Cooperation Meets Competition: The Impact of Consortia for Precompetitive R&D in the Computer Industry, 1982–92

Norman S. Zimbel

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Norman S. Zimbel
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Project Director
Oswald H. Ganley

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Chairman
Anthony G. Oettinger

Managing Director
John C. LeGates

Executive Director
Oswald H. Ganley

Norman S. Zimbel is a research affiliate of the Program on Information Resources Policy. His current interests focus on the role of cooperative undertakings in a changing information industry infrastructure. Beginning in 1947, his experience in the computer industry has encompassed leadership in research and development and consulting activities. In 1964 he was awarded a Lipsky Fellowship to the Weizmann Institute of Science.

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Executive Summary

During the 1980s, stakeholders in the information industry in the United States, concerned with the availability of the human and financial resources required to meet global competition, entered into a variety of cooperative undertakings. These included consortia, predominantly for precompetitive research, setting standards, support of university curriculum development and research, and for university-based supercomputer centers. This study of the evolution of U.S. precompetitive research consortia for high-performance computing (HPC) technologies addresses the following questions: Is there a significant role for HPC R&D consortia in the U.S. to facilitate a healthy information industry serving global markets? What are the issues and problems related to fulfilling this role? Are these addressed effectively? What has been learned? What benefits can be derived from what has been learned? The following criteria were developed to address those questions:

Resources of a Consortium	**Staff** ▪ Quality and dynamics **Industry participation** ▪ Scale and stability **Budget** ▪ Size and trends
Achievement of Goals of Consortium	**Timely Application of Advanced Technology** ▪ Technical achievements ▪ Effectiveness of technology transfer ▪ Balance between short- and long-term programs **Strengthening of Industry Environment** ▪ Impact on industry infrastructure ▪ Impact on federal policymaking

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The Japanese experience with semiconductor and computer technology precompetitive research consortia provides a useful reference for assessing similar U.S. activities. Successful application of technologies developed through R&D consortia, in an industrial policy context, have contributed to the ascendancy of Japan's industry. Key features of their approach are:

- Industry-driven technological objectives, strongly influenced by MITI through "vision" positions as guides for planning

- Company tax, antitrust, and market protection incentives

- Funding modes determined in relation to technological risk must be acceptable to participants
- Consortium organizational structures that take into account the highly competitive orientation of member companies
- Company responsibility for commercial application of research
- Consortia staffing primarily by industrial participants
- Major company members with large relevant internal programs
- Research environments that encourage broad "vision" for members

In the U.S., precompetitive research consortia are evolving in response to the need for highly responsive, industry-coordinated, market-driven applied research programs, a need addressed also both by university research "centers" and some national laboratories. The four major U.S. consortia discussed here are Microelectronics and Computer Technology Corporation (MCC) and three semiconductor consortia, the Semiconductor Research Corporation (SRC), SEMATECH, and U.S. Memories.

MCC, a for-profit, centralized laboratory-based consortium for information and user industries founded in 1982 (by industrial companies), has one of the broadest technology programs of any U.S. information industry consortium. Within the industry, MCC is regarded as a competent research entity viewed with considerable good will by its shareholders but with only a marginal impact on helping the industry to become more competitive.

As of 1991, MCC's main accomplishments were in the scope of the technology addressed, the quality of the research staff, the application by some shareholders and licensees of technology developed by MCC, and facilitation of inter-company and inter-industry cooperation. MCC has fallen short, however, in several areas: the limited success or actual failure of some its technology programs, its insufficient impact on the industry, the underrepresentation of shareholder researchers in its R&D staff, and its only minor contribution to federal policymaking.

In 1991, MCC announced a strategy for the 90s that may enhance its effectiveness. The plan emphasizes a unifying theme of universal broadband information networking: facilitation of "partnering" with industry, national laboratories, and academia; evolution from a centralized laboratory to a hybrid that combines MCC research laboratories and an administrative secretariat operation; budget leveraging by "partnering"; greater participation in standards groups and cooperation with the federal government on common interests.

The three semiconductor consortia, which serve their constituency more narrowly than the MCC consortium serves the information industry, represent an attempt to pool R&D resources, stimulate supportive federal industrial policies and practices, and enhance the technical work force.

The SRC was founded in 1982 by seven semiconductor and four computer manufacturers to strengthen the industry's skill base through university programs. It has stimulated research and significantly increased the number of engineering and science graduates in microelectronics. It is a partner of SEMATECH and, to a lesser extent, MCC in their programs with academia.

SEMATECH's goal is to achieve technology parity with Japan by 1993-94 in manufacturing processes, materials, and manufacturing equipment. Founded in 1987 by seven semiconductor companies, seven computer companies, and the Defense Advanced Research Projects Agency (DARPA), SEMATECH has progressed well. Key indicators of progress are:

- A "world-class" pilot manufacturing process facility
- Production of advanced manufacturing equipment by U.S. companies with SEMATECH support in successful competition with the Japanese
- Technology schedules for 1993 will apparently be met
- DARPA has facilitated program planning, management, and cooperation with national laboratories
- Relationship with SRC has facilitated interaction with academia

With these achievements as a foundation, in the 1990s SEMATECH, through its SEMATECH II program, plans to accomplish basic changes in manufacturing technology and industry practice so that more U.S. companies will be world-class competitors.

U.S. Memories, proposed as a DRAM memory chip manufacturing consortium, was never implemented. The rationale for its proposal was that DRAMS are a "technology driver" for semiconductor products, their production benefits the industry's technical infrastructure, and domestic production would provide a stable source of supply for users. Although the semiconductor companies as well as IBM and DEC endorsed the concept of U.S. Memories, other computer manufacturers were not supportive because of the high risk of failure and lack of federal support.

Following the formative decade of the 1980s, industry-driven consortia for product and process precompetitive R&D are now at a crossroads: lessons learned must be built on to realize significant tangible benefits in the timely application of advanced technology and a strengthened industry infrastructure. The study reached two overarching conclusions for the U.S.:

- Precompetitive R&D consortia are evolving as important vehicles for reinforcing the computer industry's technological competitiveness in an environment of diminishing resources. The industry's global competitiveness depends on such factors as technological strength; federal trade, tax, and regulatory policies; availability and cost of capital; an educated work force; and cooperation between the federal government and the industry. All these factors bear on the willingness and ability of companies to support appropriate investment for in-house and consortium-based R&D.

- Perhaps the most important contribution made by consortia in the U.S. (as of 1992) has been to stimulate cooperative practices within the industry and among industry, universities, and government. During the 1980s diffusion of cooperative practices was recognized as best stimulated by consortia organized as either a secretariat or a hybrid entity of secretariat and research laboratory to promote optimum participation by stakeholders and significant leveraging of a consortium's resources.

- Risk sharing and the realization that the products and services of the computer industry are key enablers for a modern society mean that in order to enhance competitiveness more comprehensive cooperation between the federal government and the semiconductor and computer industries, including manufacturing consortia, appears inevitable.

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Preface

This study was begun in 1989, at the end of a decade in which consortia proliferated in the information industry in the United States as part of a response to global competition. I undertook it in the belief that sufficient time had elapsed for assessment of the contribution by consortia to the technological posture of the industry to be meaningful. The study is concerned with the contributions of precompetitive research and development consortia in the computer and semiconductor industries both to generic high-performance computing technologies and to cooperative practices of the industry.

The experience of the United States is discussed in Chapters One, Three, Four, Five, and Six, that of Japan in Chapter Two. Chapters Four and Five, and their appendices, offer detailed treatments of particular U.S. consortia. Because the study is organized to allow readers interested mainly in an overview to skip Chapters Four and Five, those interested also in the detailed view will encounter some repetition of material in the final chapter, an overall examination of the "Status, Issues, and Evaluation" of consortia.

Chapter One

High-Performance Computing Consortia: Stakes and Relevance for the U.S.

1.1 Introduction

In the late 1980s, in the United States the availability of the human and financial resources needed to compete in the arenas of development, manufacture, and application of high-performance computing (HPC) technologies came into question. Consortia proliferated, with the goal of applying scarce resources more effectively to precompetitive R&D, standards setting, and supercomputer applications. The establishment of a semiconductor manufacturing consortium was proposed but not implemented.

This study investigates the evolution of consortia as a means to sustain the U.S. information industry's competitiveness in the leading HPC technologies—those that extend the range of application of information systems and products by improving their capabilities to perform functions such as:

- User interfacing
- Network management
- Database services
- On-line transaction processing
- AI/Expert systems
- Embedded computing
- Modeling
- Imaging and visualization
- Voice recognition
- Neural networks

As these advanced technologies extend product capabilities, they stimulate broader use of such products for applications ranging from home computing to the most esoteric soft or hard sciences. HPC technologies are, thus, a primary enabler of market growth of the information industry.

HPC systems, as treated here, encompass (*i*) the complete range of generic computer system products, from workstations to supercomputers, (*ii*) special purpose and embedded computers, (*iii*) high-performance networks, and (*iv*) related algorithms, as well as system and application software.

The "food chain"* includes HPC technologies for:

- Electronic material and device development
- Computer hardware and software development
- Electronic material, device, and equipment manufacturing

The study addresses the following question: Is there a significant role in the U.S. for HPC precompetitive research and development consortia for facilitating a healthy information industry serving global markets? If so, what are the significant issues and problems related to fulfilling this role? Are these being addressed effectively? What has been learned? What benefits can be derived from what has been learned?

1.2 Stakeholders' Orientation

The formation of information industry consortia in the U.S. was a growth phenomenon in the 1980s. Although consortia dealing with a broad range of issues related to standards, basic research, applied research, and computing resources resulted, the efficacy of this approach for addressing certain problems of the industry remains a concern. Even after almost a decade of experience, the ultimate contribution of large-scale, precompetitive applied research consortia to the industry's competitiveness is uncertain. One attempt to form a semiconductor manufacturing consortium failed, owing to insufficient support by computer manufacturers.

For many in the industry, the need for consortia was based on their perception of the success of Japanese cooperative programs. Support for cooperative precompetitive R&D programs, where the Japanese have most successfully applied consortium concepts, is much stronger in the U.S. than for cooperative manufacturing ventures. Companies are tentative about the potential importance of precompetitive R&D consortia as competitive vehicles, even when they acknowledge the need for pro-active policies toward the industry's problems.

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*Materials, components, software, products, systems = "food chain."

Federal participation and funding are generally welcomed, but usually for consortia initiated and controlled by the industry.

In the 1980s, federal policies related to consortia began to change and are still changing. Congress enacted significant legislation to facilitate cooperative precompetitive R&D, and in the 90s some sentiment favors legislation supporting cooperative manufacturing undertakings. Congressional interest in a more aggressive industrial policy, including federal participation in industry-based consortia, has grown with the end of the Cold War, because benefits accruing to the industry from defense research are likely to diminish. With the emergence of national concern for global competitiveness, the idea of founding a civilian equivalent of the Defense Advanced Research Projects Agency (DARPA) to sustain the industry's technological competitiveness has gained support.

In academia, attitudes are mixed, with some bias in favor of pro-active policies to reverse the industry's slide, implemented, in part, through consortia.

Attitudes toward cooperative endeavors sponsored by industry and the federal government are inseparable from those toward the larger subject of industrial policy, and, to a considerable extent, the consortium concept has served as a "lightning rod," sparking the conflict between those for and against pro-active federal industrial policies.

1.3 The Information Industry Marketplace

The scope of the "information industry," as this industry is defined here, is delineated by the crosshatched areas in **Figure 1-1**: it includes equipment manufacturers, software producers, and information service suppliers. Stakeholders include these companies and their customers, state and federal government, academic institutions, and professional associations.

In the U.S., the industry, now matured into its sixth decade, exhibits many contradictory characteristics. On the one hand, in the 1980s the environment was particularly dynamic, driven by the increasing importance of international markets, by the need for user industry modernization, by technology, and by the pro-active industrial policies of certain countries. On the other, the industry was, and continues to be, beset by concerns arising from the general economic outlook, dependence on global markets, and related changes in the industry structure and its practices. Consequently, in the 1990s the U.S. industry is faced with the need to adjust to increasingly complex markets and technologies in an environment of potentially inadequate human and capital resources for itself and its customers.

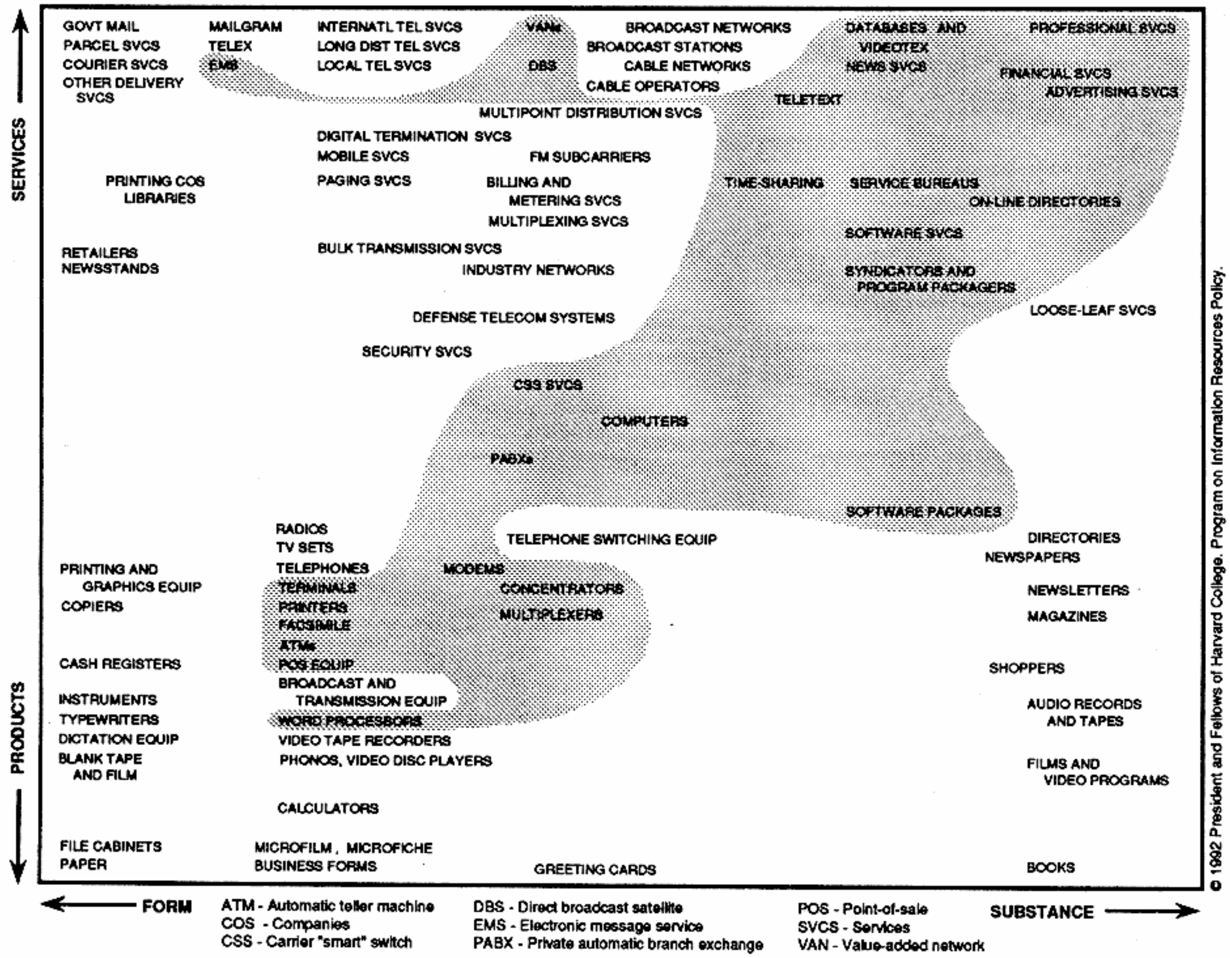


Figure 1-1

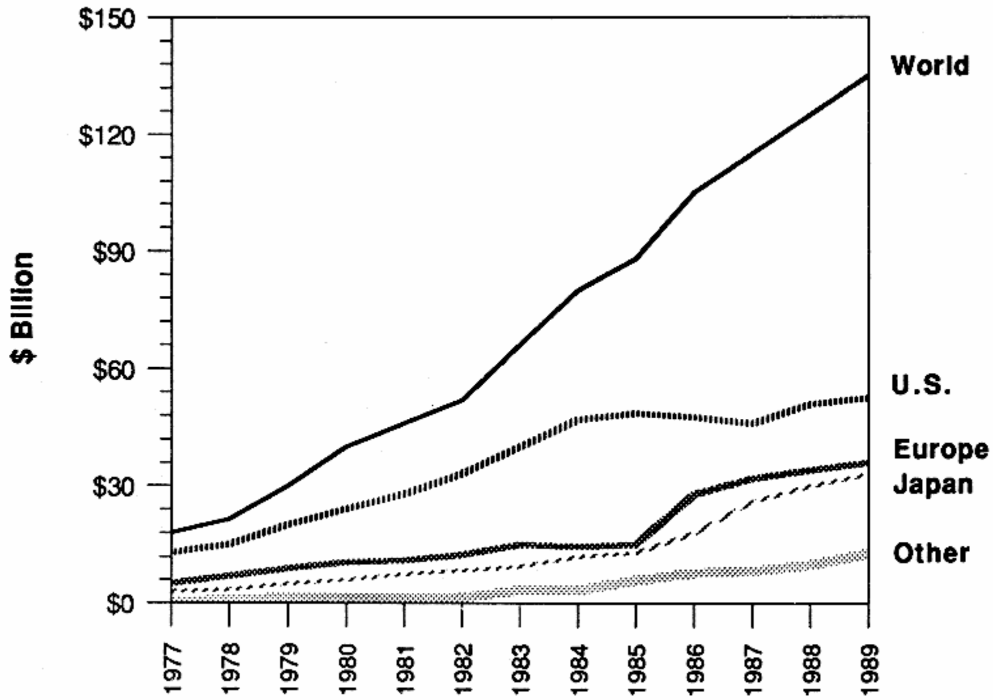
The Information Industry

The last decade has seen a steady deterioration in the once overwhelmingly favorable trade balance of the U.S. information industry; by 1990, the U.S. balance of trade in information product markets had turned negative.

As the industry matured in the U.S., the latter half of the 1980s saw a substantial decrease in the growth rate of the value of domestic shipments, from +14.9 percent compound growth rate (CGR) in 1987–88 to an estimated +5.9 percent in 1990–91. At the same time, the growth rate for the value of exports from the U.S. dropped from +23.2 percent to –4.9 percent, while imports also dropped from +24.2 percent to +4.4 percent. (The export data do not include the value of shipments by overseas branches of U.S. manufacturers.) During this period, the industry's total employment in the U.S. dropped from 286,000 to 270,000; of this, production employment was flat at 101,000. By 1990, imports were 40 percent of domestic consumption. From 1983 to 1988, the U.S.-based industry share (including overseas manufacturing) of the global market slipped from 81 percent to 61 percent. Those of Japan and Europe improved from 7 percent to 22 percent and 10 percent to 17 percent, respectively. **Figures 1-2** and **1-3** summarize global production and consumption from 1977 to 1989; **Figure 1-4** summarizes the trend of the balance of trade for the U.S. computer industry since 1980.

In the future, the pace of growth of this market is likely to continue to be set by regions other than the U.S. Because prospects for a more unified European economy and a more affluent Pacific rim sector appear good, the market potential of these areas appears excellent; the size of the market in each might eventually meet, or exceed, that in the U.S. owing to population size and markets currently less mature than those in the U.S.

At present, the industry services a diverse mix of mature and growth market segments. The growth markets are driven, in part, by increasingly useful and cost effective products for accessing and utilizing information. These products are either being integrated into systems for established applications, such as management information systems (MIS), thus extending their utility (e.g., local area networks, or LANs) or establishing new classes of application by means of new capabilities (e.g., image processing). In some instances, the newer product classes are displacing older, less cost-effective ones (e.g., minicomputers by LANs). The technologies that pace these developments are complex and expensive to develop particularly because they are increasingly incorporated into products to implement open-system networks characterized by comprehensive system integration and sophisticated, "natural" human-machine interfaces.



Source: *U.S. Industrial Outlook 1990 — Computer and Software*, U.S. Department of Trade Administration, Figure 30-3, p. 30-9.

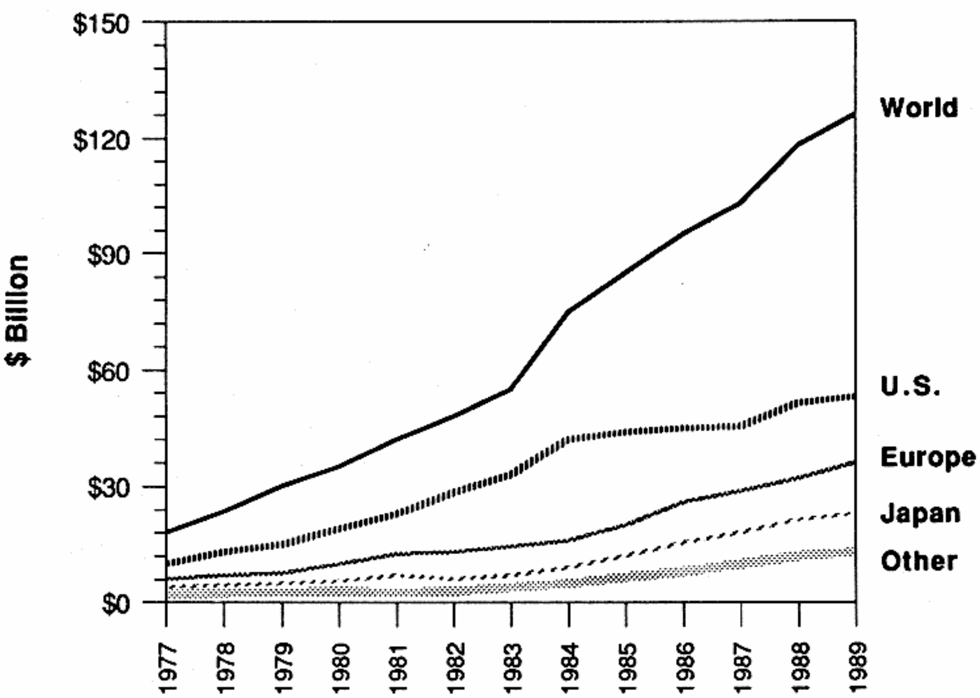
Figure 1-2

World Computer Production, 1977–89

The 1980s were unique in comparison with previous periods in the exceptional proliferation of new product classes, services, and related new companies. Although the period prior to 1980, beginning about 1965, stimulated by the Space and Defense programs, also was one of prodigious **technological** progress and industry growth, the 1980s were characterized by a greater diversity of product classes that featured innovative **application** of advanced, commercially developed technologies as the dominant aspect of the marketplace. These product developments, combined with demand for modernization by a broad range of industries and the onset of a burgeoning consumerism, resulted in changes in the marketplace on a scale never before equalled in the history of the industry.

Some important new product classes that emerged in the 1980s are personal computers and workstations; highly parallel supercomputers, "near" supercomputers and superworkstations; desktop publishing systems; integrated manufacturing systems; office information systems; heterogeneous, OSI (Open Systems Interconnection)-compliant networks; relational and object-oriented database management systems and personal computer and artificial intelligence/expert system software, among others.

Related new industry participants, while too numerous to cover, include: Apple Computer, Sun Microsystems, AT&T, Compaq Computer, Convex Computer, Sequent Computer, Thinking Machines, Silicon Graphics, Stardent Computer, Oracle, Adobe Systems, Lotus, Microsoft, 3COM, Ungerman-Bass.

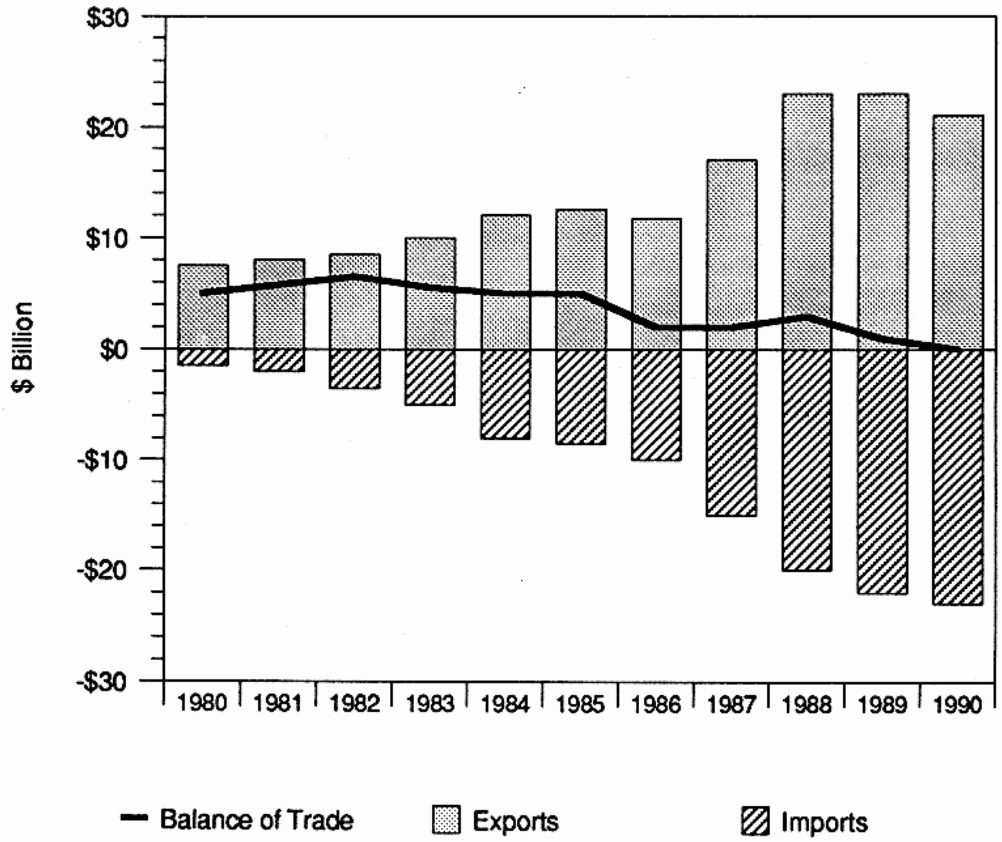


Source: *U.S. Industrial Outlook 1990 — Computer and Software*, U.S. Department of Trade Administration, Figure 30-3, p. 30-9.

Figure 1-3

World Computer Consumption, 1977–89

These lists make the point that the 80s were a prolific period. The counterpoint to all of this activity was relative stagnation in traditional mainframe and minicomputer markets as the role of these product classes shifted to computation, database, or communications servers in a network context.



Source: Perspectives on U.S. Technology Policy, Part I: The Federal R&D Investment (26 February 1991), Computer Systems Policy Project, Figure 12.

Figure 1-4

Balance of Trade for U.S. Computer Systems, 1980–90

While the 1980s were a time of growth for certain segments of the industry, for the traditional industry participants who did not adjust to the new market realities it was a period of stagnation. Entering the 90s, U.S. computer manufacturers are feeling intensifying pressure from maturing markets in a slowing global economy, market trends favoring product downsizing, and decreasing profit margins. These developments, together with the increasing prominence of the Japanese as global competitors, are making the 1990s a period of unprecedented uncertainty for most U.S. participants. The industry's structure and practices have significantly evolved, and continue to evolve, as stakeholders attempt to deal with these uncertainties.

The current climate of industry consolidation and restructuring is likely to prevail for some time, with the focus increasingly on global markets. For the foreseeable future, the forces influencing change are:

Market Factors

- Growing international competition
- Access to international markets
- Characteristics of new market participants
- Fragmentation of market requirements
- Availability of risk financing
- Cost of capital
- Federal and state government policies
- The rate of evolution of a "wired society"
- Education level of users of industry's products

Technology Factors

- Software as the pacing technology
- Further commoditization of hardware
- Manufacturing costs
- Further evolution of powerful processing engines and large-scale storage
- Proliferation of open systems
- Trends toward distributed, small-scale, powerful computer systems
- Increasing technology complexity and development costs
- Dependence on a quality engineering work force

These forces have led to a climate of intense merger, acquisition, and business alliance activities as established companies, foreign and domestic, seek to acquire a presence in the newer growth market sectors and as the successful, relatively recent market entrants attempt to build on their own achievements.

The dominant feature of change in industry practices is the proliferation of various forms of alliances, whether simple company-to-company cooperation in research and development or marketing, or multiple-organization consortia for research and development, setting standards, or other purposes.

1.4 Rationale for and Types of Consortia

1.4.1 Rationale

Consortia are cooperative endeavors that can serve a variety of purposes. According to Ouchi,[1] for generic technologies, consortia sponsored jointly by government and industry can benefit both producers and consumers, in contrast to those sponsored by purely private or purely public means, which may benefit one or the other but not necessarily both.

Ouchi and Bolton[2] identify three classes of intellectual property: (*i*) private property controlled by the developer; (*ii*) public property not controlled by the developer; and (*iii*) leaky property for which the developer has a short head start before use by competitors. This scheme can be useful to policymakers. To quote from Ouchi:

> The classes of property are important in making public policy, because each class will thrive under a quite different set of public policies. Private property is that which the inventor can practically appropriate and limit to uses and users of his or her own choosing.
>
> Thus a competitive marketplace that permits inventors to sell their invented intellectual property at a price of their choosing and in which free riding can be controlled will offer strong incentives to invest in invention. No investment of public funds is necessary in such cases, and in fact public subsidies in such cases can be expected to lead to over invention by inefficient companies and to a waste of the nation's resources.
>
> Public property, in pure form, is that intellectual property which is nct appropriable by the inventor. In this case, free riding is not controllable, and thus no inventor can be expected to invest in invention.... In such cases, it is desirable for consumers, through tax dollars, to jointly subsidize research. The result will be that ... consumers will benefit.

> Leaky intellectual property is that which is weakly appropriable by the inventor. The inventor of a new process technology may gain an advantage for two years or so but he has no feasible way to prevent that knowledge from leaking to competitors, who will soon adopt the innovations and thus compete away any advantage. On the one hand, it is exactly this kind of competitive pressure which brings about continued progress; and thus as consumers we applaud it. On the other hand, logic dictates that a firm will be reluctant to invest in developing those technologies that it knows will leak out, and thus we can expect that progress in such technologies will be slow. As consumers we seek a better way to stimulate innovation in leaky technologies. Leaky technology cannot be efficiently stimulated through the same policies appropriate to public intellectual property, however.
>
> If public monies were available to underwrite all of the costs of developing leaky technology then each inventor would have an incentive to take as much public funding as he could get because even a weakly appropriable private return would be very attractive under these conditions. Thus leaky property will be inefficiently overproduced if it is undertaken by government laboratories or other 100% publicly funded means, and it will be inefficiently underproduced if it depends solely on private investment.[3]

This rationale for joint industry-government support of R&D for generic precompetitive technologies supplies a useful frame of reference for evaluating U.S. consortia which is applied in **Chapter Six**.

It seems self-evident that logic that deals with intellectual property as applied to cooperative R&D ventures would not apply to cooperative manufacturing consortia. A different rationale is needed to justify cooperative manufacturing ventures in the form of consortia. The difference between these consortia is one of kind. A consortium for precompetitive research produces generic technology that companies commercialize, while a manufacturing consortium would produce products for sale. For the former, the industry benefits through commercialization of technology by shareholders or nonshareholders (by licensing); for the latter, shareholders compete with other companies through a jointly owned consortium, and in the long term the industry may benefit if overall improvement in the industry's infrastructure and practices results.

For the information industry, such cooperative manufacturing ventures are virtually nonexistent, although in the recent past interest in them has been on the upswing in the U.S. (Historically, no successful precedent exists in the information industry for manufacturing consortia in any developed country.) If such a venture were to be justified, it would probably be for a class of product of strategic importance to an industry or a country. That is, a cooperative manufacturing venture might be justified if an industry were at a competitive disadvantage in the global marketplace or were critical to a country's defense or overall economy. The potential benefits from such a venture are:

- Risk sharing: typically, a venture would require large capital investment
- An assured source of supply: for critical national needs or to minimize price-rigging, or both
- Resource pooling: for human and technological resources in short supply
- Stimulation of industry infrastructure: to nurture industry self-sufficiency for critical elements of the food "chain"

1.4.2 Types

Matching the organizational philosophy of a consortium to its goals and environment can determine the success or failure of the undertaking. In a useful taxonomy for consortia, Ouchi[4] identifies two classes, the secretariat and the operating entity, either of which may be temporary (a fixed term) or permanent. The secretariat serves as a coordinating body for its members and has no facilities or laboratories of its own; research programs are either performed in members' labs or contracted out. The operating entity owns and operates its own laboratory facilities with staff supplied totally or in part by its members. The designation of temporary or permanent is somewhat specious, because, while an organization may be "temporary" in the sense that it exists only to achieve particular short-term objectives, it is frequently but one phase of a program with larger, long-term objectives.

1.5 Overview of Regional Consortia

1.5.1 Europe

Consortia for the information industry first appeared in Europe in response to market dominance by U.S. mainframe companies. The consortium phenomenon was solely defensive; i.e., its purpose was to strengthen European companies in their domestic markets. The consortia were pan-European in nature and typically attempted to stimulate product line compatibility between such companies as ICL, Siemens, Bull, and Olivetti. These efforts were not successful, in part because the political environment, initially complex, was exacerbated by the participation of a single large company for each country. In the 1980s and early 1990s, European consortia activities focused on standards setting (e.g., X-Open) and research and development for critical technologies (e.g., ESPRIT). Although these are substantial, multinational programs, their impact to date appears problematical, and they are not addressed in this study.

