companies mentioned being affected, and they cited positive effects such as synergy and market expansion.

Employment

Respondents supplied their employment data in full time equivalents, hence the fractions of employees that appear in Table 2 below. These employment figures are more useful for their suggestion of trends than for their absolute value. Figures for 1993 are estimates. Total employment shows a slow but steady gain of 6.6 percent from 1989-1992. Taking estimated 1993 numbers into account, totals would show an 11.8 percent increase over the five-year period. The high ratio of scientists to marketers reflects the developing nature of the technology.

Table 2
Full-Time Employment

Occupation	1989	1990	1991	1992	1993 (est.)
Scientists, Engineers	517	541	506	554	602
Production Workers	1023	1024	1077	1024	1074
Marketing & Sales	76.5	85.5	97	98	112
Administrative, Other	274.5	298.5	336.5	348.5	356
TOTAL	1891	1949	2016	2024.5	2144

Source: OIRA Questionnaire

Companies were asked which labor concerns, if any, had adversely affected their operations in the last five years. The options supplied in the question were: shortages of technical skills, shortage of educational qualifications, excessive turnover or other (to be specified by the respondent).

Of 17 responses, nine cited a shortage of technical skills and two more cited a shortage of educational qualifications in their employees or prospective employees. Three responses specifically mentioned that skills related directly to superconductivity were in short supply, and another response made a distinction between technical skills and educational qualifications: "We, and our country in general, are extremely short of highly skilled, well educated technicians. It is much easier to find a Ph.D. than it is an able, well trained, competent technician to work in the lab."

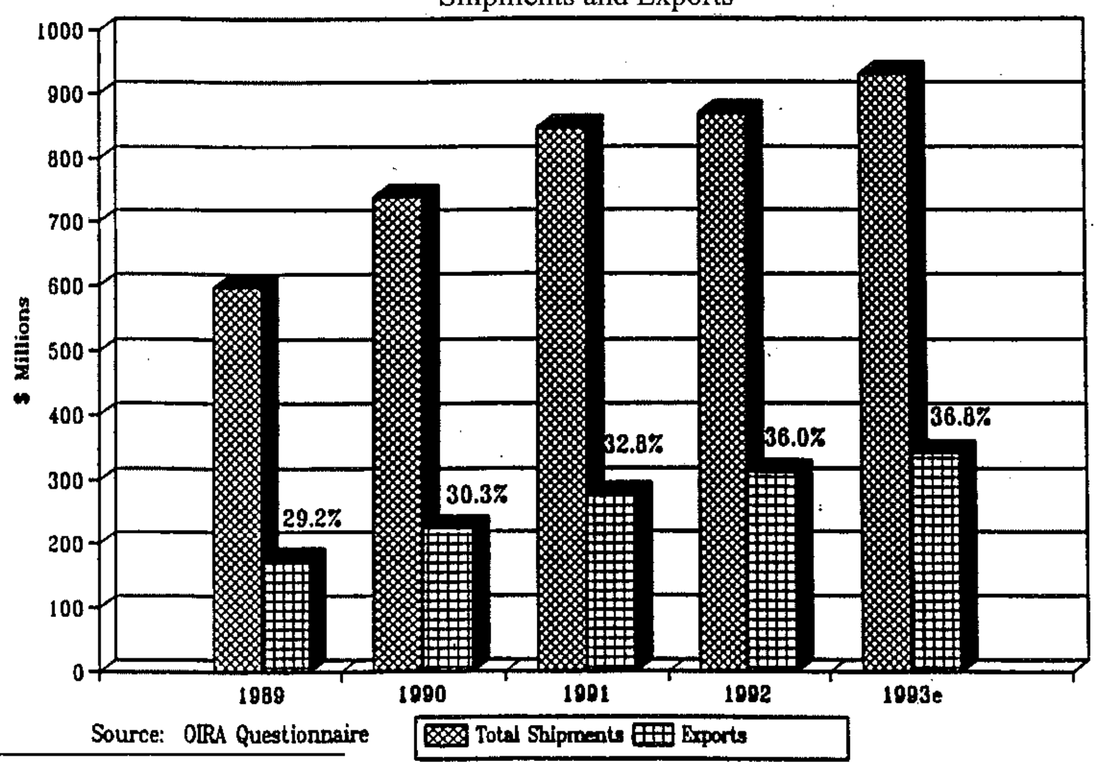
These concerns appeared to be counteracted by the recession to some degree. One company that expressed concern over both technical skills and educational qualifications went on to note, "The slow economy of the past two years has assisted. An upturn may present new problems." "Top-notch people are widely available," asserted another firm; a third noted that "Many qualified technical people are unemployed and readily available." No companies claimed to have excessive turnover.

III. PRODUCTION

Shipments consist of the dollar value of all superconductivity-related products or services shipped or sold from 1989-1991, with estimates for 1992-93. Twenty-six companies responded to this question. Nine companies specifically noted that this question was not applicable to their operations.

A report compiled by the Federal Coordinating Council for Science, Engineering, and Technology (FCCSET)[6] examined levels of Federal support for procurement of superconducting devices. Total Federal support for procurement rose from $23.2 million in FY89 to $69.7 million in FY91, and it was expected to exceed $115.8 million in FY92. The Departments of Defense and Energy were the agencies responsible for all procurement noted by FCCSET. The OIRA survey sample reflected this growth, but respondents' government sales were still dwarfed by their commercial sales. Exports accounted for a healthy and growing percentage of total sales.

Figure 1
Shipments and Exports



Source: OIRA Questionnaire

[6] As described in FCCSET's Federal Research Programs in Superconductivity, December 1992.

Table 3
Shipments
(in thousands of dollars)

Market	1989	1990	1991	1992 (est.)	1993 (est.)
Commercial End User	526,616	628,106	724,080	731,812	790,241
Commercial Manufacturer or Integrator	57,368	71,243	94,629	83,091	90,970
Department of Defense	6,455	6,848	9,187	13,440	18,091
Other Government	7,808	32,989	19,148	41,678	31,943
TOTAL	598,247	739,186	847,044	870,021	931,245
Percent Exports	29.2%	30.3%	32.8%	36.0%	36.8%

Source: OIRA Questionnaire

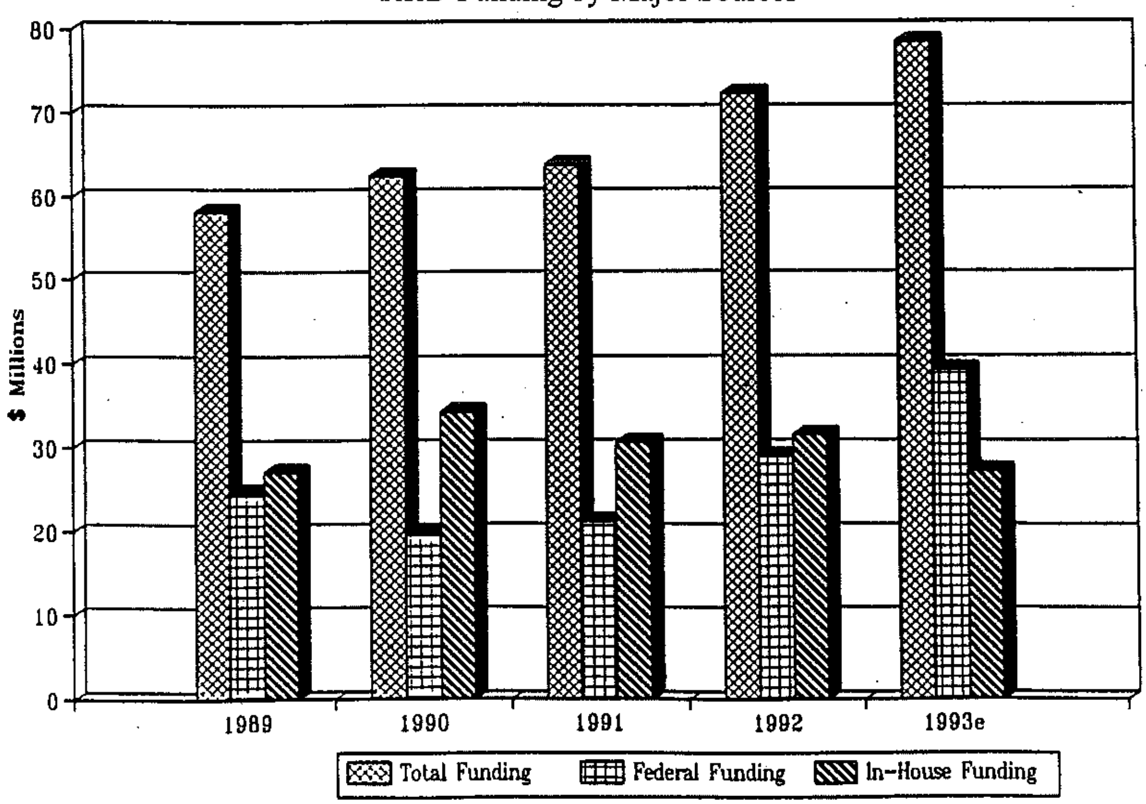
Some companies focused on systems and devices indicated that their products were not far enough along in the development stage for questions on shipments or production to be applicable to their operations. Such companies are consumers of products produced by companies further back in the production chain. Basic research supports commercial ventures that produce superconductivity-related enabling equipment; 12 companies reported a large 1991 sale in the university/research market. Eleven companies reported a large 1991 sale in the defense market, and six reported such sales in the medical market.

