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FEDERAL RESEARCH

The SEMATECH Consortium's Start-up Activities

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The Honorable Robert A. Roe
Chairman, Committee on Science,
Space, and Technology
House of Representatives

The Honorable Robert S. Walker
Ranking Minority Member, Committee
on Science, Space, and Technology
House of Representatives

As requested, this report discusses SEMATECH's initial activities in developing advanced semiconductor technology, including the federal government's role, SEMATECH's approach and organization, and its initial technology transfer activities. While the Department of Defense's oversight of SEMATECH generally has been considered beneficial, the report contains a recommendation to the Secretary of Defense to further improve oversight of SEMATECH's operations.

As arranged with your office, unless you publicly release its contents earlier, we plan no further distribution of this report until 30 days after the date of this letter. At that time, we will send copies to the Secretary of Defense; the Chief Executive Officer of SEMATECH; the Director, Office of Management and Budget; and other interested parties upon request.

This report was prepared under the direction of John M. Ols, Jr., Director, Housing and Community Development Issues, (202) 275-5525. Other major contributors to this report are listed in appendix II.

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Executive Summary

Purpose

Since the early 1980s, the U.S. semiconductor industry has lost to Japan a significant portion of its market share for semiconductors—components that allow computers and other electronic products to process and store information. In response to this loss, several U.S. semiconductor and computer companies formed SEMATECH, Inc., in August 1987 to conduct research and development to provide the U.S. semiconductor industry the domestic capability for world leadership in manufacturing. The Congress authorized the Department of Defense to participate in SEMATECH in December 1987 and appropriated $100 million in fiscal year 1988 and $100 million in fiscal year 1989. Member companies are required to provide at least 50 percent of SEMATECH's operating budget of about $200 million each year.

The Chairman and Ranking Minority Member, House Committee on Science, Space, and Technology, requested that GAO annually assess SEMATECH's progress for each of the 5 years that SEMATECH is anticipated to receive federal funding. This is GAO's first report, addressing (1) the federal role in SEMATECH, (2) SEMATECH's approach and organization for achieving its overall objectives, and (3) SEMATECH's initial technology transfer activities.

Background

SEMATECH's annual operating plans have established an initial three-phased, 5-year approach to achieve parity with Japan in phase two and regain world manufacturing leadership in phase three. This approach will develop semiconductor-manufacturing equipment and materials needed to decrease the linewidth, or diameter, of integrated circuits from the current, phase-one level of technology of 0.8 microns to the next generations of technology—0.5 microns in phase two and 0.35 microns in phase three. (A micron is a millionth of a meter.) This miniaturization will enable manufacturers to increase the components on a semiconductor and, therefore, enable computers to increase data storage capacity and decrease processing time.

The National Defense Authorization Act for Fiscal Years 1988 and 1989 required that SEMATECH develop annual operating plans in consultation with Defense and a newly established Advisory Council on Federal Participation in SEMATECH, consisting of seven business leaders and five senior government officials. While ensuring the government an important voice in SEMATECH, this arrangement established a business-like arrangement that would allow SEMATECH a reasonable degree of freedom in its operations and management. In April 1988 the Secretary

of Defense delegated oversight responsibility for SEMATECH to the Defense Advanced Research Projects Agency (DARPA).

Results in Brief

DARPA's management oversight of SEMATECH's activities generally has been viewed as beneficial. However, the industry members of the Advisory Council have not been appointed and, therefore, the council has yet to convene and provide SEMATECH the direction and oversight that the Congress expected.

SEMATECH's 1990 operating plan, approved in April 1989, revised its phase-three milestone from the end of 1992 to the middle of 1993 on the basis of its analysis of the time frames needed to achieve parity with and then surpass foreign competition. SEMATECH also reduced the scope of its phase-one manufacturing activities and reorganized its operating divisions to emphasize individual projects for developing more advanced semiconductor-manufacturing equipment.

As of September 30, 1989, 181 member-company employees filled management and engineering positions in SEMATECH's operating divisions, typically for 2-year assignments. Six SEMATECH member companies plan to replicate technology that SEMATECH transferred in a November 1988 workshop to upgrade existing fabrication facilities or construct new ones.

Principal Findings

The Federal Role in SEMATECH

According to the former Under Secretary of Defense for Acquisition, DARPA is the appropriate organization to oversee SEMATECH because it has technological expertise and management experience, and it can best coordinate various aspects of the government's semiconductor research program with SEMATECH. DARPA signed a memorandum of understanding to participate in SEMATECH in May 1988, after SEMATECH agreed to address concerns that (1) its 1988 operating plan did not sufficiently identify the tasks and milestones needed to accomplish its three-phased objectives and (2) a greater percentage of research and development should be conducted outside SEMATECH. According to the Chief Administrative Officer, SEMATECH has been satisfied with its interactions

with DARPA, stating that DARPA has helped improve SEMATECH's strategic planning efforts without micro-managing SEMATECH's activities or influencing it into performing more defense-related research.

The Advisory Council was established by legislation in December 1987 to provide the Secretary of Defense and SEMATECH with advice from a cross section of business leaders and senior federal officials. However, the council does not have a quorum to conduct business because the Secretary of Defense, for a number of reasons, has not forwarded the names of seven industry members for Presidential appointment. DARPA plans to complete the application and security clearance process for the nongovernment members of the Advisory Council by the end of 1989.

SEMATECH has been proposed as a model for other government-industry consortia, such as high-definition television and superconductivity. GAO agrees with the Congressional Budget Office, which noted in its report, The Benefits and Risks of Federal Funding for SEMATECH, that it is appropriate for the government to assist a particular firm or industry if such intervention can be justified on the basis of providing public benefits beyond any benefits to the affected firms. For SEMATECH, the report stated that potential public benefits that might justify federal funding were (1) national defense through SEMATECH's role in sustaining U.S. semiconductor production capability and technological leadership, (2) spillovers within the semiconductor industry because SEMATECH has a longer term research and development focus, and (3) spillovers to the U.S. economy because any successes in advancing semiconductor technology may translate into lower computer costs and advanced capabilities that benefit all industries.

SEMATECH's Approach and Organization

SEMATECH's 1990 operating plan revised its phase-three milestone for developing the equipment and materials for achieving an integrated circuit linewidth of 0.35 microns from the end of 1992 to the middle of 1993. According to SEMATECH planning officials, the new date reflected a new planning approach that established intermediate goals and milestones and would, on the basis of their analysis of foreign competitors' capabilities and plans, still enable U.S. semiconductor manufacturers to regain world leadership.

SEMATECH also reduced its phase-one scope for replicating 0.8-micron semiconductor-manufacturing processes to concentrate on tasks needed to move into the second phase of its program. In May 1989 SEMATECH

reorganized its operating divisions around project teams, whose members have different experience and expertise, to better advance processes and equipment technology.

SEMATECH's Technology Transfer Activities

Attracting qualified assignees from member companies is critical for achieving SEMATECH's objectives because of their role in developing advanced manufacturing technology and then transferring it to member companies. As of September 30, 1989, the number of assignees from each member company ranged from 3 to 27, generally reflecting the member's financial contributions to SEMATECH. One senior assignee stated his company screened seven applicants for every one sent to SEMATECH for interviews. To encourage members to send highly qualified assignees, SEMATECH will not hire an assignee as a permanent employee without the member's concurrence.

One of SEMATECH's first initiatives was to design and construct a state-of-the-art semiconductor fabrication facility. In November 1988 SEMATECH transferred this technology to its members through a facilities technology package and a 3-day workshop attended by over 200 member representatives. SEMATECH officials stated that 6 members plan to replicate the SEMATECH technology to upgrade or construct fabrication facilities and all 14 members will use aspects of SEMATECH's technology.

Recommendation

To give a greater cross section of input and opinion from business leaders and senior federal officials, as provided by the authorizing legislation, GAO recommends that the Secretary of Defense forward to the President the names of seven individuals from industry for appointment to the Advisory Council on Federal Participation in SEMATECH.