1.5.2 Japan

Japanese consortia under the guidance of the Ministry of International Trade and Industry (MITI) and in the context of a multifaceted industrial policy, have generally been perceived as models for success. For the computer industry, the goals of the Japanese were, first, to capture control of their domestic market and, then, to establish strong participation in global markets, initially emphasizing the United States. The Japanese faced the task of competing with large U.S. companies entrenched in their own domestic market and recognized internationally as technological and marketing leaders. Japanese industrial policy, through consortia or suitable alternatives (such as encouragement of parallel R&D programs at the facilities of major companies), implemented a broad national strategy for development of critical technologies combined with programs designed to stimulate industry to address specific targeted market opportunities. By the late 1970s, seeded by MITI cooperative programs, the Japanese computer industry had established a base for strong penetration of the global market for computer components, mainframes, and peripherals. It has since progressed to challenging the U.S. for global marketshare leadership in many sectors. Their efforts have generally been successful for mainframes, peripherals, and personal computer clones, with supercomputers most recently emerging as a product class for the export market. They lag in areas such as software, minicomputers, work stations, and system products in general.

In the late 1980s and early 1990s, Japanese consortia activity emphasized a longer range perspective such as embodied in their programs for their Fifth and Sixth Generation computer research and the Software Industrialized Generator and Maintenance Aids (SIGMA) project. The goals of the Fifth Generation project were essentially to achieve breakthroughs in new computer architectures and related technologies (for inference "engines") while nurturing a generation of basic research-oriented technologists.[5] These goals stand in contrast to those of earlier consortium-based programs whose purpose was to reach technological parity with existing foreign machine architectures, componentry, and software.[6] The Japanese experience is addressed here in **Chapter Two**.

1.5.3 The United States

Cooperative, HPC-related ventures involving industry, government, and universities became acceptable to the industry in the 1980s. Until then, cooperative ventures in the U.S. tended to center on university research laboratories (frequently with ties to DARPA, the National Science Foundation [NSF], or the National Aeronautics and Space Administration [NASA]) and federal National Laboratories. As the U.S. industry's position of global leadership came under pressure from Japanese companies and as U.S. competitiveness deteriorated, the consensus of the industry came to favor sharing risks for R&D and standards development as well as a willingness to consider consortia for certain manufacturing activities. As a result, a number of R&D and standards consortia were formed, with one attempt to form a semiconductor memory manufacturing consortium (U.S. Memories) aborted. To varying degrees, the federal government has supported some of these activities.

Whether a consortium is partially sponsored by government either directly (SEMATECH) or indirectly (MCC) through contracts and grants, it must compete for federal funds against universities and National Laboratories as well as other industry consortia. It must do so as the established players—universities and National Laboratories—are changing their roles to place greater emphasis on industry-oriented R&D.

Industry's interest in consortia has been late in developing in the U.S. As long as the information industry's dominance and double-digit market growth were not threatened, industry stakeholders felt little need for such a step. Although some consortia were formed to compete within the U.S. in the areas of software, network, and terminal standards, for some time the dominant force driving interest in consortia formation has been the need to adjust to a rapidly evolving global market environment in which this country is threatened with loss of its leadership to Japan in the computer industry manufacturing sector.[7]

On the basis of shareholder experience, prospects for industrially based consortia for precompetitive R&D, such as MCC and SEMATECH, are somewhat encouraging, but, as of 1991, their potential has been only partially realized. U.S. Memories, an attempt to form an exclusively industry-sponsored manufacturing consortium failed for lack of support from computer manufacturers. Experience with university-based consortia such as the NSF-sponsored Supercomputer Centers has been encouraging, but that with other university applied-research technology "Centers," particularly their likely near-term impact on the industry, is inconclusive.

In this author's opinion, because of the pervasiveness of information technology, the stakes implicit for the U.S. in maintaining its leadership U.S. are very high, not only for the information industry but for society in general. This technology is a key element of many companies' competitive strategies as well as of services supplied by other sectors of society related to quality of life. This author contends that the ability of user industries and other organizations to interact with a responsive domestic information industry is important to both the nation's economy and general well-being.

At this stage in the industry's evolution, consortia continue to form for diverse purposes, both with and without federal participation. The ultimate impact of these consortia is not obvious, because it may depend on a consortium's purpose (e.g., standards would differ from precompetitive research) and its ability to overcome entrenched attitudes of its members, as well as political and institutional obstacles. The national environment and objectives also strongly influence policies that dictate the sponsorship, organization, and role of each consortium. The objectives of cooperative ventures vary by country, depending upon an industry's competitive position, industry and educational infrastructure, economic resources, and national aspirations. In the U.S., consortia face the added complication of being "new kids on the block," who have needed to prove themselves.

The following discussion addresses industry-based HPC-related consortia in order to determine what has and what has not worked, and why, and to explore alternative organizations and approaches for consortia.

Chapter Two

High-Performance Computing Consortia: The Evolution in Japan

2.1 The Environment

Japan's emergence as an economic force after the Second World War has been characterized by three phases:

- Post-war reconstruction: Through the mid-1950s
- Super-fast GNP growth: Mid-1950s to 1973
- Above average GNP growth: 1973 to the present

During the second phase, policies were initiated and programs pursued to establish a viable set of high-technology industries, including electronics and computers. These policies resulted in the evolution of a growth-oriented system characterized by a unique pattern of cooperation by industry, banking, and government. Chalmers Johnson notes in *MITI and the Japanese Miracle: The Growth of Industrial Policy*:

> The high-growth system, like the basic priorities of the state, was not so much a matter of choice for Japan as a necessity; it grew out of a series of economic crises that assailed the nation throughout the Showa era.... It is of course gratifying that Japan ultimately gained a powerful conception of how to achieve its priorities and then applied this conception with rigor and thoroughness. But it would be to reason in an ahistorical and ill-informed manner to fail to note that Japan's high-growth system was the product of one of the most painful passages to modernity any nation has ever had to endure.[8]

The second phase featured an annual average growth rate of about 10 percent for the GNP. By the early 1970s, Japan's was the third largest industrial economy, with a per capita income comparable to those of Western Europe. Although this period profoundly changed the needs and conditions encountered by policymakers, very few sectors in Japan chose to push the frontiers of knowledge—thus, the approach was to apply known technologies, emphasizing incremental improvements, to realize a competitive advantage. During this period the Ministry of International Trade and Industry (MITI) began to develop its "visions" for knowledge-intensive industries.

Well into the second phase, Japan pursued trade and industrial policies typical of a developing country, that is, a "follower" country,[9] while MITI was fashioning its radical (for the time) approach to the goals of its industrial policy. Yoshimi Ojimi, author of the trade liberalization plan of the 1960s and subsequent vice-minister of MITI, described the rationale for this approach, which deemphasized labor-intensive industry and served to "promote heavy industries that require intensive employment of capital and technology, industries such as steel, oil refining, petrochemicals, automobiles, aircraft, all sorts of industrial machinery, *and electronics, including electronic computers*."[10] (For fuller quotation, see **Appendix 2.1**.)

The third phase corresponds to Japan's transformation into one of the leaders for most of the industries targeted by its industrial policies in the second phase. In keeping with its emergence as an affluent society, growth of its economy during the third phase has been domestically driven; GNP annual growth slowed to the order of 4 percent. By the mid-1980s, the balance of trade still strongly favored Japan, but the gap had narrowed. National concerns broadened to include domestic quality of life, international trade issues, the nurturing of high "value-added" as well as troubled industries, aid to underdeveloped countries, and energy and the environment. By the late 1980s, many of the targeted high-technology industries, particularly the "knowledge-intensive" ones, caught up with or passed leading international competitors.

Until the mid-1980s, the Japanese government's programs for the computer industry, dealt with a moving target—they played a game of catch-up with U.S. companies. The primary focus was on IBM: to keep IBM, the company most capable of dominating the Japanese domestic market, at bay and, as a concomitant, to build a globally competitive Japanese computer industry. It is instructive to review, by product class and by industry composition, the various stages through which the U.S. computer industry evolved as these relate to the Japanese government programs for the computer industry during the three phases of Japan's economic development. The review proves useful in assessing successes and failures of their industrial policy and related cooperative ventures (including consortia) for the knowledge industries and, in particular, for aspects relevant to high-performance computing. The highlights of each phase of the development of the U.S. computer industry are related to the three periods of Japanese economic evolution (see **Appendix 2.2**).

MITI played an important role in this transformation through championing and administering growth-oriented trade, tax, antitrust, and funding policies and by programs aimed at reaching technological parity through the National Research and Development Projects program for specific industries, particularly the computer and semiconductor industries.

2.2 MITI: A Catalyst

Although private Japanese companies fund most non-defense R&D expenditures (in fiscal year 1980, for example, 83.6 percent of the $75.1 billion [1982 dollars] expended), the government continues to pursue an active industrial policy. Its rationale is that these policies compensate for imperfections in the functioning of the free market, such as imperfect market information, excessive emphasis on short-term gain, primacy of individual company over collective interests, and inattention to national goals.

Government responsibility for R&D policymaking and administration is diffuse. Several agencies or institutions contribute to developing science and technology strategies, foremost among them the Council for Science and Technology, composed of the Prime Minister, several cabinet ministers, and prominent experts, with responsibility for promoting a comprehensive national policy. The Science and Technology Agency (STA), which consumes about one-quarter of government R&D, oversees worldwide collection of science and engineering publications and directs a technology transfer corporation. Every five years, STA studies identify research areas to be emphasized. The Ministry of Education, which receives about half of government R&D funds, administers a system of 95 national universities and affiliated research institutes. Defense R&D accounts for about 4 percent of government R&D funds.[11]

MITI is responsible for industrial policy for specific industries, including high-technology industries: it advocates and develops the policies and guides their implementation—picking "winners," aiding depressed manufacturing industries, designing programs to meet the needs of both types of industries, and facilitating programs to realize the objectives. Perhaps because of the uniquely close relationships of Japanese government, banking, and industry, observers are not unanimous in assessment of the credit due industrial policy, and, by implication, MITI, for the success of Japan's high-tech industries. (See Johnson, *MITI and the Japanese*

Miracle [note 1], and *Japan's High Technology Industries: Lessons and Limitations of Industrial Policy*, edited by Patrick assisted by Meissner [note 2].) However the credit is apportioned, MITI's policies for high-technology industries have been successful on the whole, even though a number of their programs have not achieved all their objectives.

The following excerpt from Patrick (1986) provide a perspective on MITI's recent role for high-tech industries that is still valid:

> ... coherence in Japanese industrial policy has attenuated [in recent years]. But one should not count out industrial policy or MITI's role in it, especially in the high technology areas. High tech industries have three major needs: assured markets, encouragement of R&D, and finance. Government-related procurement, including that of NTT as well as remaining public corporations, provides an immense market still substantially protected by a wide range of "buy Japanese" regulations and tax incentives. High tech R&D is encouraged through tax write-offs, government loans, subsidies, government industrial research labs (many under MITI jurisdiction), favorable antitrust provisions, and government funding for joint, cooperative, R&D projects among major corporations. Finance depends upon industrial structure. Large firms moving into high tech activities can readily utilize internal funds and borrowing capacity. The major problem has been the provision of risk capital to new, small firms. Venture capital institutions are in their infancy....[12]

The following is abstracted from an overview (1990) of MITI's computer industry-related role:

> aid (of all types) from MITI and other agencies from 1961 to 1969 amounted to 188 percent of what industry itself invested in computer-related R&D, plants, and equipment ... unlike the practice in France or the United Kingdom, Japan subsidized a handful of companies to promote competition rather than one. Subsidies took the form of direct aid, tax benefits, and low interest loans. Other help included assured purchases by giant Nippon Telegraph and Telephone Corp., Tokyo, at artificially high prices. From 1970 to 1975, Government investment rose to 168% of companies' contributions: from 1976 to 1981, 93%.
>
> In addition, Japan protected its market from the IBM 370 computer in the early 1970s and helped Fujitsu ... invest in Amdahl Corp., to gain IBM-compatible technology.... The government also created the Japan Electronic Computer Company that used low cost loans to buy Japanese computers at a standard price and rent them to users at prices below IBM's. To prompt competition among producers to make better machines, the company would only order computers that customers wanted to rent.
>
> Big companies are not the only Government beneficiaries ... each year, Tokyo allocates $27 billion in direct loans and $56 billion in loan guarantees

> to small and medium enterprises, which account for 74 percent of the nation's employment.
>
> MITI ... chooses which projects to organize and subsidize after close consultation with industry based on three criteria: they must be important to Japan's future economy; government assistance must be indispensable for the project to get underway; and the schedule must be realistic. The ministry will often divide research among companies and make them share results. (The trade ministry also grants *hojokin*, low interest loans, that need only to be repaid when the project succeeds.)[13]

MITI evolved various approaches to organizing and funding research projects that have proven effective for overcoming such barriers as: (*i*) different levels of uncertainty inherent in the technological goals of a project depending on its time horizon; (*ii*) the inherent limitations on cooperation between participating companies who are competitors; (*iii*) the reluctance of participating companies to assign top-level researchers as staff for cooperative research facilities; (*iv*) the limited technological and market "vision" of individual participating companies; and (*v*) the difficulty of achieving appropriate technology diffusion to industry members. In what Fransman, in *The Market and Beyond*, calls the Japanese Technology-Creating System, MITI developed effective incentives and organizational approaches to overcome those barriers (see **Appendix 2.3**).

2.3 MITI–Sponsored Consortia

Starting during the period of "super-fast GNP growth" (mid-1950s to 1973), MITI undertook cooperative projects—consortia—to bring leading companies to work together toward priority national industrial goals. The rationale was that, as a follower country with limited resources, Japan needed to avoid wasteful duplication by technical resource pooling to achieve economies of scale. Japan was not the first follower country to apply this philosophy to the semiconductor and computer industries; it was pioneered, unsuccessfully, in the 1970s as part of the pan-European response to U.S. dominance in these high-technology fields. Japan's undertakings yielded the first successful cooperative programs solely in an industrial context. In the U.S., early Defense and Space programs, frequently coordinated through government or university-affiliated laboratories, were instrumental in achieving a similar result.

The single focus of the Japanese cooperative projects through the 1970s and 80s was "precompetitive" R&D designed to yield a competitive advantage to the industry in the medium term, and typically the projects were but one element of comprehensive government-sponsored programs. In most cases, commercialization of the fruits of cooperative R&D projects by participating companies was realized rather quickly.

The major vehicle for Japan's cooperative programs was the National Research Project, and the philosophy was that, in achieving its generic technology objectives, a project would stimulate and augment R&D efforts of participating companies in certain critical areas; commercialization of the technologies was, and remains, the purview of industry.

Eads and Nelson neatly summarize the broad principles that guided the Japanese programs: (*i*) Get the basics right. Getting the investment climate, support for R&D, and support for education right may not be enough to ensure success for high-tech industries, but not doing so can guarantee their failure, whatever else is done. (*ii*) Be willing to move downstream from support for basic and applied research to that for development of generic technologies. But be careful to avoid making the commercialization decisions. (*iii*) Use cooperative research and development to whatever extent circumstances require. But let industry take the lead in identifying where a joint endeavor is likely to be fruitful.[14]

The activities of consortia for high-performance computing are addressed here for the second (before 1980, when activities emphasized achieving leadership in the semiconductor industry and programs to stimulate development of mainframes competitive with those of IBM) and third (after 1980, when the goal was to achieve or lay groundwork for future achievement of parity (or better) with leaders in advanced technologies) phases of Japan's emergence as an economic force.

In **Tables 2-1** and **2-2**, based on Okimoto and a panel report by the Japanese Technology Education Center (JTEC), five projects are shown as most pertinent: the VLSI project, which helped establish the semiconductor manufacturing industry, a strategic cornerstone; the 3.75 Series Computer project, a continuation of the first HPC R&D project for catching up with IBM mainframes; the Fourth Generation High-Speed Computer (supercomputer) project, an attempt to become competitive in supercomputer systems in the

Table 2-1

Government Supported Research Projects in Japan, 1960–1980

Period	Project	Amount ($ Million)
1966-71	High-performance computer R&D	71
1972-76	3.75 Series computer development	228
1971-80	Pattern information processing system	156
1976-80	VLSI development	213
1976-80	Software development	30
	Total	$698

Sources: Data from *Japan's High Technology Industries: Lessons and Limitations of Industrial Policy*, Patrick Hugh, Ed., Larry Meissner, Asst. Ed (Seattle: University of Washington Press and University of Tokyo Press, 1986), p. 62; and *Advanced Computing in Japan*, the National Technical Information Service, JTEC Panel Report, U.S. Department of Commerce (October 1990), p. 26.

short term; the Fifth Generation project, an ambitious attempt at a major breakthrough in computer architecture; and the SIGMA project, to develop UNIX-related software development tools.

The VLSI project stimulated development of manufacturing technologies required for a thriving semiconductor industry to emerge. The project funding was $213 million over four years (1976–79), about 40 percent of which was government money. The goal was to achieve the capability to manufacture 1-megabyte memory chips—what IBM was rumored to be developing then—and, generally, to anticipate IBM's extensive use of VLSI technology in its projected Future Series (FS) products. Fujitsu, Hitachi, Mitsubishi, NEC, and Toshiba were invited to participate in the consortium, known as the VLSI Technology Research Association. About 15 percent of the research (in terms of cost) was carried out in the Joint Research Institute, staffed by about 100 researchers from participating firms and MITI's Electrotechnical Laboratory. The remaining work was done in the laboratories of the member firms.

Research ceased in 1979, when the project was considered to have reached its goals. The Association continued to exist to administer a portfolio of about 1,000 patents, the royaltiesfrom which will repay the government subsidy. When repayment is complete, each patent will be assigned to the firm that developed it. This project is often cited as one of MITI's most successful undertakings, despite its failure to achieve technological breakthroughs (with the possible exception of liquid crystal technology). Noteworthy advances were made in electron beam lithography, design techniques, silicon crystal growth and processing, and device testing; of equal if not greater importance was the knowledge transfer realized over the life of the project, particularly at its end with the return of the research staff to their companies.[15]

Table 2-2

Government Supported Research Projects in Japan through the 1980s

Period	Project	Amount ($ Million)
1976-82	Software production technology	22
1979-83	Software for VLSI hardware	114
1979-86	Basic technology for Fourth Generation computer systems	156
1979-85	Optical measurement and control systems (optoelectronics applications)	128
1981-90	Basic industrial technology for the next generation	714
1982-89	Very high-speed scientific computing systems (supercomputers)	164
1981-91	Fifth Generation computer systems	714
1985-89	Software Industrialized Generator and Maintenance Aids (SIGMA)	178
1985-92	Interoperable database systems	142
	Total	$2, 332

Sources: Data from *Japan's High Technology Industries: Lessons and Limitations of Industrial Policy*, Patrick Hugh, Ed., Larry Meissner, Asst. Ed (Seattle: University of Washington Press and University of Tokyo Press, 1986), p. 64; and *Advanced Computing in Japan*, the National Technical Information Service, JTEC Panel Report, U.S. Department of Commerce (October 1990), p. 26.

The goal of the Very High-Speed Computer (Supercomputer) project was to facilitate development of a computer 1,000 times faster than supercomputers extant in 1982, when the project began. During its eight-year lifetime, the project was funded at a level of about $164 million; the participants were the six major computer firms: Fujitsu, NEC, Hitachi, Toshiba, Mitsubishi, and Oki. The research programs dealt primarily with very dense, high-speed logic and memory device technologies, including gallium arsenide chips, Josephson junctions, high-electron mobility transistor devices, and computer architectures (particularly parallel systems); the orientation was short-term, in contrast to that of the Fifth Generation project. Shortly after the project began, in 1983 Fujitsu, NEC, and Hitachi announced top-of-the-line mainframes in the supercomputer class. These systems included coprocessors for scientific computing based partly on advanced semiconductor designs of Japanese origin which resulted in exceptional performance and (for Hitachi and Fujitsu) compatibility at an acceptable level with the IBM 370. Although these systems probably were well into development by 1982 and thus little influenced by the consortium, subsequent improvements and additions to the product line benefited from the consortium's work. The funding for this project was in the *hojokin* mode (cost sharing through conditional loans) with about a 50 percent government subsidy.

Although not all mainframe projects were successful, continued support for projects with the common goal of competing with IBM had a successful result, even for the most complex supercomputer systems. Competitive products would probably have been developed without the MITI-supported Fourth Generation project but not without the support of the government's overall industrial policies. Even the earliest (1966–71) mainframe project, although technologically unsuccessful, appears to have contributed an adequate technological stimulus as one component of the total package for the participating companies, a package that included direct government subsidies, protective tariffs, and purchasing policies.

Funding for the Fifth Generation Computer Project was at a level of $714 million over its ten-year lifetime (1982–92) and was in the *itakuhi* mode—100 percent by government grants. The rationale was that the very advanced nature of the research programs made them too risky for industrial firms to support. Participants include Fujitsu, NEC, Hitachi, Mitsubishi, Toshiba, Matsushita, Oki, Sharp, Nippon Telegraph and Telephone (NTT), and ETL. The project features a central research laboratory, the Institute for New Generation Computer Technology (ICOT), which is staffed by about 100 researchers mostly supplied by member companies. ICOT also operates five other laboratories at member company sites which share the research load. Further, NTT has its own Fifth Generation computer project, conducted in cooperation with NEC, Hitachi, and Fujitsu. The chairman and directors of ICOT were chosen by MITI.[16] The goal of the Fifth Generation Project, summarized by Feigenbaum in 1990, "was to rewrite the history of computing," which, he goes on to say, it did not.[17]

The tangible culmination of this ten-year project, similar to that of other cooperative projects (such as the Pattern Information Processing [PIP] project) was to be a working model to demonstrate "inference" machine concepts resulting from the research program. The full-scale model will not be built; instead, a more specialized system is planned by completion of the program in 1992. Although viewed as falling far short of its ambitious objectives, this project has contributed to building up a basic research structure, whose absence had been a Japanese weakness, and support for research into massively parallel systems (particularly, in software technology), seen by some as required to support the goals of the original Fifth Generation Project. In a broader sense, the Fifth Generation Project may follow a pattern like that of the PIP project: at completion in 1980, the PIP project was considered a disappointment by some and a downright failure by others—primarily because participating companies were unable to realize commercialized products in the short term. In hindsight, however, many critics have come around as, over the longer term, commercial products have resulted. A view now generally held by participating companies is that the program undertook cost-effective research programs beneficial to the industry and that without the PIP project those firms would only have pursued the technology much later, if at all. It is now accepted that the technology transfer approach taken ultimately was effective, particularly the "seeding" of know-how through the return of researchers to the sponsoring companies. Whether the Fifth Generation Project will repeat the PIP experience remains to be seen.

The project ends in March 1992. Many observers believe that its most important achievement will be the cadre of technologists knowledgeable in AI design techniques who will return to their member companies. This project has also seeded a new undertaking to be called the New Information Processing Technology (NIPT), the Sixth Generation Project, which will continue research in massively parallel processing systems, emphasizing computer learning techniques. Sponsors of this project are trying to "internationalize" it by inviting participation by major foreign computer companies.

Another important future-oriented project which received less publicity was the Basic Industrial Technology for the Next Generation Project, related to the Fifth Generation Project. Begun in 1981 and funded at about $714 million for a ten-year period, it included research on device technologies (three-dimensional VLSI, superlattice devices) to achieve high performance and on biocomputer system concepts.[18]

The history of the various software projects listed in **Tables 2-1** and **2-2** has been mainly one of failure. The first few attempts, focused on alternatives to IBM's operating systems for the 360 and 370 series computer systems, failed to meet objectives. As a result, domestic mainframe manufacturers opted for IBM plug-compatible designs or acquisition of rights to operating systems through design alliances with U.S. manufacturers such as Univac and Honeywell.

The situation for the latest software project, the SIGMA Project, is fundamentally different. Its purpose is to develop a software development environment and related tools based on AT&T's UNIX operating system. Two points are significant here: (*i*) UNIX is generally acknowledged as an excellent environment for program development, and (*ii*) UNIX is, at this time (1991), more or less synonymous with the concept of open systems, i.e., those by which heterogeneous computer populations can communicate. The open system bandwagon is currently "on a roll" with UNIX as a viable alternative to IBM system software for certain application environments Of particular interest in high-performance computing are those using workstations, supercomputers, and highly parallel computers. For these reasons, the SIGMA Project appears to be paddling with the stream, while the earlier projects were paddling against it.

This project has the potential to enhance the Japanese computer industry's already formidable global stature. It was begun in 1985, with a budget of $178 million, of which the government supplied 50 percent. The 164 firms participating include all of the leading Japanese computer and software companies as well as NTT and, significantly, such foreign firms as IBM, AT&T, Hewlett-Packard, DEC, Data General, and Olivetti. The first phase was completed in 1990, and the commercialization phase was initiated.

2.4 Effectiveness of Japanese R&D Consortia

Effectiveness in prosecuting R&D programs that positively influenced the industry's technological competitiveness appears to have depended on the following factors:

- The choice of technological objectives driven by industry in cooperation with MITI, but with MITI exerting strong influence through "vision" positions as a planning mechanism
- A comprehensive package of incentives for industrial participants, including tax write-offs, protection from imports, a favorable antitrust climate, funding, assured domestic markets, and support from MITI and government laboratories
- Strong leadership by MITI, featuring close cooperation of government, industry, and banking in the conceptual and operating phases
- Flexible funding modes, featuring cost sharing between MITI and member companies tailored to the risk level acceptable to industry participants
- Member companies' highly competitive orientation taken into account by appropriate mix of "secretariat" and "operating entity" consortium's organizational structures
- Commercial application of research results the responsibility of industrial participants.
- Staffing of consortia primarily by industrial participants as a key to effective technology transfer
- Willingness to "cut losses" for failing projects, to redefine a new project with modified goals, if appropriate
- Primary dependence on large companies as the participants capable of supporting large-scale, complementary, internal programs
- Establishment of research environments that encourage broader technological and application "vision" for member companies
- Policies to stimulate diffusion of research results to the industry at large

The great strides made by the semiconductor and computer industries since the mid-1960s, culminating in Japan's challenge to the U.S. for leadership in both, attest to the effectiveness of these programs.

Along the way, consortia programs have had mixed success. Consortia dealing with high-performance computing technologies have been successful mainly for device and hardware system projects, not for software projects, SIGMA being a possible exception. For much of the consortia effort, IBM—mainframe products, semiconductors, and other strategic device technologies, as well as system and application software technologies—was the target.

The following are some useful insights (culled from material more fully included in **Appendix 2.2**) into the "thrusts and parries" of MITI's strategies with respect to certain products introduced by IBM):

- In 1965 IBM introduced the 360 series; in 1966 the Japanese responded with their High-Performance Computer R&D Project, which was not completely successful.

- In 1970 IBM introduced the 370 series; in 1972 the Japanese 3.75 Series Computer Development Project was started, which was sufficiently successful that the "M-Series" and "Facom Series" introduced in the early 1970s benefited from it.

- IBM introduced the 3033 model in 1978.

The highly successful VLSI program anticipated this announcement by two years, because IBM cancelled its "FS" series program, delaying the introduction of the next generation in the 30xx series. The VLSI program ultimately led to Japan's dominance of the Dynamic Random Access Memory (DRAM) market and generally was strategically important to the computer industry and other sectors of the electronics industry. In 1976, the Software Development Project was begun, the first of two unsuccessful software consortia; the other, Software for VLSI Hardware, was begun in 1979. As a result of these failures, the Japanese became increasingly dependent on U.S. manufacturers for operating system software, a situation that still obtains.

Once it was clear that the Japanese were globally competitive, the consortium-based programs became more forward-looking:

- In 1976, the first Cray 1 supercomputer was delivered.

The success of the Very-High Speed Scientific Computer (Supercomputer) Project, begun in 1982, contributed to the technologies of supercomputers by Fujitsu and Hitachi in 1983 and by NEC in 1985.

In 1981, the Fifth Generation Project was begun, with the major objective, as noted previously, of achieving breakthroughs in "inference machine" technology. It was the most ambitious and, by its nature, the least well defined project to that point. After failing to meet some of its important objectives, the program was reoriented.

- In the early 1980s, with the trend toward open systems incorporating personal computers and workstations, UNIX became significant.

The SIGMA Project was begun in 1985, was to develop an advanced program development environment based on UNIX in a network context. Other considerations were that the UNIX environment offers an alternative to IBM operating systems; it is the leading environment for open-systems architectures; and it is achieving acceptance for two important product classes, work stations and supercomputers.

The SIGMA Project appears to have met on time (1990) its objective of establishing standards for the target environment and is now (1991) entering the operational phase (implementation by member companies). It is still too early to say whether SIGMA will gain industry acceptance.

2.5 Current Trends for Consortia Objectives

The following material from a report by Bloom of Technology International for the U.S. Department of Commerce, titled *Japan as a Scientific and Technological Superpower, 1990*, summarizes current trends:

> In fact, a distinct trend has emerged whereby the Government's support of large-scale industrial R&D projects is declining in favor of increasing the number of smaller projects aimed at developing highly advanced technology that is still at the early stage of evolution. Only large corporations are involved in these projects. They usually have enormous R&D capacities ... often engaged in the same R&D ventures—but on a proprietary basis ... there is a natural tendency by each industrial participant to limit the extent of knowledge and information it brings to a project involving ... competitors....

> Large-scale industrial R&D projects jointly funded by government and industry are on the decline in Japan as efforts shift more toward research on advanced technologies.[19]

Bloom summarizes the perceptions by one major U.S. electronics company of Japanese strategies for the 1990s, as shown in **Table 2-3**.

Fransman, who supplies additional insights into trends, notes that the Japanese system is organic, featuring ongoing evolution of institutions and forms of organization and the role they play in the process of change. One example of evolution is the founding of the Japan Key Technology Center authorized by the law for "Facilitation of Research in Fundamental Technologies," passed 15 June 1985. The Center serves as a source of R&D funding for diverse private firms and institutions, including those in the information industry.[20] Other manifestations of evolution are noted by Bloom as shown in **Table 2-3** and the trend toward internationalization of Japanese organizations which has resulted in research programs significantly influenced more than earlier ones were by the global community.[21]

Table 2-3

Japanese R&D Strategy in the Electronics Industry (1991)

Japanese competitors targeting technological superiority through aggressive R&D

- Rapid growth of R&D spending during the 1980s
- Major competitors spending close to $1 billion each on R&D
- Focusing on intensive semiconductor R&D

Substantial and growing percentage of total R&D at corporate level

- Increasing levels of basic and other long-range R&D
- Generic and mulit-disciplinary projects
- Divisions contract half of corporate level R&D

R&D activity organized and managed to facilitate rapid commercialization of new techniques

- Strong emphasis on information flow and rapid movement of R&D results to factory floor
- Strong pragmatic emphasis on commercially-relevant technologies
- Researchers transferred with projects
- Early factory involvement in research projects

Strong corporate-level support for R&D in advanced manufacturing processes

- Dedicated labs for process R&D
- Strong internal design and development capability for robots and manufacturing systems
- Committment to retain distinctive competencies in low cost, high quality manufacturing

Intensive competition for qualified researchers

- Electronics industry employs one-fourth of all researchers
- Majority of researchers recruited directly from universities for lifelong employment
- Limited opportunities for mid-career recruiting

Aggressive programs for leadership in advanced, high-risk technologies

- Targeting U.S. high-tech companies, universities, government programs for key technologies
- Japanese government continues to play vital role in identifying organizing and supporting R&D
- Shifting from catch-up to leadership strategies

Source: J.L. Bloom, *Japan as a Scientific and Technological Superpower*, Technology International Inc.; U.S. Department of Commerce, National Technical Information Service (August 1990), p. 94.

Chapter Three

Consortia in the U.S. Context: Genesis and Criteria for Assessment

3.1 The Emergence of Consortia

By the early 1980s, the Japanese threat to U.S. dominance of global computer markets awakened in the U.S. industry interest in new forms of cooperative business activities. The epitome of high-tech glamour in a fiercely competitive environment, the industry stood in need of fundamental changes in attitudes if "cooperation" was to become the watchword. The barriers to acceptance of this mode were (and remain) substantial: the highly competitive socioeconomic environment tended to discourage significant cooperative ventures and federal antitrust statutes reflected and supported this view. Early in the decade, some leaders of the U.S. information industry saw the magnitude of the threat to its manufacturing sector and, in response, agitated for changes in trade, tax, and antitrust policies and for consideration of new forms of cooperative ventures to complement more traditional modes of business alliances and university- and National Laboratory-based research.

From 1950 to 1980, the most significant cooperative ventures involved universities, government (usually the Department of Defense [DOD]), and a few industrial firms in projects such as Project MAC at the Massachusetts Institute of Technology (MIT), the Illiac projects at the University of Illinois, various projects sponsored by the Defense Advanced Research Projects Agency (DARPA) with Carnegie-Mellon University, the University of California at Berkeley, and others. Typically, the firms involved derived the greatest initial commercial benefits, although generic technologies developed were ultimately available as public property through government-owned patents. In the past, this form of cooperative activity had been a primary driving force both for the development of computer technology and as a spawning ground for new computer companies, but it no longer adequately addresses the industry's needs for additional sources of commercial-grade R&D and electronic device manufacturing technology, needs resulting from a shortage of the financial and skilled human resources necessary to develop this inherently complex technology.

In the present environment (1992), one of the industry's greatest concerns is whether its technological capabilities will continue to match market opportunities. To meet the needs for **highly responsive, industry-coordinated, market-driven applied research programs**, other forms were sought for conducting cooperative, precompetitive research that would augment activities within university, government, and industry laboratories. This concern led to changes in emphasis at universities (the introduction of applied technology "Centers") and National Laboratories (attempts to reorient some research activities to commercial applications) and to the emergence of industrial consortia. **Table 3-1** presents the current (1992) modes of cooperative R&D.

Table 3-1

Modes of Precompetitive R&D Cooperative Activities

Type and Period	Purpose	Participants	Term	Current Examples
University-based laboratories post-WWII	Basic & applied research	Universities, government, companies	Open	Computer science and electronics "centers of excellence"
National laboratories post-WWII	Basic & applied research	Government, universities, industrial consortia	Open	Sandia Labs[1] Lincoln Labs
Business alliances post-1980	Develop products, processes, or markets	Companies	Fixed	Sun and AT&T: RISC chips IBM and Siemens: 64Mb chip IBM and Sears: Prodigy program
Consortia post-1982	Applied generic precompetitive research	Companies, government, universities	Open	MCC[2] SEMATECH[3] University supercomputer centers[4]

[1] Federally funded.
[2] Multiple company sponsors.
[3] Federal and multiple company sponsors.
[4] University administered, government and multiple-company sponsored.