IV. RESEARCH AND DEVELOPMENT

R&D Funding

As is shown in Table 4 below, the primary sources of R&D funding for superconductivity operations from 1989-1992 were the companies themselves and the Federal government. Reported aggregate in-house funding exceeded government funding each year from 1989 to 1992, but in-house funding is projected to fall short of Federal funding in 1993. Although projected funding for 1993 has the Federal portion jumping considerably higher than the in-house portion -- to 50 percent of the total -- a disproportionate amount of the '93 estimate comes from one DOD-funded project. Setting aside the money for this project, however, the estimated Federal government share would still slightly exceed the in-house share of R&D funding. While considerably less than either in-house or Federal government, state and local government funding was significant, reaching nine percent of the total in 1992. Customer-funded R&D levels were similar to those of state and local government, hitting a high of nine percent in 1991. Other funding included, but was not limited to, funds from consortia.

Figure 2
R&D Funding by Major Sources



Source: OIRA Questionnaire

Total reported R&D funding from all sources rose 19.4 percent over the period from 1989-1992.

Table 4
R&D Funding Sources
(in thousands of dollars)

Source of Funding	1989	1990	1991	1992	1993 (est.)
In-house	27,060	34,245	30,511	31,446	27,246
Federal Government	24,744	19,635	21,142	28,973	39,240
State/Local Gov't	2,660	4,592	4,862	6,326	6,250
Customer	2,316	2,567	5,575	3,401	4,245
Other	1,384	1,338	1,671	2,028	1,450
TOTAL	**58,164**	**62,377**	**63,761**	**72,174**	**78,431**

Source: OIRA Questionnaire

Table 5 below shows a breakdown by agency of Federal government R&D funding, as well as state and local government's percentage of total public funding. Department of Energy funding includes National Labs. Many smaller agencies fall under the DOD umbrella, including DARPA and the Armed Services. "NSF" denotes the National Science Foundation; the National Institute of Standards and Technology (NIST) is the Commerce agency that administers the Advanced Technology Program (ATP). As in the preceding table, one large project creates a disproportionate increase in the projected 1993 DOD funding.

Respondents' receipt of Federal funding rose 14.6 percent from 1989-1992.

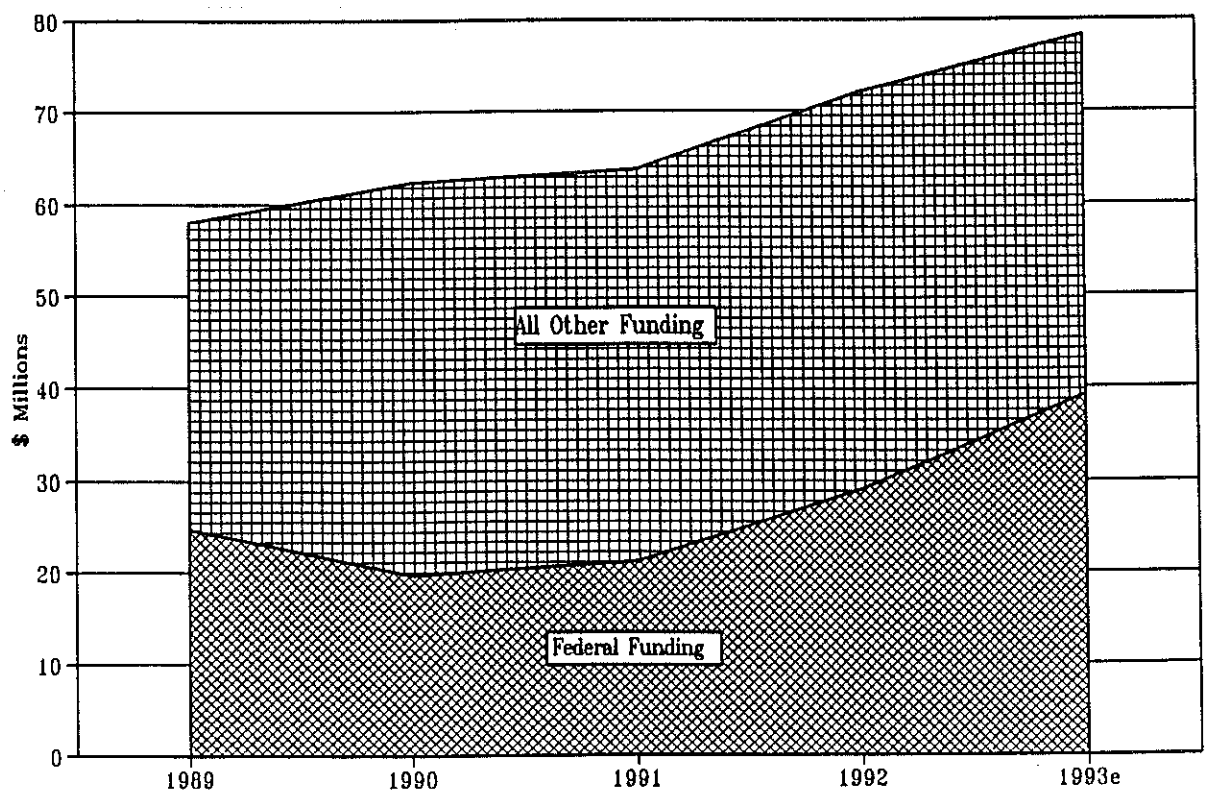
To put these funding totals in context, consider the findings of the FCCSET report mentioned in the Production section above. Although FCCSET's Federal funding totals are broken down by fiscal rather than calendar year, they provide an overall framework for the portion of Federal funding reported on the survey. According to FCCSET, total Federal funding of superconductivity R&D was $238 million in FY90, $258 million in FY91 and a projected $247 million in FY92. The CY90 Federal funding captured by this survey would thus be

Table 5
Federal and State/Local Government Funding

		Government Funding Sources						
	Total Government ($000s)	DOD	DOE	NSF	NIST	NASA	State/ Local	Other
1989	27,404	79%	7%	<1%	0	<1%	10%	4%
1990	24,227	62%	13%	1%	0	2%	19%	4%
1991	26,004	50%	10%	1%	1%	15%	19%	5%
1992	35,299	46%	12%	<1%	3%	15%	18%	7%
1993e	45,490	60%	12%	<1%	5%	4%	14%	5%

Note: Figures may not total to 100 percent due to rounding.
Source: OIRA Questionnaire

Figure 3
R&D Funding:
Federal vs. Total

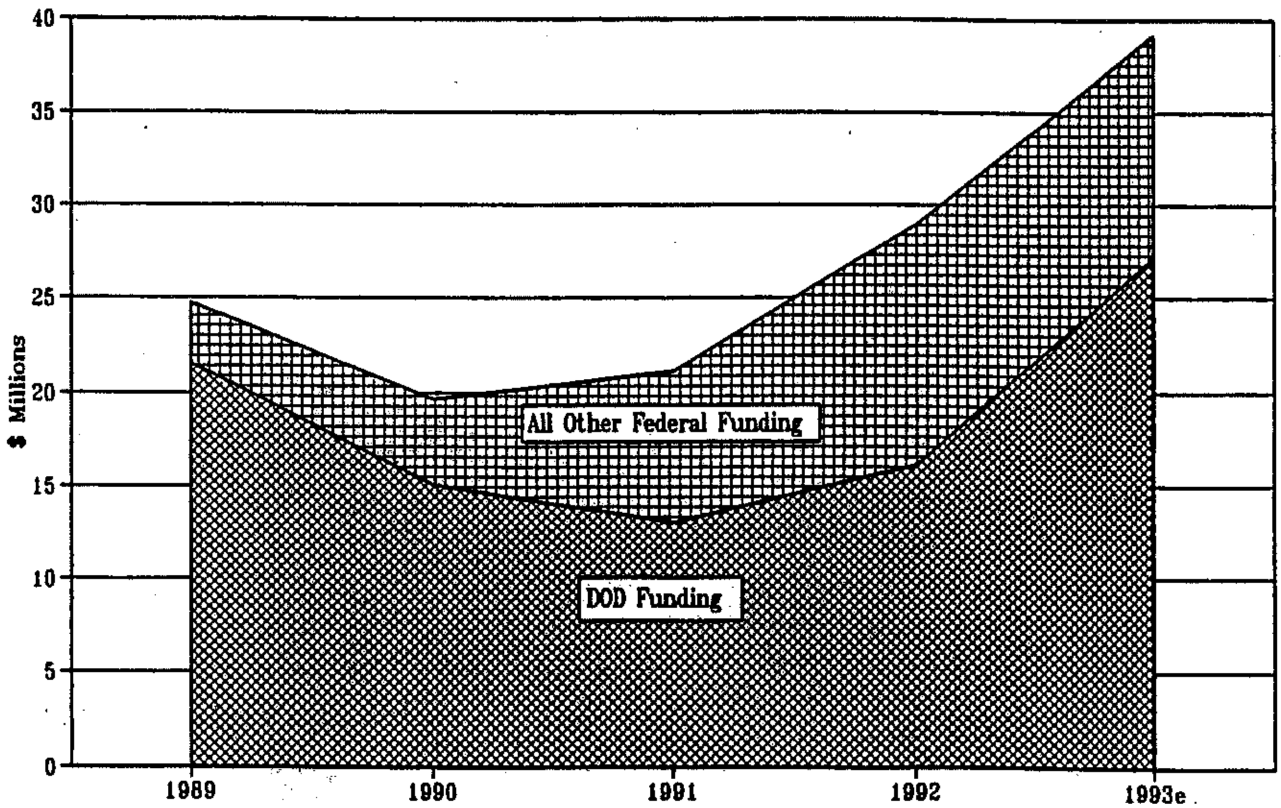


Source: OIRA Questionnaire

just over eight percent of the FY90 Federal total, and roughly the same relationship exists between the survey's CY91 portion and the FY91 total. The survey's CY92 sum comes to almost 12 percent of FCCSET's estimate for FY92.