Agency Comments

A draft of this report was sent to the Department of Defense and SEMATECH for comment. Defense, in its official oral comments, concurred in the report's findings and recommendation. SEMATECH, while believing that the Advisory Council has merit, expressed concern about possible duplication in the roles of the Advisory Council and the National Advisory Committee on Semiconductors, which was established by the Omnibus Trade and Competitiveness Act of 1988.(See app. I.) GAO found, however, that the Advisory Council was established to provide oversight of SEMATECH, which is not included in the Committee's responsibilities, and Defense is working to address the concern about duplication. SEMATECH also suggested some other changes to improve the presentation and technical accuracy of the draft report. GAO incorporated appropriate changes.

Contents

Abbreviations

DARPA	Defense Advanced Research Projects Agency
DOD	Department of Defense
DOE	Department of Energy
DRAM	dynamic random access memory
GAO	General Accounting Office
HDTV	high-definition television
R&D	research and development
SEMATECH	SEmiconductor MAnufacturing TECHnology
SRAM	static random access memory

Introduction

SEMATECH, Inc., is a consortium of 14 U.S. semiconductor manufacturers and the Department of Defense (DOD), whose objective is to provide the U.S. semiconductor industry the domestic capability for world leadership in manufacturing. SEMATECH has a 5-year plan to achieve this objective by reaching technological parity with foreign semiconductor manufacturers by 1992 and regaining world technological leadership by 1993.

Background

Semiconductors are the foundation of the electronics industry, which employs 2.6 million Americans to make consumer products, such as computers and consumer appliances, and defense weapons systems components. Until the early 1980s, the United States was the world leader in semiconductor production. However, because of the importance of semiconductors to the electronics industry, Japan has supported a major program beginning in 1975 to establish a strong industry. U.S. companies have since lost a significant portion of their market share in semiconductors and semiconductor-manufacturing equipment to Japanese companies.

In December 1985 DOD's Deputy Under Secretary for Research and Engineering requested that the Defense Science Board establish a task force to assess the impact of the semiconductor industry trends on DOD's weapons acquisition programs. The task force was composed of 12 members representing government; universities; and defense industries, including semiconductor research and manufacturing organizations. It reported that of 25 semiconductor products and processes, Japanese companies led in 12, U.S. companies led in 5, and relative parity existed in 8.[1] The report concluded that the erosion of technological leadership in U.S. semiconductor manufacturing had serious implications for the nation's economy and would seriously impair our defense capabilities that rely upon technologically superior weapons. The report recommended that action be taken to retain a domestic strategic semiconductor base and maintain a strong base of expertise in associated technologies.

Semiconductor Manufacturing

A semiconductor is a device used to regulate the flow of electricity in electronic products. Semiconductors can be divided into integrated circuits and discrete devices. Integrated circuits, known as "chips," are responsible for linking the electrical components inside a product and

[1]See Defense Semiconductor Dependency, Feb. 1987.

make up about 80 percent of the total semiconductor market. Discrete devices are composed mostly of transistors and diodes.

SEMATECH issued a pamphlet in May 1989 that describes the integrated circuit manufacturing process. The process typically consists of more than 100 steps in which hundreds of copies of an integrated circuit are formed on a silicon wafer, a 3- to 6-inch disk of purified sand. Generally, the process involves the creation of 8 to 20 patterned layers on and into the substrate of the wafer, ultimately forming the complete integrated circuit.

In the first stage of the fabrication process, the wafers are heated and exposed to ultra-pure oxygen to form a silicon dioxide film of uniform thickness on the surface of the wafer. Next, in the photo lithography stage, a photoresist (light-sensitive film) is applied to the wafer, giving it characteristics similar to photographic paper. A wafer stepper aligns the wafer to a mask and then projects an intense light through the mask, exposing the photoresist with the mask pattern. In the etching stage, the exposed photoresist is removed, and the wafer is baked to harden the remaining photoresist pattern. The wafer is then exposed to a chemical solution so that the areas not covered by the hardened photoresist are etched away. The photoresist is removed using additional chemicals, and the wafer is inspected to ensure that the image transfer from the mask to the top layer is correct. In the doping stage, atoms with one less and one more electron than silicon are implanted in the area exposed by the etch process to alter the electrical character of the silicon. These stages are then repeated several times until all active devices have been formed and the last layer of the "front-end" of the process is completed.

In the dielectric and metallization stage, the individual devices are interconnected using a series of metal depositions and patterning steps, followed by deposition and patterning of dielectric films for insulation. After the last metal layer is patterned, a final dielectric layer is deposited to protect the circuit from damage and contamination. Openings are etched in this film to allow access to the top layer of metal by electrical probes and wire bonds. An automatic, computer-driven electrical test system then checks the functionality of each chip on the wafer, rejecting any that fail the test. A diamond saw slices the wafer into single chips, and the good chips are assembled into a package that provides contact leads for the chip.

Because semiconductors can be tested only at the end of the fabrication process to determine whether they meet specifications, the percentage,

or yield, of acceptable chips on the wafer is important for minimizing production costs. Semiconductors are fabricated in a "clean room" manufacturing area that needs to be scrupulously clean.[2] A single speck of dust, or even a worker's cosmetics, can be enough to contaminate the semiconductor production process.

Because of industry competition, semiconductors are becoming smaller and the manufacturing process more efficient. Smaller minimum feature sizes create a demand for more precise lithographic equipment and better circuit designs. For example, research on x-ray lithography as an advance over photo lithography and gallium arsenide as an advance over silicon may enable the industry to reduce the size and/or improve the yield of future semiconductor generations.

SEMATECH's Initial Activities

In September 1986 the Semiconductor Industry Association created a task force to define objectives and create an organizational frame work for SEMATECH. In March 1987 a 14-member start-up team began operations in Santa Clara, California, and in August 1987 SEMATECH was incorporated in Delaware as a not-for-profit research and development (R&D) corporation. The following companies are members of SEMATECH:

- Advanced Micro Devices, Inc.
- American Telephone and Telegraph Company.
- Digital Equipment Corporation.
- Harris Corporation.
- Hewlett-Packard Company.
- Intel Corporation.
- International Business Machines Corporation.
- LSI Logic Corporation.
- Micron Technology, Inc.
- Motorola, Inc.
- National Semiconductor Corporation.
- NCR Corporation.
- Rockwell International Corporation.
- Texas Instruments, Inc.

[2]Clean rooms are designed to control airborne particle concentrations by regulating air supply, air distribution, filtration of air supply, construction materials, and operating procedures.

While not a formal member, DOD shares access to SEMATECH's technology. Each member company, DOD, and SEMI/SEMATECH, which represents U.S. semiconductor equipment and materials suppliers, are represented on SEMATECH's Board of Directors and Executive Technical Advisory Board. These boards advise SEMATECH's management of strategic goals, objectives, and progress of its technical programs.

Each member company has signed a participation agreement committing the member to support SEMATECH at full funding levels for its first 4 years of operation and requiring 2 years notice before a member can discontinue participation. A member's annual financial contributions are assessed on the basis of its prior year's sales of semiconductor devices or, alternatively, the value of its semiconductor purchases if the member produces electronic equipment. The member's contributions generally determine the number of technical employees it may assign to participate in SEMATECH's research program and transfer resulting technology and know-how back to the company. The participation agreement also outlines the policies for handling proprietary information and intellectual property rights.

SEMATECH invited each state to submit proposals offering economic inducements to be the site of its manufacturing facility. SEMATECH's start-up team narrowed the number of competing sites to 12 in late 1987 and announced the selection of Austin, Texas, as the permanent location in January 1988. To attract SEMATECH, the state of Texas, through the University of Texas at Austin, (1) provided a 46-acre site, including a five-story office building and a warehouse, in southeast Austin; (2) renovated and furnished the office building; (3) constructed a central utility building; (4) partially renovated the warehouse into a semiconductor fabrication facility; and (5) paid issuance costs and first-year interest on construction bonds. The City of Austin has provided electrical power facilities, utility connections, and building and development fee abatements to SEMATECH.

In April 1988 SEMATECH occupied the southeast Austin site, and in May 1988 SEMATECH and the University of Texas signed a 20-year lease, which became effective in January 1989. The first manufacturing equipment was installed during the first week of October 1988, and the fabrication facility was dedicated on November 15, 1988.