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It is this author's impression that after almost a decade of experimentation the concept of an industry-driven consortium for performing product- and process-oriented precompetitive

R&D is at a crossroads: the information industry needs to demonstrate that it can successfully apply lessons learned in the 1980s.

3.2 Federal Legislation

The federal government facilitated the formation of consortia for precompetitive R&D by making the changes in technology transfer legislation described in a report by the Congressional Research Service (CRS) and listed chronologically in **Table 3-2**:

> The Federal government pays for nearly one-half of the R&D performed in the United States, most of it intended to meet public objectives such as national defense, space exploration, and energy. Commencing with the Stevenson-Wydler Technology Innovation Act of 1980, Congress passed a series of laws intended to make it easier for private parties to exploit the results of such publicly supported R&D as well as to create financial incentives for such exploitation. These laws made it an explicit mission of the Federal agencies that support R&D to attend to the exploitation of the results of publicly funded R&D by private parties and by state and local governments. (Previously, a number of agencies had seen this kind of activity as antithetical to their missions.) They also made it possible for federal laboratories and their personnel and contractors to participate actively in the development, and to benefit financially from such participation. Some legislation has authorized formation of R&D consortia involving both private firms and federal R&D performers, which could receive federal funds for commercially interesting projects.... Prominent legislation of this type includes the Federal Technology Transfer Act of 1986 and the Omnibus Trade Competitiveness Act of 1988....[22]

The National Cooperative Research Act (NCRA) passed by Congress in 1984 legalized research and development consortia for precompetitive research, and the U.S. information industry vigorously participated in their subsequent proliferation.

3.3 Current State of Evolution of Consortia

By the end of the decade, although many consortia had been formed, their impact was slow to evolve; much remains to be done, because the competitive outlook for the industry has not improved, particularly its long-term prospects.

In May 1989 the Computer Science and Technology Board of the National Academy of Science sponsored a colloquium attended by leaders of the industry, government agencies, and academia to define an agenda for keeping the U.S. computer industry competitive, and its key

Table 3-2

Federal Acts to Stimulate Precompetitive R&D

1980	Stevenson–Wydler Technology Innovation Act
1984	National Cooperative Research Act
1986	Federal Technology Transfer Act
1988	Omnibus Trade Competitive Act

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findings are summarized in the following "snapshots":

> Ensuring that the United States remains preeminent in computing at the beginning of the next century requires strategic commitment, leadership, and collective will that cannot be attained with a "business as usual" approach by industry or government.
>
> What is good for one firm—even the leader—in computer-related industries may not be good for the industry in question or for the computer sector as a whole.
>
> Competing in global technology markets requires cooperation within and among firms and between industry, universities, and government.... Cooperation has already contributed to U.S. successes in the computer field, and the nation should build on those successes. Government-university-industry collaboration underlies U.S. leadership in technologies ranging from networked computing to artificial intelligence and parallel computing, and its potential underscores the value of a continuing dialogue.
>
> More and more, computers and components will resemble consumer electronics goods, taking on a commodity-like character ... firms that are successful in these large-volume markets will be those with superior product design, manufacturing efficiency, and product quality.... Erosion of the semiconductor-manufacturing segment of the computer hardware industry jeopardizes the health of the entire sector.
>
> Some standardization is essential, but the optimal level is not clear-cut—the issue is one of balance.... Computer and other technologies are converging.... This convergence can convey advantages to manufacturers with relatively broad product lines or correspondingly broad partnerships.... Systems technology is a domestic strength.... Technology transfer was the key to many of today's commercial successes, but U.S. computer firms have frequently failed to realize the commercial benefits of research conducted in the United States.... Small entrepreneurial firms may dominate the popular view of innovation in the computer sector, but many important innovations originally emerged from research at large firms.

> Enhancing information infrastructure will benefit producers and users of computing technology.... [A] national advanced-technology computing and communications network would enable a variety of computer-based activities and resources....
>
> Ultimately, the growth of the U.S. computer sector depends on high-quality education and training programs.[23]

These "snapshots" illustrate the scale of the challenges the industry currently faces in the view of a representative group of its stakeholders.

The specific motivations for interest in consortia as a vehicle for addressing these challenges are summarized by Evan and Olk:

> Rapid changes in the complexity of technology in the 1980s necessitated increased research investment by U.S. companies to remain competitive in the semiconductor and electronics industries. The costs (in some cases over a billion dollars), the risks, and the complexity associated with this type of research made it unlikely that any individual firm could succeed. Following the lead of Japan and Europe, U.S. industry became interested in amending the antitrust laws to permit for-profit R&D consortia. One of the stimuli for this change was the formation of perhaps the earliest U.S. consortium (excepting the gas and electric power research institutes)—Microelectronics and Computer Technology Corporation (MCC).... During its formation and after its establishment, MCC proposed to Congress a change in the antitrust laws.[24]

Such commitment to cooperative ventures, as Evan and Olk point out, is attended by significant risks:

> The principal reasons for joining a consortium are to achieve economies of scale, to share the risks involved in an innovation, to set a standard for a new technology, to share complementary knowledge, and to help protect "leaky technology" from being appropriated by companies not sharing in the research efforts. Companies view R&D consortium membership as risky because proprietary interests might inadvertently be compromised. There is also uncertainty over whether a company will be as successful as some of it competitors in exploiting the findings of the R&D program. Some potential member companies may believe that the returns are not worth the effort. Because of such concerns, the formation of this new type of organization is fraught with difficulties....[25]

In sum, the eventual place of consortia in, and their impact on, the industry and its infrastructure are uncertain. In the industry's efforts to remain **technologically** competitive, consortia, on the basis of their evolution to date, may yet fill a unique place between the university laboratory and the industrial laboratory. Driven by the difficulty many companies are experiencing in adequately funding precompetitive research and development programs, some consortia appear to be evolving as potentially cost-effective vehicles for such research in a cooperative mode and, in the process, effecting related (and, it is hoped, beneficial) changes in the industry's infrastructure.[26]

3.4 Assessment of Consortia Performance

Quantifying the benefits to companies from their internal R&D investments is difficult. In one sense, investment in an industrial consortium is easier to justify than in a company's internal programs because of the leverage of multiple sponsorship. (For the computer industry, R&D budgets are typically 8 percent to 12 percent of revenue. For a large company, about 10 to 12 percent of this budget may be allocated for pure or applied research. Thus, for companies with annual revenues of $5–$10 billion, research-only expenditures can be in the range $40–$150 million. Typically, such a company's annual investment in a consortium represents 3 to 5 percent of its research budget. Sponsorship of a specific consortium project may involve typically three to five companies. This leverage results in a total investment in the project equivalent to 9 to 25 percent of each sponsor's total research-only budget.) The potential ratio of cost to benefit can be substantial, provided that the consortium's research agenda, arrived at by member consensus, is appropriate for each, that the research is productive, and that the technology transfer is efficacious.

Consortia play a increasing role in stimulating progress in two important areas:

3.4.1 Timely Application of Advanced Technology

Timely application is the primary justification for the formation of most consortia. Large capital investment and more stringent product timing demands, resulting from more complex technology, more intense competition from vertically integrated Japanese companies, and shorter product life cycles, have exceeded or severely strained the resources of all but the largest companies. These considerations have driven many companies to consider consortia as another means, aside from established license, joint venture, and investment vehicles, for gaining access to advanced technologies. Consortia are seen as potential centers of excellence for identification, development, and timely exploitation (through effective transfer) of precompetitive technologies vital to the future of the U.S. information industry.

Stakeholders in the industry's R&D consortia expect to benefit in both the short and long term. In the short term, more timely application of advanced technologies to products and processes is expected, achieved either solely from consortia R&D programs or from consortia leadership of industry cooperative R&D "networking" (inter-company) efforts. In the longer term, stakeholders expect to benefit from these aspects as well as from technology breakthroughs through cost-sharing of expensive, high-risk projects.

3.4.2 Strengthening the Industry's Infrastructure

Consortia are not only breaking new ground to develop and transfer precompetitive technology to their shareholders more effectively, but in many instances they are also stimulating more cooperative relationships among companies in the product chain. As this process unfolds, relationships within the industry's infrastructure are tending toward more cooperative formal and informal undertakings. This trend is apparent in greater R&D project cooperation ("networking") between consortia and university laboratories or National Laboratories, or both; participation in the development of industry standards; facilitation of technical cooperation between product manufacturer and supplier; and contracting with companies to improve products or processes for critical technologies. (A key link in the "food chain"—the DRAM memory segment of the semiconductor industry—will require commitment of substantial resources and "patient money" for the industry to rebuild and gain a more significant global market share than its current 15 to 20 percent).

3.5 Criteria for Assessment of Performance

The barriers to achieving a consortium's goals (some pointed out by Evan and Olk and noted in **section 3.3**) are substantial, particularly for a consortium established for precompetitive research. The members of such a consortium must have common technological needs for both the short and long term, because the research agenda is, of necessity, defined by consensus. Each member must feel confident that this agenda will address topics important to its own future technological competitiveness. Members must also be willing to modify past patterns of competition and must seek out means for cooperating within a consortium's programs as well as for building cooperative relationships among themselves. They must be willing to accept consensus decisions for selection of the research agenda and for the goals, staffing and management, and methods of technology transfer of specific research programs.

To become a significant factor in enhancing the industry's competitiveness, a consortium must reach an appropriate size. It must structure itself to account for the resource limitations (people and capital) of members of various sizes and must offer modes of participation attractive to its targeted membership. Further, a consortium must determine whether federal participation is appropriate and, if so, how that should be realized and implemented.

The consortium's designers must decide if it will take the form of a secretariat or an operating entity (or some mixture of the two). Implicit in this decision is determination of the level of "partnering" to be adopted to maximize the effectiveness of both its internal research programs and its impact on the industry's infrastructure and practices.

Several criteria for assessing the performance of efforts by consortia to overcome the barriers mentioned here and meet their objectives need to be considered. The measures adopted by this author to evaluate individual consortia are summarized in **Table 3-3**.

Because consortia are a recent development in this U.S. industry, assessment of their performance should take into account the inevitable "learning curve" aspects entailed in applying this form of cooperation to its unique needs, and the following factors are relevant to these performance measures.

- **Technical Achievements: Intellectual Property, Patents, Licenses, Technology Applications**

The main purposes of an R&D consortium are to contribute to the growth of the information industry's intellectual property base and to facilitate application of advanced technologies. Because of the competitive threats posed immediately by the Japanese and in the future by them and other global competitors, the time horizons are both short and long term.

The scale of intellectual property, patents, and licenses indicates the extent of technical achievements and can serve to validate a research environment that will continue to attract high-quality staff and, in the case of patent licenses, given sufficient time, to generate income for a consortium and its members.

Table 3-3

Criteria to Evaluate the Performance of a Consortium

Resources of a Consortium	**Staff** ▪ Quality and dynamics **Industry participation** ▪ Scale and stability **Budget** ▪ Size and trends
Achievement of Goals of Consortium	**Timely Application of Advanced Technology** ▪ Technical achievements ▪ Effectiveness of technology transfer ▪ Balance between short- and long-term programs **Strengthening of Industry Environment** ▪ Impact on industry infrastructure ▪ Impact on federal policymaking

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- **Effectiveness of Technology Transfer**

The industry in the U.S., like those in other countries, has its own unique socioeconomic environment, for which its consortia have been, and are still, challenged to find and apply effective means for technology transfer. Problems, other than those resulting from the "natural" barriers to cooperation among competitors, have surfaced in the realm of technology transfer—in part because shareholders are relatively new to the game—such as with a shareholder's choice of corporate liaison level, the number or quality or both of shareholder staff assigned as either researchers or liaisons to facilitate technology transfer, and with a shareholder's internal processes for technology transfer and diffusion. Consortium-developed technology considered for use by a shareholder frequently must compete for product development funds against the shareholder's internally developed technologies. Other complications have evolved as some consortia have struggled to increase responsiveness to their shareholders by making different modes of sponsor participation available and, consequently, different modes of technology transfer for research programs.

An ongoing challenge for a consortium is to adapt and improve techniques to help shareholders implement technology transfer successfully.

- **Impact on Industry Infrastructure**

Many aspects of industry infrastructure could benefit uniquely from consortia programs, including cooperative R&D "networks" for facilitating research and development of products as well as product development and manufacturing processes; standards setting activities; formation of new companies and rescue of failing ones in critical industry segments. Most participating companies, with the possible exception of the very largest, could also benefit from access to consortia with specialized research resources which might significantly augment their internal capabilities. Further, consortia facilitate cooperative activities among companies at different levels of the "food chain." Finally, they have the potential to strengthen the industry infrastructure by serving as one of a number of vehicles for cooperation of industry and government.

- **Balance Between Short- and Long-Term Programs**

The balance between short- and long-term programs will vary over time, depending on the competitive posture of the industry and the uses to which its products are put. For example, during the 1970s Japan's MITI-sponsored consortia focused programs on short-term goals in such key competitive technologies as semiconductors and mainframe computers; currently, the emphasis is on long-term programs, such as those in optoelectronics and artificial intelligence. If earlier the industry was operating from a relatively weak competitive position and trying to catch up, now it is operating from a position of strength in a market with much more sophisticated needs. Another consideration is the overall environment for cooperative ventures; in an environment where cooperation among organizations, whether in a company, a consortium, or another entity, is commonplace, a consortium with substantial industry participation is likely to have primarily a long-term orientation. In contrast, until recently the U.S. environment featured competition, not cooperation, within the industry and thus presented consortia with an opportunity to become a vehicle to foster short-term cooperative programs. Although many U.S. consortia were initially undertaken with primary emphasis on long-term goals, the urgent need for short-term results came to be an equally (if not more) important driver of their programs.

- **Input to Federal Policymaking**

Consortia potentially can serve as sources for federal policymakers by providing complementary inputs to those from individual companies, industry associations, academia, national laboratories, etc. Because their R&D programs are either partially or totally sponsored by industry and include transfer of precompetitive technologies for commercialization, their direct industry involvement can make for particularly cogent input to policymaking.

- **Quality and Dynamics of Staff**

In addition to the reputation, accomplishments, and adaptability of permanent staff, the capabilities of sponsor-assigned staff and the different modes of participation by shareholder personnel are important. The modes of participation for shareholder personnel can be assignments that are permanent as well as temporary (for periods of from a month to two to three years). Flexibility in this aspect can be important in adapting the technology transfer process to a sponsor's needs. Another important aspect is the quality of college intern and postdoctoral programs.

Aside from the obvious need to maintain a dynamic research environment, a significant issue bearing on the adaptability of research staff is the conflict between the wish of most of staff to focus their efforts on research and the concomitant need for interaction between staff and shareholders to promote programs and accomplish technology transfer. The demands of multiple sponsors can make this conflict a substantial source of friction, and the staff must be an appropriate mix to deal with it.

Finally, the proportion of high-quality shareholder assignees in the total research staff is fundamental to a consortium's responsiveness to its members' research needs.

- **Scale and Stability of Industry Participation**

The number of sponsors and the stability of their sponsorship may be the ultimate "bottom line" measure of the success of a consortium whose intended lifetime is long or open-ended. For some shareholders, continued sponsorship may not be appropriate because of a downturn in business fortunes or changes in business goals that result from new corporate strategy or ownership. On the other hand, a consortium filling a need is likely to attract new members as its credentials grow. Growth in the number of sponsors may also be an indicator of the success of a deliberate policy change to broaden the types of sponsorship offered. (These criteria may not hold for a consortium of a select group of sponsors planned to exist for a discrete period to accomplish limited objectives.)

Another measure of the effectiveness of a consortium's industry activities is its leadership in R&D networking, standards, and other industry bodies relevant to its purpose.

- **Size and Trends of Budget**

Gross budget size by itself can be a misleading measure of either success or failure, but in combination with other measures of performance, such as budget trends and program fund allocation in relation to specific program performance, it can be useful. Sources of funds and their distribution by class of sponsor, together with trends related to the distribution also can indicate industry acceptance as well as identify those companies most involved.

Chapter Four

Microelectronics and Computer Technology Corporation (MCC): An Industry-Based Consortium

4.1 Introduction

The Microelectronics and Computer Technology Corporation is a centralized research laboratory consortium that serves sponsors from the information and related industries. Its orientation is toward helping sponsors address market opportunities with advanced information technology and in a timely manner. An implicit objective of its precompetitive research programs is to strengthen the infrastructure of the U.S. computer industry through cooperative undertakings.

In many ways, MCC is a unique consortium: it is for-profit and industry-sponsored, it addresses one of the broadest ranges of technologies of any U.S. information industry consortium and, founded in 1982, it is the industry's oldest major precompetitive R&D consortium.

4.2 Genesis, Purpose, Philosophy

By the early 1980s, concerns of some leaders of the U.S. computer industry that this industry would go the way of the U.S. consumer electronics and semiconductor industries crystallized with the advent of the Japanese ICOT program, which was designed to achieve technology breakthroughs in high-performance, non-von Neumann computing** that would change the Japanese computer industry from a technology follower to a—even the—leader.

William Norris, the founder of Control Data Corporation, acted on his concerns: he canvassed the attitudes of industry and government executives toward the perceived threat. Because the consensus of industry stakeholders was that past and current Japanese programs made its computer industry likely to achieve, at the least, competitive "parity" in the 1980s, Norris's initiative met with a positive response. The consortium as a vehicle for

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**von Neumann computing architecture features sequential, deterministic logic structures, while non-von Neumann architectures feature parallel, nondeterministic logic structures that incorporate techniques of, for example, parallel processing and memory arrays, artificial intelligence, and neural network processing.

precompetitive research became the important focus of his initiative. A steering committee of senior executives from 13 major computer and semiconductor companies was formed to define what turned out to be MCC, which was chartered in August 1982, with ten founders, as a centralized, laboratory consortium that was to be for-profit, exclusively domestic industry-sponsored, and, if necessary, long-lived. At its founding, MCC was the largest industrial organization for precompetitive research in information technology ever attempted in the U.S. MCC's mission was:

> To strengthen and sustain America's competitiveness in meeting broad industry needs through application-driven research and the development and timely deployment of innovative technology.[27]

In view of the venture's pioneering nature and its founders inexperience with this form of organization, the goals and form of MCC needed to be considered carefully. One of the most difficult aspects was satisfying the diverse needs of its constituency, its shareholders. Superficially, such problems appeared common to most start-up ventures. When, however, as in this case, your owners are your customers and have widely divergent interests, putting the appropriate organizational structure, practices, and programs in place was not easy.

When MCC was formed, the organization was designed as an operating entity with research performed in a central research laboratory environment so that constant communication with shareholders would be the norm. Key areas of concern in the design were (*i*) management structures, (*ii*) staffing, (*iii*) research areas, (*iv*) intellectual property, and (*v*) technology transfer.[28]

The shareholders and MCC management agreed on a research agenda largely conceived by the shareholders. Initially there were to be four research programs with the following topics: advanced computer architecture, computer-aided design for very large-scale integrated circuits, software technology, and microelectronics packaging and interconnect.

In October 1983, MCC began operation with a skeleton staff in leased facilities at the Balcones Research Center of the University of Texas at Austin. By the end of the year, MCC had 14 shareholders, a management team headed by Bobby Inman, former deputy head of the Central Intelligence Agency (CIA), with three research program directors, a staff of 72, and a

$19 million budget in place, and research programs began. In December 1991, MCC had 22 shareholders and 48 associate members (see **Appendix 4.1**), a management team headed by Craig Fields, former director of the Defense Advanced Research Projects Agency (DARPA), a staff of 400 involved in 35 projects, and a budget of $50 million.

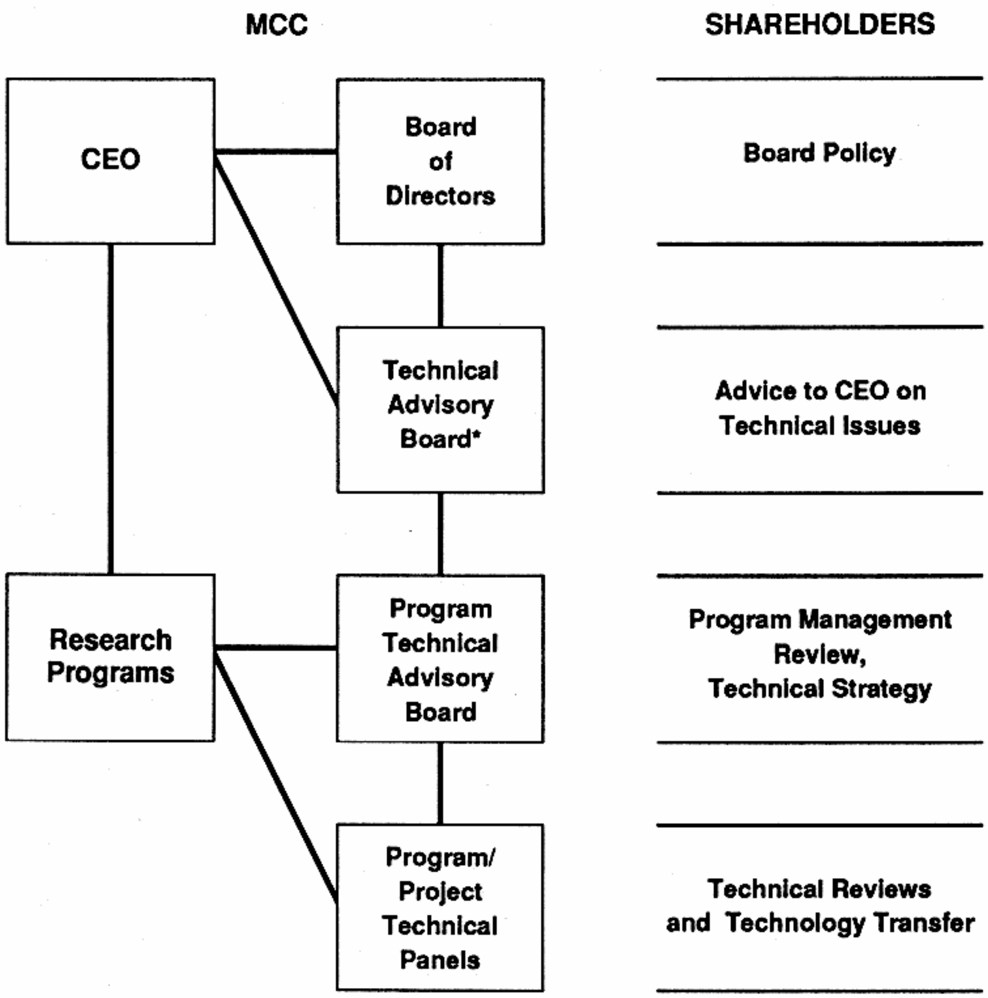
4.3 Governance of the Research Programs

Although the four research program topics (**section 4.2**) are important to the basic electronics, architecture, and software of high-performance computer systems, significant technologies were not included, such as for semiconductor and other electronic materials, networks, displays/graphics, and peripherals. Some aspects of the omitted technologies subsequently were subsumed by the programs adopted. Each program evolved a core research component and related projects (satellites).

The governance philosophy that evolved to promote program self-sufficiency treats each research program as an independent, self-contained entity, and, as a result, MCC personnel frequently refer to the organization as "a consortium of consortia." In the opinion of some shareholders, although this philosophy protected the participants' interests in individual programs or projects, it tended to inhibit potentially important interdisciplinary interactions of MCC groups and among companies sponsoring different activities. The structure of MCC's governance as of mid-1991 is shown in **Figure 4-1**.

Governance of programs features a style of research management and incentives similar to corporate R&D rather than to either academic research or a government laboratory. Each program has a Program Technical Advisory Board (PTAB), which functions as an advisory council, and a Program Technical Panel (PTP). Not all projects, however, have incorporated formal PTABs or PTPs into their organization.

The Technical Advisory Board (TAB). Composed of senior research and engineering directors from the shareholder companies, the TAB, which meets quarterly, monitors MCC's research plans and budgets, makes recommendations on long-term, strategic research issues, and advises the board of directors, the CEO, and the research program directors. In 1991, the board's title was changed to **Requirements Advisory Board**, to describe its function more accurately—to define member requirements for new research programs.



*Changed to Requirements Advisory Board in 1991.

Source: *MCC Technology Catalog*, Version 1.4, June 1990, p. 10.

Figure 4-1

Governance of MCC

Program Technical Advisory Board (PTAB). The members of the PTAB are usually senior-level engineering or research directors from shareholder companies who serve those companies as technical advisors for MCC programs. They monitor the general direction, objectives, and progress of programs. The role of the PTAB is to assure that a program is responsive to those companies' needs. PTABs establish the qualifications of a research program's personnel, its annual budget, its technical plan, incentive payments to personnel, the addition of participants to the program's research areas, and licensing plans and royalty rates for the program's technologies. Decisions are made by majority vote.[29] In 1991, the role of this PTAB came into question as a result of changes to a project structure for managing research and development activities. This Board was subsequently replaced by the Program Advisory Board, which serves only High Value Electronics projects and the First Cities Project. Licensing issues, previously handled by the PTAB, became in most cases the province of the project team and the legal department.

Program Technical Panels (PTP). PTP personnel, hands-on researchers and engineers, are charged with evaluating a program's technical requirements, understanding the relevance of MCC research programs to their company's product and operational needs, and facilitating technology transfer.[30]

The panels and boards have provided useful forums for shareholders to interact with one another and to influence MCC's projects and programs. In this author's view, however, MCC, in comparison, for example, with SEMATECH (a precompetitive semiconductor research consortium; see **Chapter Five**), has not realized its full potential in relation to technology seeding and cooperation between shareholders and other companies in the industry.

4.4 Budgets and Sources of Funding

Table 4-1 summarizes the growth in budget and staff from 1984, MCC's first full year of operation, through 1990.

Table 4-1

MCC's Operating Budgets and Full-Time Staff

	1984	1985	1986	1987	1988	1989	1990
Budget ($Million)	19	45	60	63	62	60	58
Number of Staff	72	261	400	450	430	430	430

Source: Based on interviews with William Stotesbery, MCC Communications Director (October 1991).

Since becoming fully operational in 1985, MCC has attracted and held a sufficient number of predominantly commercial sponsors to maintain a budget in the range of $45 to $63 million. In 1990, the budget was $58 million. At program initiation in 1984, shareholders committed to fund three years of research. Since 1986, staff size has been in the range of 400 to 450. By 1989, the full-time staff was augmented by 60 part-time staff and 50 students.[31]

Shareholders are the major source of funds: each currently pays a one-time stock ownership fee of $250,000 and pays an annual fee from a few hundred thousand to $3 million to participate in specific programs. A shareholder must participate in at least one research project. The one-time ownership fee set by the board of directors has varied with time: the original ten members paid $150,000; in 1986, the highest fee of $1 million was reached; since then, the fee has been stable at $250,000. (In the 1980s, a company in this industry typically budgeted about 10 percent of gross revenue to R&D, mostly for product development. Precompetitive research typically accounts for 10 percent of the total R&D. Thus, a company with sales of $1 billion would allocate about $10 million for precompetitive research; a company with $10 billion, $100 million.)

In 1988, the options for participation by Associate Members were expanded to be more consistent with Norris's original intent of offering smaller companies appropriate vehicles for program participation as well as to expand the sources of funding. For an annual fee of $25,000, Associate Members receive nonconfidential technical reports and the monthly newsletter of the International Liaison Office and can participate in three workshops per year. Associates may participate in all research projects for a fee and have access to much of MCC's proprietary research, but, unlike shareholders, neither are represented on the board or the TABS nor share ownership of MCC technology or development tools. Associate members pay from a few thousand to $1 million for access to selected research activities and for participation in selected projects. The board adopted this program at about the time that it authorized federal contracting, the eligibility of Canadian companies to become shareholders (through the U.S.–Canadian Free Trade Agreement of 1988), and new institutional arrangements such as third-party licensing of MCC technologies. In 1991 there were 50 associates.

Since this board took this action, a number of government (DARPA and Department of Energy [DOE]) contracts have been undertaken, including: development of a toolkit for distributed systems experimentation, fabrication of critical components for interfacing semiconductors to superconductors, and flat-panel display research. An important feature of these contracts is that research results will be available only to MCC shareholders, associates, and universities with research contracts with the DOD. As of 1991, government contracts or grants accounted for 15 to 20 percent of annual revenue.

Until 1991, a shareholder's annual fee was allocated in two parts to the programs the shareholder supports: (*i*) the ongoing core program and (*ii*) specific projects usually of two to three years' duration. A shareholder has representation on the board and the TAB and owns the technology and tools developed in research programs in which it participates. (Over time, the trend toward less program "bundling" has allowed shareholders to fund parts of programs (projects), rather than a total program. This trend has exacerbated the tendency of some shareholders to push for short-term results. The policy changes initiated by MCC in 1991 to make projects the principal business focus are significant, because they give shareholders a clear choice for finding the balance between short- and long-term projects applicable to their individual needs.)[32]

MCC holds all intellectual property rights to technology it develops. For the first three years, sponsors of a given research program have exclusive free access to technology developed by the program, and during this period a program's sponsors can choose to license the technology to other shareholders. After those three years, the MCC board can vote to license a technology to other shareholders and nonshareholders. Licensing revenues are shared—a third each to shareholders, to MCC retained earnings, and to future MCC research.

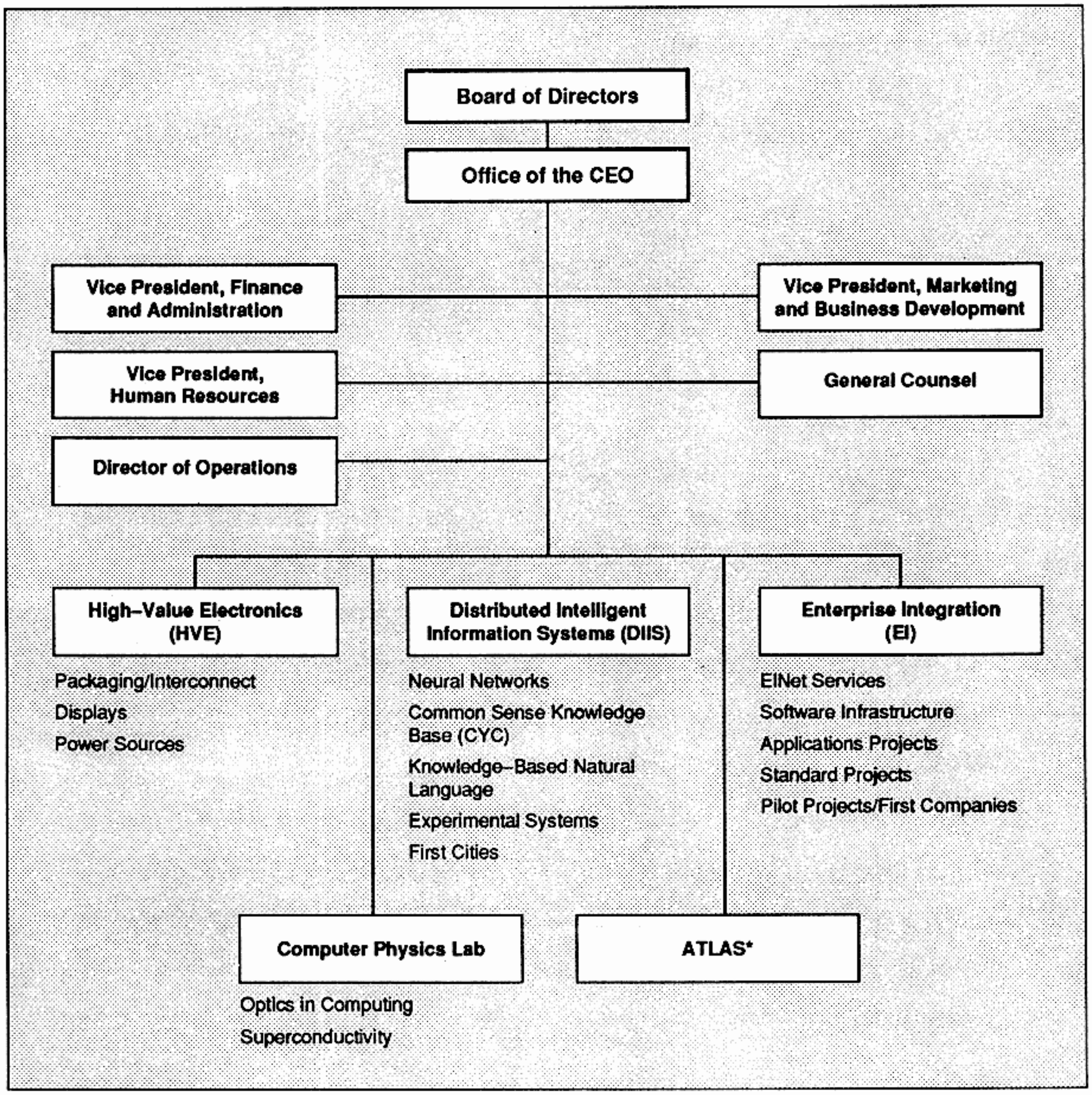
Overall, the changes to broaden MCC's sources of income have been driven by competition from other consortia; by resistance on the part of many domestic companies to the concept of a consortium, to DARPA's willingness to support programs for technologies that may become critical to its mission; and by the increasing importance of exploitation by MCC of technological research performed outside the U.S.