The Departments of Energy and Defense are responsible for the major share of government R&D funding captured by the survey, as they are for the funding documented by FCCSET. Not all funding goes directly to industry; some supports R&D within the Federal government itself, as in the National Laboratories.

Figure 4
R&D Funding:
DOD's Share of Total Federal Funding

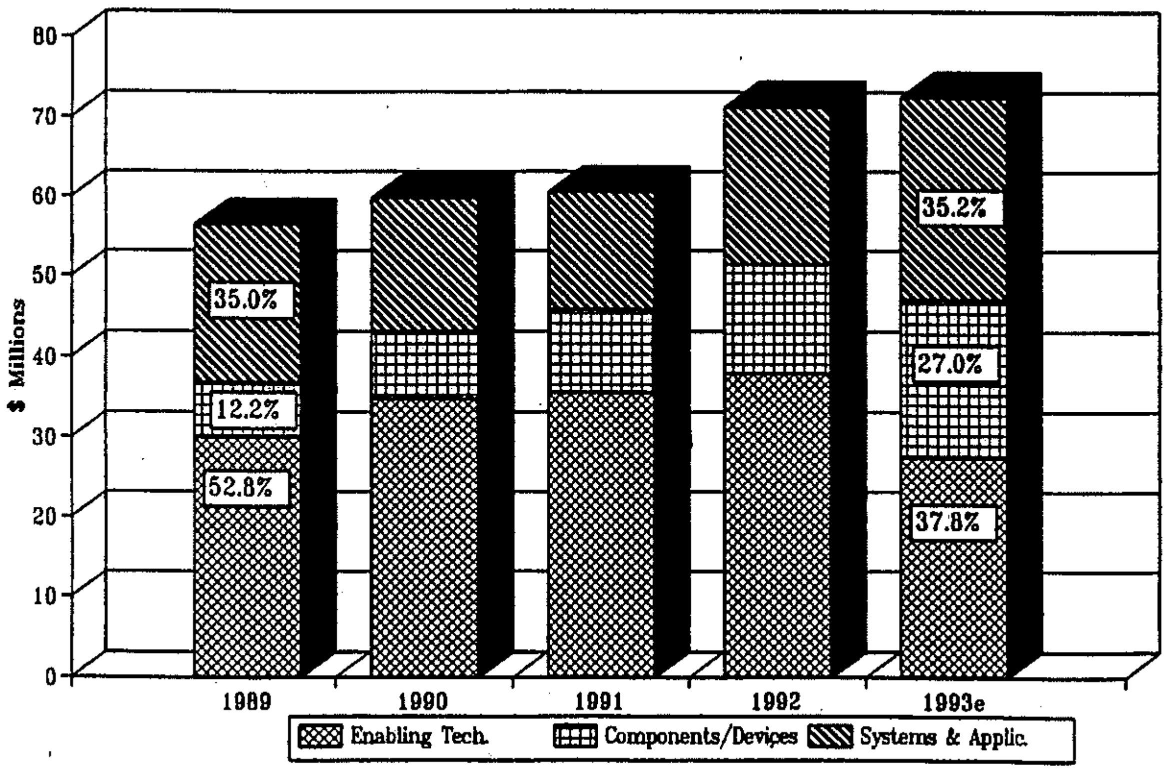


Source: OIRA Questionnaire

R&D Expenditures

Total R&D outlays by responding companies showed a 20.3 percent increase over 1989-1992, as is shown by Table 6 below. While spending supporting R&D on enabling technologies rose every year from 1989-1992, respondents projected a significant drop in their estimate for 1993. Components and devices, as a category of R&D expenditures, almost doubled from 1989-1992 and was projected to continue rising in 1993. These trends may reflect a general movement away from the more basic enabling technologies toward more commercially-oriented devices.

Figure 5
R&D by Application Area



Source: OIRA Questionnaire

Systems and applications outlays fluctuated from year to year, without showing a clear trend. The projected jump in 1993 can be more than accounted for by the large DOD project mentioned above; without that project, the total for this category would drop below the 1992 level, closer to the 1991 level.

It is important to remember that the superconducting portion of any given system may represent a relatively small cost of that system, and that many companies responding focus on the superconductor. Therefore, the aggregate R&D for this category consists for the most part of the total spent on the superconducting portions and to a degree underrepresents the amount spent on whole systems. Additionally, the survey sample was weighted in favor of enabling technologies. Twenty-eight of 35 respondents reported outlays in the enabling technologies; eighteen reported R&D on components and devices; and only ten respondents reported expenditures on 12 systems and applications. Of these ten companies, five reported R&D on medical systems and applications, the most common application mentioned.

Table 6
R&D Expenditures
(in thousands of dollars)

Area	1989	1990	1991	1992	1993 (est.)
Enabling Technologies	30,012	34,715	35,537	37,828	27,407
Components/Devices	6,950	8,418	10,411	13,752	19,625
Systems & Applications	19,885	16,867	14,991	19,770	25,500
TOTAL	56,847	60,000	60,939	71,350	72,532

Source: OIRA Questionnaire

Fifty percent, or 17 out of 34 companies, expected their R&D expenditures to either increase greatly or increase somewhat over the next five years. Eight companies, or 24 percent, anticipated that their expenditures would stay the same over this period; the same number expected them to decrease somewhat. One company expected its R&D expenditures to decrease greatly, but this company is exiting the field.

V. FINANCIAL INFORMATION

The financial section of the survey consisted of a current balance sheet and three years of corporate income statements (1989-1991). Many companies chose to furnish annual reports in lieu of the corporate income statements included in the survey.

Company respondents were asked to provide financial data on a corporate basis. Information was not collected on a division basis because of the way the superconductivity industry is structured. The entities in this sample tended either to be small or midsize companies devoted to superconductivity, or operating units smaller than an actual division within a larger corporate structure. Therefore, profits and sales for larger companies also reflect products and services that are not necessarily superconductivity-related. All forty study participants provided financial information for some or all of the period covering 1989 to 1991. Of these firms, 28 firms provided information for each of these years. Seven of the nine largest companies provided data for all three years; the remainder were small and midsize firms. The aggregated data from all forty companies will be presented for the purpose of comprehensiveness; the aggregated data from the 28 companies will be presented separately in order to establish what trends may exist.

Table 7: Industry Financial Information
(in thousands of dollars)

All Respondents (n=40)			
	1989	**1990**	**1991**
Sales	$ 65,968	105,245	123,943
Net Income	$ 3,728	5,209	2,685
Profit Margin	5.7%	4.9%	2.2%
Losses Reported	52% (16/31)	47% (16/34)	56% (19/34)
Respondents Reporting All Years (n=28)			
Sales	$ 65,946	54,734	71,906
Net Income	$ 3,795	3,435	694
Profit Margin	5.8%	6.3%	1.0%
Losses Reported	46% (13/28)	43% (12/28)	54% (15/28)

Source: OIRA Questionnaire

As can be seen from the table above, aggregate sales of all respondents show an increase each year, increasing 87.9 percent between 1989 and 1991. Net income peaked in 1990 and then declined, with a resulting net change between 1989 and 1991 of - 28.0 percent. Aggregate profit margins declined steadily each year, dropping by more than half from 5.7 percent in 1989 to 2.2 percent in 1991. About half the companies reporting had a net loss in each year, with the most respondents (19 of 34), or 56 percent, reporting losses in 1991.

The financial information from companies who submitted data for all three years of the review period provides a constant sample from which to draw trends, more so than the aggregated data from all respondents. The aggregated sales of those 28 reporting firms exhibit a fluctuation, dipping by 17 percent in 1990 from 1989 levels. In 1991 aggregate sales recovered, increasing nine percent over 1989 levels. While aggregate sales fluctuated during the review period, aggregated net income declined steadily, dropping nine percent in 1990 from the 1989 total of $3.8 million and then plummeting in 1991 by 82 percent from 1989 levels. The aggregate profit margins were slightly higher in 1989 and 1990 for this sample than for all respondents, peaking in 1990 at 6.3 percent. Profits dropped dramatically in 1991 to only one percent. In 1991 over half of the reporting firms (15 of 28, or 54 percent) were operating at a loss, while in 1989 and 1990 slightly less than half experienced losses (46 percent and 43 percent, respectively).