SEMATECH has established a three-phased R&D program for regaining U.S. semiconductor-manufacturing leadership and prepared annual operating plans for 1988, 1989, and 1990. Phase one, which began in

November 1988, is intended to demonstrate manufacturing capability at the current level of technology of 0.8-micron linewidths.[3] Phase two, which began in April 1989, is intended to enable U.S. companies to achieve parity with Japanese companies in fabricating semiconductors with 0.5-micron linewidths. Phase three is intended to enable U.S. companies to regain world manufacturing leadership by fabricating semiconductors with 0.35 linewidths. During 1988 SEMATECH increased its staff from 40 to 400.

Federal Participation in SEMATECH

Finding that it was in the national economic and security interests of the United States for DOD to participate in a government/industry consortium on semiconductor-manufacturing technology with SEMATECH's member companies, the National Defense Authorization Act for Fiscal Years 1988 and 1989 (P.L. 100-180, Dec. 4, 1987) directed the Secretary of Defense to make grants to SEMATECH for R&D. Both the Continuing Resolution for Fiscal Year 1988 (P.L. 100-202, Dec. 22, 1987) and the DOD Appropriations Act for Fiscal Year 1989 (P.L. 100-463, Oct. 1, 1988) appropriated $100 million for SEMATECH. In addition, both the Senate and the House Appropriations Committees have designated $100 million for SEMATECH in DOD's appropriations for fiscal year 1990, which currently are being provided by the Joint Resolution Making Continuing Appropriations for Fiscal Year 1990.

In authorizing DOD participation in SEMATECH, the National Defense Authorization Act required the Secretary of Defense to enter into a memorandum of understanding with SEMATECH with provisions that (1) SEMATECH have an annual operating plan developed in consultation with the Secretary of Defense and the Advisory Council on Federal Participation in SEMATECH; (2) available funds for R&D activities from federal, state, and local governments for any fiscal year may not exceed 50 percent of the total cost of such activities; and (3) SEMATECH cooperate with and draw on the expertise of the Department of Energy's (DOE) laboratories and U.S. universities.

The National Defense Authorization Act also established the Advisory Council on Federal Participation in SEMATECH to advise SEMATECH on appropriate technology goals for the R&D activities and the plan to achieve the goals. The Advisory Council is to be composed of 12 members as follows:

[3]A micron is one-millionth of a meter.

- DOD's Under Secretary for Acquisition, who serves as the Advisory Council's chairman.
- DOE's Director of Energy Research.
- The Director of the National Science Foundation.
- The Department of Commerce's Under Secretary for Economic Affairs.
- The Chairman of the Federal Laboratory Consortium for Technology Transfer.
- Seven members appointed by the President, including four representing semiconductor and related industries, two who are eminent in the fields of technology and defense, and one representing small businesses.

The Advisory Council is required to recommend to SEMATECH any appropriate modifications to the plan or the technological goals and submit an annual report to the Secretary of Defense and the congressional Armed Services committees that describes SEMATECH's progress in achieving its goals. In addition, section 5422 of the Omnibus Trade and Competitiveness Act of 1988 (P.L. 100-418, Aug. 23, 1988) directed the Advisory Council in its annual report to assess (1) possible alternative sources, methods, and terms of federal funding; (2) the appropriateness of continued federal participation; (3) SEMATECH's performance, including its accomplishments and shortfalls in the preceding fiscal year, and a summary of its most recent plans, milestones, and cost estimates; (4) coordination of interagency participation in SEMATECH; and (5) any related policy issues.

The National Defense Authorization Act further required that SEMATECH retain an independent public accountant to determine the extent that SEMATECH's use of federal funds is consistent with the purposes of the act, SEMATECH's charter, and its operating plan. The act requires that we comment on the accuracy and completeness of the auditor's annual reports and provide any additional appropriate comments on the reports. SEMATECH's public accountant, Price Waterhouse, issued its opinion on SEMATECH's 1988 financial statements in a report dated January 27, 1989. We currently are reviewing that report and plan to issue our report later this year.

In April 1988 the Secretary of Defense delegated to the Defense Advanced Research Projects Agency (DARPA) responsibility for overseeing SEMATECH. In May 1988 DARPA entered into a memorandum of understanding with SEMATECH and signed a grant agreement. DARPA provides overall technical guidance and approves the consortium's operating plans.

DARPA delegated grant administration functions, including approval of disbursements, to the resident office of DOD's Office of Naval Research in Austin, Texas. The grant requires SEMATECH's public accountant to certify the amount of funds contributed by member companies to ensure compliance with the 50-percent matching requirement before a disbursement is processed. SEMATECH's budget is projected at about $200 million a year over 5 years, with half provided by member companies and half by federal, state, and local government contributions. As of July 24, 1989, SEMATECH had received about $143 million from member companies and $142 million from DARPA. SEMATECH members plan to match the amortized value of the University of Texas' contributions starting January 1989, when the fabrication facility's certificate of substantial occupancy was issued and the lease became effective.

Objectives, Scope, and Methodology

In a letter dated June 9, 1988, the Chairman and Ranking Minority Member, House Committee on Science, Space, and Technology, asked that we provide annual assessments of SEMATECH's activities for the duration that it receives federal funding. Specifically, the Committee asked us to address 21 issues regarding (1) federal oversight of and involvement in the consortium; (2) technological issues, including SEMATECH's objectives, milestones, and accomplishments; (3) the transfer of technology from SEMATECH to its member companies; and (4) the participation of semiconductor equipment and materials suppliers in the consortium.

This first report addresses issues related to the federal role in SEMATECH, the consortium's approach and organization for achieving its strategic objectives, and its initial technology transfer activities. Because SEMATECH is completing only the second of a multiyear R&D program, it is too early to assess SEMATECH's overall success. Accordingly, as agreed with the Committee, subsequent GAO reports will address, in more detail, issues including SEMATECH's efforts to (1) strengthen semiconductor equipment and materials suppliers, (2) achieve its technical goals and milestones, and (3) transfer technology.

To assess federal agencies' oversight of and involvement in SEMATECH, we interviewed the federal members of the Advisory Council on Federal Participation in SEMATECH or their designees, senior DARPA officials, and officials from agencies and laboratories that conduct or fund R&D on semiconductors. We obtained pertinent documentation from DARPA and other federal agencies and laboratories, including the Advisory Council's charter and workshop reports on DOE's national laboratories and the semiconductor industry.

To assess SEMATECH's organizational structure and approach for achieving its objectives, we interviewed SEMATECH's senior management officials; DARPA's program manager; the President of SEMI/SEMATECH, which coordinates SEMATECH's activities with semiconductor equipment and materials suppliers; and the Staff Vice President and Chief Scientist of Semiconductor Research Corporation, which coordinates industry and government funding of semiconductor-related research at universities. We also reviewed SEMATECH's 1988, 1989, and 1990 operating plans, the minutes of meetings of its Board of Directors and Executive Technical Advisory Board, and documents related to its reorganization.

To assess SEMATECH's initial technology transfer activities, we interviewed SEMATECH officials and member company representatives. We also reviewed SEMATECH's (1) technology transfer policies, (2) fabrication facility technology package, and (3) policies and records on its assignee program.

DOD and SEMATECH were given an opportunity to formally comment on a draft of this report. DOD provided official oral comments on the draft report, and SEMATECH provided written comments. Their comments are characterized at the end of chapter 2, and SEMATECH's written comments are reprinted in appendix I.

We conducted our review between January 1989 and July 1989 in accordance with generally accepted government auditing standards. Selected data were updated through September 30, 1989.

The Federal Role in SEMATECH

The National Defense Authorization Act for Fiscal Years 1988 and 1989, in authorizing DOD to grant funds to SEMATECH, required that SEMATECH develop annual operating plans in consultation with DOD and a newly established Advisory Council on Federal Participation in SEMATECH. According to the conference report, this arrangement would ensure the government an important voice in SEMATECH, but at the same time establish a businesslike arrangement that would allow SEMATECH a reasonable degree of freedom in its operations and management.