4.5 Organization and Staff

The initial organization consisted of executive managers, directors of programs and research, and researchers, but as MCC matured the organization was fleshed out for market-oriented functions, corporate administration, and additional research functions.[33]

There have also been changes in the content and structure of programs. A fifth program added in 1988, High-Temperature Superconductivity, which in 1990 was combined with Optics in Computing research and other high-risk, potential breakthrough research activities into the Computer Physics Research Laboratory. In the same time frame, the exploratory initiatives program was established to examine and evaluate new directions for research. Within the four original research programs, projects were eliminated or redirected as appropriate, and the structure of programs evolved into a core and satellites (projects). By 1991, MCC had instituted a reorganization consistent with its plans for the 1990s that established four major groups: High-Value Electronics, Distributed Intelligent Information Systems, and Enterprise Integration, and the Computer Physics Laboratory, as well as a proposed subsidiary, the Advanced Technology Laboratory for Acceleration of Standards (ATLAS) (**Figure 4-2**). In the reorganization instituted in 1991, a further change in the organization of research programs integrated the core and satellite activities into a multiple project structure for each program, so that each project become a business unit, that is, the principal business focus for research activities. In mid-1991, about 40 projects were active.

As of 1990, 75 percent of MCC's staff were engaged in research activities. The plan at inception for research staff to consist mostly of personnel from the shareholder companies on loan for a specified period (typically two to three years) offered a number of possible advantages: from a shareholder's viewpoint, direct participation of its staff would tend to assure the relevance of the program's research to its own objectives and facilitate technology transfer both during the course of the program and at its completion; from MCC's viewpoint, the plan would make programs responsive to the shareholder's needs and, potentially, simplify technology transfer by relying on shareholder personnel as the primary agents. Unfortunately, the premises of this plan were never tested, because MCC rejected six out of seven candidates put up by the shareholders for program directorships. Inman was determined to build a center of excellence at MCC, and in his view the candidates just did not measure up: he exclaimed, "I will not preside over a turkey farm.... The reality was that the talent was not in the companies, or [else] they didn't make it available, and I think it was the former."[34]



*Advanced Technology Lab for Acceleration of Standards — Planned Effort.

Source: MCC internal material, adapted with permission.

Figure 4-2

Organization of MCC, November 1991

The dilemma, once recognized, was quickly addressed by recruitment of most program directors on the open market, from industry, academia, and national laboratories, and, as a consequence, most program directors and research staff came primarily from nonshareholder organizations. With such attractions as outstanding facilities and equipment, guaranteed program funding for a three-year period, high salaries, and the vision of being part of a center of excellence, staff ramp-up was relatively rapid and—most important—of high quality. From the beginning, direct hires have represented from 65 to 85 percent of the staff, with the remainder shareholder-supplied—either as assignees, who are researchers-in-residence at MCC, or liaisons, who may or may not be in residence. The shareholder-supplied personnel typically work only on the programs in which their company is a member.[35]

Although this approach to staffing resulted in quality, its disadvantage is less integration of MCC operations with those of shareholders and, as an important consequence, an adverse affect on technology transfer and interaction between shareholders. Until late in 1990, most MCC programs consisted of a long-term core activity and shorter term satellite activities. MCC's change early in 1991 to a project structure signaled its intention to evolve from its initial orientation as a centralized research laboratory to one in which research activities provide the base for facilitating cooperative research by shareholders.

4.6 Performance of Research Programs

MCC's initial time horizon for core program research undertakings was six to ten years. Since its founding, MCC has also successfully developed technology by means of two- to three-year-long projects performed within the ongoing core programs. In many cases, the technologies have been applied by shareholders, and, in this sense, the research output has been prolific, consisting of many incremental improvements to shareholders' products or processes, or both. To date, no "major" technology breakthroughs have occurred, although a number of long-term research programs have this potential. As of 1991, 65 patents and 182 licenses had been issued.[36] **Table 4-2** summarizes the performance of MCC's research programs.

4.6.1 High-Performance Computing (HPC) Research Projects

Much of MCC's research relates to HPC technology. Three projects, each dealing with a different aspect of high-performance computing and each representative of technologies for short-, medium-, or long-term, are examined: the Experimental Systems Laboratory's ES-Kit Project (short-term); the Computer Physics Laboratory's Photorefractive Holographic Storage—Bobcat II—Project (medium-term); and the Neural Network Project (long-term).

The ES-Kit Project. The ES-Kit project focused on development of a toolkit, both hardware and software, for prototyping cooperative computing networks. Its goal is to develop the technology whereby the latent computing power implicit in a network of computers can be flexibly allocated to apply shared (parallel) processing to a broad range of computing requirements, up to and including those for supercomputers. This project undertook, in a sense, to extend and generalize more primitive capabilities of the type available at its inception. Its first phase (three years), sponsored mostly by DARPA, was completed in 1990, and, in the main, initial objectives were met. The ES-Kit technology is now used by a number of DARPA's federal projects, by DOD, DOE, and NASA laboratories, and by several universities. Five non-royalty-bearing and two royalty-bearing licenses have been granted, and two patent applications have been made.

Commercialization, however, remains uncertain. A small start-up licensee is currently (1992) incorporating the technology into products for Apple Computer's Macintosh market, and NCR and Motorola are evaluating it. The project's most significant product is the software technology delivered to DARPA, industrial sponsors, and licensees.

The Bobcat II Project. The Bobcat II project is an attempt to reduce to practice a concept originally proposed in the early 1970s. Its goal is to develop a technology that would use photorefractive crystals as a holographic storage media for a random access store.

Research to date is promising, owing to advances (beyond earlier industry efforts, abandoned in the late 1970s) in the science and technology of photorefractive crystal materials. This project is attempting to achieve a technological breakthrough that could significantly improve random access file performance and reduce cost in comparison with magnetic disk technology. Storage capacities could equal or surpass those of the largest magnetic disk stores, with access times on the order of 1,000 times shorter and with the capability to store information in multimedia form. If this technology turns out to be feasible,

Table 4-2

Sample of MCC's Research Results

Sample of Research Results Through 1991
Laser chip bonder — first licensing of MCC technology
CAD technology — in Cadence Design Systems Very High Density Logic (VHDL) product
Neural net algorithms — helping Eastman Kodak solve process control problems in production of chemicals
Software tool — used by Bellcore to translate source code into visual representations automatically
Tape automated bonding (TAB) process — used in DEC's VAX 6000 Model 400 systems
NCR's Design Advisor — first MCC-based commercial product — faster, better first-pass chip designs through AI (Artificial Intelligence)
ES-Kit rapid prototyping parallel processing technology — used by DARPA, universities, Motorola, and other participants
CYC knowledge base — helping DEC develop Sizer — a system to "size" computer systems to a task
CAD Framework Initiative — MCC technology supporting industry standards
Software tools — enabling NCR to improve productivity and reliability of design process for a retail point-of-sale system
CAD technology — used by several participants to increase productivity, reduce layout area, and facilitate design reuse by layout designers
STP (Software Technology Program) technology — used by several participants for prototyping designs of distributed systems
Cooperation software product (NCR) — workflow automation feature modeled on MCC's Coordination Technology
Evolutionary Technologies, Inc. — a spin-out company formed to commercialize MCC's EXTRACT technology
Corporate Memory Systems, Inc. — a spin-out company marketing a software system based on MCC's developed gBIS technology for the electrical power industry
Itasca System's Distributed Object Database Management Systems — based on Orion–2, MCC's fully distributed object-oriented database
Motorola — incorporates MCC's DESIRE software recovery and reengineering technology into an internal design recovery system
Pacific Bell — incorporates MCC's Large Data Language into enterprise modeling system

Sources: MCC Briefing — Corporate Overview (December 1990); MCC Fact Sheet, MCC Communications Department (no. 381, 19 November 1991), pp. 4-5.

it might be inherently less expensive to manufacture than high-performance magnetic disks. A laboratory prototype in development has an operational target date in 1991-92. If successful, the technology could be commercialized in five to seven years.

This project is an excellent example of "networking" through a syndicate of MCC, its six sponsoring companies, and university laboratories. Research to develop the crystals for optical storage is performed at Stanford University; material is supplied by both Stanford and an industrial company; parallel projects are in progress in the laboratories of some of the six industrial sponsors; and cooperative programs exist at the universities of Colorado and Rochester (N.Y.). The project has also stimulated cooperation among its suppliers in the "food chain." Although not particularly significant now, if this technology is eventually applied to products, supplier experience with MCC may help facilitate commercialization. Looking to the future, experience with syndication may be useful as a precursor to a vertically integrated commercial syndicate.

In March 1991, MCC was awarded one of the first grants in the National Institute of Standards and Technology's Advanced Technology Program (ATP), which is intended to support R&D in precompetitive generic technology. This MCC Optics in Computing Project has the following objectives:[37]

- To establish the technology infrastructure to permit low-cost manufacturing of a volume holographic mass storage device and promote widespread acceptance of the technology

- To design and fabricate key electro-optical components for cost-effective production

- To produce a prototype 2-gigabyte volume holographic mass storage system and integrate it into computer systems for performance evaluation

Funded at $10.3 million, with matching private sector funds of $12.7 million for a five-year period, this project, features "syndication," according to Stephen Redfield, the project director:

> This is a new type of endeavor for MCC and one which may very well serve as a model for establishing significant new technologies in the marketplace. We are, in effect, building an entire new market within the computer storage

> industry and that requires carefully piecing together all the different types of companies required to support this market....[38]

The Neural Network Project. The neural network project has a long-term time horizon—on the order of ten years—to establish the classes of applications for which this technology is appropriate and to incorporate it into relevant products. In the short term, the technology is being applied in optical and handwritten character-recognition products and as a tool for optimization of functions of process control for the manufacture of a particular product. In 1991, DEC and NCR announced products based on this technology, implemented in part by specialized integrated circuits, which are expected to be highly competitive with existing character-recognition products.

The relatively few sponsors of this project have benefited, or expect to shortly, from technology developed by it. The blend of short- and long-term research appears excellent. To date, the impact, while important to individual participating companies, has been minor; the overall impact on the industry is likely to build slowly through incremental improvements in both products and processes. Major breakthroughs, if they occur, can be expected to evolve over the longer term.

Even in its brief history, this project has stimulated a few important industry undertakings. Some shareholders as well as nonshareholders are working on joint development programs which resulted from shareholder interaction through MCC. For example, researchers in voice recognition at Bellcore, US West, MCC, Stanford University, SRI, and the University of Lund (Sweden) are cooperating through a loose "network," with MCC participating through its shareholders. Also, MCC-developed technologies are attracting industry-wide interest as potentially significant developments for applications for character recognition and for nonlinear prediction. Generally, MCC's application orientation, and its shareholders' good track record in applying MCC technology, has led to growing interest by the industry in this Neural Network Program. In 1991, a spin-off company was formed to market the technology for process-control applications.

Table 4-3 is an overview of these three projects (**Appendix 4.2** provides details).

Table 4-3

Overview of Three High-Performance Computing (HPC) Projects

Overview Criteria	ES-Kit	Photorefractive Holographic Store	Neural Nets
Objectives	Develop prototyping kit; parallel network processing system	Develop high-speed capacity/optical store	Develop vision, speech, sensory motor control processing
Technical Achievements	First phase goals met	1991-92 target for system demonstration	Modeling capability
Technical Transfer Effectiveness	In use by government and university labs	Research cooperation with universities, companies	Applied by companies to process control and products
Industry Impact	Minor, two companies evaluating	Some research at companies	Minor, but growing
Short- vs. Long-term Balance	Short term	Potentially excellent	Potentially excellent
Quality and Dynamics of Staff	Comparable to commercial	Small, high-quality; network of university and company researchers	High quality
Scale and Stability of Industry Participants	Small scale, few companies; goal: 50-50 gov't–industry; stable	Six sponsors — goal to double support; stable	Four sponsors, growing interest; stable
Size and Trends of Budget in 1991	$4 million/up	Estimated $3-$4 million/up	Estimated $2.5 million/up
Federal Policy Impact	None	None	Minor

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4.7 Challenges to MCC

As the pioneering attempt to apply a consortium approach to cooperative precompetitive research for the information industry, MCC's very survival is a notable accomplishment, particularly given its diversity of programs, which resemble, on a small scale, those of the much larger laboratories of IBM and AT&T. MCC nevertheless faces a number of challenges, the most basic being to realize an appropriate return on shareholders' investment. Because it is a sponsor-paid **applied research** laboratory, sponsors expect commercial products or processes based on MCC technology to be forthcoming in a timely manner. Given the fees involved and the uncertainties inherent in research and technology transfer, shareholders run the risk of not benefiting sufficiently to justify their investment.

MCC's ability to satisfy shareholders on this count depends, in part, on its research staff, its management, and its skill at technology transfer. Equally important is the need for shareholders to be active in setting goals, guiding program management, supplying specialized research resources, and taking appropriate actions to facilitate technology transfer. Thus, the norm is a complex, dynamic relationship between MCC and its shareholders that requires considerable dedication by both sides. The evidence so far appears to support the notion that shareholders who exhibit such dedication tend, on the whole, to be relatively satisfied. (Interviews with managers of the program at DEC, Eastman-Kodak, Hewlett-Packard, Motorola, and NCR, however, indicated that even such strong supporters are ambivalent about MCC's value.)[39]

In addition to serving its shareholders, MCC is attempting to be a vehicle for improving the nature of and practices in the industry's infrastructure. Although this objective might be regarded as an indirect benefit of its research activities, MCC ultimately exists to help keep its members and **the industry** competitive. Its contribution is through "networking" companies, universities, and federal agencies in specific MCC research programs, through involvement with professional advisory and standards groups of the industry or government, and, recently, through seeding new companies based on MCC-developed technology. In this author's opinion, significant impact by MCC on the industry's practices and infrastructure is inherently a slow process, and shareholder interviews suggest that during its nine-year lifetime its influence has fallen short of expectations. MCC must first achieve greater credibility in the industry.

Technologies MCC has acknowledged transferring to industry, universities, or federal agencies through 1990 cover a broad range, including those for semiconductor packaging, computer-aided design (CAD) for design of semiconductors, neural networks for character-recognition products and continuous process optimization, large system software development tools, database tools, and tools for prototyping distributed networks of scalable parallel systems. Common to these developments is that all have been, or soon will be, successfully applied to commercial products or processes, a result due largely to the shift initiated about 1987 at the request of shareholders to supplement the long-term core programs with more short-term projects (two to three years in duration, compared with the original term of six to ten years).

Technical developments to date, do not represent breakthroughs, e.g., seed technologies that would have major impact on the industry, but, rather, are evolutionary improvements to existing technologies. The potential for breakthroughs exists in some MCC programs, in particular, the Bobcat II project (**section 4.6.1**), which, if successful, could overcome the performance limitations of present file-accessing technology. A few others have similar potential, most of them also in relation to high-performance computing. Whether a breakthrough comes in a single product class, such as Bobcat II, or is the result of incremental technology advances, as in software development tools or neural networks applied to process optimization, its achievement is usually a long-term proposition (on the order of a decade).

On the downside, a number of MCC's research programs have failed. Perhaps the most noticeable failure related to HPC was the parallel computing undertaking of the Advanced Computing Technology program, which, however, did seed such currently active projects as the ES-Kit and CARNOT (a comprehensive set of software services for OSI [Open Systems Interface]-compliant distributed heterogeneous system environments). There is no question that management of the MCC enterprise has, of necessity, been a huge learning experience. At this stage, MCC's reputation in the industry, if not exactly prospering, is gaining strength from a number of solid accomplishments. This conclusion is based on interviews with a sample of shareholders and MCC staff involved with projects relevant to high-performance computing.[40]

MCC's accomplishments as of 1991 include:

- Work on important applied technology topics

- Technical performance of good quality

- Research staff of a quality equal to or better than those of most shareholders

- MCC-developed technologies incorporated into a number of shareholder products or processes; modest overall impact, but working relationships for technology transfer established

- Has become a useful proving ground for testing technology transfer techniques

- To a limited degree, has facilitated inter-shareholder, inter-industry cooperation within its technological purview

- Participates in some industry standards activities

- Has the potential now to develop into a useful information source for international technology developments

Whether MCC will ultimately prove sufficiently productive to justify ongoing shareholder support is not clear. For it to achieve its goal of influence in sustaining the industry's technological competitiveness depends now on how well its sponsors and management facilitate MCC's ability to do the following:

- Assess technology needs as these relate to market opportunities

- Focus research programs and technology transfer methods to achieve sustained, positive technology impact

- Achieve working relations with the industry that positively influence change in the industry infrastructure and practices

- Influence the quality of the industry's technical work force

- Influence national initiatives of industry and government policymaking and standards groups

4.7.1 Observations on MCC's Progress

As MCC strives to fulfill its mission, the following observations may help in evaluating its progress.

- Shareholders typically joined MCC because senior management perceived **specific benefits** in the context of a broad strategy[41]:

  - **Eastman–Kodak** needed assistance to develop capability in computer technologies related to new business opportunities.

  - **Bellcore** needed a collaborator with overlapping technology interests but a different approach to managing a research laboratory with multiple sponsors.

  - **NCR** needed to add significant capability to its applied research resources because of the rapid evolution of technology.

  - **DEC** joined as part of its strategy of sponsoring a number of cooperative programs to augment in-house programs and sustain the health of the U.S. industry.

- Although shareholders justified joining MCC at the level of senior management, over time funding and day-to-day interaction have gravitated from the corporate office to operating levels. Consequently, sponsorship of an MCC program tends to be dependent on the needs of operating management. For this management to benefit from the relationship, MCC must sustain a reasonable flow of significant technology developments—with an occasional breakthrough—as well as give working-level shareholder staff access to both MCC consultants and other shareholders with related interests.

- As programs and projects mature, shareholders may shift funding in-house as the technology is incorporated into products, or, put another way, funding from some shareholders may be cyclic. Revenue generated from matured programs and projects through licensing, new company seeding, etc., could offset the effects of such shifts.

- Although failure is inherent in research, shareholders can benefit from it as well as from success, provided liaison and technology transfer methods facilitate appropriate interaction (a point made by some shareholders in interviews).[42]

- An aggressive program to increase the proportion of shareholder research assignees could stimulate the MCC research environment and assure a steady flow of "champions" for MCC in the shareholders' organizations. (On the basis of interviews with shareholders and MCC staff, this author sees this as an important need.)

- Better mechanisms for participation in industry associations, standards groups, and groups influencing federal policy are needed. (On the basis of interviews, such participation appears very spotty and needs strengthening.)

- Finally, the ability of shareholders to apply MCC developments is critical, i.e., the technology transfer challenge. In the end, contributions from MCC to the art of technology transfer could be one of its most important "technology" contributions.[43]

The *MCC Vision for the 1990s*, released in 1991, represents the consensus of management and shareholders on the future market environment and conveys MCC's strategy for addressing the industry's perceived needs in this environment. In an unpublished draft of the *Vision*, MCC's management described its position in the industry infrastructure:

> MCC is positioned to provide greater control of intellectual property, shorter time scale, more attention to application (particularly when integration of technologies is required), and greater focus on industrial requirements and technology transfer to member company product lines than are *universities*. MCC also is positioned to pursue inherently multi-company projects, and to provide greater financial leverage than *in-house* company funded projects or contract *research organizations*. MCC is positioned to provide more tailored technology, greater exclusivity, and earlier access to technology than would be available to *vendor-suppliers* which are not members of MCC.

With regard to trends in policy issues, the draft appears to emphasize the following:

> **Breadth of research**: Continuation of current scope with increasing emphasis on distributed systems, enterprise integration, and high-value electronics;
>
> **Operating entity vs. secretariat**: Evolution toward a hybrid organization that would combine laboratories at several regional sites (operating entity) and facilitation of cooperative undertakings among shareholders and others (secretariat);
>
> **Facilitation of cooperative environment in industry**: Greater participation in industry and government standards and advisory bodies to influence improved industry infrastructure and practices and federal policies;
>
> **Implementation of shareholder benefits**: Improved techniques for more effective technology transfer, including emphasis on consulting to facilitate the process.

Chapter Five

Semiconductor Industry Consortia: Industry-Based and Industry with Government

The computer industry has a symbiotic relationship with manufacturers of semiconductors and of semiconductor materials and equipment (SM&E). The proliferation of computer products became possible with the advent of integrated circuits (ICs); conversely, the semiconductor industry and other manufacturing industries that use semiconductor-based and SM&E products are important markets for the computer industry.

As the foundation of all electronics-based industries, the semi-conductor industry has major strategic importance—economically and militarily. In November 1989, in testimony before Congressional subcommittees, Ian Ross, chairman of the National Advisory Committee on Semiconductors (NACS) and head of AT&T Bell Laboratories, emphasized this strategic importance:

> The manufacturing capabilities of many industries are directly linked to the use of semiconductor chips. Improvements in chip technology thus directly enhance production capabilities in other industries. Purer chemicals and materials, more powerful computer-aided engineering and design, computer-integrated manufacturing-all promoted in the semiconductor industry-find broad application in other industries, such as computers, communications products, and consumer products.... [M]any of the manufacturing tools essential for achieving increased productivity, lower costs, and higher quality in industrial production are products of the semiconductor industry. Leadership in semiconductors can result in leadership in many industries.[44]

Ross went on to say that more than 2.6 million American jobs depend on the world market for electronic products and that $750 billion of this market is leveraged by the $50 billion world semiconductor industry. He noted that in the U.S. the chip industry employs more than double the labor force of the steel and automobile industries combined.

In the 1980s, Japan took over leadership of the merchant semiconductor industry from the U.S.: by the end of the decade, Japan's share of the world market was more than 50 percent, the U.S., 40 percent. Key drivers of computer chip manufacturing technology are technologies for producing DRAM chips. In 1990, the Japanese industry's share of this world market sector was approximately 80 percent.

According to Ross, the top five Japanese manufacturers spend nearly twice what the top five U.S. companies spend on R&D and new manufacturing facilities, even though the U.S. semiconductor industry is a leader in R&D and manufacturing facilities investment (as a percentage of total revenues) compared with other domestic industries. Because investment in a manufacturing facility to produce the next generation of submicron chips is forecast to be in the range of $500 million to $750 million (after an eight-fold increase for such a facility in the 1980s), if present trends continue, the U.S. industry will be at an even greater competitive disadvantage in the future than currently.

A concomitant development, posing a further threat to U.S. industry, is the leadership position the Japanese SM&E industry achieved in the 1980s for certain technologies, most strikingly those relevant to future high-performance logic and memory chips. Plants equipped with these technologies are coming on-line in Japan. To quote Ross, "Eighty-five percent of all leading-edge manufacturing capacity for submicron wafers is now in the Far East."[45] From the computer industry's viewpoint, vertically integrated Japanese companies are evolving a significant and growing competitive advantage in manufacturing high-performance computer chips.

The critical factors the American semiconductor industry must overcome are identified by Ian Ross as (*i*) the high cost of capital, (*ii*) a very weak consumer electronics industry, (*iii*) the past tendency not to pool R&D resources, (*iv*) a need for government policies and practices to be more supportive of industry, and (*v*) a need for a more educated, high-quality work force. The following discussion of the cooperative efforts of this industry addresses the last three factors (*iii*, *iv*, and *v*) and includes two operating consortia (the Semiconductor Research Corporation and SEMATECH) and one consortium that was proposed but never implemented (U.S. Memories).

5.1 The Semiconductor Research Corporation

The Semiconductor Research Corporation (SRC) was founded in 1982 as a consortium of eleven companies—seven semiconductor manufacturers and four computer manufacturers—initially without federal participation. Its purpose was to establish and oversee university-based programs for research and education that would help strengthen the competitiveness of the U.S. semiconductor industry and, further, facilitate technology transfer from SRC-sponsored university research to its members. The first significant partnership between the industry and a large number of universities for an integrated research effort, the SRC pioneered in establishing such relationships.[46] In form the SRC is organized as a secretariat. It has no laboratory facilities; research is performed at universities. Its role is to plan and manage a research program to broaden the generic technology base of the mainstream semiconductor industry.[47]

As the first semiconductor research consortium initiated by the industry, the SRC sees itself as contributing significantly toward sustaining U.S. research leadership in the field:

> In 1982, university research efforts relating to mainstream silicon technology were scarce, and engineers entering the industry had to be reoriented and trained before they could become productive. In 1989, hundreds of faculty members and students are participating in the integrated, goal-driven SRC research program. This program is now contributing more than 100 additional engineers and scientists with training and experience in silicon micro-electronics to the work force each year.
>
> The SRC has provided the funding which has sustained and reinforced major research studies in silicon micro-structures, computer-aided design, and integrated circuits. It has created new programs on many campuses and has introduced new areas of academic research, including semiconductor manufacturing and microelectronic packaging sciences. Today, estimates indicate that in the research areas in which it is active, the SRC provides over half of the total funding for academic research. This is evidenced by the many citations of SRC support that occur in papers in the United States and abroad.[48]

The SRC's claim to support research at universities that contributes to the evolution of a new technology structure for the industry that addresses international competition more effectively is justified in this author's opinion; as noted in their publication *Semiconductor Research Corporation: A Decade of Collaborative Semiconductor Research*, its partnership with industry has:

- directed university semiconductor research to create an integrated response to industry needs;

- created an important industry resource by forming the community of SRC researchers;

- developed close interactions among universities;
- and initiated important areas of applied research new to universities.[49]

5.1.1 Research Goals

In 1984, the SRC formulated research goals, with strong industry involvement, to accelerate projected ten-year integrated circuit technology evolution by two years. Performance toward achievement of this broad goal is measured against specific quantitative research targets for three areas: microstructure science (device and interconnect structures, new and improved processes, advanced devices, materials and equipment, and mathematical modeling of processes and devices); manufacturing science (yield and reliability enhancement, computer-integrated manufacturing, packaging, and manufacturing processes); and design science (new computer tools, systems and methodologies applicable to the design of integrated circuits). The global research goals for 1994 are summarized in **Table 5-1**.

Table 5-1

Research Goals of the SRC for 1994

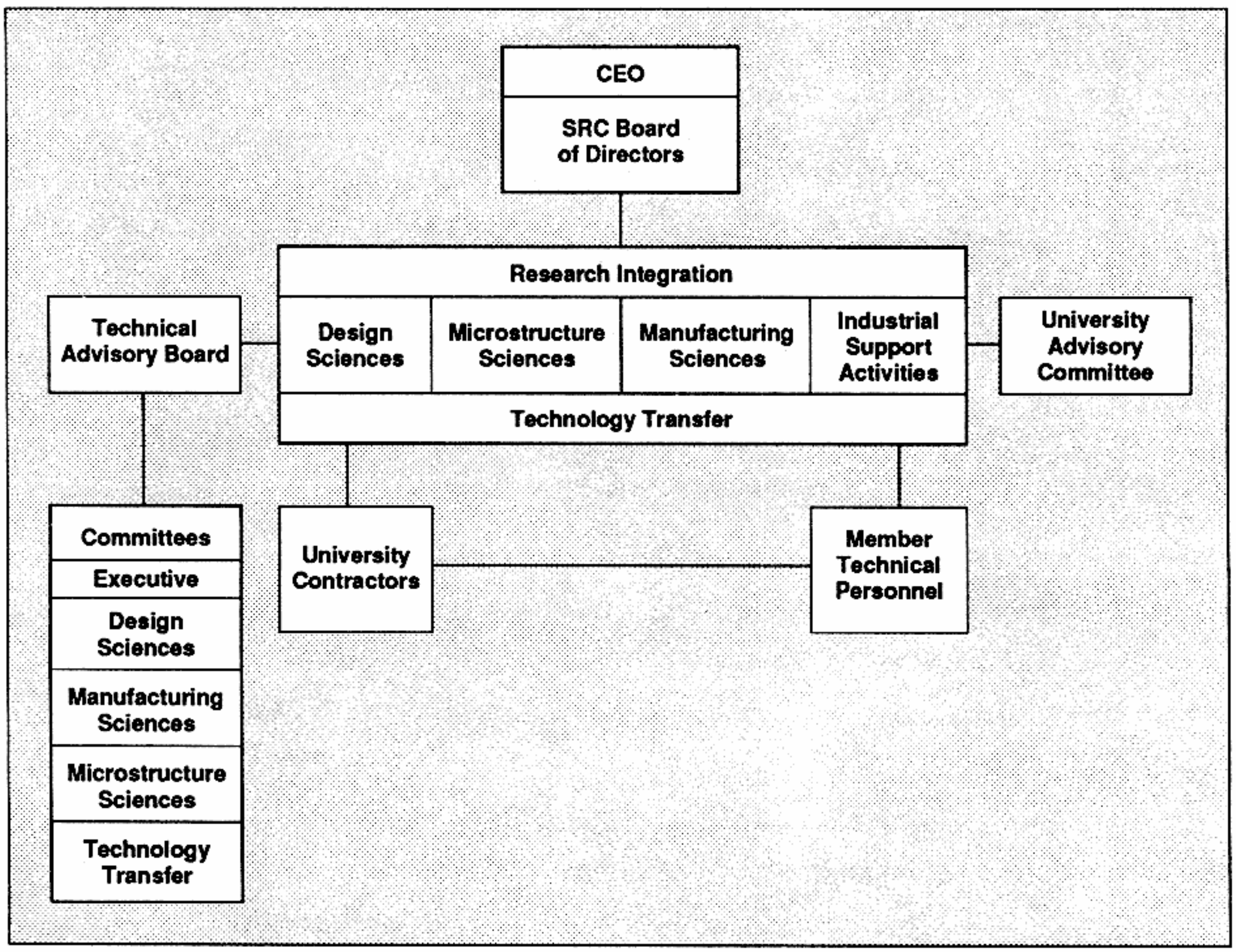
Reference	1984 industry technology
Agenda	Integrated circuit technologies
Impact	Two-year acceleration
Metric	Existence of engineering prototypes in the member companies of the SRC (Semiconductor Research Corporation)
Complexity	250-fold increase in density
Performance	10,000-fold increase in functional throughput rate (gate-Hz/sq-cm)
Reliability	10 FITS
Cost	500-fold decrease in cost per functional element

Source: R.K. Cavin III, L.W. Sumney, and R.M. Burger, "The Semiconductor Research Corporation: Cooperative Research," *Proc. IEEE*, 77, 9, 1328.

There are two classes of performance metrics for each category: research "thrusts" (in such categories as materials, packaging, reliability, processing, or metrology) and demonstration vehicles for chip technology. To track progress, the management of the SRC's research programs uses road maps with two dimensions, one research thrusts, the other technology demonstration vehicles.[50]

5.1.2 Organization and Operations

The organizational structure of the SRC is shown in **Figure 5-1**. Corporate headquarters are in Research Triangle Park, North Carolina. The staff is small, about 40 technical, administrative, and support staff. The technical staff is responsible for establishing research plans in cooperation with members and for management of research programs. (Cavin, Sumney, and Burger's useful summary of the SRC's staffing practices and operating style is



Source: R.K. Cavin III, and L.W. Sumney, R.M. Burger, "The Semiconductor Research Corporation: Cooperative Research," *Proc. IEEE*, 77, 9, 1330.

Figure 5-1

Organization of the Semiconductor Research Corporation (SRC)

included in **Appendix 5.1.**) Other activities, in addition to financial and contract administration, include a library, through which reports on SRC-sponsored research are disseminated, and operation of a computerized database accessible to industry, government, and academia.

The SRC research program consists of three categories of organization: centers of excellence, programs, and projects. An extensive review process assures that research activities are responsive to industry's needs.

Centers of Excellence are centers for specific, long-term generic research, each with annual funding at a level of $1 million to $2 million to support 25 to 75 graduate students. There are five Centers, each specializing as follows:

- Carnegie-Mellon: computer-aided design (CAD)
- University of California (Berkeley): CAD
- Cornell: microstructure science
- Michigan: manufacturing science
- Stanford: manufacturing science

Programs, each funded at $250,000 to $1 million annually, typically support 15 to 40 researchers for research on specific topics. A sample taken from among the 12 participating universities and the topics explored there includes: Clemson, reliability; Renssalear Polytechnic, advanced processing; MIT, BICMOS; University of Texas, design for test; Cornell, packaging.

Projects, each funded annually at about $50,000 to $200,000, typically support one to six researchers. About 30 projects, typically two to three years in duration, complement programs sponsored at Centers of Excellence.

By 1991, the SRC included 27 member companies, four associate members, 29 affiliate members, seven U.S. government agencies, and 56 research organizations.[51]

5.1.3 Technology Transfer

Technology transfer is performed by the SRC through the following vehicles:

- **Research papers and reports**: Several hundred are submitted to the SRC annually for dissemination to members. In 1988, more than 12,000 requests were serviced. Beyond this, the SRC also facilitates direct interaction between researchers and industry personnel.

- **Topical conferences and workshops**: By 1988, the SRC had held 27 topical conferences and 31 workshops, which serve multiple purposes, such as to report on significant new findings, to provide input to SRC technical program planning, and to serve as forums for interaction of university and industry personnel.

- **Satellite seminars**: Electronic seminars, on such subjects as computer-aided design, which are directly connected to 30 companies in order to reach a broad audience, have been well received.

- **Technology transfer courses**: Courses given on campus to member personnel have proved valuable for transfer of recently completed research findings.

- **On-line electronic database**: The database contains abstracts for several thousand technical papers and reports are available 48 hours after requests. Frequently upgraded, this resource is an important vehicle for technology transfer.

- **Software packages**: By 1988, more than 95 university-developed software packages had been distributed to members. Although the SRC does not support this software, it promotes software engineering guidelines to aid university researchers in the production of portable software, and it depends on the CAD marketplace as the arbiter of the usefulness of these software tools. The SRC acknowledges that technology transfer of software represents a major ongoing challenge and is seeking innovative techniques to improve their response to it.

- **Technology ownership**: The SRC offers ownership of intellectual property to universities where research is sponsored; its members are offered a royalty-free, nonexclusive license to the intellectual property that results from SRC-sponsored research. The SRC retains the right to patent intellectual property in countries where a university declines to do so. As of 1988, more than 40 patent disclosures had been submitted.