Aggregated current ratios were calculated for all respondents and for those 28 reporting all three years. This ratio measures the ability of a company to pay its debt quickly, usually in less than a year. A standard ratio of 2 to 1 indicates that a company is in sound financial condition and can comfortably pay its bills. Based on the mathematical relationship between these companies' current assets and current liabilities for the 1991 fiscal year, the current ratio for all respondents was an unhealthy 0.5 to 1. For the sample of 28 companies, however, the companies appear to be in much healthier financial shape, with a current ratio of 2.17 to 1. Aggregated debt ratios were calculated as well. This indicates the percentage of assets that are financed by debt. There is no standard against which to compare; such standards vary from industry to industry. In this case the aggregate debt ratio for all respondents in fiscal year 1991 was a significant 40 percent, while the debt ratio for the sample of 28 was 31 percent.

VI. COMPETITIVE CONSIDERATIONS AND THE ROLE OF GOVERNMENT

Competitive Prospects

Overall, competitive prospects looked bright to the survey respondents. Out of 36 responses, almost half (17) expected their prospects to improve, either greatly or somewhat, over the next five years. Even those who did not project improvement were, for the most part, not pessimistic; as one of the seven companies that thought their prospects would "stay the same" stated, "We are the leader in this area for our market and we plan to stay in our position." These companies have strong technology bases, they either have established product lines or their commercialization efforts are well under way, and they see imminent expansion of the superconductivity market. As was mentioned above, eighteen companies expressed this optimism in a concrete way by planning expansion of their superconductivity-related operations.

Interestingly, most of the eight companies that expected their competitive prospects to decline somewhat, as well as the additional three who were uncertain or ambivalent about their prospects, also based their projections on the growing market for superconductors. As these markets grow, more competitors enter the field. As one firm put it, "Because of the interest in high temperature superconductivity, more firms will compete for the same market base." Only one firm expected its competitive prospects to decline greatly; this firm is discontinuing its superconductivity operations.

Since these surveys were completed, an important development has occurred: Congress has halted support for the SSC. The SSC was a large customer for superconductors, and three respondents mentioned it specifically as key to their competitive prospects, including a company that estimated an SSC award "would afford ... growth of two or three times [its] current employment levels." How the SSC's cancellation will affect the U.S. superconductivity industry is yet to be seen, but the effects are unlikely to be positive for this sample of companies.

Nevertheless, one company's response seems to sum up the industry's tenacious attitude: "We are going to hang in there, come hell or high water, and eventually we hope that persistence and

fortitude will win the day. If we can get the other operations that we have expanded into so that it can help support the superconducting effort, we can make a little progress, we believe."

Expected Impact of Defense Cuts

Ten of 32 companies responding did not think their superconductivity-related operations would be adversely affected by cuts in the defense budget over the next five years. The remaining companies could be affected by the cuts in two ways: directly, since over 50 percent of reported Federal R&D funding came from DOD; and indirectly, by restricting defense-oriented customers of superconductivity-related products, restricting these products' sales and thus producers' money for R&D. Nine firms expect the cuts to hit their R&D capabilities. Quantitative estimates made by individual firms ranged from a 20 percent cut in market potential over the next five years to 40 percent drop in the next year. One respondent noted that, given the amount of research still to be done on HTS, "Industry cannot fund long-term research and small businesses cannot afford to do so." An additional company qualified its response; it would be affected if certain advanced programs were eliminated, but it would probably not be affected if cuts focused on hardware or personnel.

Twelve companies expect both production and R&D to be adversely affected by defense cuts. As one company succinctly said, "Government funding keeps R&D in superconductivity afloat. No R&D, production suffers." Five companies sounded variations on the government as "first customer" theme; military systems are traditionally the initial endusers of highly advanced technology that is financially risky to develop. "If the customer is not as strong, the technical development will proceed at a slow pace." Two other companies' comments showed the effect down the supplier chain. While they are not directly funded by DOD, they supply equipment and materials used to perform research, and therefore expect their customers' loss of funding or procurement business to affect them in turn.

Defense Conversion

As an emerging technology, superconductivity has not been locked in to defense applications the way some more mature technologies have been. Despite extensive DOD funding for

superconductivity, respondents to our survey repeatedly stressed the fact that the technology has both defense and commercial applications. One company said, "We constantly evaluate our defense-related product lines for commercial application. One product we originally conceived for commercial applications has been shown to be useful to the military."

When asked if they were aware of any Federal, state or local government programs to assist firms in converting defense-related operations to commercial programs, more than half, or ten of 17 companies responding, said they were not aware of any such programs, including one company that said, "Heard talk only." Two respondents mentioned state programs in New York and Virginia. One elaborated that "New York State offers assistance for converting companies. Program which assist in the definition of existing or emerging-commercial markets would be most useful." Four companies cited Federal programs through DARPA, DOE Labs and SBIR. A final company was aware of programs, "but [they are] not focused on SC technology."

Government Programs

Twenty-eight respondents indicated participation in one or more government programs. Twenty of those participated in the Small Business Innovative Research (SBIR) program, grants to small businesses for development and commercialization that are administered by various agencies. Seventeen respondents reported working with Pilot Centers, centers dedicated to cooperative high-temperature superconductivity efforts with industry established at Argonne, Los Alamos, and Oak Ridge National Labs. Ten participated in the ATP. Three reported participating in the Strategic Partnership Initiative (SPI), a teaming effort administered by DOC's Technology Administration to encourage vertically integrated, pre-competitive, inter-company projects.

According to nine respondents, the SBIR was the government program best suited to their funding needs. Although this reflects the small business bias of the response base, the effectiveness of the SBIR program has been widely reported in the press as well. Five companies found the ATP most suitable. Both the SBIR and the ATP have been targeted for

budget increases in coming years. By 1997, the SBIR should have a $1.1 billion pool, up from $702 million in FY94[7], and the ATP should be increased to $750 million from $60 million in 1993.[8]

Obstacles to Competitiveness

This section addresses more specifically the technological, financial and legal or regulatory obstacles to competitiveness in the field of superconductivity over the next five years, as well as possible changes, strategies or breakthroughs that would help overcome these obstacles. Thirty-four firms answered one or more parts of this question.

Technological Obstacles

Technological obstacles facing the advancement of superconductivity included the need for further development of HTS wire, particularly for increasing its current density, and for development of other devices, such as low-noise HTS SQUIDs, linear motor drives and solid state power switches. Those companies involved in LTS need to contend with the maturing of their technologies and the challenge that HTS presents by either improving on their current specialties or branching out to other areas. A number of responses mentioned the necessity of compact, low cost and reliable cooling systems. Other obstacles mentioned but not elaborated on were those associated with commercialization.

To overcome these technological obstacles, most companies suggested more research, in one form or another. In support of this research, they suggested prototyping, licensing technology and teaming or partnerships to achieve some degree of vertical integration.

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[7] Randy Barrett, "A Decade of Success for SBIR," Washington Technology, October 7, 1993.

[8] Michael Scully and Beau Brendler, "New Year, Nothing New," Washington Technology, December 16, 1993.

Financial Obstacles

The recession was cited as a financial obstacle to competitiveness. There was a strong need for capital, particularly in those firms pushing through the difficult commercialization stage, going from R&D to manufacturing.

Strategies included the need for more stable, long term-funding, from industry as well as government, and for a "[b]etter venture capital environment" since, as one company put it, "Speculative technologies cannot be developed using profits from operations only." The stability of government funding was generally of as much concern to respondents as the level of funding.

Legal/Regulatory Obstacles

Small businesses have found regulation -- such as environmental or export controls or workers' compensation -- to be burdensome. A maker of medical diagnostic equipment pointed out that, in order to be competitive, it needs to have Medicare or third parties reimburse patients for the costs of these diagnostic procedures. Superconductors have found a successful niche in medicine, but regulatory, as well as market, forces strongly influence this market.

Answers to this question do not always split neatly into three categories. There is considerable interplay among the technological, financial and legal or regulatory spheres. For instance, most technological obstacles must be addressed by more research, which in turn requires funding -- often from the government. In answer to the wire quality problem, one company said what was needed was "[m]ore basic R&D by national laboratories to solve weak-link and flux-creep problems. Labs should not be developing wire and other commercial products."

Financial obstacles were often linked to legal/regulatory obstacles. "Timeliness of reimbursement for government contract work" was an obstacle to competitiveness for one company. Dealing with National Labs presented both financial and legal obstacles, especially for small companies. "Technology transfer is too expensive," wrote one such company. Their suggestion? "Make all technology at universities and national laboratories free for use by U.S. industry. After all, the taxpayer paid for it already." Another small company said of the

National Labs, "even the 50/50 deals they offer on technology transfer take money -- and we see the [government] labs mainly using the money to keep their own staffs together in preference to using some of the money to help keep the small innovative impecunious companies funded at low levels." "Modest level SBIR's" were seen by this company as the best way for small businesses to "stay abreast of the science."