DARPA's management oversight of SEMATECH has generally been viewed as beneficial. However, the industry members of the Advisory Council on Federal Participation in SEMATECH have not been appointed and, therefore, the council cannot fulfill its legislative responsibility to provide direction and oversight to SEMATECH. While it is too early to determine whether SEMATECH will be successful in improving semiconductor-manufacturing technology, government reports and senior officials have pointed to important elements of the SEMATECH consortium that may provide some criteria in determining whether to establish other government/industry research-related consortia.

DARPA's Oversight of SEMATECH

In April 1988 the Secretary of Defense delegated oversight responsibility for SEMATECH from the Office of the Secretary of Defense to DARPA, which is experienced in managing R&D projects in general and semiconductor technology in particular. In May 1988 DARPA signed a memorandum of understanding with SEMATECH after reaching an agreement on how certain concerns of DARPA's would be met. Federal agencies other than DOD are unlikely to oversee future government/industry consortia unless funds for that purpose are appropriated.

Delegation of Oversight to DARPA

The former Under Secretary of Defense for Acquisition told us that DARPA is the appropriate agency within DOD to oversee SEMATECH because DARPA has expertise in both semiconductor technology and R&D project management.[1] Alternatively, the Office of the Secretary of Defense is better able to provide broad management direction for acquisition programs. Both the Director of the National Science Foundation and Commerce's Under Secretary for Economic Affairs supported the decision to delegate oversight to DARPA, stating that DARPA is more

[1] In addition to participating in SEMATECH, DARPA funded about $500 million in advanced R&D related to semiconductor manufacturing in fiscal year 1989.

involved with commercial research and would be more willing than the Office of the Secretary of Defense to let SEMATECH's goals be commercially oriented.

DARPA's Review of SEMATECH's Program

The National Defense Authorization Act required DOD to enter into a memorandum of understanding with SEMATECH before it could provide funds. Before DARPA signed the memorandum of understanding in May 1988, SEMATECH agreed to address DARPA's concerns that (1) SEMATECH's operating plans should include more complete and consistent goals and milestones and (2) 20 percent of SEMATECH's annual budget should be dedicated to advanced development projects that involved member companies, equipment manufacturers, universities, and federal laboratories. DARPA's program manager for SEMATECH stated that SEMATECH's 1989 and 1990 operating plans greatly improved upon the 1988 plan by providing more detailed tasks, intermediate objectives, and milestones. At its April 1988 meeting, the SEMATECH Board of Directors agreed that 20 percent of the SEMATECH budget could be committed to outside projects.

DARPA's program manager is a nonvoting member of SEMATECH's Board of Directors and a member of the Executive Technical Advisory Board. To assist DARPA's program manager, Commerce assigned a staff member in April 1989 and DOD assigned a staff member in July 1989 to work with SEMATECH on its competitive strategies.

SEMATECH's Chief Administrative Officer told us that SEMATECH has been satisfied with its interactions with DARPA, noting that DARPA has contributed to improving SEMATECH's strategic planning efforts. The Chief Administrative Officer stated that DARPA has not tried to influence SEMATECH into performing more defense-related R&D or micro-manage SEMATECH's activities.

Other Federal Agencies That Could Oversee SEMATECH

One element of the debate to authorize federal participation in SEMATECH was whether DOD was the appropriate agency to oversee SEMATECH's activities because SEMATECH has commercial, rather than defense, R&D objectives.[2] The former Under Secretary of Defense for Acquisition stated that because DOD is a major user of the devices, it

[2]Other agencies that funded semiconductor-related R&D in fiscal year 1989 were DOE (about $80 million, mainly for nuclear weapons R&D), the National Science Foundation (about $55 million, mainly at universities), and Commerce's National Institute of Standards and Technology (about $6 million for developing measurement standards).

has a vested interest in funding SEMATECH and getting access to its technology. The Director of DARPA noted that DARPA made funds available from its budget because of SEMATECH's perceived importance for the long-term health of the U.S. semiconductor industry and the implications that industry has for both the national defense and the national economy. SEMATECH's Chief Administrative Officer noted that DARPA has a sound technological understanding of the semiconductor-manufacturing process, which has facilitated the government/industry partnership.

Commerce's former Acting Under Secretary for Technology told us that DOD was selected because (1) the only way federal participation in a private R&D consortium can be justified is on the merits of national security and (2) DOD was the only federal agency with sufficient funds available to support SEMATECH since the Congress did not appropriate any new funds. Commerce's former Under Secretary for Economic Affairs similarly stated that DARPA is the best federal agency to oversee SEMATECH because it has the time, staff, and money to devote to SEMATECH. The Under Secretary added that DARPA is doing an excellent job of overseeing SEMATECH and it would be a mistake to remove SEMATECH from DARPA's oversight. The Director of the National Science Foundation said that it does not matter on a theoretical basis where SEMATECH fits because other federal agencies, such as the National Science Foundation and Commerce, could not afford to give SEMATECH a $100 million-per-year grant over 5 years. The Washington, D.C., representative of the Federal Laboratory Consortium for Technology Transfer noted that, while the business community initially was concerned about having SEMATECH under a DOD agency, DARPA has a good reputation and few organizational layers, which allows it to get things done efficiently.

Regarding whether DOD or a civilian agency would best oversee any future government/industry R&D consortia, Commerce's former Under Secretary for Economic Affairs stated that Commerce is unlikely to oversee a consortium unless the Congress provides funding to support the consortium. The Under Secretary noted that the Omnibus Trade and Competitiveness Act of 1988 authorized the National Institute of Standards and Technology to establish a new Advanced Technology Program to assist U.S. industry in developing new technologies. However, although the National Institute of Standards and Technology requested $20 million for the program in fiscal year 1989, no funds were appropriated.

Industry Members of Advisory Council Have Not Been Appointed

The National Defense Authorization Act established the Advisory Council on Federal Participation in SEMATECH to provide the Secretary of Defense and SEMATECH advice on SEMATECH's objectives and plans from a cross section of business leaders and senior government officials. Although the act established the Advisory Council in December 1987, the council has not met because the Secretary of Defense has not forwarded to the President the names of seven industry members to be appointed and, consequently, the council does not have a quorum to conduct business.

DOD officials told us that the principal reason for the delay in appointing the members and convening the Advisory Council was that DOD was concerned that the council would have some of the same members and duplicate some of the functions of the National Advisory Committee on Semiconductors, which section 5142 of the Omnibus Trade and Competitiveness Act of 1988 established. The objective of the committee is to devise and promulgate a long-term national semiconductor strategy, including R&D, that will ensure the continued U.S. leadership in semiconductor technology.

After exploring the need for the Advisory Council and the committee, DOD determined that it would convene both advisory groups. To avoid duplication, DOD decided that while the Advisory Council will oversee SEMATECH's operations, it will not address semiconductor industry policy issues involving SEMATECH.

The former Under Secretary of Defense for Acquisition and DARPA officials told us that they have used their involvement in the National Advisory Committee on Semiconductors to informally obtain semiconductor industry leaders' views on SEMATECH's plans and progress. DARPA's program manager for SEMATECH added that DARPA has identified the seven appointed members and two alternates for the Advisory Council. However, one of these individuals has not submitted the necessary paperwork. DARPA plans to complete the application and security clearance process for the nongovernment members of the Advisory Council by the end of 1989.

In response to the requirements of section 273 of the National Defense Authorization Act and section 5422 of the Omnibus Trade and Competitiveness Act of 1988, the Under Secretary of Defense issued the Advisory Council's first annual report, SEMATECH: Progress and Prospects in May 1989. The report, which was prepared by Commerce's Under

Secretary for Economic Affairs, recommended continued federal funding for SEMATECH at the $100 million level in fiscal year 1990. It also recommended against any shift or division in project funding responsibilities away from DARPA.