5.1.4 Educational Initiatives

In 1986, in an attempt to stimulate student interest in careers in manufacturing, the SRC formed a manufacturing education subcommittee to plan a program to develop courses for both graduate and undergraduate curricula; work is underway at five universities. Since the SRC's inception it has offered fellowships annually in the field of integrated circuits. By 1992, it had founded the Educational Alliance (SRCEA) to support the following projects:

- The Graduate Fellowship Program, supporting (in 1992) 30 fellows, among them 24 already holding Ph.D. degrees
- Curriculum development for more than 35 manufacturing courses in programs leading to bachelor's and master's degrees at five universities
- The VISION program, notable for its innovative approach to enhanced teacher preparedness in secondary school science and mathematics[52]

If a graduate opts to work for an SRC company or a U.S. government agency, the stipend is treated as a gift; if for a non-SRC company, then 50 percent is treated as a low-interest loan.[53]

5.1.5 Overview of Accomplishments

The SRC summarizes its activities as follows:

> SRC extends its activities into the larger semiconductor technology community of the industry through a diversity of activities. The industry consensus views on semiconductor research policy and programs are voiced to government bodies, and participation in the activities and publications of technical societies are encouraged.
>
> With the government, SRC interacts with the Congress and various technical agencies—testifying, advising, reviewing, and planning.
>
> With technical societies, SRC staff participation includes serving as editors, reviewers, organizers, and committee members....
>
> SRC interacts directly with and supports activities of the Semiconductor Industry Association (SIA) and SEMATECH, and is increasing its presence in the international semiconductor community.[54]

Cavin, Sumney, and Burger summarize the SRC's accomplishments and challenges:

> It is the SRC's experience that focused university research can provide substantial contributions to the advancement of semiconductor technology as well as an additional work force to enhance the industry, university, and government technical infrastructure of the United States.... The SRC has developed many mechanisms to enhance technology transfer between universities and member companies, but this remains a difficult problem for a number of reasons.... In some cases, the research was conducted primarily at a single university; in other cases ... at several universities .... A strength of cooperation among several institutions is that the services of geographically diverse specialists can be applied to various aspects of the problem. A difficulty ... lies in the integration of the research elements into a larger and more industrially useful result.... A challenge

> faced by the SRC on one hand is to develop mechanisms for industrial evaluation of university results and, on the other, to provide industrial problems of sufficient scale and complexity so that university researchers can realistically test proposed algorithms, software, processes, and so forth.... SRC is responsible for defining other appropriate cooperative initiatives in support of its members. SEMATECH and the National Advisory Committee on Semiconductors [are] new cooperative activities whose formation has been supported by the SRC.... As the SRC moves into the future, it must continue to carefully focus limited resources on high-impact issues of concern to its members.[55]

The SRC posed the question, what would the alternatives have been, "Without the SRC?"

> What would be the current status of semiconductor research in the United States had the SRC not existed for this last decade? The need for a cooperative research effort may have been so compelling that an alternative government or industry response would have occurred. However, if no SRC alternative had come into existence, then certain conclusions are possible:
>
> - An integrated goal-oriented semiconductor research effort would not exist.
> - Silicon device research would exist in only a few marginally supported university programs.
> - Very little bipolar silicon device research would be carried out in the United States outside of one major industrial laboratory.
> - The rate of progress in computer-aided design for integrated circuits would have been substantially less than which has occurred.
> - Semiconductor manufacturing would be absent from the academic research agenda.
> - University research in semiconductor device packaging would be minimal.[56]

5.2 SEMATECH

5.2.1 Genesis

By the mid-1980s, several U.S. cooperative efforts supported basic and generic applied semiconductor research, including: the SRC (**section 5.1**), which supports research at universities and National Laboratories; the Microelectronics Center of North Carolina (MCNC), a university-based research consortium; and the Microelectronics and Computer Technology Corporation (MCC), an industry-based applied research consortium (see **Chapter Four**).[57]

A Defense Science Board report of 1987 on the dependence of the DOD on the semiconductor industry included recommendations to reverse negative trends:

> The first recommendation called for the creation of a semiconductor manufacturing institute, equally supported by both the semiconductor industry and DOD. The cost of this institute would be $1 billion over 5 years with the appropriate technology focussing on mass production of the 64-megabit DRAM. The second was to establish eight university centers of excellence, at a cost to DOD of $50 million per year. The third was to increase DOD spending for R&D in semiconductor technologies by $60 million in the first year to $250 million by the fourth year. The fourth recommendation was to supply a source of discretionary funding of $50 million per year to defense semiconductor suppliers for unspecified R&D. Last, the report recommended providing for a common forum in which DOD and industry representatives would meet to discuss technology issues, at a cost of $200,000 per year to DOD.[58]

Later in the same year the Semiconductor Industry Association (SIA) proposed formation of a consortium to address these recommendations, to be called SEMATECH after the SIA **SE**miconductor **MA**nufacturing **TECH**nology proposal. Within the SIA, there was disagreement on whether the consortium should manufacture chips (with assured orders from larger consortium member-users) or focus on development of new manufacturing processes and production equipment. Although the latter approach prevailed for SEMATECH,[59] another attempt was made, which was ultimately aborted, to form a manufacturing consortium (U.S. Memories).

In May and June 1987, the SIA proposed a comprehensive business plan for SEMATECH that included a list of committed manufacturers of semiconductors and semiconductor equipment as well as a six-year "sunset" provision. SEMATECH was formally incorporated on 7 August 1987, and a list of fully committed founders was released in September. Funds for FY 1988 in the amount of $100 million (50 percent of SEMATECH's nominal budget) were included in federal budget bill P.L. 100-180, passed in December. The bill authorizing DOD participation in SEMATECH included a provision for an interagency advisory council chaired by the Under Secretary for Defense Acquisition at DOD. Federal participation was formally announced on 26 January 1988, and in April the DOD assigned DARPA the responsibility of overseeing SEMATECH. In January 1988, Austin, Texas, was chosen as the site for its headquarters, where by April the initial staff of 45 had arrived.[60]

5.2.2 The Mission

According to SEMATECH's 1989 annual report:

> Sematech ... is a unique, non-profit public/private partnership consisting of 14 U.S. manufacturers, the American companies that represent the infrastructure of the industry, and the federal government, formed to sponsor and conduct research in semiconductor manufacturing.
>
> The objective of SEMATECH is to achieve parity with and overtake Japan in semiconductor manufacturing in the 1993/94 time frame. To reach this goal, SEMATECH has three quantifiable phases of manufacturing development:
>
> Phase 1: Demonstrate manufacturing capability at the current level of technology, at circuit line widths of 0.8 micron.
>
> Phase 2: Achieve parity with Japan by manufacturing narrower line widths of 0.5 micron, as well as defining the standards and specifications for chemicals and equipment.
>
> Phase 3: Target the unprecedented achievement of 0.35 micron manufacturing, thus reclaiming worldwide semiconductor manufacturing leadership.[61]

5.2.3 Operational Concept

According to that report:

> One of the major factors in its [projected] success is SEMATECH's operational concept of partnership. SEMATECH depends on support and coordination from many groups and organizations that are key players.... The member companies, American equipment and materials suppliers (SEMI/SEMATECH), the Department of Defense through the Defense Advanced Research Projects Agency (DARPA), American universities and government laboratories designated as SEMATECH Centers of Excellence and the Semiconductor Research Corporation are all partners in this national mission.[62]

Partnership with industry is manifested by an industry-driven research program in which approximately 58 percent[63] of the research staff are member assignees (by the end of 1990); by facilitation through SEMATECH of member company-to-company and industry-to-government interaction; by extensive technology transfer programs, including seminars, workshops, symposiums, and equipment user group meetings; by programs to upgrade the quality of manufacturing technicians; and by joint programs with the SEMI/SEMATECH consortium for suppliers of manufacturing equipment and materials.

Partnership with government is primarily through DARPA but also involves the National Advisory Committee on Semiconductors (NACS), the DOE, and the Department of Commerce. "DARPA's extensive experience facilitating technical research and development projects and its ability to serve in a consulting role has been a boon to the SEMATECH program," according the 1989 Annual Report (p. 5).

SEMATECH is also a valuable source of information on technical and industry issues to NACS, which was established by the Office of Science and Technology to advise the president on strategy for national semiconductor competitiveness, including research priorities. Chaired by Ian Ross, of AT&T, NACS, which consists of five government and eight semiconductor industry participants, is charged with assessing possible contributions from government and national laboratories to strengthen the industry's technical base. Within its purview, working agreements are in place between SEMATECH and Sandia National Laboratories to develop a national center for tool design and between SEMATECH and the Oak Ridge National Laboratory, as part of a design optimization program for electron cyclotron resonance etchers applicable to submicron geometries. Both laboratories are under the jurisdiction of DOE. A program to develop a metrology standard to define a way to measure ultrafine line widths is active between SEMATECH and the National Institute of Standards and Technology (NIST), a branch of the Department of Commerce.

Partnership with academia is implemented through the Centers of Excellence, initiated in January 1988 and managed cooperatively by the SRC and SEMATECH. These Centers support research in SEMATECH's Phase 3 program, and beyond, as well as development of curricula and sponsorship of graduate students in the manufacturing sciences. The roles of SEMATECH and the SRC are defined in SEMATECH's 1989 Annual Report: "The Centers of Excellence program is a partnership between SEMATECH and SRC. The SRC formed by the industry in 1982 to conduct generic semiconductor research, funds manufacturing-related research at numerous other universities in the United States. SEMATECH provides funding and overall program direction, while the SRC oversees research contracts, acts as an interface between SEMATECH and the Centers, and helps transfer Center-developed technology to SEMATECH."[64] The first grants for the program were made in June 1988.[65]

5.2.4 Evolution of Programs and Organization

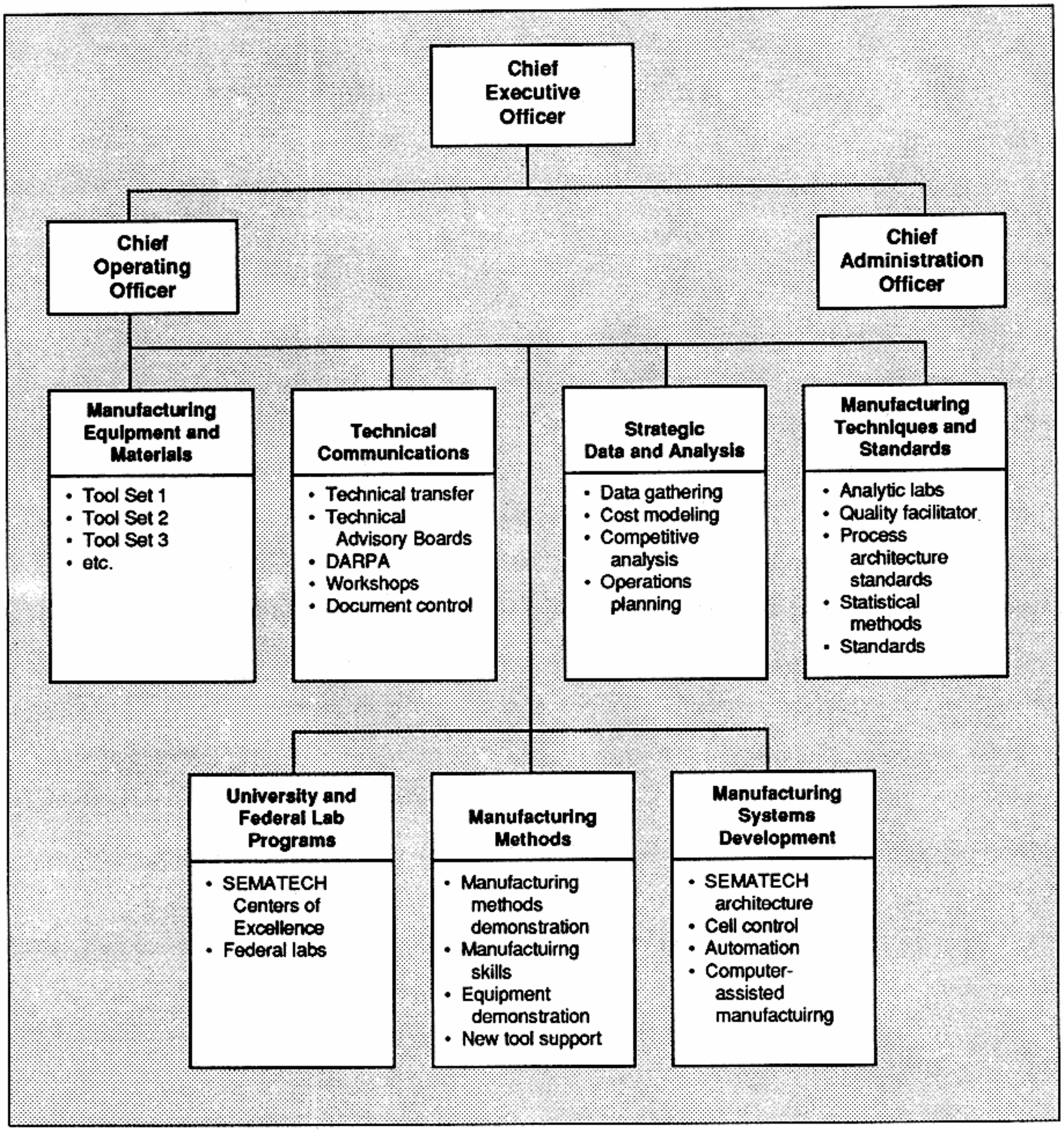
In April 1988, SEMATECH moved from Santa Clara, California, to Austin, Texas, where operations began with a staff of 45, which by December had increased to 350 and by late 1990 to approximately 700. In 1989 it achieved its goal of a technical staff that consisted of about 50 percent of member assignees (for a nominal two-year period).

Initially organized along hierarchical, functional lines, SEMATECH was characterized by Charles Ferrell, manager of the Manufacturing Systems Development Division, as "looking like any semiconductor manufacturer member only without marketing and sales."[66] This organization was consistent with its primary emphasis on development of manufacturing processes and a secondary but important emphasis on support for the manufacturing equipment sector. In 1989, partially in response to funding limitations and partially in response to rapid deterioration of elements of that sector, SEMATECH reversed the order of its priorities. It also reorganized along project-oriented lines (making each project responsible for specific deliverables), using a "flat" structure to improve its response to "time-driven" industry needs. SEMATECH's current organizational structure is shown in **Figure 5-2**. An important aspect of the reorganization was inclusion in the governance of the research programs of Technical Advisory Boards (TABS), at both the executive (ETAB) and the more narrowly focused working level (FTABS), which serve as mechanisms (*i*) for feedback to members and (*ii*) for guidance of SEMATECH programs by members and as forums (*iii*) for sharing members' problems and solutions. A Technology Transfer Council consisting of a single representative from the senior management of member company was also formed to facilitate communication on technology transfer issues.

With respect to partnering with industry, SEMATECH's change in program emphasis to bolster the SM&E sector was reflected in structural changes adopted in June 1989 and described in a May 1990 report to Congress by its Advisory Council on Federal Participation in SEMATECH:

> SEMATECH is now organized to expedite an increased volume of off-site R&D projects that meet specific equipment, materials, and manufacturing process requirements for 0.5 and 0.35 micron production. A new executive-level Investment Council reviews and approves all projects. Responsibility for contract management is vested in a large supplier relation staff. And a single engineering team, directly accountable to senior management, pushes each project from conception to conclusion. The new structure incorporates a well defined process

for project definition, selection, support, and demonstration. Project-based operations also clarify staffing requirements and ensure a close fit between assignees' skills and opportunities.[67]



Source: GAO Report, Federal Research, *The SEMATECH Consortium's Start-up Activities*, November 1989.

Figure 5-2

Organization of SEMATECH

5.2.5 Performance

SEMATECH differs from MCC substantially in four ways: (*i*) it has been operational for about four years, in contrast to nine for MCC; (*ii*) its mission is more specialized; (*iii*) government is one of its major sponsors; and (*iv*) it is attempting to redress some competitive weaknesses of an industry that has lost a larger share of the global market to the Japanese than the computer industry has. These differences provide the context for the following evaluation.

The criteria shown in **Table 3-3** and applied to MCC in **Chapter Four** (cf. **Table 4-3)** and are shown in **Table 5-2** below and applied here to SEMATECH.

Table 5-2

Criteria to Evaluate the Performance of a Consortium

Resources of a Consortium	**Staff** ■ Quality and dynamics **Industry participation** ■ Scale and stability **Budget** ■ Size and trends
Achievement of Goals of Consortium	**Timely Application of Advanced Technology** ■ Technical achievements ■ Effectiveness of technology transfer ■ Balance between short- and long-term programs **Strengthening of Industry Environment** ■ Impact on industry infrastructure ■ Impact on federal policymaking

Note: The material presented in this table is the same as Table 3–3.

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5.2.5.1 Quality and dynamics of staff. Interviews with SEMATECH managers (Peter Mills and Charles Ferrell) in November 1990 indicated that, despite the rapid ramp-up of staff, the overall quality of assignees was excellent. Hiring occurred in three distinct waves: (*i*) initial staffing (30), from mid-1987 to June 1988; (*ii*) a major surge in growth (to 500) between June 1988 and December 1989; and (*iii*) a period of more gradual growth (to 700) from December 1989 on. In keeping with a maturing organization, staff added in the third wave tended to be more stratified according to function.

According to a General Accounting Office (GAO) report from 1989 which provides a useful overview of how assignee staff were selected (see **Appendix 5.2**), the process has proved successful for recruiting assignees of high quality. By 1991, approximately 58 percent of the technical staff were assignees.[68] In this author's opinion, it is too early to determine the impact in such areas as technology transfer and advocacy of assignees who return to their companies at the completion of their term at SEMATECH.

5.2.5.2 Scale and stability of industry participation. The fourteen founding members from industry are:

Advanced Micro Devices	LSI Logic
AT&T	Micron Technology
Digital Equipment Corporation	Motorola
Harris	National Semiconductor
Hewlett–Packard	NCR
Intel	Rockwell International
IBM	Texas Instruments

The federal government, represented by DARPA, is the fifteenth member, funding $100 million of the approximately $200 million annual budget. Of the 14 industry founders, semiconductor manufacturers account for approximately 80 percent of the industry's production capacity. Most of the other members are manufacturers of commercial computers or communications products, or of both, and a few are defense electronics firms. Most of the firms are large, with annual revenues of over $1 billion, although the annual revenues of two are less.

The funding formula of semiconductor founders consists of an annual contribution corresponding to 1 percent of a company's previous year's sales, up to a cap of $15 million; the contribution of semiconductor users is based on a percentage that corresponds to the previous year's semiconductor purchases.

SEMATECH deals with the semiconductor manufacturing equipment and materials sector primarily through SEMI/SEMATECH, a national organization comprising 131 suppliers as of 1990 who represent a good cross section of this sector: most are small companies, 85 percent with sales of less than $50 million annually and the majority with sales of less than $10 million.[69]

The issue of the stability of industry support is now (1992) moot, because its industry members have made five-year commitments. Members are now in the process of determining whether they will participate in the next phase, SEMATECH II, to run for five years beginning 1993. Although most apparently plan to do so, two have indicated they will not continue past their current term.[70]

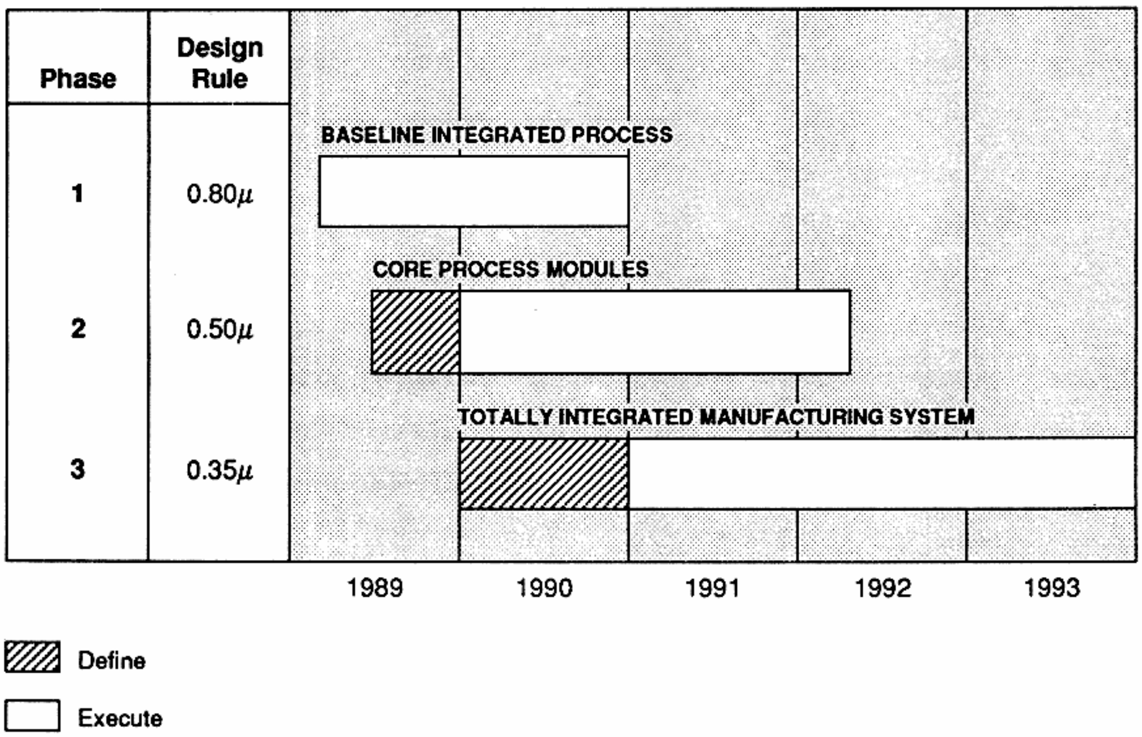
5.2.5.3 Size and trends of budget. The nominal annual budget is $200 million split 50–50 between industry members and the federal government. Funding limitations in 1989 required the revision of certain programs to eliminate nonessential activities and to extend the target dates for completion of Phases 2 and 3. SEMATECH does not view these changes as in any way jeopardizing its goal of enhancing U.S. competitiveness.

In 1989, on the recommendation of NACS, SEMATECH attempted, but failed, to increase federal support to $250 million annually; this, with industry matching funds, would have increased annual funding to $300 million.[71] SEMATECH's strategic plan for its next phase (SEMATECH II) assumes approximately the same annual funding level ($200 million) and participation by industry members and the federal government.[72]

5.2.5.4 Technical achievements. The following is excerpted from the SEMATECH 1991 Update report to Congress:

> SEMATECH's objectives are to develop key tools, materials, and methods within SEMATECH's defined Thrust Areas that give member companies the capability of regaining a world-leadership position by 1993.
>
> Baseline, 0.5 and 0.35 micron manufacturing capabilities will occur only in SEMATECH's identified Thrust Areas. These Thrust areas include lithography, multilevel metals, furnace and implant, and manufacturing methods.[73]

SEMATECH's overall medium-term technical objective is to develop the manufacturing technologies required for U.S. industry to produce semiconductors with 0.35 micron line widths by 1993, which, in SEMATECH's judgement, will represent advanced commercial products at that time. **Figure 5-3** shows the schedule for the three phases toward accomplishment of this goal.



Source: SEMATECH, *Innovation for America's Future*, 1991 Update, p. 11.

Figure 5-3

SEMATECH: Phase 1, 2, and 3 Overview

According to SEMATECH, as of October 1991, Phase 1 manufacturing demonstration objectives, as modified in 1989, had been met, and the Phase 2 program was on schedule. In 1990, Phase 2 manufacturing capability was demonstrated at SEMATECH facilities, using all American-made equipment.[74] At the completion of the first five-year program, SEMATECH forecast that "fabrication tools and their associated processes will be available from U.S. suppliers that provide U.S. manufacturers capabilities for manufacturing state-of-the-art ICs on a par with or better than those available elsewhere."[75] **Appendix 5.3** summarizes progress in manufacturing equipment and materials required by each Thrust Area through March 1991 according to the 1991 Update.

Programs dealing with manufacturing methods, processes, and systems also are described in the excerpts from the 1991 Update. Current joint development projects include the following:

- With Wilson Oxygen, Semi-Gas Systems, and the Linde Division of Union Carbide, to develop a gas-delivery system, now in use, that resulted in higher purity, higher yield, and lower cost
- With Advantage Production Technology, Inc., to develop a gas-phase wafer-cleaning system to support the goals of SEMATECH's Phases 2 and 3 by replacing the two-step wet cleaning with one-step gas cleaning
- With Hewlett-Packard, to design test chips and other manufacturing capabilities
- With NCR, developed a generic process advanced isolation technology for testing and improving SEMATECH's Phase 2 equipment

Twelve research contracts have been placed at SEMATECH Centers of Excellence in this area, as summarized in **Table 5-3**.

5.2.5.5 Effectiveness of technology transfer. To implement programs, SEMATECH, member companies, and suppliers are integrated into project teams. The operating style, although still at an early stage of evolution, appears to this author to result in effective technology transfer. SEMATECH's first success was implementation of a class 1 clean room designed as an advanced facility. The specifications and techniques developed for it have been adopted by a number of member companies.

SEMATECH's projects for equipment improvement and for joint development which involve technology transfer over the life of the project also appear to be working well, as indicated in SEMATECH's 1991 Update.

> Phase 1 baseline process was brought up on 5-inch wafers with NIKON steppers in March, 1989. Today, 6-inch wafers are yielding 40% with all U.S. made equipment.

Recently, a Phase 2 (0.5 micron) integrated flow has been demonstrated in SEMATECH's lab with 6 consecutive test lots, using all American-made equipment.[76]

Table 5-3

SEMATECH Centers of Excellence and Research Contracts 1990–91

Strategic Priorities	SCOEs/ National Labs	Deliverable
Cycle time reduction	MA, NC, TX	▪ Single wafer process
Factory process and equipment modeling	SETEC*, MA, NM, NJ, NC, TX, WI, PA, FL	▪ Queue flow and cost modeling ▪ Mechanical and CFD** modeling ▪ Process and process control modeling ▪ Yield modeling
Defect reduction	AZ, FL	▪ Particle generation ▪ Transport and removal procedures ▪ Metallic impurity detection and identification of electrically active defects
Process transfer-time reductions	FL, PA	▪ Design for manufacturability methodology ▪ Rapid yield learning methodology
Equipment uptime	SETEC*	▪ Reliability guidelines ▪ Modeling for software reliability

* SETEC: Semiconductor Equipment Technology Center (Sandia)
** CFD: Computational Fluid Dynamics

Source: SEMATECH: Innovation for America's Future, 1991 Update, p. 26.

By late 1991, the impact of the equipment improvement and joint development projects was significant, as noted in a draft of SEMATECH's next five-year strategic plan:

> The impact of SEMATECH equipment and qualification activity is evident in the fraction of U.S. designed and manufactured equipment purchased for new advanced technology wafer fabrication lines. At SEMATECH's creation, U.S. IC producers expected to make less than 40% of their submicron equipment purchases from American suppliers. Actual purchase fraction now averages over 70%, and industry's most recent major fabrication facility (Motorola's MOS 11) is equipped with 87% U.S. production equipment.[77]

5.2.5.6 Balance between short- and long-term programs. The primary emphasis of programs at SEMATECH is on the short and medium term, with the goal of strengthening the sectors of manufacturing equipment and materials and of achieving by 1993 the technological capability to manufacture semiconductors with 0.35 micron line width technology. Longer term goals are defined in the SEMATECH II operating plan; current programs that address aspects of future manufacturing technology are pursued through partnering with universities and National Laboratories.

According to Noyce in testimony before Congress in 1989, SEMATECH spent $108 million on the supplier industry infrastructure that year, and for 1990 the planned level was $130 million.[78] These priorities were based on the board's view of the industry's needs, a view that reflected the concerns of larger semiconductor manufacturers whose domestic supplier infrastructure had eroded. The smaller member companies' need for SEMATECH to supply them with manufacturing processes led to disagreement about these priorities. To this author, however, SEMATECH's balance between short-, medium-, and long-term programs appears a reasonable response to the industry's needs.

5.2.5.7 Impact on industry infrastructure. In its short history, SEMATECH has achieved an impact, tangible and intangible, on industry infrastructure. First, it augments the SRC and NACS with industry-led, focused programs to reestablish the domestic industry as world-class and technologically competitive for advanced semiconductor manufacturing. Tangible results have been in clean-room technology and practices and in upgrading specific U.S.-made manufacturing equipment and manufactured materials. Intangibly, through partnering programs with industry, government, and academia, SEMATECH has encouraged an environment of cooperation in an industry previously noted for the opposite. In particular, dealings between semiconductor manufacturers and their suppliers appear to be changing from arms' length relationships to close cooperation to assure that the suppliers' products both meet the market needs and are available in a timely manner. To date, SEMATECH's efforts to nurture this change appear to work well; according to the SEMATECH II long-range strategic plan:

> Competing firms are working together to define common precompetitive process, equipment,and materials requirements; manufacturing methods; and interconnect standards for semiconductor wafer fabrication equipment. SEMATECH has also developed methods for estimating the total cost of

> equipment ownership and standardizing the qualification of manufacturing equipment. Such activities result in cost savings and eliminate substantial and unnecessary duplication of effort within the industry.[79]

5.2.5.8 Impact on federal policymaking. Together, the SRC, NACS, and SEMATECH significantly represent the industry to government policy-makers. Through SEMATECH's Advisory Council on Federal Participation, Congress and the executive branch receive direct, timely exposure to issues that the industry faces and to the effect on it of these consortia.

The relationship between SEMATECH and DARPA, according to the SEMATECH II long-range strategic plan, offers "substantial benefits":

> DARPA plays a critical role in SEMATECH's accomplishment of its mission by helping define strategic objectives and monitoring performance toward these objectives as well as providing financial and technical resources to aid in the achievement of the mission. DARPA plays a key role in communication by facilitating coordination with and technology transfer to and from DOD, by advocating SEMATECH within DOD, and by providing information to the legislative and executive branches of the government. SEMATECH fulfills its role in the partnership by planning and effectively executing its programs.[80]

A specific example of cooperation in technology programs is in the lithography industry: "Lithography technology for the next generation of ICs is now being developed in DARPA's X-ray and 193 nm programs. SEMATECH's commercialization and qualification of this research will promote member companies' application of the developments into integrated, commercial processes."[81]

5.3 U.S. Memories

5.3.1 Rationale for U.S. Memories

In 1986-88, within the Semiconductor Industry Association (SIA) sentiment was strong to get U.S. semiconductor companies back into the manufacture of DRAMs (dynamic random access memories), for reasons spelled out in a background document published in September 1989 by U.S. Memories (see **Appendix 5.4**). According to this document, there were three motives: (*i*) DRAMs are a "technology driver" of manufacturing processes for microprocessor and other semiconductor types, (*ii*) advanced DRAM production knowledge and training contributes qualitatively and quantitatively to the overall technical infrastructure of the industry, and (*iii*) domestic DRAM production provides a stable source of supply for American systems and product manufacturers.

5.3.2 The Market Environment

The background document offers this perspective on the DRAM market environment:

> America has always led and continues to lead the world in semiconductor design. The 1K DRAM was introduced by Intel in 1970, and, more recently, IBM corporation was the first to use 256K-bit, 1-megabit, and 4-megabit DRAMs in its products. However, because DRAM chips are a commodity product, leadership in the DRAM market results more from production capacity and the availability of investment dollars than from design skills.
>
> The Japanese have come to dominate this market because they have been more successful at acquiring the large amounts of capital needed to invest in DRAM production, and because they have used that production capacity to compete aggressively for market share. In brief, there were three key reasons the Japanese overtook the U.S. lead in DRAM production:
>
> 1. The Japanese government set DRAM dominance as a national goal, and protected new DRAM makers there from foreign competition through tariffs and other market access restrictions.
> 2. Large, vertically-integrated electronics firms like Hitachi and Toshiba made huge investments in state-of-the-art DRAM production, aided by a financing system that didn't emphasize short-term profitability, and secure in the knowledge that they would buy some of their own production.
> 3. The Japanese government provided additional R&D funding, and encouraged other Japanese electronics firms to buy Japanese-made DRAMs exclusively.[82]

Further background on the market environment of 1991 can be found in **Appendix 5.5**.

5.3.3 Chronology of Negotiations

The following chronology is based mainly on discussions with Sanford Kane, who had been the president of U.S. Memories, in April 1990, after the collapse of attempts to launch the company.[83]

In the late 1980s, IBM tried to influence U.S. semiconductor manufacturers to reenter the DRAM market by offering to license its 4M DRAM technology; only one firm was seriously interested, but after six months of discussion it bowed out. The combination of high risk and large investment was daunting in view of past failures and formidable Japanese competition.

In the summer of 1988, the SIA considered some form of joint venture, but this possibility died quickly, primarily because of antitrust concerns. By September, the DRAM shortage was hurting the computer and other electronics industries. In January 1989, Norling, an executive of Motorola, representing the SIA, and Canion, founder of Compaq, representing the American Electronics Association (AEA), wrote an "RFP," soliciting companies to meet to address the problem. About 25 to 30 positive responses were received. A plan of action was needed. In January 1989 the SIA formed a strategic planning committee led by Gordon Moore (Intel) and including Kane (IBM), Weber (TI), Corrigan (AMD), Procassini (president of SIA), Sporck (National Semiconductor), and White (Motorola). At their next meeting, in Washington, D.C., on 1 March, the board dealt with the question, Is this issue important and, if so, why, and what can be done about it?

The reasons for concern were compelling:

- Simple economics: DRAMS represented 21 to 22 percent of the dollar volume of annual global sales of semiconductors, and the percentage was growing.

- DRAMS are a primary "technology driver" for development of other semiconductor devices and manufacturing equipments.

- A DRAM shortage existed: for the first time, prices actually went up. At this time (1989), Toshiba's chairman publicly stated that U.S. customers (*i*) would need to accept quantity allocations from their Japanese suppliers and (*ii*) would need to order ASIC and microprocessor devices as a condition for DRAM deliveries.

- The semiconductor industry had broad support for its thesis that it was itself fundamentally important to the future well-being of the economy. If it did not take action on the DRAM issue, such support would wither away.

The following possible responses were considered: (*i*) current U.S. producers could increase capacity, but, considering the risk and investment involved, this approach was not likely; (*ii*) the return into the market of companies that had stopped producing DRAMS and the entrance of new companies—again not likely; (*iii*) some form of industry cooperative effort, but a pure start-up probably could not be expected to catch up with entrenched competitors. At this point, IBM resolved the dilemma by offering to license both its 4M DRAM designs and their manufacturing processes; to supply support in the start-up phase;

and by making an (informal) commitment, conditional on success with the 4M product, to license the next generation (16M) product.