Two additional companies found the "[l]oss of proprietary position" and "[i]ntellectual property protection with National Labs" obstacles to competitiveness. They suggested that industry be given "rights to the technology even if government funds have been used in developing" it and that "companies participating in joint work with the National Labs have the maximum protection of their data for a period of at least five years."

The points raised in the survey responses extend beyond superconductivity to other technologies as well. The Administration, Congress and the Labs themselves are engaged in ongoing attempts to overhaul the process of technology transfer from National Laboratories to industry.

Procurement Procedures

Despite the importance of Federal support to the superconductivity industry, many respondents pointed out some of the difficulties of dealing with Federal government procurement policies. As one respondent expressed it, "Any procedure with government or national labs is long, painful, legally tortuous and expensive."

Some small businesses found their resources strained. "Many of the proposal procedures ... are burdensome and bureaucratic in terms of the ability of a small business to effectively compete against large defense companies with their in-house staffs of contracts, financial, marketing and legal departments."

While many companies singled out problems that affected small businesses, larger companies also weighed in with specific concerns; one company said that "the Government emphasis on supporting small businesses as the only true innovators is wasting a major portion of the funding

on companies that will not survive and that cannot bring products to market. This has handicapped the larger companies who would have the capital and staying power." Another noted, "Our U.S. competition has received many SBIR awards (we are categorized as a large business)."

One company's response to this question again showed the importance of the Federal government as "first customer" for nascent technologies: "The best way to develop a strong superconductivity industry is to utilize it. In the past, labs have been reluctant to 'subcontract' to industry. In addition, some of the work subcontracted by labs has been to foreign companies. This doesn't help our company or foster U.S. capability."

International Competitiveness

Major Foreign Competitors

Hitachi of Japan and Siemens of Germany led the list of companies that respondents considered their major foreign competitors, followed closely by Oxford of the U.K., and Sumitomo and Furakawa of Japan. Of the 25 companies responding to this question, 20 included companies from either Japan or Germany, or both.

Emerging Competitors

When asked which regions or countries had emerging superconductivity capabilities, aside from the major competitors mentioned above, most of the 26 respondents still expected Japan and Germany to field their major international competitors in the future -- these two countries were mentioned a total of 22 times. The third most often mentioned emerging competitor was China. A smaller number of respondents focused on regions: the Pacific Rim, Europe and the former Warsaw Pact countries also figured in companies' projections.

With particular attention to Eastern Europe and the former Soviet Union, 29 companies noted their perception of the current state of development of superconductivity and related enabling technologies. "They are strong in basic knowledge, but weak in applied research and development; major capital problems" seems to be the consensus among respondents. Two

companies were aware of specific -- and competitive -- commercial products, however, and one had worked with former Soviet scientists. Their perceived strength lies mainly in metallic, LTS technology, although a considerable HTS effort was known to be underway.

The political and economic upheaval associated with the former Soviet Bloc's move away from communism seems to have taken its toll on superconductivity research, and transition to a market economy has changed development of superconducting products. One company pointed out that, despite the high quality of their research, they generally have little "concept of 'customer' or 'quality' or 'reliability.'" Beyond that, scientific efforts cannot escape the heavy economic pressures facing the larger societies. "Superconductivity development efforts in the former USSR have deteriorated due to funding unavailability the last couple of years," writes one company. Adds another, "Currently, the programs seem to be in a state of total disarray."

Nevertheless, the fact that some viable products have emerged, in conjunction with the strong knowledge base, keeps companies from ignoring the former Eastern Bloc regardless of its problems. As one respondent put it, "I am familiar with the developments in the former USSR, and the science is excellent (as it is in many fields). However, at this time, they have not shown the capability to turn this science into commercial products, although they are, for the first time, thinking in that mode. So, I say, watch out in 5 years -- we will be winding magnets of Russian or Czech High T_c wire."

VII. FOREIGN INDUSTRY ANALYSIS

BXA's Office of Foreign Availability prepared an assessment of the foreign superconductivity industry. Excerpts of that assessment are given below. The entire report is available by contacting the National Technical Information Service at (703) 487-4650 and requesting PB 93-183184 LIB.

Japanese Efforts in the Development of Superconducting Materials and Equipment

The United States and Japan have by far the largest share of the market for superconducting materials and systems. The reason for this is two-fold: i) the United States and Japan have the largest applications market, viz., superconducting magnets for medical imaging equipment, high-speed trains (in Japan), particle accelerators, and super-fast circuits for electronic measuring equipment; and ii) these two countries have the most sophisticated academic and industrial research bases to support insertion of superconducting materials and devices into commercial systems. Additionally, the United States has a significant developmental driving force for superconducting technology in the form of space-based systems for SDI-type projects.

Since so many superconducting applications are in the domain of intense magnetic fields generated by the current in a superconductor, it is no surprise that the most fundamental superconducting industry is that of wire and cable production. There are seven Japanese companies that make wire and cable from superconducting materials, primarily for use in superconducting electromagnets. The four largest producers are Furukawa, Sumitomo, Fujikura, and Kobe Steel.[1] It is interesting to note that Sumitomo and Furukawa are producers of numerous state-of-the-art materials, e.g., gallium arsenide wafers for the semiconductor industry. Sumitomo, in particular, has put a great effort into developing high-Tc-oxides for superconductor magnet applications.

Table 8[2] shows general financial and marketing data for nine Japanese companies that are active in superconducting technology research and development.

Table 8
Characteristics of Japanese Companies Active in Superconductivity Research

Company	Sales ($B)	Net Income ($M)	Income (% of sales)	R&D ($B)	R&D (% of sales)	Growth (% per year)	Capital Expenditures ($B)
Fujitsu	13.7	256	1.9	1.47	10.8	8.5	2.8
Furukawa	4.0	52	1.3	0.09	2.3	7.9	0.6
Hitachi	24.5	700	2.9	2.20	9.0	4.0	6.8
Matsushita	38.6	1302	3.4	2.17	5.6	5.1	1.4
Mitsubishi	18.9	178	0.9	0.82	4.3	5.9	1.8
NEC	21.9	204	0.9	3.46	16.0	7.0	2.0
NTT	45.3	1944	4.3	1.45	3.2	5.2	5.4
Sumitomo	4.4	100	2.3	0.18	4.1	4.8	1.9
Toshiba	28.6	486	1.7	1.74	6.1	7.7	1.7

SOURCE: M.S. Dresselhaus, et al., "JTEC Panel Report on high-temperature superconductivity in Japan," Japanese Technology Evaluation Center (Loyola College, Baltimore, MD), p. 8, Nov. 1989).

Fujitsu[3],[4] is Japan's largest computer maker, and the world's second largest. It is fifth among Japanese companies in overall electronics sales. Fujitsu has 156,000 employees and has an export ratio of 14 percent.

Hitachi[5] is Japan's largest electric machinery manufacturer. It is a strong supporter of research and accounts for 6 percent of Japan's corporate R&D spending. Hitachi has 320,000 employees and has an export ratio of 23 percent.

Matsushita[6] is the world's largest manufacturer of consumer electronic products. It exports products under the "Panasonic", "National", "Technics", and "Quasar" brand names. Matsushita has 242,000 employees and has an export ratio of 35 percent.

Mitsubishi[7] manufacturers a broad range of electronic products. The company has developed collaborative relationships with AT&T and Hewlett-Packard. Mitsubishi has 103,000 employees and has an export ratio of 23 percent.

NEC[8] (Nippon Electric Company) manufactures numerous semiconductor and electronic-system products. It has 50 percent of the Japanese personal computer market. NEC has 128,000 employees and has an export ratio of 18 percent.

NTT[9] (Nippon Telephone and Telegraph) is a major telecommunications company. It is a service company, rather than a manufacturing company. NTT has 258,000 employees.

Sumitomo[10] is a research-oriented solid state products manufacturer. It plans to be a leading supplier of optical fiber to NTT. Sumitomo has 15,000 employees and has an export ratio of 10 percent.

Toshiba[11] is the world's second largest electric machinery manufacturer. It is a leader in telecommunications and has extensive R&D facilities. Toshiba has 168,000 employees and has an export ratio of 25 percent.

Table 9 shows 1992 performance data for the above companies.