SEMATECH as an Appropriate Model

Other U.S. industries have pointed to SEMATECH as a model for government/industry consortia for technologies such as high-definition television (HDTV) and superconductivity. We agree with the Congressional Budget Office, which noted in its report, The Benefits and Risks of Federal Funding for SEMATECH, that it is appropriate for the government to assist a particular firm or industry if such intervention can be justified on the basis of providing public benefits beyond any benefits to the affected firms. For SEMATECH, the report stated that potential public benefits that might justify federal funding were

- national defense through SEMATECH's role in sustaining our semiconductor production capability and technological leadership;
- spillovers within the semiconductor industry because SEMATECH has a long-term R&D focus, as opposed to industry's short-term bias due to the ease that new technologies can be duplicated and, therefore, the inability of firms to recapture their R&D investments; and
- spillovers to the U.S. economy because any successes in advancing semiconductor technology may translate into lower computer costs and advanced capabilities that benefit all industries.

If another government/industry consortium is justifiable on the basis of providing public benefits, a second issue is whether SEMATECH's approach and structure would be appropriate. Although it is too early to tell whether SEMATECH will succeed and therefore determine whether it should be duplicated by other consortia, we note that the semiconductor industry will likely differ from other industries in many ways so that each consortium will have unique goals that should dictate its appropriate structure and approach.

In assessing whether SEMATECH is an appropriate model for other consortia, the Advisory Council's 1989 report noted that a unique combination of factors led to federal participation in SEMATECH. These include (1) a widely shared belief in the importance of a strong national semiconductor industry for military and economic strength; (2) the existence of a large and resourceful U.S. industry and active involvement of the industry's largest firms; and (3) clear technology objectives that are far enough removed from the product end of the R&D spectrum to allow

members to cooperate, yet near enough to be practically useful in a commercially significant time frame. In authorizing federal participation, the National Defense Authorization Act required that SEMATECH's member companies have a significant financial stake in the consortium by providing at least 50 percent of the consortium's funding.

The former Under Secretary of Defense for Acquisition stated that many government/industry collaborations failed in the past because the government took the lead in defining the objectives and operating plans. The Director of Commerce's Office of Economic Policy told us that the government's role in encouraging industry consortia is not limited to providing funds. He noted that alternative federal actions, such as relaxing antitrust laws that prohibit cooperation in production, may be more appropriate for a proposed HDTV consortium. The Deputy Associate Director of DOE's Office of Basic Energy Sciences stated that while consortia are appropriate to enable an industry to compete better internationally, he believed industry should provide the funding while the government should provide leadership by, for example, reducing the federal budget deficit. He noted that lower U.S. interest rates would stimulate industrial R&D funding by allowing businesses to wait longer for a return on their investment.

The Director of the National Science Foundation stated that to determine if SEMATECH is a good model for other industries, such as HDTV or superconductivity, the details of each industry must be analyzed. For example, SEMATECH differs from the proposed HDTV consortium because the technology for HDTV already exists and the concern is about price. The Director said that because an HDTV consortium would need to focus on marketing the product rather than improving manufacturing operations, the government's role may more appropriately include relaxing antitrust laws, providing tax benefits, or bringing companies together on marketing and manufacturing issues. Alternatively, because superconductivity's primary need is research, the government can assist a consortium through its existing R&D funding structure and may also need to help in other ways. The Director also stated that the government should not fund 50 percent of a consortium's costs, even when the industry is related to defense.

The President of SEMI/SEMATECH noted that SEMATECH's R&D effort involves the whole semiconductor industry, including semiconductor producers, equipment manufacturers, and materials suppliers. He also

noted that the members of SEMATECH's Board of Directors are sufficiently senior to implement new approaches and technology within their companies.

Conclusion

DARPA's oversight of SEMATECH's activities, primarily through its comments on SEMATECH's annual operating plans, generally has been considered beneficial. However, the Advisory Council on Federal Participation in SEMATECH has not met almost 2 years after the National Defense Authorization Act established it in December 1987. Although DOD officials and industry executives have informally discussed SEMATECH's objectives and plans, we believe that SEMATECH and the Secretary of Defense would benefit from the advice of a cross section of business leaders and senior federal officials on SEMATECH's technological goals and operating plans that the Advisory Council would provide.

Recommendation

To give a greater cross section of input and opinion from business leaders and senior federal officials, as provided by the authorizing legislation, we recommend that the Secretary of Defense forward to the President the names of seven individuals from industry for appointment to the Advisory Council on Federal Participation in SEMATECH.

DOD and SEMATECH Comments

DOD concurred in our findings and recommendation to forward the names of seven individuals from industry for appointment to the Advisory Council on Federal Participation in SEMATECH. DOD plans to complete the application and security clearance process for the nongovernment members of the Advisory Council by the end of 1989.

SEMATECH stated that, while our recommendation to appoint the Advisory Council members has merit, we did not acknowledge the role of the National Advisory Committee on Semiconductors, which SEMATECH believes has met the intent of the Congress for a joint industry/government advisory panel. While it does not oppose the formation of the Advisory Council, SEMATECH expressed concern about possible duplication in the roles of the National Advisory Committee on Semiconductors and the Advisory Council, which it would hope the Congress would address. SEMATECH also stated that it is willing to work with the Congress to achieve common goals; however, each new group overseeing SEMATECH requires SEMATECH's managers to take time away from their mission to explain its operations to the group.

While we agree that some overlap could occur between the Advisory Council and the National Advisory Committee on Semiconductors, which will require some coordination, the two advisory groups have different objectives. The Advisory Council is to (1) advise SEMATECH and DOD on SEMATECH's technology goals and operating plan and (2) report annually on its assessment of SEMATECH's progress in carrying out the operating plan. The National Advisory Committee on Semiconductors is to develop a national semiconductor strategy to ensure continued U.S. leadership in semiconductor technology. This includes (1) identifying the components of a successful strategy; (2) analyzing options, establishing priorities, and recommending roles for participants in the national strategy; and (3) assessing the effective use of federal laboratories, industry resources, universities, and private/public R&D efforts. While the National Advisory Committee on Semiconductors expects to issue reports in November 1989 and in 1990, the committee has not determined whether it will need to continue operations to prepare a third report.

SEMATECH also suggested some other changes to improve the presentation and technical accuracy of our draft report, which we incorporated as appropriate.

SEMATECH's Approach and Organization

To provide the U.S. semiconductor industry the capability to regain world manufacturing leadership, SEMATECH is seeking to (1) develop equipment and materials to reduce the linewidth of semiconductors' integrated circuits from the current level of technology (0.8 microns) to 0.35 microns; (2) increase the size of the silicon wafers that it can process; and (3) maintain or increase the yield, or percentage, of semiconductor chips that meet industry specifications. A smaller integrated circuit linewidth will enable manufacturers to increase the components on a semiconductor and, therefore, enable computers to increase data storage capacity and decrease processing time. The increased wafer size and higher yields will improve manufacturing efficiency. These advances require state-of-the-art clean room facilities, with purer gases and chemicals to reduce exposure to contaminants, and improved manufacturing equipment and processes.

During 1989 SEMATECH revised its strategic approach and organizational structure. To concentrate on tasks needed to move into phase two of its R&D program, the consortium reduced its phase-one scope from fully replicating the process for fabricating semiconductors with 0.8-micron linewidths to demonstrating the capability to fabricate them. Its 1990 operating plan revised the phase-two milestone for achieving an integrated circuit linewidth of 0.5 microns from the end of 1990 to the end of 1991 and its phase-three milestone for achieving 0.35 microns from the end of 1992 to the middle of 1993. SEMATECH planning managers stated that this change (1) reflected a new planning approach that established target dates for achieving intermediate milestones and (2) still will enable the U.S. semiconductor industry to regain world manufacturing leadership. SEMATECH reorganized its operating divisions by adopting a project management structure in an effort to more effectively develop competitive manufacturing technology. According to SEMATECH's Chief Operating Officer, the new organizational structure will seek to reduce integrated circuit linewidths and improve wafer yield by giving more emphasis to individual projects for improving existing or developing the next generation of semiconductor-manufacturing equipment and less emphasis on the total semiconductor fabrication process.