At the meeting on 1 March 1989, a committee was formed, chaired by Corrigan, to develop a rudimentary business plan. On 10 May, the SIA board reviewed the plan and accepted its basic structure with the following stipulations:

- Intellectual property was not an issue. The manufacturing operation was to be based solely on licensing, although this could be reconsidered in the future to determine whether a design capability would be added.

- The venture would be commercial and self-supporting.

- The technology would be licensed.

- The ramp-up to large production volume would be rapid in order to become a world market participant.

Acceptance by the board, which represented a cross section of the producing and using industries, including memory producers and non-memory producers, was a significant milestone.

Because the SIA is a trade association, an independent entity had to be formed, which was led by Kane, to carry the commercial venture forward. Its first move was to approach the major firms in both producer and user industries informally, in order to garner tentative commitments from four or five. It circulated an investment commitment letter that requested a statement of support and indicated both willingness to invest and the amount as well as the following conditions: full commitment by a viable founding group; agreement by IBM for technology transfer; and clarification of antitrust and patent issues. By November 1989, these conditions were met and in June the attempt to sign people up began. Public interest in this first cooperative manufacturing venture in the U.S. was considerable.

The business plan for U.S. Memories originally assumed $1 billion in financing, split equally between equity and debt. Two plants were to be constructed with a commitment to buy 50 percent of their first product runs. A plan modified late in 1989 called for an investment of $725 million divided into $350 million for equity and $375 million for debt, construction of one plant, and commitment by members to buy 75 to 80 percent of the first product run.

5.3.4 The Demise of U.S. Memories

With IBM, DEC, Intel, National, AMD, and LSI committed to participation in U.S. Memories and NCR, Hewlett–Packard, AT&T, Tandem, and Compaq seriously interested, prospects for success looked promising, but the venture unraveled when Apple, Sun, and Compaq decided not to participate. Subsequently, NCR, AT&T, Hewlett–Packard, and Tandem agreed to participate but only at inadequate levels of investment and product purchasing. Thus, certain companies would commit only 2 to 3 percent of their total annual semiconductor procurement rather than the 20 to 30 percent requested, and, a result, the total commitment for all participants would have been less than half the required 75 to 80 percent.

At the demise of U.S. Memories, there were four classes of players:

(*i*) Users (IBM, DEC) who were very supportive for both investment and product commitments

(*ii*) Semiconductor manufacturers (LSI, Intel, National, AMD) who were very supportive because they considered this venture important to their customers

(*iii*) Tentative users (NCR, H–P, AT&T, Tandem, Compaq)

(*iv*) Prospects with no interest

Because U.S. Memories was conceived as a self-supporting commercial venture, direct federal financial support was not included in the plan. Federal loan guarantees might have helped, but the six months of lobbying typically required for Congressional approval would endanger a timely start-up. Similarly, amendment of the 1984 National Cooperative Research Act to include manufacturing and to change the treble provisions for antitrust damages for suits by private company would have sent a positive signal to the industry. If the administration had openly supported the U.S. Memories concept, Kane believes it would have helped convince some of the prospects.

The factors that ultimately led to the rejection of the concept of U.S. Memories can be summarized as follows[84]:

- The shortage of DRAMs disappeared during negotiations for formation of U.S. Memories. As a result, DRAM prices fell and electronics manufacturers lost their sense of urgency.

- Typically, most U.S. computer manufacturers did not invest in their semiconductor manufacturers.

- The computer industry companies (excepting IBM and DEC), under pressure for short-term performance in a fiercely competitive market, lacked the long-term strategy needed to support a cooperative manufacturing venture.

- Sources of supply other than Japanese companies (e.g., Samsung in Korea and Siemens in Germany) were coming on stream.

- Given the Japanese companies' market share and dominance, U.S. Memories was unlikely to be profitable in its early years. The Japanese companies would, in all likelihood, cut prices to retain their market share. U.S. Memories would have needed to absorb substantial losses to gain market share, just as the Japanese companies had earlier, to capture a major share of the DRAM market. Given the uncertainty this introduced into determination of the likely required investment, the computer manufacturers were not willing to support the venture on the proposed terms. The alternative to exclusive industry sponsorship was, in effect, a federal subsidy, but the government was passive, if not hostile, to the concept of a manufacturing consortium. U.S. Memories would have established a precedent for cooperative ventures in manufacturing.

- Having decided not to pursue a federal subsidy, its decision also not to pursue federal loan guarantees as an alternative may have been a tactical error. However, because the perceived window of opportunity for U.S. Memories was short, the length of time required for Congressional action was considered unacceptable.

- If the administration had indicated support for the concept of U.S. Memories, it might have favorably influenced hesitant candidate founders on the margin.

- Joint ventures between U.S. firms and between U.S. and foreign firms remained possible alternatives.

Chapter Six

High-Performance Computing Consortia in the U.S.: Status, Issues, and Evaluation

By the 1980s, the manufacturing segment of the information industry in the U.S. was clearly in trouble. If appropriate remedies are not taken in the 90s, this segment could suffer the same fate as the U.S. steel and automobile industries. In the extreme, the specter of a collapse looms, similar to that of the U.S. consumer electronics industry although, in this author's view, that is unlikely.

Japanese companies in this key strategic industry are overtaking or passing their U.S. counterparts, in part as a result of Japan's policies of cooperation between industry and government and of related industry practices coupled with relatively ineffectual responses by U.S. companies and the U.S. government.[***] Those who study the industry understand that many complex factors contribute to these negative trends, such as the representative factors summarized below:

Market Factors

- Growing international competition (particularly from Pacific Rim countries)
- Access to international markets ("level playing field")
- Characteristics of new market participants (large, integrated, well financed)
- Fragmentation of market requirements (impact of "downsizing")
- Availability of risk financing and "patient money" (impact of problems of financial institutions)
- Cost of capital (high cost of R&D and manufacturing facilities)
- Federal and state government policies (whither "industrial policy"?)
- The rate of evolution of a "wired society" (a complex process)

[***]Japanologists recognize other important factors, such as work habits, education, union attitudes, attitudes toward savings, etc.

- Education level of users of industry's products (a future barrier?)

Technology Factors

- Software as the pacing technology
- Further commoditization of hardware
- Manufacturing costs
- Further evolution of powerful processing engines, architectures and large-scale storage
- Proliferation of open systems
- Trends toward distributed, small-scale, powerful computer systems
- Increasing technology complexity and development costs
- Dependence on a quality engineering work force (to design and apply products and processes)

Both market and technology factors have led to a climate of ongoing change in the infrastructure and practices of the U.S. industry. In the 80s government and the industry began a slow transition, still underway, from a laissez faire, free-market orientation to various cooperative undertakings within the industry and between the industry and government to marshal the industry's resources better in order to reverse the downward trend of that decade. The dominant change in industry practice was toward proliferation of various forms of business alliances, whether simple company-to-company cooperation in research and development or marketing or multiple-organization consortia for research and development, standards setting, or other purposes.

Excerpts from reports by the Computer Systems Policy Project (CSPP), a group consisting of chief executive officers (CEOs) of the major domestic computer manufacturers, provide a useful perspective on the road ahead, if current (1992) trends are to be reversed:

> the international challenge to the computer industry's technological leadership cannot be met with a short-term, quick-fix approach. Effectively meeting the challenge requires thoughtful analysis and incremental, concrete changes by our individual companies and our industry as a whole. Equally important, it

> will require a long-term commitment to increased cooperation between U.S. industry and government.[85]
>
> We have concluded that the cooperative R&D investments by the private sector and governments worldwide demand a new level of cooperation between industry and government in the United States.... CSPP has concentrated its initial technology policy strategy on R&D policy—specifically, on improving the U.S. research and development investment. Nevertheless, skilled personnel and business environment issues are critical to the success of the computer industry and most other technology industries. In fact, without a well-educated work force and a business environment conducive to investment, industries like ours cannot undertake the research and development efforts needed to make the technological advancements that will prevent further erosion of our technological base, let alone improve our position.[86]

6.1 Focus and Approach of This Study

The focus of this study is on efforts at cooperation through consortia for research on applied, generic, high-performance computing (HPC) technologies, which, broadly defined, include technologies that are the basis for advanced performance computing systems. This chapter addresses questions posed in **Chapter One**.

- Is there a significant role for HPC research and development consortia to redress weaknesses in the development and manufacturing segments of the U.S. information industry?
- What are the important issues and problems related to fulfilling this role? Are they being addressed effectively? What has been learned and how might that benefit the industry?

6.1.1 Approach

The consortia evaluated here are four major cooperative efforts, three operational—the Microelectronics and Computer Technology Corporation (MCC), the Semiconductor Research Corporation (SRC), and the SEMATECH Corporation—and the fourth, U.S. Memories, never implemented. The operational consortia have two broad goals: timely application of generic advanced technologies and strengthening the development and manufacturing segments of the information industry's infrastructure. As shown in **Chapter Three (Table 3-3)** and as applied in **Chapter Four** (cf. **Table 4-3**) and **Chapter Five (Table 5-2)**, this study uses the following criteria to evaluate operating consortia:

Table 6-1

Criteria to Evaluate the Performance of a Consortium

Resources of a Consortium	**Staff** ■ Quality and dynamics **Industry participation** ■ Scale and stability **Budget** ■ Size and trends
Achievement of Goals of Consortium	**Timely Application of Advanced Technology** ■ Technical achievements ■ Effectiveness of technology transfer ■ Balance between short- and long-term programs **Strengthening of Industry Environment** ■ Impact on industry infrastructure ■ Impact on federal policymaking

Note: The material presented in this table is the same as Table 3-3.

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6.2 The Microelectronics and Computer Technology Corporation (MCC)

MCC is a for-profit, centralized research laboratory-based consortium serving shareholders from the information and user industries (see **Chapter Four**). Neither federal nor state governments were among its founders. This unique consortia was founded exclusively by industrial companies; founded in 1982, it is the oldest major precompetitive R&D consortium in the industry; and its technology program has the broadest range of any U.S. information industry consortium.

MCC has been supported by a relatively stable shareholder population, which is its primary funding source. Other sources of income are government contracts (15 to 20 percent of revenue in 1991) and, on a very small scale, licenses. Since 1986, annual budgets have been in the range of $58-63 million, peaking in 1987 and falling by 1990 to $58 million.

It has built a competent research staff by recruiting on the open market; shareholder assignees account for about 15 percent. In keeping with its mission to develop generic applied technology, the staff represents an appropriate mix of technology and application skills.

Its range of research programs encompasses five major technology subdivisions: advanced computer technology, computer-aided design (CAD), packaging and interconnect, software, and the computer physics laboratory. In 1991, these were reorganized into four research areas: High-Value Electronics, the Distributed Intelligent Information System Division, the Enterprise Integration Division, and the Computer Physics Laboratory (see **Figure 4-2**).

MCC's accomplishments as of 1991, can be summarized as follows:

- Work on important applied technology topics
- Technical performance of good quality
- Research staff of a quality equal to or better than those of most shareholders
- MCC-developed technologies incorporated into a number of shareholder products or processes; modest overall impact, but technology transfer relationships have been established
- Has become a useful proving ground for testing technology transfer techniques
- To a limited degree, has facilitated inter-shareholder, inter-industry cooperation within its technological purview
- Participates in some industry standards activities
- Has the potential now to develop into a useful information source for international technology developments

MCC was the pioneering effort of the industry in precompetitive R&D, but over its approximately nine-year lifetime, the benefits yielded to its shareholders and the industry have been marginal. MCC has not yet lived up to its founders' expectations.

Its tangible and intangible accomplishments, however, offer positive indicators for the future. A sampling of tangible accomplishments in technology transfer includes: artificial intelligence software incorporated into product and product-support functions by computer manufacturers; contact bonding techniques adopted by shareholders in electronic packaging;

software standards adopted by CAD companies; parallel processing, scalable, distributed-system technology in use by federal agencies, a few shareholders, and universities; and neural network software applied to chemical manufacturing plant processes and character recognition products. Licenses have been granted for MCC-developed technology, and MCC research has seeded a few company start-ups. Finally, shareholder access to MCC technical staff consultants is proving a noteworthy benefit.

With respect to intangibles, the development of certain technologies would not otherwise have been undertaken by some shareholders because of staffing and cost, but risk- and cost-sharing considerations inherent in MCC justified participation in programs to develop them. Shareholders have also benefited from progress in technology transfer not only as it relates to adopting MCC technology but also in the management of their internal programs. Another intangible is the cooperation fostered between some shareholders directly as a result of the interaction at MCC.

6.2.1 Lessons Learned from the MCC Consortium

The downside to MCC's performance to date is its inability to reach certain (explicit and implicit) goals:

- Limited success or failure of some potentially important technology programs (e.g., in parallel computing technology and human interfaces)
- Shift of primary emphasis to short-term programs, with an average reduction for from six to ten years to three to five
- Scale of activities insufficient to impact industry infrastructure and practices significantly; participation in industry standards groups and industry associations insufficient (but in 1991 policies were changed to increase participation in standards groups)
- Shareholders' technical staffs were underrepresented on MCC's staff
- Overall scale of cooperative activities of shareholders and MCC is marginal to inadequate
- MCC's contribution to federal policymaking for the industry is marginal to inadequate (but in 1991 policies were changed to improve interaction)

This author sees the following few underlying causes of the shortfall from expectations.

6.2.1.1 A lack of clear purpose perceived by senior management of large shareholders. Although some of these shareholders are steadfast supporters, MCC's level of effort is not significant for large share-holders in comparison with the level of their internal efforts. (For example, in the late 80s the total R&D budget of DEC, a strong supporter, was in the range of $1 to $1.3 billion, of which an estimated 10 percent, or about $100 million, was precompetitive research funding, but DEC funded only about $3 to $4 million of MCC's approximately $60 million annual budget.) For such sponsors, MCC tends to be a "gap filler," serving the sponsor's research agenda as an added source for exploratory research. Because to senior management of large shareholders MCC is not a high priority, their support typically is not sufficient to nurture the level of cooperation in strategic planning needed for significant joint programs.

A "chicken and egg" aspect is also recognizable here. In this author's opinion, for some time, MCC's programs have lacked any unifying theme that could focus its undertakings and provide a vehicle to energize the requisite support from shareholder senior management. As noted later in this section, MCC's strategy for the 1990s attempts to rectify this failing.

In original conception, MCC's time horizon was medium- to long-term (six to ten years). In 1988, five years after its founding, shareholders and associates were permitted to sponsor projects with a two- to three-year time horizon. Typically derived from long-term core programs, these projects are usually related to a sponsor's near-term product development plans and, as such, have proved productive. This shift has led to a shift in shareholders' support toward shorter term projects; by 1991, the time horizon for programs was on average three to five years. Although one benefit of the shift, when combined with a policy to permit participants to sponsor individual projects (rather than a program in the pre-1991 sense), could be an increase in the sponsor population, there are also drawbacks: support for longer term projects may decrease; the level of the average sponsor's funding may decrease (increasing MCC's marketing expenses); and, perhaps most important, the level of involvement of senior management of shareholders may decrease.

The balance between long- and short-term research projects is subject to change as the industry's needs change. In the present climate, MCC's shorter term programs are responsive to such needs. Its longer term programs have the potential to be cost-effective for shareholders faced with budget pressures from declining profit margins and increasing R&D costs and who recognize the need to sustain long-term research activities to remain competitive. This potential cost-effectiveness notwithstanding, shareholder participation in longer term programs is a strategic decision and, as such, requires the support of senior management.

6.2.1.2 Lack of federal sponsorship of MCC. One rationale for joint government-industry sponsorship of a consortium for R&D in generic applied technology is that such an undertaking deals with so-called leaky technologies—those for which the developer has a short head start before the competition uses them. The argument goes that 100 percent public funding of leaky technology will result in inefficient overproduction, that 100 percent private investment will result in underproduction, so joint public-industry sponsorship is clearly optimum.[87]

MCC's founders apparently did not subscribe to this argument or chose not to seek federal participation during its formation for a variety of reasons, ranging from reluctance to deal with the federal bureaucracy to possible conflict of interest for Bobby Inman, the former deputy head of the CIA who headed MCC's management. Potential benefits from federal participation were obvious, specifically: (*i*) funding leverage, which could accelerate research programs, and (*ii*) a better two-way flow of cooperative activities, which could broaden MCC's access to government technical and managerial resources and to government policymakers. Accelerated research programs could offer the advantage of undertakings on a scale more meaningful to MCC's industrial sponsors than is currently the case, with potentially greater benefit to the industry. Access to policymakers could enhance MCC's currently weak contribution to programs for industry-government cooperation; although it was not an original goal of the founders, such access is now recognized as desirable.

6.2.1.3 Insufficient number of shareholder researchers assigned. MCC originally intended that the majority, or at least a substantial percentage, of its research staff would be shareholder assignees who at the completion of their term would return to their companies. (This is similar to the way such consortia have been staffed in Japan, although recently Japanese consortia have evidently experienced reluctance among member companies to assign staff.) Unfortunately, candidates for the position of the key research directors proffered by shareholder companies were not of acceptable quality to MCC management. Although opinions differ as to the reasons for the low quality, this problem is another indicator of many shareholders' less-than-complete commitment to the concept of MCC. Of course it can be argued, with considerable merit, that shareholders could not spare their top-quality people.

Staffing undertaken on the open market resulted in technical staff that was only 15 percent shareholder assignees, a result necessarily yielding weaker ties between MCC and its sponsors than the original approach would have done. Program planning, technology transfer, and general acceptance by sponsoring organizations of the proposed role of MCC all are adversely affected.

By 1991, within the industry MCC is considered a competent research organization viewed with considerable good will by its shareholders but of marginal effectiveness in helping the industry to increase its competitiveness.

In 1991, Craig Fields, formerly director of DARPA, took over as CEO of MCC. His reputation for initiating and managing large-scale R&D programs at DARPA is outstanding. His background in working with the computer industry, academia, and federal laboratories and particularly in computer networking is especially cogent in relation to MCC's recent blueprint "Vision for the 1990s," much of which addresses MCC's weaknesses, in particular the following points paraphrased here:

- Focus on universal broadband information networking as the unifying theme for MCC's programs

- Evolve from the orientation of a centralized research laboratory to that of a laboratory-based facilitator of cooperative R&D with, and by, its sponsors

- Leverage its budget through (*i*) cooperative programs with universities, whereby MCC would serve to "harden" university research for application by industry; (*ii*) facilitation of direct company-to-company cooperation on research programs; (*iii*) becoming a licensee of technology from domestic and foreign sources; (*iv*) investing in MCC-related company start-ups; and (*v*) expanding government contract programs

- Facilitate cross-industry projects by (*i*) defining open architectures, standards, and protocols relevant to new markets; (*ii*) reducing market entry risk through cross-industry cooperative initiatives; and (*iii*) involving the supplier base in the process

- Focus on technical programs in the three areas important to universal broadband information networking: distributed information systems; enterprise integration; and high-value electronics

- Initiate additional laboratories at sites with outstanding technology communities (such Boston and San Francisco) to assure presence in the mainstream technology establishment

- Strengthen ties with the Semiconductor Research Corporation (SRC), to integrate MCC's university programs, and with other consortia, as appropriate

- Establish a Washington office to focus on cooperation between industry and government concerning industry competitiveness

This "Vision," if successfully implemented, would respond to most of the problems identified in this chapter. It is very ambitious, significantly expanding the scope of MCC's cooperative relationships. MCC's future as an important contributor to the industry's competitiveness very likely depends on its successful implementation.

6.3 Semiconductor Industry Consortia

The computer industry has a symbiotic relationship with the semiconductor industry—with manufacturers of both semiconductors and semiconductor materials and equipment (SM&E) (see **Chapter Five**). The proliferation of computer products was enabled by integrated circuits (ICs); conversely, the semiconductor industry and other manufacturing industries that use semiconductor-based and SM&E products are important markets for the computer industry. Clearly, high-performance computing systems depend, to a considerable degree, on the most advanced semiconductor technology. In the larger view, this industry is the foundation for all electronics-based industries and has major strategic importance, both for the economy and for the defense establishment. These considerations were emphasized by Ian Ross, chairman of the National Advisory Committee on Semiconductors (NACS) and head of AT&T Bell Laboratories, in testimony before Congressional subcommittees in November 1989. Ross stated that more than 2.6 million American jobs depend on the world market for electronic products and that the $750 billion world market for those products is leveraged by the $50 billion world semiconductor industry.[88]

During the 1980s Japan wrested the leadership of the merchant semiconductor industry from the U.S., and by the end of 1988 its share of the world market was more than 50 percent, that of the U.S., 40 percent. Because Japanese computer manufacturers frequently are members of the same group of companies as their chip supplier(s), they can use the relationship to a competitive advantage. Key drivers of computer chip manufacturing technology are technologies for producing DRAM chips, and in 1988 the Japanese share of this market sector was approximately 80 percent. The Japanese SM&E industry is the dominant supplier of lithography and other equipment for next-generation semiconductor manufacturing. As a result, to quote Ross, "Eighty-five percent of all leading-edge manufacturing capacity for submicron wafers is now in the Far East."[89]

According to Ross, the top five Japanese manufacturers spend nearly twice what the top five U.S. companies spend on R&D and new manufacturing facilities. The cost of investment in a manufacturing facility to produce the next-generation submicron chips is forecast to be $500 million to $750 million (after an eightfold increase for manufacturing facilities in the 80s), and if present trends continue the U.S. industry will be at an even greater competitive disadvantage in the future than now.[90]

Ross identified several critical factors to be overcome by the U.S. semiconductor industry: (*i*) the high cost of capital, (*ii*) a very weak consumer electronics industry, (*iii*) a tendency in the past not to pool R&D resources, (*iv*) a need for more supportive federal policies and practices, and (*v*) a need for a more educated and higher quality work force. The following discussion of cooperative efforts of the semiconductor industry addresses the last three factors.[91]

The SRC and SEMATECH and the proposed but aborted consortium U.S. Memories represent attempts to increase the competitiveness of the industry in the U.S. The membership of the SRC and SEMATECH accounts for the major share of the U.S. merchant production capacity; nevertheless, a few smaller semiconductor manufacturers oppose the formation of consortia for precompetitive research. Their opposition stems from concerns that large member companies of a consortium would control the research agenda and that the resultant bias might prove a disservice to the smaller members.

The participation of major computer manufacturers in the SRC and SEMATECH attests to the vital stake of the computer industry in the success of the semiconductor industry's efforts to revitalize itself through cooperative efforts.

6.3.1 The Semiconductor Research Corporation (SRC)

The SRC was founded in 1982, initially without federal participation, as a consortium of 11 companies, seven semiconductor and four computer manufacturers, to establish and oversee university-based programs for research and education intended to strengthen the competitiveness of the U.S. semiconductor industry. Its organizational form is that of a secretariat. It has no laboratory facilities; research is performed at the universities. The SRC's role is to plan and manage a research program to broaden the generic technology base of the mainstream semiconductor industry.

6.3.1.1 Research goals. In 1984, the SRC formulated its research goals, with strong industry involvement, to reduce the evolution of new technology over a predicted ten-year period by two years. Achievement of this broad goal is measured against specific quantitative research targets in three categories: microstructure science, manufacturing science, and design science. For each category there are two classes of performance metrics: research "thrusts" (e.g., materials, packaging, reliability, processing, metrology, etc.) and demonstration vehicles for chip technology.

6.3.1.2 Staff and budget. The SRC's staff consists of about 40 technical, administrative, and support personnel, with experienced research managers supplied by industry and government for a two-year term and an ad hoc university advisory committee to advise the SRC on topics related to the research program.

The SRC's budget for 1991 was $35 million, of which industry funded $22.6 million, the federal government $2.4 million, and SEMATECH $5 million.

6.3.1.3 Technology transfer. Technology transfer occurs through a variety of vehicles, including publications, conferences, and workshops, electronic satellite seminars, campus technology transfer courses, an on-line electronic database, software packages, and staff assigned by members.

6.3.1.4 Educational initiatives. To stimulate student interest in careers in manufacturing, in 1986 the SRC formed a manufacturing education subcommittee to formulate a plan for a program to develop courseware for graduate and undergraduate curricula. Curriculum development for more than 35 manufacturing courses in programs leading to bachelor's and master's degrees has been supported at five universities. In 1992, a Graduate Fellowship Program supported 30 fellows including 25 already holding Ph.D. degrees.

6.3.1.5 Overview of accomplishments. The SRC's claim to support research at universities that contributes to the evolution of a new technology structure for the industry that addresses international competition more effectively is justified in this author's opinion; as the SRC noted in its publication *Semiconductor Research Corporation: A Decade of Collaborative Semiconductor Research,*[92] its partnership with industry has:

- directed university semiconductor research to create an integrated response to industry needs;
- created an important industry resource by forming the community of SRC researchers;
- developed close interations among universities;
- and initiated important areas of applied research new to universities.

The SRC has evolved a significant relationship with SEMATECH (and may also with MCC in the near future) to facilitate commercialization of university-developed semiconductor technology.

6.4 SEMATECH

By the mid-1980s, several cooperative efforts existed to support basic and applied semiconductor research, including the Semiconductor Research Corporation, the Microelectronics Center of North Carolina, and the Microelectronics and Computer Technology Corporation. In 1987 in a report on the defense semiconductor dependency, the Defense Science Board of the Department of Defense recommended actions to reverse negative trends in the industry's competitiveness. In response, the Semiconductor Industries Association proposed formation of the **SE**miconductor **MA**nufacturing **TECH**nology (SEMATECH) consortium, formally incorporated on 7 August 1987. Its founders were 14 semiconductor and computer manufacturers (split evenly between the two industries), representing most of the infrastructure of the semiconductor industry, and the federal government, through DOD, which has a six-year "sunset" provision. Funding is supplied equally by the industry group and DOD, at an annual budget of $200 million.

6.4.1 Research Goals

SEMATECH's objective is to achieve technological parity with and overtake Japan in semiconductor manufacturing in the 1993–94 time frame. According to SEMATECH's 1989 annual report, this program is planned to culminate in the technology to manufacture semiconductors with the 0.35 micron feature size by 1993.

6.4.2 Operational Concept

To improve the competitiveness of the U.S. semiconductor industry through "partnership," the SEMATECH programs are intended (*i*) to facilitate development of advanced semiconductor manufacturing processes and equipment and (*ii*) to strengthen suppliers of semiconductor materials and equipment (SM&E) to the manufacturing segment.

Partnership with industry is manifested by an industry-driven research program in SEMATECH facilities in which by the end of 1990 approximately 58 percent of the research staff were member assignees; by facilitation of cooperation among member companies and between industry and government; by extensive technology transfer programs; by programs to upgrade the quality of manufacturing technicians; and by joint programs with the SEMI/SEMATECH consortium of suppliers of manufacturing equipment and materials.

Partnership with government, primarily through DARPA, also involves the National Advisory Committee on Semiconductors and the departments of Energy and Commerce.

Partnership with academia is implemented through the program of Centers of Excellence, founded in November 1987 and managed jointly with the SRC. The Centers support SEMATECH's Phase 3 research program, and beyond, as well as the development of curricula and the sponsorship (through fellowships) of graduate students in the manufacturing sciences.

6.4.3 Evolution of Programs and Organization

SEMATECH began operation in April 1988 in Austin, Texas, with a staff of 45; by December the staff had reached 350; by late 1990, approximately 700. In 1989 it achieved its goal of a technical staff consisting of 50 percent member assignees. The initial organization was consistent with a primary emphasis on development of manufacturing processes and a secondary one on support for the SM&E sector. In 1989, partly in response to funding limitations and the rapid deterioration of the SM&E sector, these priorities were reversed. SEMATECH reorganized along project-oriented lines and took other steps to better its responsiveness to industry's short-term needs. The reorganization led to significant changes in the structure of SEMATECH related to SM&E projects.

This consortium differs substantially from MCC: (*i*) by 1991, it had operated for about four years (MCC has operated for nine); (*ii*) its mission is more quantified than that of MCC; (*iii*) the federal government is a major sponsor; (*iv*) it is attempting to redress competitive weaknesses of an industry that has lost a larger market share to the Japanese than the computer industry.

Although staffing required a fast "ramp-up"—about 700 in about two years—a GAO review in 1989 of its quality was favorable. As stated, the goal of at least 50 percent of the technical staff consisting of member assignees was reached after a rigorous screening process.

There are a total of 14 industrial founders. The founding semi-conductor manufacturers account for about 80 percent of the industry's production capacity. Most of the other members are commercial manufacturers of computer or communications products, and a few are defense electronics firms. Most are large firms with annual revenues of more than $1 billion, although two have smaller annual revenues.

The funding formula for the semiconductor manufacturer members is an annual fee that corresponds to one percent of its previous year's sales with a cap of $15 million; the semiconductor users' fee is based on a percentage of the previous year's semiconductor purchases.

SEMATECH's channel to the SM&E sector is primarily through SEMI/SEMATECH, an organization of 131 (1990) suppliers who represent a good cross section of the sector, most of them small, 85 percent with annual sales of less than $50 million and the majority with annual sales of less than $10 million.

The stability of support by industry members and of funding levels since SEMATECH's inception is moot, because the members made a five-year commitment (through 1992). Two members have indicated that they may leave at the end of their commitment because of the reversal in priorities to emphasize SM&E programs. (The smaller manufacturers tend to benefit more from the process research programs than the larger ones, who therefore did not favor the change.) Member companies, with the possible exception of the two who have indicated they may leave, have committed to support a second five-year program at about the same level as the first.[93]

According to SEMATECH's March 1991 Update to Congress, the industry has realized a number of tangible and intangible benefits from its programs, including building and staffing a "world-class" semiconductor fabrication facility which manufactures functional 0.8 micron chips and 0.5 micron test-demonstration chips, using only American-made tools. The report states that much of the 0.8 micron technology is used by member companies and DOD facilities as a result of dozens of many joint development contracts with suppliers. Another contribution is cooperation among semiconductor manufacturers and suppliers in precompetitive R&D for process, materials, and tool designs facilitated by SEMATECH, acting as a forum: "SEMATECH is changing the culture of the industry by changing the way the semiconductor industry interacts with its suppliers."[94]

The Update notes that Joint Development Projects with SM&E companies "have produced tools which are unsurpassed in the world ... some of which are in member companies production lines." Half of SEMATECH's external budget is spent in Joint Development Projects and Equipment Improvement Projects, and these funds are further leveraged by investments of the selected supplier companies. SEMATECH has founded 11 Centers of Excellence, involving 27 universities and three National Laboratories. "The university programs have yielded several vital research results in each of SEMATECH's Thrust Areas and have graduated 45 students with advanced degrees in semiconductor manufacturing. The

National Laboratories programs have made significant contributions in ECR etching, metrology and scatterometry, the last of which is being delivered to the member companies. SEMATECH has also been involved in developing a number of industry standards in areas such as cluster tools, communications protocols, statistical methods and computer-integrated manufacturing."[95]

6.4.4 Future Focus

SEMATECH points out that semiconductor manufacturing is particularly amenable to collaborative efforts facilitated by consortia for one particular reason:

> the development and perfection of manufacturing technology inherently depends upon the flow of ideas between researchers, semiconductor producers, and production equipment and materials suppliers. In the U.S., these groups are in different industry segments. SEMATECH facilitates the give-and-take between researcher, producer, and toolmaker that enriches the development of manufacturing technology. This communication forum is a particularly significant development for the semiconductor industry, in which traditional producer/producer and producer/supplier relationships have been adversarial.[96]

Recognition of SEMATECH's potential role as a *primary* facilitator of cooperation among members of industry, academia, and government is a cornerstone for future activities. Because its performance to date has established its credibility to serve in this role for the community of interest, SEMATECH is proposing to shift its mission for the second five-year period to "Create fundamental change in manufacturing technology and the domestic infrastructure to provide U.S. semiconductor companies the capability to be world class."[97]

SEMATECH's key technology areas during its first five years were Lithography; Multilevel Metals; Furnace and Implant; and Manufacturing Methods, Processes, and Systems. In the next five years, while work in those areas will continue, one area, Manufacturing Methods, Processes, and Systems, will be divided between two principal thrusts, (*i*) Computer Integrated Manufacturing (CIM)/Manufacturing Systems and (*ii*) Manufacturing Methods, and a third new technology thrust, Contamination-Free Manufacturing, will be added.[98]

SEMATECH's strategy to fulfill its mission is summarized in the following extract:

The increasing complexity of IC production is driving sophistication and cost of production to a level beyond the means of many current industry participants. SEMATECH II proposes to develop technology for a flexible, highly automated IC "factory of the future," which is capable of improved efficiency at all production volumes and which draws from the best available equipment, manufacturing methods, factory automation systems, and processing capability....

The technology agenda proposed ... uses well-established U.S. strengths in systems and software as the basis for a revolutionary concurrent industry approach to developing semiconductor production systems in which device, process, and equipment models are interlaced for flexible production capability. Extensive computer-based modeling and simulation will guide each phase of the effort.

New fabrication tools and processes will be essential to advance the drive toward smaller geometries, but future tools must also be more flexible and produce more controllable, reproducible results. The computer-based factory system of the future will go well beyond product tracking; it will directly control each tool to match specific wafer process requirements. New tools and factory control systems are essential if future factories are to have the volume flexibility, process capability, and controlled cost needed for competitive manufacturing in the 21st century.

Further, SEMATECH II proposes to shorten deployment cycle times by addressing the manner in which new manufacturing technology is developed and put into practice. Today's serial development process does not meet the need to advance semiconductor technology at a faster rate than in the past. SEMATECH II will build on its proven base of industry/government cooperation to establish parallel development efforts within national laboratories, equipment and materials developers, and semiconductor manufacturers.[99]

6.5 U.S. Memories

The U.S. Memories consortium was proposed but failed to be implemented. Its supporters gave the following rationale for its undertaking.