Table 9
1992 Financial Data for Selected Japanese Firms

Company	Total Sales ($B)	Net Profit ($M)	R&D Expenditures ($B)
Fujitsu	18.2	255	2.946
Hitachi	29.4	616	3.081
Matsushita	37.4	819	3.130
Mitsubishi	19.6	221	1.370
NEC	22.8	290	2.395
NTT	48.1	---	2.157
Sumitomo	5.9	142	0.187
Toshiba	23.8	317	2.090

SOURCE: See References 12-20

Development of Small-Scale Superconducting Systems

Fujitsu has produced a Josephson junction-based 8-bit digital signal processor in a 1.5-micron niobium metallization technology. The processor has a peak rate of 1000 million operations per second (1 giga ops) and consumes only 12 mW of power. The chip has 23,000 Josephson junctions and is processed by methods familiar to the semiconductor industry. In both the United States and Japan, there is considerable work that must be done before a full-scale Josephson-junction computer can be built. However, the Fujitsu chip demonstrates the determination of Japanese industry to create such a machine. The Japanese government-sponsored Electrotechnical Laboratory, Hitachi, and NEC are also developing Josephson junction chips and are at the cutting edge of this technology. These organizations each have about 15 senior researchers on Josephson junction projects.[12]

By comparison, U.S. research of superconducting circuits, particularly digital circuits, has been less aggressive.[13] Until 1989, IBM had a program to develop Josephson circuits for main-frame

computers. This effort had over 100 personnel, but was terminated when Josephson junction RAM circuits proved to be disappointing even though they achieved sub-nanosecond performance. There are similar stories for AT&T Bell Labs and Sperry Research. Since these programs were terminated or down-scaled, there has been little Josephson junction-based digital industrial research in the United States. However, some other U.S. companies, e.g., Hypres, Hewlett-Packard, TRW, and Westinghouse have more recently started modest Josephson junction circuit development programs. These programs have produced experimental digital shift registers and analog A/D converters, but few commercial products have so far been produced. An exception is Hypres Company, which now produces and sells a Josephson junction-based oscilloscope for characterizing extremely fast analog signals.[14] U.S. government sponsored laboratories have also produced Josephson circuits. The MIT Lincoln Laboratory and NIST/Boulder, in particular, have done pioneering research in superconducting analog circuits to take advantage of the low microwave losses associated with the superconducting state. Several U.S. companies now produce superconducting microwave components, e.g., Superconductor Technologies in California. This company produces high-Tc thin films for microwave resonators and other microwave components. It recently completed a DARPA contract to develop high-Tc thin films.[15]

Not all superconducting electronics are built around Josephson junctions. Recently, superconducting thin films have been used in quasi-conventional transistor structures. Sanyo Electric has developed a bipolar transistor that uses a thin film of barium-potassium-bismuth oxide for that part of the transistor known as the base. This has the effect of significantly increasing the speed of the device. The transistor is operated at 28 K where the thin film oxide becomes superconducting. [A problem with this approach is that the resistivity of the **semiconductor layers** (not the superconducting material) tends to increase drastically at very low temperatures due to a phenomenon known as impurity "freeze-out". Further research is necessary before this device will have commercial value.] Meanwhile, U.S. researchers have also developed a quasi-conventional transistor structure that employs a superconducting thin film. This device is a field-effect transistor (FET) that uses a thin film of yttrium-barium-copper oxide which becomes superconducting at a sufficiently low temperature. However,

this transistor is not so fast as silicon FETs, and has no immediate commercial application. Other promising areas in superconductor electronic circuits include HTS interconnects and leads.

Overall, with respect to Josephson junction-based digital circuits, it can be said that Japan is well ahead of the United States in the effort to produce commercial products.[16] Fujitsu, in particular, has become a leader in this field of research and development, and has already produced several experimental microprocessors. On the other hand, the United States appears to have a lead in the development of superconducting analog circuits.

As indicated above, a major application of superconducting materials is in the manufacture of superconducting electromagnets (magnets). A primary insertion candidate is **magnetic resonance imaging (MRI)** for non-invasive imaging of internal organs. The electromagnets operate in a superconducting current mode so as to produce an extremely intense magnetic field. Most MRI machines use superconducting magnets. The use of superconductors in MRI equipment lowers the annual operating cost by over $17,000 per machine. There are now over 3000 MRI machines worldwide, and the annual production rate is about 1100 per year.[17] The machines in Japan have been supplied by Hitachi, Mitsubishi, and Toshiba, with each company producing about one-third of the MRI systems.[18] By comparison, most MRI systems in the United States are produced by U.S. companies.

Development of Large-Scale Superconducting Systems

Several Japanese companies are aggressively developing large-scale superconducting systems[19], and are already in the production stage of superconducting technology. The four largest research and development efforts are by the companies Hitachi, Mitsubishi, Toshiba, and Sumitomo. They each have between 25 and 70 senior researchers in the superconductivity field. Hitachi has the largest effort in terms of research staff, with 70 personnel.

A major driver for the development of superconducting materials in Japan is the Japanese National Railways (JNR) magnetic levitation (MAGLEV) project.[20,21] This project is funded by the Railway Technical Research Institute (RTRI) in Tokyo and is now in its 19th year.

MAGLEV trains ride on a non-contact magnetic cushion about 10 cm above guide rails and can achieve very high speeds. RTRI has built a 7 km test bed on the coast of Kyushu Island and has achieved speeds with a full-size bullet-shaped vehicle (the MLU002) in access of 500 km/hr (310 mi/hr). The MLU002 can carry 30 passengers and is mounted on two magnetic levitation guides (bogies), one made by Mitsubishi and the other by Toshiba. Each bogie is built around six superconducting magnets, cooled by expensive liquid helium. As of 1989, JNR was planning the construction of a 50 km test bed. Overall, Japan is investing $3 billion dollars to construct a commercial superconducting MAGLEV train.

The United States by comparison has initiated a serious MAGLEV effort only recently. In 1991, the National Maglev Initiative awarded $12.9 million in contracts for MAGLEV transport studies.[22] Congressional indications are that there will be no startup funding for the Maglev Initiative in 1993.

Superconducting MAGLEV technology has a strategic significance for both Japan and the United States in that it offers the potential for vast petroleum conservation.[23] The transportation sector accounts for about 27 percent of all energy consumed in the United States and for about 62 percent of petroleum-based fuels. Petroleum provides about 97 percent of the energy used in the transportation sector.[24] While estimates are fuzzy at this point, any large-scale conservation of petroleum would be particularly important to Japan - a country that imports all of its petroleum.

MAGLEV technology, both in the United States and Japan, would compete mostly with short-haul (100 - 600 miles) air transportation. Estimates of the energy and money that could be saved by short-haul MAGLEV transportation have been made.[25] In the United States, short-haul air transport accounts for about 50 percent of the 3 quads (1 quad equals one trillion Btu) of energy consumed each year by the airline industry. Short-haul air transportation consumes about 8000 Btu per passenger-mile. It is estimated that a MAGLEV system would consume about 3000 Btu per passenger-mile. This represents an energy conservation potential of 0.9 quad/year per system, with a corresponding cost savings. If all short-haul air transportation was assumed by MAGLEV systems, the conservation potential would be about 5 percent of the total annual U.S.

energy consumption. Additionally, MAGLEV systems will have the advantage of substituting more abundant fuels (e.g., coal for electric power generation) for the more-expensive petroleum-derived fuels.

The Japanese are also making an effort to develop superconducting rotor magnets for commercial steam turbine-powered electric generators. The superconducting material is used for the winding of the magnet. The use of superconducting rotor magnets can improve useful power output by 1 percent, which is not an insignificant amount over the roughly 30-year lifetime of the machine. The companies Mitsubishi, Hitachi, Toshiba, and Fuji Electric have been active in this research, with funding from the Japanese Ministry of International Trade and Industry (MITI) since 1974. Mitsubishi has constructed a 6 MW generator, Fuji a 30 MW generator, Hitachi a 50 MW generator, and Toshiba a 3 MW generator. In 1983, Mitsubishi built a 1/4-scale rotor for a 1000 MW machine. Based on this effort, MITI set up a 10-year development program (called Super GM) in 1987. The plan is for a 200 MW machine to be built and tested in the 1995-2000 time frame.

By way of contrast, there is no national program on superconducting generators in the United States. At one time, there was a 270 MW superconducting generator project in the United States, but this was abandoned in 1983.

An interesting large-scale military application of superconductivity that is being investigated both in the United States and Japan is the use of superconducting magnets in magnetohydrodynamic (MHD) propulsion systems for nuclear submarines and, perhaps, surface ships.[26,27] The great military advantage of MHD propulsion is that it does not involve the use of a propeller, and thus, the tell-tale cavitation noise of a submarine is removed. MHD relies on a common concept in electrical engineering called the Lorentz force. For an MHD system to be of engineering significance, it must use very strong magnetic fields, and thus, the application of superconducting technology. A Japanese consortium that includes Mitsubishi Heavy Industries, has worked on this problem since the 1970s. It has built and demonstrated a prototype surface ship (the Yamato), started in 1983, and costing $40 million.[28] The Yamato is 30 meters long and

displaces 168 metric tons. It uses two MHD thrusters that employ liquid helium-cooled niobium titanium superconducting coils. It is thought that this application of superconducting technology will not be useful until HTS materials can be developed for system insertion.

The United States, by comparison, has a less aggressive MHD propulsion development effort, with some funding coming from DARPA and the Newport News Shipbuilding and Drydock Company (NNSDC).[29] DARPA has funded the development of a one-fiftieth-scale test model of an MHD thruster by Textron Company. NNSDC, one of two submarine builders in the United States, has completed year-long thruster tests and is planning an unmanned demonstration submersible. So far, there has been no U.S. demonstration of an actual ship or submarine.