SEMATECH (1) obtained manufacturing technology for phase one from two member companies and contracted with a third member to develop the manufacturing test devices for phase two; (2) established a Tool Application Program to enable U.S. semiconductor equipment suppliers to install and test equipment in a manufacturing environment; (3) awarded eight contracts to develop advanced manufacturing equipment technology and three contracts to improve existing tools; (4) contracted

with DOE's Sandia National Laboratories to establish a Semiconductor Equipment Technology Center to improve the reliability of semiconductor equipment and materials; and (5) is providing about $10 million annually for long-term R&D on semiconductor-manufacturing technology through a centers of excellence program involving U.S. universities, Sandia National Laboratories, and Commerce's National Institute of Standards and Technology.

Changes in SEMATECH's Approach and Organizational Structure

During 1989 SEMATECH reduced the scope of its phase one activities, revised its planning approach for achieving its overall objectives, and reorganized its structure. These changes were intended to (1) streamline activities to devote SEMATECH's limited resources to essential projects, (2) identify the tasks and milestones for achieving SEMATECH's overall objectives, and (3) better measure managers' and the consortium's performance in achieving objectives.

Revised Scope of Phase-One Activities

Phase one of SEMATECH's R&D program, which began in November 1988, is intended to demonstrate capability for high-yield, factory-scale production for 64-kilobit static random access memory (SRAM) chips and 4-megabit dynamic random access memory (DRAM) chips that have an integrated circuit linewidth of 0.8 microns.[1] The first SRAM devices that were entirely manufactured at SEMATECH were completed 3 days ahead of schedule on March 27, 1989.

SEMATECH reduced the scope of its phase-one activities for the 4-megabit DRAM-manufacturing test device by manufacturing only the "back end of line" portion of the device.[2] This decision was approved by SEMATECH's Executive Technical Advisory Board in February 1989 and Board of Directors in April 1989.

The minutes of the February 1989 Executive Technical Advisory Board meeting noted that dropping the front end of line work for the DRAM was advantageous for schedule, timing, and resources because it would enable SEMATECH to move more quickly into phase two. According to SEMATECH's Director of Manufacturing Equipment and Materials,

[1]SRAMs and DRAMs are standard-design, high-volume chips used mainly in computers. DRAMs primarily are used for main memory. SRAMs, which are faster but have less storage capacity, provide quick-access memory.

[2]Manufacture of the SRAM and the DRAM is divided into two major process zones—the front end of line and the back end of line.

phase one activities were scaled back because (1) the primary purpose of the phase-one program was for process and tool validation to prepare for phase two, (2) management recognized in the first half of 1989 that it did not have the resources to accomplish all the manufacturing tasks established in earlier plans, and (3) some of these earlier tasks would not benefit the member companies. He noted that manufacturing tasks for the SRAM's front end of line and the DRAM's back end of line have applications for phase two because of the designs of those portions of the devices and the physical properties of materials.

SEMATECH began preliminary engineering work on phase two in April 1989 utilizing phase-one devices. This early engineering effort involved tasks such as film deposition, oxidation testing, thinner films development, and metal layer processes using the front end of the SRAM and the back end of the DRAM. SEMATECH met its milestone to begin phase two in April 1989 and awarded a contract to Hewlett-Packard in May 1989 for developing the phase- two manufacturing test devices.

The 1990 Operating Plan

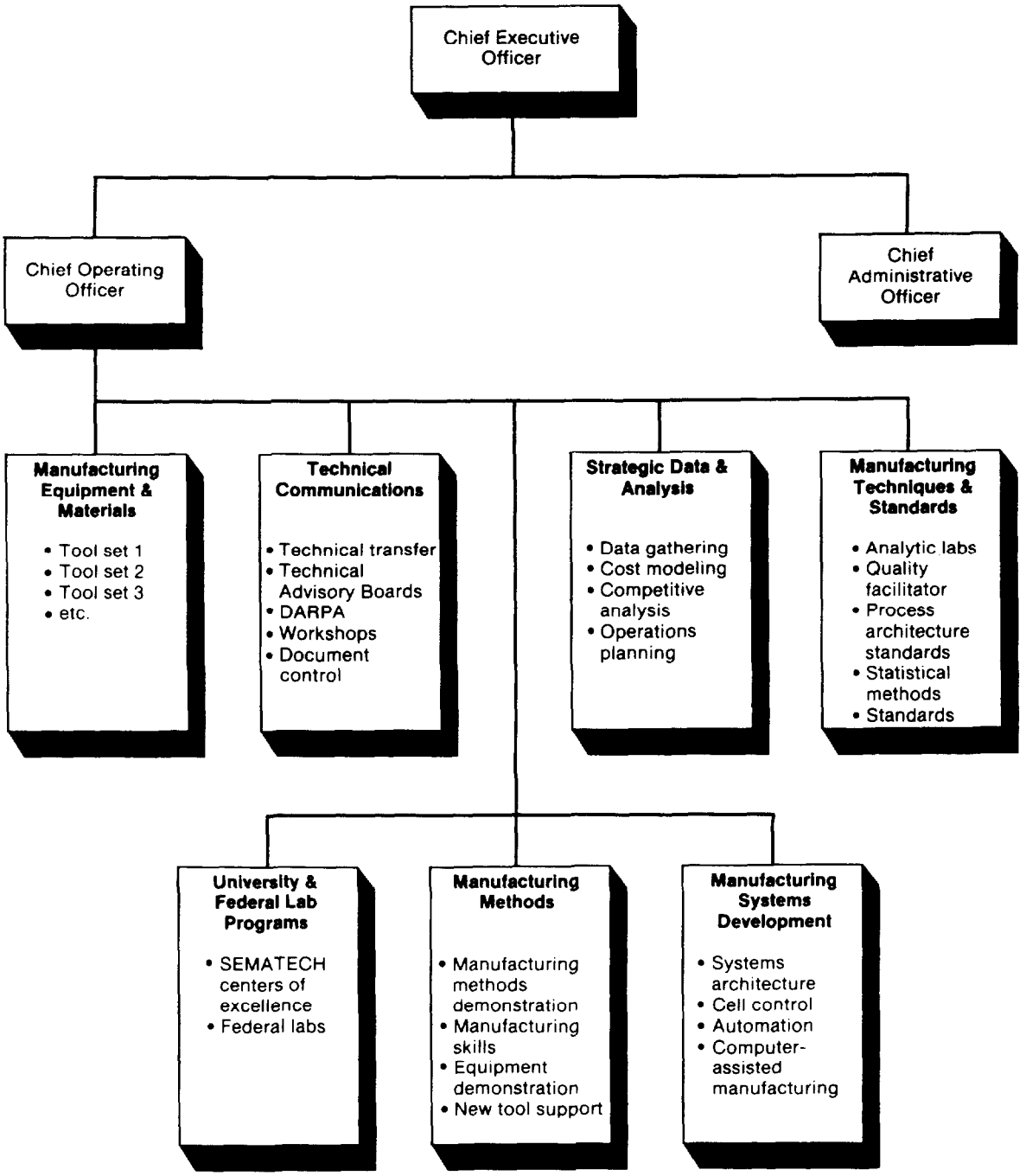
SEMATECH's 1989 operating plan primarily defined SEMATECH's broad objectives, organizational framework, and scope of work. On the basis of its analysis of semiconductor-manufacturing technology trends and projections of when Japanese competitors would likely achieve the integrated circuit linewidths, the plan established a phase-two milestone of achieving parity with Japanese companies for 0.5-micron linewidths by the end of 1990 and a phase-three milestone of taking the lead for 0.35-micron linewidths by the end of 1992.

SEMATECH's 1990 operating plan, which was completed in April 1989, was the first operating plan to establish technical milestones using a project format for each phase of its R&D program. On the basis of the time frames for achieving the intermediate technical milestones, the 1990 plan stated that SEMATECH will achieve 0.5-micron linewidths by the end of 1991 and 0.35-micron linewidths by the middle of 1993. SEMATECH planning officials stated that, based on their analysis of foreign competitors' capabilities and plans, the new 1993 phase-three milestone still will enable the U.S. semiconductor industry to regain world manufacturing leadership. According to DARPA's program manager for SEMATECH, the decision to revise the phase-three milestone was based on one of the most comprehensive competitive analyses ever conducted of the semiconductor industry. DARPA was consulted before the change.