6.5.1 Rationale for Proposal

1. Dynamic Random Access Memories (DRAMs) are a "technology driver" for other semiconductor manufacturing processes. DRAMs have a simple structure and advances in DRAM technology are almost completely advances in production technology, because the production process allows designers to pack more and more bits of memory on a chip. To make each new generation of DRAMS, manufacturers must use increasingly advanced production equipment. The well-established pattern is that once a technology for DRAM manufacturing is proven, it is subsequently applied to manufacturing microprocessors and other logic circuits.

2. Advanced DRAM production contributes to the overall technical infrastructure of the semiconductor industry. The pool of engineers and the knowledge base developed during the design and production of advanced DRAMs raise the overall level of semiconductor manufacturing knowledge that contributes to the growth of the industry infrastructure.

3. Domestic DRAM production provides a stable source of supply for systems companies and other electronics manufacturers. Japan is both the world's largest DRAM producer and the world's largest DRAM consumer. American firms that rely on Japanese firms for their supply of DRAMs must compete with Japanese customers, who have greater volume demands. Many Japanese producers are divisions of large, vertically integrated companies whose other divisions buy DRAMs for use in computers and other products. The market structure of foreign DRAM suppliers who are their own customers, and thus have first priority on DRAM production, has led to oscillations in the supply and pricing of DRAMS in the U.S.[100]

Key to the proposal of U.S. Memories was IBM's offer to license its 4-megabit DRAM designs and their manufacturing processes, to supply support during the start-up phase, and to commit (informally) to license the next generation of 16-megabit product if the 4-megabit product proved successful. The sponsors felt, with considerable justification, that, in face of established competition, such a venture could become viable only through this kind of licensing arrangement.

6.5.2 The Demise: Lessons Learned

The proposal to form U.S. Memories could not muster enough support when Apple Computer, Sun Microsystems, and Compaq decided not to participate and then AT&T, Hewlett-Packard, NCR, and Tandem Computer agreed to participate but only at inadequate levels of investment and product purchasing. In the end, insufficient support by computer companies led to the failure of U.S. Memories to form.

In this author's view, the following major factors led to the rejection of the concept of U.S. Memories:

- The shortage of DRAMs disappeared during negotiations, prices fell, and electronics manufacturers lost their sense of urgency.

- U.S. computer manufacturers typically do not invest in their semiconductor suppliers.

- Computer companies, with the exception of IBM and DEC, under pressure for short-term performance in a fiercely competitive market, lacked the needed long-term strategic view to support a cooperative manufacturing venture.

- Sources of supply other than Japan were coming on stream (e.g., Samsung in Korea and Siemens in Germany).

- U.S. Memories was not likely to be profitable during its early years because of the market share dominance and resources of the Japanese companies. These companies would probably cut prices to retain market share. U.S. Memories would need to absorb losses to gain market share, as the Japanese had (to capture the major share of the DRAM market). Given the uncertainty price cutting introduced into determining the required investment, the computer industry members were not willing to support the venture. The alternative to sole industry sponsorship was, in effect, a federal subsidy, but the U.S. government was passive, if not hostile, to the concept of a manufacturing consortium. U.S. Memories would have established a precedent for cooperative ventures in manufacturing.

- Having decided not to pursue a federal subsidy, U.S. Memories also decided not to pursue federal loan guarantees, as an alternative. This may have been a tactical error. However, because the perceived window of opportunity for U.S. Memories was short, the time required for Congressional action was deemed not acceptable.

- An indication by the administration of support for the concept of U.S. Memories might have had a favorable influence on candidate founders at the margin.

- Joint ventures of U.S. firms and U.S. and foreign firms remained possible alternatives.

6.6 Semiconductor Industry Consortia: Lessons Learned

Although covering less than a decade, the experience through 1991 of SEMATECH, the SRC (in cooperation with SEMATECH), and U.S. Memories is instructive. The lessons learned can be summarized as follows:

- Although SEMATECH represents a significant commitment by the semiconductor and computer industries and the federal government to deal with precompetitive semiconductor manufacturing technology, its existence is a necessary but in itself insufficient step toward restoring the competitiveness of the industry. The industry and its supporters in government and academia have emphasized the need for a comprehensive program, including appropriate changes in trade and tax policies, and greater cooperation between government and industry, particularly to address capital requirements for next-generation manufacturing plants.

- SEMATECH's performance, in its short existence, has been very encouraging.

- Its partnering programs are well conceived and have already benefited its members, the SM&E industry sector, and the SRC.

- Because the government is a sponsor, SEMATECH, along with NACS and the SRC, make up an effective bloc representing the industry to federal policymakers.

- Access through DARPA to government-related technologists and managers has proved valuable to SEMATECH.

- Its success in constituting about 50 percent of its technical staff as member assignees greatly facilitates cooperation in planning and executing programs.

- SEMATECH appears well on the way to fostering new cooperative interaction between semiconductor manufacturers and their suppliers, which is essential if the SM&E sector is to supply manufacturers with the tools to meet global competition.

- In one important instance, SEMATECH demonstrated its ability to adjust priorities to meet contingencies and implement appropriate programs.

The following issues are for the future to decide:

- Will the 0.5 micron and 0.35 micron technologies developed by SEMATECH be compatible with members' production equipment and production practices?

- How will members finance manufacturing facilities for these technologies?

- Will SEMATECH's networking with other R&D organizations at member, university, and government laboratories be effective in covering the range of R&D necessary to compete with Japan?

The lessons learned from the demise of U.S. Memories are few and sobering:

- The merchant semiconductor candidate members were committed to the concept. They recognized that the stakes were fundamental to the future competitiveness of the industry.

- The computer manufacturers, with the exceptions of IBM and DEC, were not willing (or able) to support an attempt by the semiconductor industry to recapture market share for DRAMs, even though consequences in the medium to long term for the computer manufacturers were likely to be negative.

The following issues are brought into focus by the U.S. Memories experience:

- A progressive decline is possible, with alarming implications for the competitiveness of the U.S. electronics industry, because the weak DRAM manufacturing sector might further weaken the semiconductor manufacturing industry, which, in turn, would weaken the computer and other electronics industries.

- The need for risk sharing and the realization that the products and services of the computer industry are key enablers of a modern society suggest that more comprehensive cooperation between government and the semiconductor and computer industries, including manufacturing consortia, appears inevitable.

6.7 A Perspective on the Status and Issues of Consortia

Faced with short- and long-term threats to the U.S. manufacturing base of the information industry, leaders of the industry have initiated various cooperative undertakings within the industry and between industry and government. At the level of national policymaking, current advisory bodies include the National Critical Technologies Panel (NTCP), composed of members from industry, academia, and government; the National Advisory Committee on Semiconductors (NACS), with the same source of membership; and the Computer Systems Policy Project (CSPP), composed of CEOs of computer manufacturing companies. These bodies are essentially ad hoc and lack the continuity of industry associations or government policy research groups. At the other extreme are consortia for various operational purposes (including precompetitive R&D, standards setting, operation of supercomputer centers, etc.).

Through the 1980s, the influence of consortia on the negative trends of the global competitiveness of the U.S. industry was minor. In this author's opinion, some consortia have proved (or are proving) viable by filling important industry needs, particularly those dealing with software and networking standards, basic and precompetitive semiconductor technology, and supercomputer applications. Other consortia in these and other areas of information technology, proved less successful. Some progress has also been made in facilitating cooperative business practices.

If the 1980s were the learning period for such cooperative ventures in the U.S., the 1990s will be a period for proving or disproving their efficacy in facilitating improvement of the industry's technological competitiveness.

What needs to be done in the areas of finance, industry structuring, and marketing is beyond the scope of this study, but all aspects of response to competition will depend on the industry's will to compete in the manufacturing sector. Its willingness and ability to invest the resources necessary to assure competitiveness and to invest in consortia as a technology resource that will contribute to meeting this goal will depend on an environment that assures an adequate return on investment. Without this environment, adequate support for the needed programs, including for precompetitive research consortia, is unlikely to be forthcoming.

Although differences of opinion are inevitable within the industry and the federal government on approaches for enhancing global competitiveness, there is agreement on the scope of the problems besetting the industry. A report by the NCTP, which advises the Director of the Office of Science and Technology Policy, identified the information or communications technologies critical for the information industry: software; microelectronics and optoelectronics; high-performance computing and networking; high-definition imaging and displays; sensors and signal processing; data storage and peripherals; and computer simulation and modeling; as well as the relevant manufacturing technologies: flexible computer-integrated manufacturing, intelligent processing equipment, micro- and nanofabrication, and system management technologies. The complexity of these technologies demands both substantial financial resources for development and for manufacturing facilities and a work force skilled in the requisite scientific and engineering disciplines if the industry is to remain competitive.[101]

U.S. manufacturers in the industry are competing with highly integrated, well-financed Japanese companies. The U.S. manufacturers, typically not integrated, are thus the antithesis of their Japanese counterparts. Furthermore, cooperation between industry and government is substantially less in the U.S. than in Japan. The factors that contribute to the effectiveness of the undertakings of a Japanese consortium (identified in **Chapter Two**) are:

- The choice of the technological objectives driven by industry in cooperation with MITI, but with MITI exerting strong influence through "vision" positions as a planning mechanism

- A comprehensive package of incentives for industrial participants, including tax write-offs, protection from imports, a favorable antitrust climate, funding, assured domestic markets, and support from MITI and government laboratories

- Strong leadership by MITI, featuring close cooperation of government, industry, and banking in the conceptual and operating phases

- Flexible funding, featuring cost-sharing between MITI and member companies, at a level of risk acceptable to industry participants
- Account taken of member companies' highly competitive orientation by appropriate mix of "secretariat" and "operating entity" consortium organizational structures
- Commercial application of research results the responsibility of industrial participants
- Staffing of consortia primarily by industrial participants as a key to effective technology transfer
- Willingness to "cut losses" for failing projects and, if appropriate, to redefine a new project with modified goals
- Primary dependence on large companies as participants capable of supporting large-scale, complementary, internal programs
- Establishment of research environments that encourage broader technological and application "vision" for member companies
- Policies to stimulate diffusion of research results to the industry at large

In principle, where applicable, consortia hold out the possibility of more effective leveraging by the U.S. industry of human and financial resources to counter the systemic advantages of Japanese companies, rather than each U.S. company having to go it alone. This study of the evolution of three operational consortia—MCC, the SRC, and SEMATECH—toward this goal suggests criteria for success for such undertakings summarized here.

6.7.1 Criteria for Success

Clarity and scope of mission. The more explicit a consortium's goals are, the easier it is to focus resources and programs to meet those goals and to measure success. Of the consortia evaluated here, only the SRC and SEMATECH have explicit, quantifiable goals in specific time horizons.

The scope of a consortium's mission can range broadly from network standards at one extreme to generic precompetitive information technology research at the other. Although diversity in scope may be endemic to a consortium's mission, it can also greatly complicate both the sponsors' understanding of potential benefits from and therefore their commitment to the effort. In this author's opinion, MCC's slow progress can be largely attributed to the diversity of its programs which, to date, lack a unifying theme, a weakness its strategy for the 1990s attempts to rectify.

Agreement on the specifics of a consortium's mission and the strategy to fulfill it is achieved by negotiation among members, many of whom are competitors, each with a particular agenda. As MITI has demonstrated, in negotiation government guidance as an interested party can facilitate a successful outcome. This author believes that the lack of government participation in this process is a handicap for MCC; in contrast, SEMATECH has clearly benefited from DARPA's presence.

Composition of shareholder population. Although the composition of a consortium's shareholder population would seem intuitively and obviously to be directly related to its mission, its potential benefits to an individual shareholder will vary depending on the need, dictated to a considerable extent by the shareholder's markets and size. For MCC, which has primarily a commercial orientation, the benefits to its computer manufacturing members are probably greater than to its defense electronics members. For SEMATECH, its larger members' concerns for the decline of certain capabilities of the SM&E sector resulted in 1990 in a change in priorities at the expense of process research, a change opposed by some smaller shareholders with needs in the process area.

A member population featuring common needs combined with different options for sponsor participation will establish, at a minimum, a reasonable environment for cooperative definition and implementation of appropriate programs.

Shareholder commitment of resources. Founding shareholders should realistically match the sources of funding and staffing and a consortium's life span to its mission. The funding philosophy should determine whether federal participation is necessary and feasible and should adopt an appropriate funding mechanism for the classes of sponsor of interest.

MCC and SEMATECH are examples of different approaches dictated by perceived missions. MCC was initially exclusively industry sponsored, but by 1991 government contracts and grants accounted for about 15 to 20 percent of revenues. Its fee structure initially consisted of a fee to join and a guaranteed minimum annual fee tied to program participation. This structure was primarily attractive to large companies. Associate membership, changed in 1988, featured the option of participant sponsorship at the project level (in contrast to full program sponsorship) to attract smaller companies and others not interested in full participation.

SEMATECH's large capital requirements and its relationship to both commercial and DOD needs led to joint sponsorship by industry and the DOD. Its fee structure for commercial members is based on an annual fee which is a percentage of the previous year's sales for semiconductor manufacturing members and a percentage of the value of semiconductors used by its system product manufacturing members, up to a fixed cap. SEMATECH's members generally have annual sales greater than $1 billion.

Perhaps even more important than the funding approach is the willingness of shareholders to assign staff of appropriate quality and numbers to the venture and to support complementary in-house programs of a commercially appropriate scale. The extent of cooperative activity between a consortium and a shareholder is of overriding importance to the benefits accruing to each member's in-house programs. The resources demanded by these considerations imply that mainly large companies will be able to fulfill the requirements.

Match of organizational structure to mission. A consortium may be organized as a secretariat (no central laboratory facilities, but manages programs performed at members' or other sites), an operating entity (own staff and facilities), or a combination of the two. Extensive cooperation through "partnering" is important for a consortium whose mission includes improvement of the industry's infrastructure and business practices; organization as a secretariat or hybrid secretariat-operating entity is appropriate for this orientation.

MCC and SEMATECH began as operating entities, but in order to fulfill their missions both are evolving into hybrids. This change resulted from stakeholders' appreciation that cooperative relations between member and nonmember companies, universities, national laboratories, and federal agencies are essential to the success of each consortium's respective missions.

Interaction with the federal government. If technologies nurtured by consortia are to impact the industry's competitiveness positively, the business environment necessary to facilitate investment by industry to exploit these technologies must be improved. Increasingly, consortia members are attempting to support effective representation to Congress and the administration to bring about appropriate changes in tax policy, antitrust laws, tariffs, and federal cooperation with the industry in research policymaking and implementation. To date (1992), consortia activity in this area has varied from MCC's relatively passive approach to SEMATECH's activist orientation, resulting from federal participation as a founder.

Stimulate diffusion of technology to the industry at large. Both MCC and SEMATECH have had some modest success here, for example, through "partnering," licensing, and company spin-offs. Progress in this area will probably continue to be made. This author believes that mechanisms to speed it up should be aggressively pursued.

6.8 Parting Thoughts

During the 1990s, the semiconductor and computer industries will face mounting challenges as technological and structural changes continue apace. U.S. stakeholders, recognizing the need for greater cooperation within each industry and between industry, academia and the federal government, are changing these industries' infrastructures and practices to meet escalating cost and risks. In this author's view, in the 1980s precompetitive research and development consortia proved one important means for dealing with the challenges to these industries.

Consortia in Japan and the U.S.[****] are serving as catalysts for change by seeding various cooperative undertakings between their shareholders and between their shareholders and other interested parties. Some notable successes have occurred in short- to medium-term programs (six years or less)—e.g., the VLSI program in Japan and the SEMATECH Phase I program in the U.S.—and in long-term programs (seven years or more)—e.g., the Very High Speed Computing Program (supercomputers) in Japan and the SRC's Educational Alliance (SRCEA) program in the U.S.

[****] No European Community projects were examined for this study.

As the Japanese semiconductor and computer industries, to a significant extent, have reached technological parity with their counterparts in the U.S., MITI's emphasis has shifted to long-term applied and basic research programs for major consortium undertakings. Shorter term applied research cooperatives involving a few participants (frequently a mix of Japanese and international companies) are now initiated by industry. In contrast, the U.S. semiconductor industry has, of necessity (in the perspective of the interested parties), stressed short- to medium-term consortia programs (SEMATECH's Phases I and II) to stem its loss of marketshare as well as long-term educational programs (the SRCEA) to address technical work force needs. For the information industry, MCC's original long-term horizon for programs (six to ten years) has been substantially changed to short- and medium-term (three to five years) emphasis as shareholders have emphasized their own shorter term needs and as the original programs have been either redirected or matured sufficiently for participating companies to focus on application of a technology to commercial products or processes. Further, industry initiatives in applied research cooperation, domestic and international, appear to be building momentum in both the semiconductor and the information industries. In this author's opinion, the U.S. precompetitive R&D consortia studied have made some notably successful contributions to industry efforts to address both short- and long-term problems more effectively. A role for consortia in the changing industry infrastructure appears assured, although relationships will continue to evolve.

Aside from the specific successes or failures of consortia programs, the most important contribution that consortia in the U.S. may have made (as of 1992) is to stimulate cooperative practices within the industry and among industry, academia, and government. The learning experiences of the 1980s have led to the recognition that diffusion of cooperative practices can best be stimulated by consortia organized either as a secretariat or as a hybrid secretariat-operating entity in order to realize optimum participation by stakeholders and significant leveraging of a consortium's resources.

In the last two decades the Japanese have demonstrated outstanding skill in defining technology objectives appropriate to becoming a force in high-technology industries, in adjusting objectives to meet changing needs, and in using consortia as one very important mechanism to achieve their objectives. Some of the Japanese experience is useful to U.S.

planners, but the needs and environment of the U.S. industry present unique challenges to the successful application of this mechanism.

This author believes that the U.S. is making headway in meeting the challenges ... not to the extent needed ... but nonetheless headway.

Appendices

1.1 Public Policy and Classes of Intellectual Property

From William G. Ouchi, "The New Joint R&D," *Proc. IEEE*, **77** (September 1989), 9, 1319-1320:

> The classes of property are important in making public policy, because each class will thrive under a quite different set of public policies. Private property is that which the inventor can practically appropriate and limit to uses and users of his or her own choosing.
>
> Thus a competitive marketplace that permits inventors to sell their invented intellectual property at a price of their choosing and in which free riding can be controlled will offer strong incentives to invest in invention. No investment of public funds is necessary in such cases, and in fact public subsidies in such cases can be expected to lead to over invention by inefficient companies and to a waste of the nation's resources.
>
> Public property, in pure form, is that intellectual property which is not appropriable by the inventor. In this case, free riding is not controllable, and thus no inventor can be expected to invest in invention.... In such cases, it is desirable for consumers, through tax dollars, to jointly subsidize research. The result will be that ... consumers will benefit.
>
> Leaky intellectual property is that which is weakly appropriable by the inventor. The inventor of a new process technology may gain an advantage for two years or so but he has no feasible way to prevent that knowledge from leaking to competitors, who will soon adopt the innovations and thus compete away any advantage. On the one hand, it is exactly this kind of competitive pressure which brings about continued progress; and thus as consumers we applaud it. On the other hand, logic dictates that a firm will be reluctant to invest in developing those technologies that it knows will leak out, and thus we can expect that progress in such technologies will be slow. As consumers we seek a better way to stimulate innovation in leaky technologies. Leaky technology cannot be efficiently stimulated through the same policies appropriate to public intellectual property, however.
>
> If public monies were available to underwrite all of the costs of developing leaky technology then each inventor would have an incentive to take as much public funding as he could get because even a weakly appropriable private return would be very attractive under these conditions. Thus leaky property will be inefficiently overproduced if it is undertaken by government laboratories or other 100% publicly funded means, and it will be inefficiently underproduced if it depends solely on private investment.

2.1 Ojimi on the Evolution of Japanese Industrial Policy

From Martin Fransman, *The Market and Beyond: Cooperation and Competition in Information Technology Development in the Japanese System* (Cambridge [Eng.] and New York: Cambridge University Press, 1990), 24-25:

> There was a great outgrowth of industries that depended on low wage labor during the pre-war period and the post-war period of transition when Japan was plagued by shortages of capital. At the same time, these industries enjoyed an advantage from the viewpoint of the theory of comparative advantage.... Should Japan have entrusted its future to the development of those industries characterized by the intensive use of labor?... If Japan had adopted the simple doctrine of free trade and chosen to specialize in this kind of industry, it would have sentenced its population to the Asian pattern of stagnation and poverty. The Ministry of International Trade and Industry decided instead to promote heavy industries that require intensive employment of capital and technology, industries such as steel, oil refining, petrochemicals, automobiles, aircraft, all sorts of industrial machinery, *and electronics, including electronic computers.* In terms of the comparative cost of production, these industries should be the most inappropriate for Japan. From a short-run, static viewpoint, promoting their development would seem to conflict with economic rationalism, but from a long-range viewpoint, these are precisely the industries where the income elasticity of demand is high, technological progress is rapid, and labor productivity rises fast.

2.2 Chronology of the Japanese Economic Evolution and Developments in the U.S. Computer Industry

Japanese Post-war Reconstruction Period—Through the Mid-1950s, U.S. Computer Industry Miniprofile

1955 **Products:**

First commercial electronic (vacuum tube) digital computers

Dominant Companies:

IBM, Univac

Japanese Super-Fast GNP Period—Mid-1950s to 1973, U.S. Computer Industry Miniprofile

1955–65 **Products:**

Mainframes: IBM 360 Series (introduced 1965)
Minicomputers: DEC PDP 8 (1964)
Supercomputers: CDC 6600 (1964)
Integrated circuits (1964)
System software: IBM–OS concept (OS 360)

Dominant Companies:	Significant Companies:
Mainframes: IBM, Univac	Burroughs, NCR, Honeywell, GE, RCA
Minicomputers: DEC	H–P, Varian, Honeywell, IBM
Supercomputers: CDC	IBM
Integrated circuits: TI, Motorola	Many firms, including IBM

1965–73 **Products:**

Mainframes: IBM 370
Minicomputers: DEC PDP 11
Supercomputers: CDC 7600 (Cray 1 in development; introduced 1976)
Microprocessor chips: Intel 8080, Motorola 6800
System software: IBM OS 370, Burroughs MCP

Dominant Companies:	Significant Companies:
Mainframes: IBM	BUNCH group, Amdahl
Minicomputers: DEC	H–P, Data General, Honeywell, Varian, IBM
Supercomputers: CDC	
Microprocessor chips: Intel	Motorola, TI, National Semiconductor, Fairchild

continued ➤

Japanese Above Average GNP Growth—1973 to the Present, U.S. Computer Industry Miniprofile

1973–85

Products:

Mainframes: IBM 3000 series
Minicomputers: DEC VAX series
Supercomputers: Cray XMP series
Personal computers: IBM PC series, Apple
Microprocessor chips: Intel 386, Motorola 68000
System software (OS-based): IBM and UNIX

Dominant Companies:	Significant Companies:
Mainframes: IBM	Unysis, Honeywell
Minicomputers: DEC	H–P, IBM
Supercomputers: Cray	CDC
Personal computers: IBM, Apple	Compaq
Microprocessor chips: Intel, Motorola	AMD
System software: IBM, AT&T	Many specialized software firms for databases, spreadsheets, networks, wordprocessing, etc.

1985 to Present

Products:

IBM 3000 Series
Minicomputers: DEC VAX series
Supercomputers: Cray YMP series
Parallel processors: Convex C series, Thinking Machines' Connection Machine
Personal computers: IBM PC series and clones, Apple
Workstations: Sun Microsystems series
Microprocessor chips: Intel 486 series, Motorola 86000 series
System software (OS-based): IBM and UNIX
Network products: IBM SNA, DEC DECNET, AT&T ISDN, and LANnets

Dominant Companies:	Significant Companies:
Mainframes: IBM	Unysis, Bull, Amdahl, Hitachi
Minicomputers: DEC	H–P, IBM, Bull
Supercomputers: Cray	
Parallel processors: Convex	Alliant, Sequent, Intel, Thinking Machines
Personal computers: IBM, Apple, COMPAQ	AST, NEC
Workstations: SUN, H–P, IBM, DEC	Data General, AT&T
Microprocessor chips: Intel, Motorola	AMD
System software: IBM, AT&T, Microsoft	Lotus, Oracle, Ashton Tate
Network products: IBM, AT&T, DEC	NCR, Novell, Sun, H–P

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2.3 Fransman's View of Japanese Technology-Creating System

In *The Market and Beyond: Cooperation and Competition in Information Technology Development in the Japanese System* (Cambridge [Eng.] and New York: Cambridge University Press, 1990), Martin Fransman makes the following points concerning the barriers to cooperation between industry and the government:

- In all cases an important degree of uncertainty surrounded the commercial viability of the technologies chosen, with the result that the firms probably would have allocated significantly less resources to research in these areas in the absence of the MITI-initiated projects.... Taken as a whole, the technologies chosen for development in these projects represent many of the 'core' technologies that may, on the basis of present knowledge, be important in the computer and electronics devices industry until the end of the century.... In most of the projects, it was MITI/ETL officials who initiated the proposals for research, rather than representatives from the ... companies.... It may therefore be concluded that MITI officials in this period played an important role in reducing the effects of uncertainty by identifying and subsidizing areas for longer term oriented-basic research (275).

- A puzzle is presented by the coexistence of potentially important economies of research cooperation and the relative absence of spontaneous research cooperation [directly between competing companies].... The main reason for the lack of spontaneous research cooperation is the transaction costs involved in setting up inter-firm cooperative research.... However, an important conclusion ... is that government or a large procurer is able to economize on transaction costs thus reducing the cost of research cooperation and ensuring that a greater amount of research cooperation takes place, which in turn facilitates the realization of economies of research cooperation (280-281).

- Another of the important conclusions ... is that JRJF (Joint Research in Joint Facilities), involving the highest degree of research cooperation, with the joint creation and sharing of knowledge, has been extremely limited in the Japanese computer and electronic devices industry.... [T]he Japanese government has played an important role in facilitating research cooperation between competing Japanese corporations. While this cooperation has taken the form primarily of coordinated in-house research [the dominant mode of cooperation], in some cases joint research in joint research facilities has also been established (282-283).

- [G]overnment intervention results in a significantly wider diffusion of knowledge than would have occurred in the absence of such intervention. The major way in which a wider diffusion of knowledge was brought about was through the inclusion of relatively weaker firms in the ... project ... there was initial opposition from the stronger firms to the inclusion ... of the weaker firms ... as a result of government insistence, motivated by a desire to strengthen the national system as a whole, on the one hand, and generous government financial subsidies which tended to compensate the stronger firms for low-cost riding, on the other, agreement was reached (283).

- [T]he different kinds of organization which have made up the Japanese System, namely for-profit corporations, government technology planning bodies, government research institutions and universities, differ systematically in terms of their technological "vision," that is, in their ability to perceive particular areas of science and technology as being important to their purposes, and to acquire and develop the knowledge in these areas.... It is significant that particular institutional practices, aimed at instilling a broad ... vision, have become routine in MITI ... (284-285).

4.1 MCC Members

Shareholders	
Advanced Micro Devices	Honeywell
Andersen Consulting	Hughes Aircraft Company
Bellcore	Lockheed Corporation
Boeing Company	Martin Marietta Corporation
Cadence Design Systems	3M
Control Data Corporation	Motorola
Digital Equipment Corporation	National Semiconductor Corporation
Eastman Kodak Company	NCR Corporation
General Electric Company	Northern Telecom
Harris Corporation	Rockwell International Corporation
Hewlett–Packard Company	Westinghouse Electric Corporation

Associates	
Advanced Packaging Systems*	National Security Agency
Allied–Signal, Inc.	Northrop Corporation
Amoco Production Co.*	Occidental Chemical Corporation*
Apple Computer, Inc.*	OIS Optical Imaging Systems*
AT&T*	Olin Corporation*
Cherry Display Systems*	Photonics Imaging, Inc.*
Conner Peripherals, Inc.*	Planar Systems*
Dover Corp.*	Plasmaco, Inc.*
DSC Communications Corp.	Projectavision*
E.I. duPont deNemours	PROMEX
E.I.T. Corporation*	Rogers Corporation*
Electro–Plasma, Inc.*	SAIC
ERIM	SEMATECH*
E–Systems, Inc.*	Software Engineering Institute
FBI	Standish Industries*
Fairchild Space and Defense Corp.	Sun Microsystems, Inc.*
ITASCA Systems, Inc.	Tandem Computers, Inc.*
Lawrence Livermore Labs	Tektronix, Inc.*
LTV Missilcs & Electronics	Teradyne, Inc.
Magnascreen*	Texas Instruments*
Microsoft Corporation*	TRW, Inc.*
The Mitre Corporation*	United Technologies Corp.
Multichip Technology, Inc.	Valid Logic*
NASA JSC*	Western Technologies Automation

*Research participant

Source: MCC Overview and Research Project Summaries (Version 3.0, November 1991).

4.2 Three HPC-Related Projects

Much of what follows is based on interviews with R.J. Smith II, Director, Experimental Systems, ES-Kit; G.R. Willenbring, Program Manager, Optics in Computing, Bobcat II; T. Magnusen, Manager, Neural Networks, Advanced Computing Technology.

Experimental Systems Project (ES-KIT)

This project, funded initially by a three-year contract with DARPA that ran through late 1990, is the first and largest contract with a branch of the federal government. It has served as an excellent vehicle for access to DARPA-related industry and university organizations. Although DARPA will continue to be the largest funding source, two industrial firms (NCR and Motorola) now are sponsors.

Project Rationale and Objectives. The profitable application of both parallel and distributed computing concepts has been substantially delayed by the cost and time required to prototype appropriate hardware and software. Initially funded by DARPA, the Experimental Systems Project (ESP) was established at MCC in 1988 to provide technologies for rapid prototyping of parallel and distributed application systems. The project has five interdependent objectives that will ultimately allow development and execution of scalable parallel applications in a manner that makes them functionally insensitive to the hardware and operating system. These objectives are:

> (*i*) To develop basic hardware and run-time software building blocks—the ES-Kit. ES-Kit users at MCC, university, commercial, and government research facilities are conducting experiments to determine the impact of various architectural models on application specific performance. The object-oriented software allows development of application programs automatically scalable to the hardware environment in which they are executed.
>
> (*ii*) To extend the basic ES-Kit software modules to exploit combinations of high-end commercial systems and application accelerators. This capability allows compute-intensive applications to utilize a broad range of existing parallel and networked platforms in developing and testing object-oriented algorithms in a hardware-independent manner.
>
> (*iii*) To extend the software environment to allow the use of a commodity multiprocessor PC platform as a dedicated application accelerator.

(*iv*) To enhance the software environment to allow the dedicated application accelerator to become a shared application server within a network. This software will enable applications to make use of a heterogeneous network of peer processors in a totally transparent manner.

(*v*) Commercial exploitation by project sponsors and through licensing. One license has been granted to a vendor that is not an MCC sponsor, other licensing opportunities are being explored. (MCC Technology Catalog, Version 1.4, June 1990, 24-26)

Technical Achievements. In the main, these five objectives were met by the completion of the initial DARPA contract (1990). The ES-Kit technology is in use by a number of DARPA's federal and university projects and at projects in a number of DOD, DOE, and NASA laboratories. Five non-royalty-bearing and two royalty-bearing licenses have been granted. Two patent applications have been made—one, already granted, for an electrical connector, the other for an aspect of object-oriented software technology. Publications have been extensive.

Commercialization prospects for the ES-Kit technology are uncertain. A small start-up company is currently licensed and is incorporating the technology into its products for Apple Computer's Macintosh market. In 1990 NCR and Motorola evaluated the technology; by 1992 Motorola announced products that incorporated it.

The most significant product of the ES-Kit project is the software technology delivered to DARPA and industrial sponsors.

Technology Transfer Effectiveness. Extensive documentation of the technology has been disseminated to sponsors; six copies of the ES-Kit hardware system have been supplied to collaborating organizations. Semiannual technology transfer seminars are held for sponsors, with participants including DARPA and other federal government agencies as well as industrial companies and universities. These seminars are perceived as quite productive, often leading to new opportunities for collaboration.

Technology transfer to the government and universities is perceived as going well. Owing to governmental budgetary uncertainties, timely deployment of the technology is a problem where federal funding is involved.

Technology transfer to industry is a major challenge facing this program, which at this time (1992) has only a few industrial sponsors. Although the technology represents a potentially important capability to harness the latent computing power in distributed systems more effectively than is the current norm, historically, the market for new system software technologies has been slow to develop. MCC appears to have successfully demonstrated the feasibility of the technology with the support of DARPA; now it must find industrial sponsors for its commercial application.

Industry Impact. Minor to date.

Balance between Short- and Long-Term Goals. The ES-Kit program has a very strong focus on applications and consequently is oriented toward the relative short term. Research is focused on a twelve to eighteen month time frame; the long term is perceived as three to five years. Contracts negotiated in 1990 were for programs with a duration of two and one-half to four years.

Quality and Dynamics of Staff. The original staff (transferred from the Advanced Computing Technology [ACT] parallel processing research) of five researchers and three graduate students has grown over a four year period to twenty-four full-time personnel support staff, all of whom have come solely from industry. There are two Ph.D.'s and seven graduate student interns. Consultants and collaborators include Professor Seitz of the California Institute of Technology and Justin Rattner of Intel Research. All graduate student interns come from the University of Texas (Austin). The staff is considered strong at the levels of intermediate level researchers and student intern group but thin at the level of senior researchers. Staff turnover appears to be at the industry's norm.

Scale and Stability of Industry's Participation. The ES-Kit project was proposed to DARPA in June 1987 at an $11 million funding level. Initially DARPA was the sole sponsor, beginning in 1988 at the funding level of $6.3 million for a three-year period. The management of MCC viewed the project as exploratory, because it was the first federally funded program. Since the inception of this project, three shareholders have become project sponsors: NCR, Motorola, and Eastman Kodak. The technology has been licensed to one vendor—a small company specializing in scientific and engineering applications for Apple Computer's Macintosh personal computer.

MCC's goal for 1991–92 was to increase sponsorship by industry to account for 40 to 45 percent of the budget (up from 15 percent in 1990).