Superconducting electromagnets are used in particle accelerators, the most powerful of which would have been the SSC. As of March 1993, eight 22-month contracts beginning in October 1991 and totaling $21.4 million had been awarded.[30] Three of these contracts (totaling $9.4 million) went to U.S. companies[31] (Emerson Electric, Martin Marietta Strategic Systems, and Babcock and Wilcox). Three contracts went to Japanese companies.

Another large-scale application is that of superconducting magnetic energy storage (SMES).[32] From electromagnetic theory, it is known that whenever a current passes through a wire, a magnetic field is created. There is an energy stored in this magnetic field. Since the current in a superconductor will continue indefinitely without any attenuation, energy can be stored for long periods of time in the associated magnetic field. The user can tap the energy at any time by diverting the current to some device that does work, e.g., an electric motor. Japanese National Railways (JNR) has a project to develop a superconducting magnetic energy storage system to be used as a trackside power source for the MAGLEV train.
In contrast, for the United States, the primary insertion candidate (i.e., applicable system) for a large superconducting magnetic energy storage system is found in the military sector rather than in the commercial sector.[33] The Strategic Defense Initiative (SDI) requires such a system for use in orbiting pulse-powered beam weapons. The U.S. Government has commissioned two

contractors to design liquid helium-cooled Nb-Ti alloy coils to store energy at about the 30 MW-hr (108 billion joules) level.

Other Major Foreign Efforts in Superconductivity

Researchers at the University of Birmingham and the University of Cambridge have recently developed a ceramic oxide superconductor with a critical temperature of 122 K.[34] This is a thallium-barium-calcium-copper oxide and is similar to other high-Tc oxides. In 1988, the UK Department of Trade and Industry started a three-year high-temperature superconductivity program funded at 8 million pounds.[35] The center of this research is at Cambridge.

An important industrial application of superconductivity could be in the area of materials separation.[36] This technology is based on the principle that materials of different magnetic susceptibility will move at different speeds in a magnetic field. Such a system is most effective with the application of intense fields. The UK (Cryogenic Consultants), Czechoslovakia, and Germany (KHD Humboldt) have each demonstrated large-scale superconducting magnetic separators. All of these systems employ liquid helium cooling. They have capacities of between 15 and 100 metric tons per hour. (By comparison, the United States company Eriez Magnetics has demonstrated a liquid helium-cooled superconducting magnetic separator that can process 20 metric tons per hour.)

The International Thermonuclear Experimental Reactor (ITER) in Europe will use superconducting magnets to confine and shape a fusion plasma. The magnets will be much bigger than those used in the SSC. The total cost for ITER will be $7.5 billion.[37]

Summary

Superconducting technology **is** on the verge of a massive application expansion. This is reflected in the large number of patents that have recently been filed in this field. For example, there were 37 U.S. patents granted in the two month period June-July 1991.[38] However, many of these inventions and manufacturing processes will be commercially feasible only with the further

improvement of high-Tc materials. Most of the large-scale and small-scale applications still depend on low-Tc materials that require expensive and bulky liquid helium cooling.

In order for large-scale superconducting-technology systems to become commercially significant, improvements must be made in three areas.

i) Material systems with Tc values considerably above the temperature of liquid nitrogen (77 K) must be identified and produced with a high degree of manufacturing consistency.

ii) Jc values for HTS systems need to be increased somewhat, though, this is not such a critical issue.

iii) A theory of superconductivity that applies to HTS materials must be developed to guide future research.

There are now several small-scale applications that are proving very remarkable, including superconducting magnets for MRI machines, SQUIDs for extremely sensitive magnetometers used in medical diagnostic and geophysical exploration environments, and Josephson junctions for very fast electronic measuring equipment. While the Japanese lead the world in digital-application research, the United States has a lead in analog-application research. The U.S. military is also advancing the state of the art in Josephson junction technology by funding the development of highly-sensitive magnetometers for submarine detection.

In the large-scale arena, the Japanese are the leaders in efforts to develop superconducting magnetically levitated high-speed passenger trains and superconducting transmission lines. The U.S. Government is stimulating research in huge superconducting magnets, originally for insertion in the superconducting supercollider, but also for other large particle accelerators (including focused ion-beam systems for SDI-type projects).

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APPENDIX A

INDUSTRY SURVEY

PART I. FIRM IDENTIFICATION

1. COMPANY ADDRESS: Please provide the name and address of your firm or corporate division.

____

____

____

2. PARENT FIRM: If your firm is wholly or partly owned by another firm, indicate the name and address of the parent firm.

____

____

____

Year Acquired, Merged or Spun Off_______

3. MANUFACTURING ESTABLISHMENTS: Please identify the location of your establishments **manufacturing** superconductivity-related products and briefly identify those products. Please note the year the establishment was founded.

YEAR	LOCALITY	STATE	COUNTRY	PRODUCT

4. RESEARCH FACILITIES: If you are a research organization, or if you have a separate facility which is dedicated to superconductivity-related research, please provide the facility's location, current number of full-time employees dedicated to superconductivity-related research, and year that this facility was established.

YEAR	STATE OR COUNTRY	EMPLOYEES	RESEARCH AREAS

5. FUTURE PLANS FOR MANUFACTURING ESTABLISHMENTS: Does your firm have plans for plant expansion/construction over the next five years? If so, please list them below.

EXPANSIONS/NEW CONSTRUCTIONS		
DATE	**CITY/STATE OR COUNTRY**	**PRODUCT LINE(S)**

6. FUTURE PLANS FOR RESEARCH FACILITIES: Does your firm have plans for facility expansion/construction over the next five years? If so, please list them below.

EXPANSIONS/NEW CONSTRUCTIONS		
DATE	**CITY/STATE OR COUNTRY**	**RESEARCH AREA**

7. FOCUS: Broadly characterize your firm's superconductivity operations. Please check all that apply.

Low T_c _____ High T_c _____ Organic _____

MAGLEV____ MHD Propulsion _____ Industrial Mfg _____

Contract Research _____ Research Consortium _____ Electronic Components _____

Medicine _____ Energy _____ Electrical/Power Systems _____

Computers _____ High-Energy Physics _____ Cryogenics _____

Metals _____ Ceramics _____ Fabrication Equipment _____

Wire/Tape Mfg _____ Thin Film Mfg _____ Other (please specify) _______

____

My firm is primarily engaged in manufacturing/developing (check all that apply):

_____ Products containing superconductors _____ Superconducting components

_____ Superconductivity-related enabling technologies

8. DOMESTIC AND FOREIGN RELATIONSHIPS: With regard to your superconductivity operations. please indicate the arrangements you have with domestic and foreign entities and briefly describe the relationship(s). Check all that apply.

Domestic:

Joint Venture _____ Consortia _____ Licensing _____ Marketing Agreement _____

Long-Term Customer/Supplier _____

Other (please specify) ______________________________

Relationship: ____

Foreign:

Joint Venture _____ Consortia _____ Licensing _____ Marketing Agreement _____

Long-Term Customer/Supplier _____

Other (please specify) ______________________________

Relationship: ____

9. EMPLOYMENT: Enter the number of employees (end of year) involved in superconductivity or related enabling technology operations from 1989-1991, as requested below, and enter the projected numbers for 1992-1993. (See definitions of Scientists and Engineers, and of Production Workers)

OCCUPATION	1989	1990	1991	1992	1993
Scientists, Engineers					
Production Workers					
Marketing & Sales					
Administrative, Other					
TOTAL					

PART II. COMPETITIVE CONSIDERATIONS AND THE ROLE OF GOVERNMENT

1. COMPETITORS: Please identify your two major domestic and foreign competitors.

	Domestic Competitors	State	Foreign Competitors	Country
a)	____________	____	____________	________
b)	____________	____	____________	________

2. COMPETITIVE RANKING: With regard to your **major foreign competitors,** please comment on your competitive advantages and disadvantages as requested below. In comment area also note (with +, - , =) whether this advantage will change over the next five years.

Competitive Area	My Firm has Advantage yes/no	Comments
Overall Technology	____	____________________
Design Capability	____	____________________
Engineering Capability	____	____________________
R&D	____	____________________
Innovation	____	____________________
Price	____	____________________
Product Quality	____	____________________
Delivery	____	____________________
Customer Satisfaction	____	____________________
Capital Costs	____	____________________
Government Assistance	____	____________________

3. MERGERS & ACQUISITIONS: Have mergers, acquisitions and takeovers affected your company? If so, please explain.

Yes _____ No _____ Comment: ______________________________________

____

____

4. COMPETITIVE PROSPECTS: How do you view the competitive prospects for your firm's U.S. superconductivity operations over the next five years?

They should:
- improve greatly _____
- improve somewhat _____
- stay the same _____
- decline somewhat _____
- decline greatly _____

Please discuss the basis for your answer: ______________________________

____

____

____

5. CONSTRAINTS: What obstacles -- technological, financial and legal or regulatory -- do you see to the competitiveness of your superconductivity operations over the next five years? What possible changes, strategies or breakthroughs would help overcome these obstacles?