SEMATECH's Reorganization

In May 1989 SEMATECH reorganized its operating divisions from a functional to a project focus to better achieve its objective of advancing semiconductor-manufacturing technology. (See fig. 3.1.) SEMATECH's Chief Operating Officer stated that during its first 18 months of operations, SEMATECH used a functional structure similar to that of its 14 member companies. Under this structure SEMATECH had divisions with overall responsibility for phase one project management, phases two and three project management, manufacturing operations, manufacturing systems, and manufacturing technology.

Figure 3.1: SEMATECH's Reorganization of Its Operating Divisions



The Chief Operating Officer stated that SEMATECH's new organizational structure centers around R&D projects that can better be pursued by bringing together team members with different expertise and organizational experience and, correspondingly, will place less emphasis on manufacturing wafers from beginning to end, which duplicates what member companies do. The new organizational structure reflects SEMATECH's approach to concentrate R&D on

- critical tools and materials, such as ultraviolet steppers, to which U.S. semiconductor manufacturers are in danger of losing access;
- tools and methods, such as cluster tools and advanced etch processes, that will give the member companies a manufacturing advantage in the shortest time; and
- high-risk, high-return manufacturing approaches, such as x-ray lithography.

Under the new organization, the phase one and phases two and three projects are among several project-level efforts within the Division of Manufacturing Equipment and Materials.

According to the Chief Operating Officer, the reorganization created three levels of managers under his office—division managers, project group managers, and project managers. Each of these managers was given a written mission statement, including objectives and key milestones to measure progress toward meeting the mission, that is directly related to a project for the development of technology that can be transferred to member companies. Progress reviews for all levels of management under the new organization started in July 1989. The Chief Executive Officer will conduct progress reviews of division directors once each quarter, while the Chief Operating Officer will conduct monthly progress reviews of the other two management levels. DARPA's program manager for SEMATECH stated that the reorganization has effectively streamlined SEMATECH's management and that DARPA was consulted before the reorganization's initiation.

SEMATECH's Efforts to Leverage Its Resources

SEMATECH is seeking to leverage, or extend, its resources by effectively using the skills and technological resources of its member companies, U.S. semiconductor equipment and materials suppliers, and U.S. universities and federal laboratories. Its success is based on a cooperative effort to advance U.S. semiconductor-manufacturing capabilities.

Member Companies' Contributions

As discussed in chapter 4, assignees from the member companies play a major role in developing advanced manufacturing technology on a compressed schedule and transferring this technology to the member companies. SEMATECH also has formed 14 technical advisory boards, listed below, that typically meet four times annually to review SEMATECH's technical strategy and plans.

- Assembly and Packaging.
- Design and Process Council.
- Environmental Safety.
- Facilities.
- Lithography.
- Manufacturing Systems.
- Metrology.
- Plasma Process.
- Process Technology.
- Quality.
- Silicon Materials and Epitaxy.
- Standards.
- Technology Transfer.
- Yield Management.

Because of time and resource constraints, SEMATECH used member companies' technology, including manufacturing test devices, to achieve phase-one manufacturing capabilities. American Telephone and Telegraph Company shared (1) the manufacturing technology and manufacturing test devices for its 64-kilobit SRAM, (2) temporary assignees from two facilities to assist in transferring the technology to SEMATECH, and (3) partially processed wafers to start the fabrication process. The Chief Operating Officer stated that SEMATECH's SRAM yields demonstrated the capability to fabricate SRAMs at the current level of technology. He noted, however, that members would not benefit by further improving the yield rate because American Telephone and Telegraph considers the SRAM technology proprietary so that process flow data could not be transferred to the other members.

International Business Machines Corporation has provided the manufacturing technology and manufacturing test device for its 4-megabit DRAM and brought temporary assignees from its Burlington, Vermont, facility to assist in transferring the technology to SEMATECH. The first DRAM devices are scheduled to be completed in December 1989.

In May 1989 SEMATECH awarded a contract to Hewlett-Packard for the design and development of the phase-two manufacturing test devices. SEMATECH intends to use improved equipment as it becomes available to support later portions of phase-two work. Phase-two technology, including process flow data, will be transferred to the member companies.

Equipment and Materials Suppliers

A major part of SEMATECH's effort to advance semiconductor-manufacturing technology is to strengthen the U.S. semiconductor equipment and materials supply industries, which consist mainly of small businesses with less than $10 million in annual sales. These companies provide the manufacturing equipment; materials, such as the chemicals for etching the integrated circuits on the silicon wafers; and pure gases used in the clean room to minimize any contamination of the wafers during the fabrication process.

SEMATECH interacts with equipment and materials suppliers through SEMI/SEMATECH, which is limited to U.S. companies. SEMATECH relied primarily on existing equipment and materials supplied by U.S. vendors for phase one of its R&D program. In phase two, which began in April 1989, SEMATECH is working with equipment and materials suppliers to develop enhanced equipment and better materials.

To assist U.S. semiconductor equipment and materials suppliers, which typically do not have the budget to construct clean room facilities to test their equipment, SEMATECH established the Tool Application Program. SEMATECH has designated a portion of its clean room and provides manufacturing support for (1) Joint Development Projects to develop equipment and processes that support manufacturing requirements for future generations of technology and (2) the Equipment Improvement Program to improve existing tools. Through these programs, suppliers can install and test equipment in a manufacturing environment and receive technical support and analysis services from a team of engineering and manufacturing specialists. As of September 30, 1989, SEMATECH had awarded eight Joint Development Project contracts and three Equipment Improvement Program contracts.

In June 1989 SEMATECH conducted a 2-day workshop in Austin, Texas, for representatives of 83 U.S. semiconductor equipment and materials suppliers that make wafer fabrication equipment, assembly and test equipment, materials and chemicals, facilities, analytical equipment, and

automation equipment. The workshop was intended to encourage teaming arrangements among suppliers and between suppliers and member companies and to describe SEMATECH's approach to its Joint Development and Equipment Improvement programs. SEMATECH also conducted miniworkshops on lithography, plasma processing, process modules, metrology, mask, contamination, assembly, packaging, and systems.

In August 1989 SEMATECH signed a technical assistance agreement with Sandia National Laboratories, a DOE contractor-operated laboratory, to establish a Semiconductor Equipment Technology Center for improving the reliability of semiconductor equipment and materials. The center, which is part of SEMATECH's Equipment Improvement Program, will assess reliability of equipment and materials, develop diagnostic techniques and sensors to enhance process control on the production line, and evaluate existing codes and develop new models for designing and analyzing chemical reactors and processes.

SEMATECH's Long-term R&D Program

As of September 30, 1989, SEMATECH had established centers of excellence, typically involving two or more universities and/or federal laboratories, in nine states. (See table 3.1.) According to SEMATECH's Chief Operating Officer, the centers are intended to (1) create an atmosphere of prestige for advancing manufacturing engineering technology, (2) develop highly talented manufacturing engineers, and (3) conduct R&D needed to develop phase-three manufacturing technology. SEMATECH also is in the final stages of negotiating an agreement with the University of Florida to establish a center for test technology and is negotiating another agreement with Carnegie-Mellon University to form a center for software architecture for computer-integrated manufacturing. The centers are funded through three-party contracts between SEMATECH; a primary university; and the Semiconductor Research Corporation, which was formed by the semiconductor industry in 1982 to fund and coordinate research at U.S. universities. The total annual center of excellence program is about $12.6 million, comprised of about $10 million from SEMATECH and about $2.6 million from matching funds required by the contracts.