Sizes and Trends of Budget. As stated, the DARPA contract committed $6.3 million for three years beginning in 1988. The budget history is as follows:

1987	$0.33 Million	Pre-DARPA
1988	$2.0 Million	~98 percent DARPA
1989	$2.0 Million	~98 percent DARPA
1990	$3.39 Million	~85 percent DARPA
1991	$3.6 Million	~70-75 percent DARPA

In 1990,an MCC subsidy of $300,000 was "off budget" for special projects.

Input to Federal Government Policymaking. Contribution is informally through DARPA.

Photorefractive Holographic Storage (Bobcat II)

The speed of access to the files of a computing system is a performance bottleneck that has come to be accepted by system designers virtually as a given. Two factors essentially lead to a performance mismatch between file accessing and data processing: the complexity of data base accessing software and the limitations of the electro-mechanical disk drives that store files. The first limitation can be mitigated by the use of high-performance processors and algorithms for accessing functions; the second is more intractable.

Redfield and Hartmann undertook a study under the Advanced Computing Technology (ACT) Program to identify technologies that might significantly improve the performance of database accessing systems within a five- to ten-year period. Ultimately, they decided to focus on the hardware bottleneck as a means for MCC to take a leadership role in research for addressing this limitation.

Their investigations led them to become interested in holographic storage, a technology abandoned in the 1970s by other research groups because of the inadequacies of storage media and electro-optical component technologies then available.

A seed project under the ACT Program led to progress in identifying a material with good prospects to serve as a storage media. Important end products of this work were two patent applications: one for a non-destructive readout technique, particularly as applied to strontium barium niobate (SBN) crystals, the other for an array of SBN crystallites for physically implementing storage.

After five years, this work culminated in early 1989 in sufficient shareholder support to launch the Bobcat II project.

If the technology of nonvolatile, erasable holographic storage crystals is mastered, a technological "breakthrough" will have been achieved that not only will yield much higher performance systems than at present but also has the potential both for simpler, less costly system architectures and for multimedia storage.

Rationale and Objectives for Project. The goals of this project, which is part of the Optics in Computing Program of the Computer Physics Laboratory, are:

> to develop a demonstration and test assembly of a read/write holographic data storage subsystem, delivering both access speeds three orders of magnitude faster and transfer bandwidth several orders of magnitude greater than magnetic disk. This medium will be non-volatile, with per-bit costs between that of magnetic disk and DRAM and with storage density approaching that of optical disk. It also has the potential for unequaled reliability and durability since it has no moving parts and has relative insensitivity to vibration or harsh environment. (MCC Technology Catalog, Version 1.4, June 1990, 43)

Technical Achievements. To date, research results of the two-year-old project are encouraging. Progress has been such that a laboratory system for feasibility demonstration and performance characterization of the technology is under development and is planned to be operational in 1991–92. MCC researchers believe that the state of the art of the relevant technologies has progressed sufficiently to warrant optimism that problems with the volatility of the storage media and inadequacies of the electro-optic component technologies which have frustrated previous attempts to apply this technology can be overcome. MCC researchers and co-researchers colleagues at other sites have applied a storage material (SBN) and a proprietary read/write technique that they believe have good prospects to overcome the storage media problem. They have also developed techniques for producing tiny crystallites and for using assemblies of such crystallites as the storage structure, which potentially can not only mitigate problems with storage media manufacturing but also simplify deflection system requirements.

Research is in process in three areas: (*i*) Materials development and characterization; (*ii*) Beam addressing techniques; and (*iii*) Demonstration and test system development. In part because of the variety of complex technologies involved and the difficulty of assembling an in-house staff with expertise in all areas, MCC has undertaken a "syndication" approach for staffing. Thus, research is carried out in the laboratories of some sponsors as well as at MCC and in the laboratories of university colleagues. Materials development and a significant part of materials characterization are performed in the facilities of co-researchers. System development is performed at MCC for the test and demonstration vehicle to evaluate materials characterization, beam deflection approaches, and optical designs. MCC is also responsible for system design approaches related to different classes of product applications. To date, sponsors have benefited, to different degrees, depending on their in-house capabilities and business interests, from access to the project's research findings for SBN characterization, volume holography techniques, planar processing techniques, and optical and beam scanning design. As a result, MCC believes that certain sponsors are developing new, and other sponsors enhanced, in-house capabilities. Concurrent with research activities, studies dealing with business planning for commercialization of the technology are being performed to expedite technology transfer in a timely way.

Technology Transfer Effectiveness. The Bobcat II project pioneered the "syndication" approach at MCC which introduced incorporation of co-researchers both to gain access to needed expertise for the project and to integrate technology transfer into everyday project activities. (This technique has been widely used by European consortia in this field.)

To date, this mode of operation has worked well. Each sponsor is represented by a co-researcher and a management liaison contact. The project does not have a PTAB as such. The functions usually allocated to the project's board are largely subsumed by its management team. While the project is in its current phase—evaluating technology feasibility, characterizing design parameters, and business planning—the products of its research are generic. At this stage, sponsor consensus on technology transfer issues is not a problem. Management of the technology transfer process is expected to become more challenging if current programs succeed and research then becomes focused on support of commercialization of the technology. This tendency may be exacerbated by the large market opportunities a successful project could make available to its sponsors or licensees.

Impact on the Industry. The Bobcat II project is a good example of "networking" through a syndicate of a consortium, industrial companies, and universities. Research to develop SBN material with appropriate characteristics is performed at Stanford University: the university and an industrial company supply the material; parallel projects are in progress in the laboratories of some of the six industrial sponsors; cooperative programs exist at the University of Colorado and the University of Rochester. The project has also stimulated cooperation between its suppliers in the "food chain." Although not particularly significant now, if this technology is eventually applied to products, supplier experience with MCC may help facilitate its commercialization. Further, looking to the future, experience with syndication may be useful as a precursor to a vertically integrated commercial syndicate for product development and manufacture or some other derivative form of cooperative approach.

Balance between Short- and Long-Term Programs. The primary focus of the current research program is to demonstrate feasibility and, assuming success, to plan for commercialization. This phase is scheduled to run for about two years more. If successful, the next phase will focus on helping sponsors and licensees to commercialize the technology.

Quality and Dynamics of Staff. The syndication approach together with the potential impact of the technology have made it relatively easy to attract top-flight co-researchers. Consequently, the Bobcat II project involves a number of respected scientists and engineers at universities and in the industry, including Professor Hesselrink of Stanford. In 1990, the MCC staff consisted of four researchers as well as support staff; by 1992, the staff is larger, although no definite number is available. Co-researchers and management liaisons from sponsoring companies visit as needed, the former typically for one or two weeks at a time.

Staffing has been stable and of excellent quality; its size has been constrained by project funding.

Scale and Stability of Industry Participation. The original goal was to have five to ten sponsors. By 1990, there were six, four shareholders and two associates; although that number has held steady, a few companies dropped out owing to changes in their business environment only to be replaced by others. Sponsors include a preponderance of computer, communications, and military product manufacturers. Some defense companies have withdrawn because of business conditions. New sponsors pay a larger fee than founding sponsors to participate in the program and for technology rights.

A significant development in 1991 was the award to the program covering a five-year period of one of the first National Institute of Standards' Advanced Technology Program grants. (MCC "Syndicate" to Help Remove Barriers to Commercialization of Holostore Device, MCC Collaborations, Austin, Texas, September 1991, vol. 1, no. 3, 14)

Size and Trends of Budget. Although funding information was not available from MCC for this study, given the size of the staff and budget implications of syndication, an annual budget in the range $3 to $4 million seems likely. By 1991, MCC did not subsidize any part of the Bobcat II project.

Input to Federal Government Policymaking. Through 1991, involvement in this area was minor, consisting of informal contacts with representatives of organizations such as the Congressional Office of Technology Assessment, NSF, and DARPA. The National Institute of Standards' grant in 1991 may result in closer collaboration with federal policymakers.

Neural Networks

The Neural Network Program was begun after research by Dr. Carsten Peterson, supported by the Exploratory Initiatives Program, produced a new algorithm based on Mean Field Theory (MFT). This work, performed over a two-year period, resulted in a deterministic form of the Boltzman learning algorithm. The significance of the MFT algorithm is that it is relatively straightforward to implement in a VLSI chip, which, in turn, makes feasible implementation of the very high speed learning processes required to apply neural network technology to many applications.

Independent of this development, the PTABs involved with various AI activities had decided to consolidate neural network research, and the MFT development served as a catalyst for establishing the Neural Network group. In September 1988, Dr. James Keeler joined MCC as the MFT project director. Presentations to shareholders demonstrated the significance of MFT for neural network technology applications and led to sufficient shareholder commitment to the Neural Network Program for it to be undertaken.

Rationale and Objectives for Project. Research in this technology probably has the longest time horizon of the three projects. In the long term, neural networks could fundamentally change the way computing is performed for applications such as generalized vision, speech recognition, and sensory-motor control. Short-term applications which are yielding, or are expected shortly, to yield, commercial benefits to sponsors include process-control optimization and optical and handwritten character-recognition products.

Exploratory initiatives for this technology include:

- **Prediction and Process Control**: To investigate neural network algorithms for learning and then predicting the behavior of nonlinear systems (chemical processing plants, VLSI wafer fabrication facilities, economic data, weather data, etc.) and combine this predictive network in a hierarchical structure to control the system to achieve desired performance (quality, yield, etc.).

- **Integrated Algorithms for Character and Image Segmentation and Recognition**: To investigate hybrid neural network algorithms for image segmentation and recognition, with the goal of building a generic integrated architecture that uses neural networks for doing recognition and segmentation at the same time.

- **Speech Recognition**: To launch an exploratory speech recognition investigation that leverages the character-recognition and segmentation work previously performed at MCC.

- **Core Research**: To focus on the integration of various neural network subsystems into a single, coordinated functioning system (i.e., integration of visual processing with motor control) and continue theoretical investigations into Mean Field Theory Algorithms, Information Theoretic

Adaptive Algorithms, and Cerebellar Neural Networks. (MCC Technology Catalog, Version 1.4, June 1990, 20)

Technical Achievements. MCC's orientation toward research on neural networks features a unique blend of theoretical and application capabilities. Current research is conducted primarily through computer simulations. Two shareholders are developing specialized IC chips, based on the MFT learning algorithm developed at MCC, which are expected to improve operating speeds for this class of algorithm by a factor of 1,000 to 1,000,000; chips with this performance level are important for implementing neural network solutions for character-recognition applications.

MCC serves as a consulting resource to the chip developers, as well as to shareholders for other applications for algorithms and architectures it has developed. An important aspect of its involvement is that its researchers benefit from real-world testing of their research products—resulting in a useful feedback process.

Current shareholder application of MCC technology is for pattern recognition for handwritten characters and improved OCR products. MCC is recognized internationally as among the research leaders in pattern recognition for handwritten characters. One sponsor is expected to market soon an OCR product, based on MCC technology, of superior performance compared with the present state of the art.

In the realm of process control, the Texas-Eastman subsidiary of Kodak has applied MCC-developed techniques to optimize yield from a chemical production plant with significant cost savings, and Texas-Eastman is exploring other process control applications.

The Gaussian Bar algorithm promises to become important for complex, nonlinear prediction applications. Implementation in products and processes are anticipated within one to two years.

Patents pending or about to be filed include those for the MFT algorithm, a related content addressable memory, an Integrated Segmentation and Recognition (ISR) algorithm, and a new Gaussian Bar algorithm—a high-dimensional nonlinear regression technique; four or five patent applications are expected in 1991.

Technology Transfer Effectiveness. Besides ongoing core research, shareholder-specific projects mainly consist of application of MCC-developed algorithms to shareholder supplied data. Typically, the products of a project are a report and appropriate software to be incorporated either into the sponsor's product or process. This narrow focus greatly simplifies technology transfer, and, to date, the process has been relatively smooth. Other important factors for successful transfer are the existence of a shareholder staff "champion" and very careful definition of a shareholder's project goals before undertaking research. Visiting scientist assignees are important "champions"; their terms at MCC vary from weeks to one or two years. Company presentations are, on average, given twice a year. Other means of communications include videos and electronic mail.

Of the four shareholders supporting the neural network program, three (NCR, DEC, and Texas–Eastman) are manufacturers and the fourth (Bellcore) is a research organization. For Bellcore, e-mail has proved a very useful means for closely linking their research efforts with those of MCC.

Industry Impact. The impact, minor to date, is likely to build slowly through incremental improvements in both products and processes. Major breakthroughs, if they occur, are likely to evolve over the long term.

Even in its brief history, the neural network group has stimulated a few important industry undertakings. Some shareholders as well as non-shareholders are working together on joint development programs resulting from their interaction through MCC. For example, researchers in voice recognition at Bellcore, US West, MCC, Stanford University, SRI, and the University of Lund (Sweden) are cooperating through a loose "network," with MCC participating directly with its shareholders.

Balance between Short- and Long-Term Programs. For this program, short term is nine to fifteen months; long term is five to ten years. Eighty percent of research effort is in character-recognition and process-control technology (with a short-term bias); long-term programs with a potential for application breakthroughs are conducted in pattern recognition and in prediction and forecasting. Sponsors appear to be satisfied with the current balance.

Quality and Dynamics of Staff. Prior to 1989, three MCC groups were variously involved with neural network research. Reorganization in 1989 consolidated these programs under a single group and reduced the staff somewhat. In 1990, the human interface and the neural network activities were merged and the budget increased by about a factor of 2. The initial reorganization (1989) focused research in this subject, particularly to emphasize short-term results.

In 1991, this group consisted of 14 staff members including a manager, four direct hires, one sponsor assignee (to be increased to three), one temporary research associate, and seven graduate students.

Consultants include two prominent academics—Dr. Carsten Peterson of the University of Lund and Dr. David Rumelhart of Stanford University—who visit MCC every four to six months and regularly publish with MCC staff members. A program of invited speakers featuring leading practitioners is active.

Cooperation with the University of Texas is substantial: the seven graduate students on the Program's staff are from this university, where MCC sponsors a graduate assistance program. Strong links also exist with Stanford and the University of Lund.

The staff has been stable, adequate for its mission, and its performance appears excellent if measured by productivity and the continuity of sponsor support.

Scale and Stability of Industry Participation. Sponsors include the four shareholders and members of the associates program. Only one of the original sponsors has been lost, a loss due to a business downturn. A marketing program to add new sponsors has been underway since 1989. Because of the relatively high shareholder fee, prospect development is slow: as of 1991, no new shareholders had been added. Marketing, supported by the central MCC marketing group, takes about 25 percent of the program managers' time; relatively little involvement of researchers in this effort has been required.

Size and Trends of Budget. The current budget of about $2.3 million annually resulted from reorganization of 1989–90. In the near term, the budget is expected to be stable or to grow, depending on the number of sponsors added to the program. New modes, or changes in existing modes, of sponsorship are constantly being evaluated.

Current shareholders have made a two-year commitment at an annual funding level of $500,000; associate members pay an annual fee of $25,000, essentially for access to program publications and presentations that are not shareholder-specific and for licensing rights. MCC contributes $300,000 to the current budget for marketing efforts and transitions related to the 1989–90 reorganization.

The budget has grown significantly since the consolidation of neural network activities in 1989, from $900,000 then to its current level of $2.3 million. As noted previously, about 80 percent of the budget is allocated to short-term, highly sponsor-responsive research.

Input to Federal Government Policymaking. To date, inputs have been indirect and minor, consisting of participation in federally sponsored conferences (e.g., an NSF conference on Neural Networks related to Process Control) and meetings with individuals involved with technology assessment for federal programs.

5.1 Overview of Staffing Practices and Operating Style of the SRC

Excerpt from R.K. Cavin III, L.W. Sumney, R.M. Burger, "The Semiconductor Research Corporation: Cooperative Research," (*Proc. IEEE* 77, 9 [1989], 1330):

> One of the methods for minimizing overhead in the management of SRC research is the industry/government resident manager program. Residents are employees of SRC member companies or government agencies assigned to staff positions at corporate headquarters for periods of up to 2 years. The sponsoring company or government agency pays the salaries of residents while the SRC assumes the cost of their operational support. Resident staff represent the SRC's corporate interests and carry a full load of responsibilities, including management of one or more technical thrusts of the research program, coordination of SRC events, development of new programs, and leadership for research planning. During the term of the resident's assignment, the sponsoring company or government agency derives increased technology transfer advantages from the employee's direct involvement in SRC activities.
>
> The SRC's board of directors is chosen annually according to a formula that provides for sustaining membership of the largest fee-paying members and guarantees that ultimately all members of the SRC will serve on the board. The board ... establishes SRC policy, sets the annual budget, and develops long-range ... corporate goals.
>
> Member companies have the right to assign representatives to serve on any of the five committees of the SRC technical advisory board: the executive, design science, manufacturing science, microstructure science, and technology transfer committees. The SRC technical advisory board (TAB) is charged with advising the president of SRC on matters pertaining to the technical content and direction of the research program. The TAB has 140 members who participate in annual contract reviews, evaluate proposals, provide assessments to SRC on the state of integrated-circuit technology, and work with SRC corporate staff to prioritize research needs. TAB members also serve as important points of contact with their company for technology transfer.
>
> Mentors are member company or government agency employees who provide technical advice and assistance to university researchers but are not called on to critique the research. In some instances, mentors have arranged access to unique equipment or processing, provided industrial circuits for use in software evaluation, or even co-authored technical papers. Over 300 industry and government personnel are participating in the mentor program.
>
> Another mechanism that has been initiated by the SRC to foster interaction between universities and industry is the university researcher in residence program that allows industry personnel to be placed on campus full time to participate in SRC research. Assignments to this program have been infrequent because U.S. industry generally prefers to deal directly with academia in arranging the placement of personnel on campus, for reasons of visibility and relocation complexities.
>
> An ad hoc SRC university advisory committee advises the SRC on a broad range of topics relating to the research program. The committee has been serving as an important advisory body on matters pertaining to curriculum, SRC

contractual policies, the SRC fellowship program, electronic connectivity, and many other issues.

5.2 1989 GAO Overview of Staff Selection Practices

From Federal Research, The SEMATECH Consortium's Start-Up, GAO Report to Congressional Requesters (November 1989), 35-37:

> Attracting qualified assignees from the member companies is critical for achieving SEMATECH's objectives because the assignees have a primary role in developing advanced manufacturing technology and transferring it to member companies. Consequently, the consortium has developed policies and procedures for obtaining high-quality assignees, which include:
>
> - Seeking assignees who have 5 to 10 years of directly related experience, are among the top 10 to 15% in their field, are recognized within their field for the quality of their work, and are capable of adapting to a consortium environment.
> - Screening resumes and scheduling interviews for applicants before deciding where to place them within SEMATECH.
> - Not hiring an assignee as a permanent employee without the member companies concurrence because such action would likely make member companies reluctant to send high-quality professionals and also reduce the effectiveness of technology transfer to members.
>
> SEMATECH's Chief Administrative Officer told us that as long as the member companies perceive a position at SEMATECH as career enhancing, the consortium will continue to attract the quality of assignees needed for a successful program. He stated that the types of positions that assignees obtain upon returning to their companies will have a long range impact on how member companies' professionals perceive a tour at SEMATECH....
>
> SEMATECH's top management has established a goal of having assignees comprise 50 percent of its technical work force. As of September 30, 1989, 197 assignees were at SEMATECH, including 181 in engineering or management positions in the 7 operating divisions that report to the Chief Operating Officer. The 181 assignees represent 51 percent of the operating division positions ... positions in finance, law, communications, supplier relations, and human resources normally are filled by permanent employees....
>
> As of September 30, 1989, the number of assignees per member company ranged from 3 to 27 and generally reflected each member's assessed contributions to SEMATECH....
>
> According to SEMATECH's Employment Manager, member companies identify potential assignees in a variety of ways, including announcing SEMATECH openings in the same way openings within their own companies are announced, using screening panels, and/or relying on their SEMATECH assignees to assist in identifying potential assignees.... [W]e interviewed the senior resident assignees—upper level managers—at SEMATECH from four member companies that accounted for about 44 percent of the assignees as of June 30, 1989. One senior assignee told us that his company looked for individuals who have superior

performance ratings, are respected by their peers for their technical expertise, have sufficient time—generally 5 years—with the company to have developed good networking relationships within the company, and are flexible enough to work in a consortium environment. He stated that all of these qualities in assignees were essential for effective technology transfer. He also stated that it was important to start out with high-quality assignees because they will help attract other high-quality assignees. The senior assignee noted that his company screened seven applicants for every one sent to SEMATECH for interviews.... [T]he other three companies ... also had processes to screen assignee applicants. Generally, the qualities, skills and experience of assignees they looked for were similar to those described above.

... We randomly selected the names of 20 assignees and reviewed their personnel files to determine SEMATECH managers' overall evaluation of the applicant assignee.... [T]he interviewers ... rate the applicant as outstanding, acceptable, unacceptable, or not appropriate for the job requisition. Of the 20 assignees, 10 had at least 1 outstanding evaluation, 6 had no outstanding evaluations but received at least 1 acceptable evaluation; and 4 files contained no evaluation form.... Of the six assignees who did not have outstanding evaluations, five were hired in late 1988 or January, 1989, when SEMATECH's work force was rapidly expanding. According to one senior assignee we interviewed, his company has improved its screening of assignees as SEMATECH's programs have become more clearly focussed and more is known about the positions being filled.

... SEMATECH has rejected only a handful of assignee applicants ... about 10 percent of the applicants reject SEMATECH's offers.

5.3 Progress in Manufacturing Equipment and Materials Programs through 1991

The following is based on information in SEMATECH: Innovation for America's Future, 1991 Update (4 March 1991), 19-24:

Lithography

Through its equipment improvement projects SEMATECH worked with two manufacturers to bring their products up to appropriate standards to be world competitive. Working with the GCA division of the General Signal Corporation,the reliability of the GCA AUTOSTEP 200 i-line stepper was improved to be 2.5 times more reliable than the previous model. Through SEMATECH fourteen of these steppers are being evaluated at four member companies in actual production environments. Working with ANGSTROM MEASUREMENTS CORPORATION, this company's submicron scanning electron microscope critical dimension measurement tool, the Scanline II was improved to be operated at magnifications 10 to 50 times higher than present optical microscopes. The Scanline II will allow hands-off automation of critical dimension line-width measurements of features as small as 0.2 micron.

Active joint lithography development projects focussed on the medium or long term include: ATEQ's CORE-2500 laser mask writer; KLA's patterned wafer defect detection inspection system; SILICON VALLEY GROUP's submicron photolithography processing track systems; SVG LITHOGRAPHY SYSTEMS' advanced step-and-scan exposure system; HAMPSHIRE INSTRUMENTS development of an improved collimated X-ray source; and New Mexico SEMATECH Center of Excellence research results in scatterometry and chemometrics which are delivered to member firms.

Multilevel Metals

Programs for this area encompass etch, planarization, and deposition techniques. These programs support automation and integration of multilevel metal operations by using standard machine interfaces and communications protocols. Although the U.S. currently is strong in this area, foreign competition has developed superior next-generation technology based on electron cyclotron resonance (ECR) techniques. Because ECR is viewed as critical to the success of multilevel planarization and, ultimately, smaller feature sizes, it is a key element of the program.

For this area, equipment improvement projects include the following:

- SEMATECH is working with GENUS, Inc., "to establish and implement new industry performance standards for specialized tungsten-based chemical vapor deposition (CVD) semiconductor manufacturing equipment." The two significant benefits from this program are expected to be higher current carrying capabilities of microchips manufactured with tungsten-based CVD technology and higher wafer processing throughput due to reduced manufacturing equipment down time. As of March 1991, GENUS had demonstrated "substantial improvement in machine dependent availability."

- SEMATECH, APPLIED MATERIALS, and NATIONAL SEMICONDUCTOR are partnering in an equipment improvement project to evaluate APPLIED's tungsten chemical vapor deposition process for depositing metals or refractories between layers of semiconductors for dielectric applications.

- SEMATECH and APPLIED MATERIALS are working together to evaluate APPLIED's Endura 5500 high vacuum physical deposition system used to deposit thin films of aluminum and refractory metals on semiconductor wafers. This evaluation is sited at IBM's advanced Semiconductor Technology Center in East Fishkill, New York.

- SEMATECH is working with EATON's SEMICONDUCTOR EQUIPMENT DIVISION to develop a metal deposition system that positions interconnections between circuits on silicon wafers. This will be an evolution from EATON's present sputter deposition system to the next generation systems required by SEMATECH's Phase 2 program.

Longer range joint development projects include:

- Work is in process with LAM Corporation on the LAM 3000, an ECR CVD tool to achieve more uniform dielectric layers between several layers of conducting lines on a silicon substrate by means of relatively low temperature deposition techniques. This tool now meets SEMATECH's Phase 3 requirements for multilevel metallization.

- Work with WESTECH,INC. on a mechanical wafer planarization tool has exceeded its targets—"Though initially slated as a feasibility study, the Westech Joint Development Project delivered a means to achieve flatness to specification two orders of magnitude greater than any previously available technology and discovered a set of process conditions that will achieve Phase 3 goals as well."

- Work with ASTex, Inc. is in process to develop a manufacturing tool utilizing an advanced plasma etching technology. The project will evaluate and select the best available plasma etching reactor, and develop a processing chamber and supporting subsystems to make up an integrated system.

- The DRYTEK Division of General Signal is designing and characterizing a low temperature plasma etching system with the goals of reducing the use of toxic chemicals in the process and providing higher yields.

- Work with OAK RIDGE NATIONAL LABORATORY and the University of Cincinnati is in process on a plasma etching project to direct the plasma from the reactor accurately to the wafer.

- Work with OAK RIDGE is in process also to develop advanced plasma etch manufacturing technology. "Several experimental etch concepts were developed, optimized and evaluated. New technology was transferred to a tool manufacturer for incorporation into a production etch tool."

Furnace and Implant

Japan's world market share of furnace sales was 53 percent in 1988. However, the U.S. installed base of vertical furnaces, the most technologically advanced, is only one-tenth that of Japan. Vertical furnaces have an advantage in a number of important areas: i.e., uniformity of product, ability to automate, and less atmospheric contamination.

SEMATECH, SVG THERMCO SYSTEMS, and NATIONAL SEMICONDUCTOR have partnered to improve SVG's VTR series of vertical furnaces from its THERMCO Division. This project has speeded up the availability of this important class of equipment.

In a joint development project, SEMATECH and ION IMPLANT SERVICES are characterizing a high-energy implanter, through a consortium to provide manufacturers access to high-energy implantation with the Genus 1500 at "one tenth the cost normally incurred."

Current research in furnaces and implant is concentrated at the SEMATECH Centers of Excellence at Texas, New York, and Massachusetts.

5.4 The Rationale for U.S. Memories

This following is excerpted from U.S. Memories, Inc.: Background Information (U.S. Memories, N.Y., September 1989), 2-4:

> There are three fundamental reasons why DRAMS are strategically important to the future of the American semiconductor and electronics industries.
>
> (1) DRAMS are a "technology driver" for other semiconductor manufacturing processes. DRAM manufacturing is in many ways the beginning of a "technology chain" that enables design and manufacturing advances in other types of semiconductors and in many types of electronic products and systems. DRAMs have a simple structure, and advances in DRAM technology are almost entirely advances in production technology, because the production process used allows designers to pack more and more bits of memory on one DRAM chip. Since the 1K-bit DRAM chip appeared in 1970, the density of DRAM chips has doubled every year. The current state of DRAM technology on the market is the 4-megabit DRAM, but most of today's high-volume DRAM production is still in 1-megabit parts.
>
> In order to make each new generation of DRAMs, DRAM manufacturers must design and build increasingly advanced production equipment. The 64K-bit DRAMs of 1985 used 2-micron production machinery, for example, while today's 1-megabit DRAMs use 1-micron production machinery. The cost of a DRAM plant has doubled with each generation of chip: a DRAM plant today costs about $400 million. New generations of DRAM equipment are eventually adopted by other companies or production lines for producing microprocessors or other logic circuits. Thus, DRAM production technology drives the advances in semiconductor production technology as a whole.
>
> The decline in DRAM production in the U.S. has already begun to affect the overall state of semiconductor production technology here. Because Japan has been the most aggressive in investing in the latest DRAM production equipment during the last ten years, it has more advanced chip-making equipment than U.S. merchant semiconductor companies. The average age of chip-making equipment in U.S. manufacturing plants is eight years, while that of such equipment in Japan is two to three. Most Japanese production now uses 1-micron processes, while most in the U.S. still uses 2-micron processes. While the U.S. still leads the world in circuit design, many of our most advanced circuits must be fabricated in Japan because their DRAM production investments have given them a much larger share of the best production technology.
>
> (2) Advanced DRAM production contributes to the overall technical infrastructure of a community. The pool of talented engineers and the knowledge base developed during the design and production of advanced DRAMs raises the overall level of semiconductor manufacturing knowledge. The knowledge and talent are eventually transferred to other semiconductor and electronics firms. The original employees of companies such as Hewlett-Packard, Shockley Semiconductor, and Fairchild, for example, went on to found dozens and dozens of other successful technology firms.
>
> (3) Domestic DRAM production provides a stable source of supply for U.S. systems companies and other electronics manufacturers. Japan is both the world's largest producer and consumer of DRAMs. U.S. firms that rely on Japanese firms for their supply of DRAMs must compete for those chips with Japanese customers with

greater demands. Many Japanese DRAM producers are divisions of large, vertically integrated industrial companies whose other divisions buy DRAMs for use in computers, calculators, and other products. So, for example, an U.S. computer firm relying on Toshiba for DRAMs often must compete for them against Toshiba's own computer division.

This market structure of foreign DRAM suppliers who are their own customers has led to boom-or-bust cycles of supply and pricing in the American DRAM market. As recently as 1988, intense demand for DRAMs in Japan led to serious shortages and price escalation in the U.S. which directly affected the ability of American electronics firms to sell their goods.

5.5 Overview of the Environment of the DRAM Market

The following is an excerpt from U.S. Memories, Inc.: Background Information (U.S. Memories, N.Y., September 1989), 5-7:

> The billions of R&D dollars invested by government and industry in Japan had yielded world-class DRAM manufacturing and design facilities by the 1980s. Government protection for Japan's large domestic market allowed DRAM makers to justify building high-capacity plants. In 1985, Japanese DRAM producers began dumping chips in the United States at below-cost prices. American electronic companies bought the lower cost Japanese chips, and American DRAM producers lost market share. With shrinking market share, American DRAM companies—whose ability to attract investors relied on short-term profits and the potential for a stable market—could no longer afford to risk the enormous investment needed to keep pace with DRAM technology. (The exceptions to this rule were IBM, Micron Technology, and Texas Instruments.)
>
> The cutbacks in American DRAM production had a material effect on the industry and on the U.S. economy: the U.S. semiconductor industry laid off 25,000 workers and lost nearly $2 billion in 1985 and 1986. Between the late 1970s and 1988, the number of American merchant DRAM producers dropped from eleven to three.
>
> During 1987–88, the Japanese DRAM companies became overwhelmed by the demand from their own domestic buyers, and they cut back on U.S. shipments. American computer makers, telecommunications firms, and other companies couldn't buy enough DRAMs, prices skyrocketed, and American systems firms were forced to cut back their financial projections along with their shipments of finished goods.
>
> Today, Japanese firms control 90% of the world market for 1-megabit DRAM chips. And with this virtual monopoly, Japan's suppliers are making up the losses sustained during the period of dumping in 1985–87. In 1988 alone, it is estimated that Japanese firms made over $5 billion in profits on DRAM chips.
>
> It is obvious today that we must reverse our country's decline in DRAM manufacturing. The challenge is to do this without violating our traditional values of free enterprise and open markets. The investment requirements for a DRAM plant are huge. Few semiconductor companies can afford such an investment without some guarantee of a stable market for its products. However, approaching these challenges through market access restrictions and government funding, as our foreign competitors have done, is a difficult solution for the American people to accept. U.S. Memories addresses these challenges without violating American values.

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Acronyms

ACT	Advanced Computing Technology Program
AEA	American Electronics Association
AI	artificial intelligence
ATP	Advanced Technology Program, National Institute of Standards and Technology
CAD	computer-aided design
CEO	chief executive officer
CGR	compound growth rate
CIA	Central Intelligence Agency
CIM	Computer-Integrated Manufacturing
CRS	Congressional Research Service
CSPP	Computer Systems Policy Project
CVD	chemical vapor deposition
DARPA	Defense Advanced Research Projects Agency
DOD	Department of Defense
DOE	Department of Energy
DRAM	dynamic random access memory
ECR	electron cyclotron resonance
ES-Kit	Experimental Systems Project (MCC)
GAO	General Accounting Office
HDTV	high-definition television
HPC	high-performance computing
IC	integrated circuit
ICOT	Institute for New Generation Computing Technology (Japan)
IEEE	Institute of Electrical and Electronic Engineers
ISR	Integrated Segmentation and Recognition
JRJF	Joint Research in Joint Facilities
LANs	local area networks
MCC	Microelectronics and Computing Technology Corporation
MCNC	Microelectronics Center of North Carolina
MFT	Mean Field Theory
MIS	management information systems
MITI	Ministry of Trade and Industry (Japan)
NACS	National Advisory Committee on Semiconductors
NASA	National Aeronautics and Space Administration
NCTP	National Critical Technologies Panel

NCRA	National Cooperative Research Act (1984)
NIPT	New Information Processing Technology (Japan)
NIST	National Institute of Standards and Technology
NSF	National Science Foundation
OCR	optical character recognition
OSI	Open Systems Interconnection
PIP	Pattern Information Processing (Japan)
PTAB	Program Technical Advisory Board (MCC)
PTP	Program Technical Panel (MCC)
SBN	strontium barium niobate
SEMATECH	SEmiconductor MAnufacturing TECHnology Corporation
SIA	Semiconductor Industry Association
SIGMA	Software Industrialized Generator and Maintenance Aids (Japan)
SM&E	semiconductor materials and equipment
SRC	Semiconductor Research Corporation
SRCEA	SRC Educational Alliance
STA	Science and Technology Agency (Japan)
TAB	Technical Advisory Board (MCC)
VLSI	very large systems integration