Technological obstacle: ______________________________________

Change/Strategy: ____

____

Financial obstacle: ____

Change/Strategy: ____

____

Legal/Regulatory obstacle: ____________________________________

Change/Strategy: ____

____

6. PRODUCT ACCEPTANCE: What difficulties, if any, have you encountered in marketing your products as alternatives to other, more established products?

____

____

____

7. PROCUREMENT PROCEDURES: Has your firm been adversely affected by government or national lab procurement procedures? If so, please explain.

____

____

____

8. GOVERNMENT PROGRAMS: Do you work now or have you ever worked with any of the following government programs? Please check all that apply.

High-Temperature Superconductivity Pilot Center (e.g., Pilot Contract)	____	Advanced Technology Program	____
Strategic Partnerships Initiative	____	Small Business Innovation Research Program	____

Other (specify): ____________________

Which government programs best suit your R&D funding needs? ____________

____

____

9. FOREIGN GOVERNMENT ASSISTANCE: To you knowledge, do foreign governments provide loans, loan guarantees, grants or other forms of assistance to underwrite development of new technologies? If so, please identify them.

____

____

____

10. STRATEGIC ALLIANCES: (Please check all that apply.) Do you perceive U.S. antitrust laws to be a barrier to strategic alliances:

with other U.S. firms _____ with foreign firms _____

in horizontal relationships _____ in vertical relationships _____

Have you had actual experiences in which U.S. antitrust laws have created a barrier to cooperation with other firms:

in R&D partnerships _____ in manufacturing partnerships _____

Do you currently have or have you in the past had vertical alliances with suppliers, manufacturers or distributors in your field? Please indicate whether these involve:

foreign firms _____ R&D _____ manufacturing _____ marketing _____

short-term (1 - 5 years) _____ long-term (5 years or more) _____

11. LABOR CONCERNS: If in the last five years you experienced any labor concerns, such as shortages of certain skills, excessive turnover, etc. that adversely affect(ed) your operations, please indicate them below.

Shortage of technical skills _____ Excessive turnover _____

Shortage of educational qualifications _____ Other: _____________________

Comment: ____

____

____

12. DEFENSE CUTS: Do you think your firm's superconductivity-related production or R&D will be adversely affected by cuts in the defense budget? Please try to project over the next five years and discuss the basis for your answer below.

No _____ Production _____ R&D _____ Both Production and R&D _____

____

____

____

13. EMERGING COMPETITORS: Aside from your current major foreign competitors, what other regions or countries have, to your knowledge, emerging superconductivity capabilities and may be major international competitors in the future?

____

____

To your knowledge, what is the state of development of superconductivity and related enabling technologies in Eastern Europe and the former Soviet Union?

____

____

14. DEFENSE CONVERSION AND DUAL USE: Are you currently converting any defense-related product lines to commercial business, or do you plan to begin such a conversion within the next five years? Do you produce products that have both commercial and military applications?

_____Current conversion _____Future conversion _____Dual use

Comment:____

____

____

Are you aware of any federal, state or local government programs to assist firms in converting defense-related operations to commercial operations? What kinds of programs would be useful?

____

____

15. OTHER COMPETITIVE CONSIDERATIONS: Please comment on any other competitive considerations that have a significant impact your firm, and that should be brought to our attention.

____

____

____

____

PART III. PRODUCTION

1. SHIPMENTS: On the following table please report dollar values (in thousands-- $53,000 would be reported as 53 or 53K) of **all** superconductivity-related products or services shipped by your firm from 1989-1991. On the last line, please list the value of those shipments exported from the United States. Please try to project shipments and exports for 1992-1993.

MARKET	1989	1990	1991	1992	1993
Commercial End User					
Commercial Manufacturer or Integrator					
Department of Defense					
Other Government					
TOTAL					
Exports					

2. APPLICATIONS AND MARKETS: Please complete the following table, identifying your largest sale in 1991 of superconductivity products for use in each of the following markets. For each market, provide the type of product and use to which the product will be put. If you sold **directly** to the U.S. Government, please check the right-hand column.

MARKET	PRODUCT	END USE	GOVT
Defense (Non-space)			
Space			
Medical			
Energy			
Electronics (Commercial)			
High-Energy Physics			
Land/Sea Transportation			
University/Research			

PART IV. RESEARCH & DEVELOPMENT

1. RESEARCH AND DEVELOPMENT (R&D) FUNDING: Please enter 1989-1991 R&D expenditures, and projections for 1992-1993, associated with your superconductivity operations. Enter separately the dollar amounts (in $000s) financed by your firm (in-house), the government, a customer, or as part of a consortium. (See definition of Research and Development)

SOURCE OF FUNDING	1989	1990	1991	1992	1993
In-house					
Federal Government					
State/Local Gov't					
Customer					
Consortium					
Other (specify)					
TOTALS					
% Foreign					

For government funding listed above, please identify the source agency(ies), using the most specific choice (i.e., DARPA rather than DOD if both apply).

AGENCY	1989	1990	1991	1992	1993
DOE					
National Lab					
DOD					
DARPA					
Armed Services (specify)					
NSF					
NIST					
Other (specify)					
TOTALS					

5. AREAS OF R & D EFFORT: For 1989-1993, please enter research and development expenditures (in $000s) in the areas specified.

AREA	1989	1990	1991	1992	1993
Enabling Technologies					
Materials					
Thin Film Processing					
Thick Film Processing					
Wire/Tape Processing					
Cryogenics					
Other:					
Components/Devices					
Magnets					
Analog Devices (e.g., delay lines)					
Digital Devices (e.g., logic, memory)					
Detectors					
SQUIDs					
A/D Converters					
Motors					
Generators					
Bearings					
Semiconductor Hybrids					
Interconnects					
Other:					
SYSTEMS & APPLICATIONS					
Medical Applications					
MRI					
Magnetoencephalography					
Other:					
Energy Applications					
High-Energy Physics					

AREA	1989	1990	1991	1992	1993
Energy Storage (SMES)					
Energy Transmission					
Fusion					
Radiation-resistant Materials					
Other:					
Transportation/Industrial Applications					
MAGLEV					
MHD Propulsion					
Ore Separation					
Other:					
Electronics Applications					
Signal Processing					
Computers					
Satellites					
Other:					
Other Applications					
Other:					
Other:					
Other:					

6. PROJECTED R&D: Over the next five years, how do you expect your R&D expenditures will change?

They should: increase greatly _____
increase somewhat _____
stay the same _____
decrease somewhat _____
decrease greatly _____

Please discuss the basis for your answer: ____

____

____

____

PART V. FINANCIAL INFORMATION

PLEASE NOTE: Information requested below is necessary to fulfill the provisions of the Defense Authorization Act. It will remain confidential and will not be disclosed except in aggregated form. If you possess this information in another form, such as an annual report, you may attach the appropriate material in lieu of listing the information below.

1. CORPORATE INCOME STATEMENT: Please enter the financial information (in $000s) as specified below for your firm as a whole for the years 1989-1991.

	1989	1990	1991
Sales			
Cost of Goods Sold			
Selling, Admin. and General Expenses			
Development			
R&D			
Interest Expense			
Other:			
Other:			
Total Expenses			
Operating Income (Before Taxes)			
Less Income Taxes			
Net Income			

2. BALANCE SHEET: Please provide the balance sheet information (in $000s) as specified below for your latest accounting period.
NOTE: For Land and Buildings, *please use Book Value.* Short Term Debt *has principal payable in less than one year,* Long Term Debt *in more than one year.*

ASSETS		LIABILITIES	
CURRENT ASSETS:		CURRENT LIABILITIES:	
Cash & Equivalents		Accounts Payable	
Accounts Receivable		Short Term Debt	
Inventories		Current Portion, Long Term Debt	
Other		Other	
PROPERTY, PLANT & EQUIPMENT:		NON-CURRENT LIABILITIES:	
Land and Buildings		Long Term Debt	
Equipment		Other	
Depreciation Allowances			
OTHER ASSETS		EQUITY	
TOTAL ASSETS		TOTAL LIABILITIES	

3. INVESTMENT: Enter expenditures and planned expenditures for plant, new equipment, and employee training (in $000s) from 1989-1993 as requested below.

INVESTMENTS	1989	1990	1991	1992	1993
MANUFACTURING FACILITIES:					
Buildings					
Equipment					
Training					
SUBTOTAL					
RESEARCH & DEVELOPMENT:					
Buildings					
Equipment					
Training					
SUBTOTAL					
GRAND TOTAL					

CERTIFICATION

I, the undersigned, certify that the information herein supplied in response to this questionnaire is, to the best of my knowledge, complete and correct. The U.S. Code, Title 18 (Crimes and Criminal Procedure), Section 1001, makes it a criminal offense to willfully make a false statement or representation to any department or agency of the United States as to any matter within its jurisdiction.

__________ ____

(Date) (Signature of Authorized Official)

________________________ ____

(Area Code/Telephone Number) (Type or Print Name and Title of Authorized Official)

________________________ ____

(Area Code/Telephone Number) (Type or Print Name and Title of Person to Contact re this Report)

COMMENTS: Please use the space below to provide any additional comments or information you may wish regarding your operations, or other related issues that affect your firm. Attach extra sheets if needed.