Table 3.1: SEMATECH's Centers of Excellence

Center members	Research area
University of Arizona and Sandia National Laboratories	Contamination/defect assessments and control in the manufacture of semiconductors
University of California at Berkeley and Stanford University	Optical lithography and pattern transfer research
Massachusetts Microelectronics Center and Northeastern University	Single-wafer processing for flexible integrated circuit manufacturing
The New Jersey Institute of Technology, Rutgers University, Stevens Institute of Technology, and Princeton University	Advanced plasma etch processing technology
University of New Mexico and Sandia National Laboratories	On-line analysis and metrology for semiconductor manufacturing
Rensselaer Polytechnic Institute, Colorado State University, Sandia National Laboratories, and the National Institute of Standards and Technology	Multilevel metallization
North Carolina State University, University of North Carolina, Duke University, Research Triangle Institute, and North Carolina A&T	Automated microelectronics manufacturing
University of Texas and Texas A&M University	Submicron complementary metal oxide semiconductors and manufacturing systems research
University of Wisconsin	X-ray lithography

Federal laboratory participation in SEMATECH's long-term R&D program has been limited. Sandia National Laboratories is participating in the centers of excellence at the University of Arizona on contamination/defect assessment and control and the University of New Mexico on semiconductor metrology. In addition, both Sandia and the National Institute of Standards and Technology are participating in Rensselaer Polytechnic Institute's center on multilevel metallization. Oak Ridge, Lawrence Livermore, and Los Alamos National Laboratories also submitted proposals for funding in fields such as plasma source and free electron laser lithography. While SEMATECH and the Semiconductor Research Corporation did not approve any of the proposals, SEMATECH's Director of Manufacturing Equipment and Materials stated that the consortium is negotiating with (1) Oak Ridge and a university for a Joint Development Project and (2) the National Institute of Standards and Technology to develop linewidths control standards. SEMATECH also may discuss x-ray lithography R&D with Lawrence Livermore after SEMATECH formalizes its plans.

DARPA's program manager also is responsible for coordinating SEMATECH's R&D program with DARPA's other semiconductor-related R&D programs. Project managers from DARPA and SEMATECH met on

June 29, 1989, to exchange information about advanced manufacturing technology projects that each is funding. This included discussions about DARPA's research on (1) x-ray lithography, (2) very large scale integrated circuits, (3) millimeter wave and microwave monolithic integrated circuits, (4) microelectronics manufacturing, and (5) advanced packaging of semiconductors. In addition, Air Force's Lincoln Laboratory discussed its direct excimer processing research.

SEMATECH's Technology Transfer Activities

SEMATECH's objective is to develop advanced semiconductor-manufacturing technology on a compressed schedule and then quickly and effectively transfer this technology to its members. Assignees play a principal role in technology transfer by participating in projects to develop the technology and transfer it to member companies. As of September 30, 1989, 181 assignees were in management and engineering positions in SEMATECH's operating divisions. Assignees typically are scheduled to complete a 2-year assignment at SEMATECH before returning to their companies.

In November 1988 SEMATECH transferred a technology package to its members and conducted a workshop on the construction of its semiconductor fabrication facility. According to SEMATECH officials, 6 members plan to replicate this technology by upgrading existing fabrication facilities or constructing new ones, and all 14 members will use aspects of the facilities technology. In addition, SEMATECH has transferred technology by providing technical documentation to its technical advisory board members and receiving, on average, five visitors per day from member companies.

Attracting and Retaining Qualified Assignees

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 the 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 percent 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 company's concurrence because such action would likely make member companies reluctant to send high-quality professionals and also reduce the effectiveness of technology transfer to the members.

SEMATECH's Chief Administrative Officer told us that as long as member companies' professionals 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. He also noted that, in developing its procedures for assignees, SEMATECH contacted another semiconductor R&D consortium that uses assignees to discuss the "lessons learned" to more effectively manage its assignee program.

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 represented 51 percent of the operating division positions. According to SEMATECH's Chief Administrative Officer, positions in finance, law, communications, supplier relations, and human resources normally are filled by permanent employees because they have little or no technology transfer role.

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. The member company pays its assignees' salaries while they are at SEMATECH; however, SEMATECH reimburses the member companies for these expenses. Members and SEMATECH carefully safeguard assignee salary information because of its sensitive nature.

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. To determine how assignees are identified, we 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. The senior resident assignees of the other three companies told us that their 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.

According to SEMATECH's Employment Manager, placing assignees begins when a SEMATECH manager completes an employee requisition form and it is approved by management and the finance office. This requisition includes the title of the position; a job description; and desired education, experience, and skills. Requisitions are provided to the member companies, and assignees are recruited in groups during recruiting windows. Prior to the applicant interviews, SEMATECH managers, comprising permanent hires as well as assignees, review the resumes and decide which applicants to schedule for interviews. After interviews are completed, the SEMATECH managers meet and discuss where each applicant would best fit into the organization.

We randomly selected the names of 20 assignees and reviewed their personnel files to determine SEMATECH managers' overall evaluation of the applicant assignee as recorded on an evaluation form after the applicant was interviewed. The form required the interviewers to 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 because, according to SEMATECH's employment manager, the assignees had been hired before SEMATECH began placing evaluation forms in the personnel files. Of the six assignees who did not have any 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 focused and more is known about the positions being filled.

SEMATECH's Employment Manager stated that SEMATECH has rejected only a handful of assignee applicants. He added that about 10 percent of the applicants reject SEMATECH's offers for a wide variety of reasons, such as better job offers from the member company, the applicant or his/her spouse did not want to relocate, or the applicant did not understand SEMATECH's mission until the interview and visit.

We asked SEMATECH to analyze the records of assignees who had left SEMATECH as of June 30, 1989, to determine where they were

employed after leaving and the reason they had left. Of the 41 assignees who had left, 9 were part of the start-up team in California and had made it known that they intended to leave if SEMATECH relocated to another part of the country, 8 were on temporary assignment, 8 either retired or resigned from their member company, 12 completed the assignment period and returned to the member company, 3 either were sent back or mutually agreed to return to the member company because they did not fit into SEMATECH operations, and 1 left early to accept a position offered by his member company. One senior assignee told us that the four assignees who had returned to his company had been assigned to positions that he considered to be career advancements.

It should be noted that technology transfer is a continuing process while an individual is an assignee. Because a large number of assignees have not completed their SEMATECH assignment, it will be at least another year before a more meaningful assessment of the assignee program can be made.

Transfer of Clean Room Technology

One of SEMATECH's first initiatives was to construct a modern semiconductor fabrication facility consisting of a clean room, supporting facilities, and a central utilities building. Construction began in February 1988 with structural changes to an existing warehouse at the Austin site. According to SEMATECH's construction manager, the facilities were largely complete on November 23, 1988, although the first manufacturing equipment was actually installed in the fabrication area during the first week of October 1988. In late November 1988 SEMATECH provided a facilities technology package consisting of plans, specifications, and documentation to each member and conducted a 3-day workshop. The technology package and workshop provided SEMATECH the opportunity to evaluate its technology transfer procedures through feedback from its members.

Planning for the fabrication facility began in 1987, while the start-up team was still in California. According to SEMATECH's former Director of Facilities, three assignees with experience in planning and constructing semiconductor fabrication facilities were assigned to plan the SEMATECH facility. He said they conducted over 20 workshops with representatives of member companies, semiconductor equipment manufacturers, and materials suppliers to discuss the facilities, equipment, chemicals, materials, and gases that would be needed for a state-of-the-art facility that could later be enhanced to further advance manufacturing technology. The former Director of Facilities stated that construction

was completed in 32 weeks in comparison with typically a 2-year period for constructing a similar facility and credited the construction contractors as major factors for finishing construction so quickly. The former Director said that SEMATECH selected the premier design contractor for the semiconductor industry and the general construction contractor had worked with his company on more than one occasion to build semiconductor-manufacturing facilities.

SEMATECH transferred information about the construction of the fabrication facility to member companies and DOD in late November 1988 through a facilities technology package, a 3-day workshop, and a tour of the fabrication facilities. Over 200 representatives of the 14 member companies and DOD attended the workshop. Each member company, through its facilities technical advisory manager, received a complete facilities technology transfer package. The package consisted of reports, proposals, schedules, logs, manuals, specifications, blueprints, and drawings pertaining to construction of the clean room and supporting facilities. The subject areas ranged from bulk liquid and gas distribution systems and environmental health plans to utility, site grading, and roof plans. The package also included a catalog section to enable members to order additional sets of individual documents.

After the workshop, SEMATECH provided an 11-hour video tape of the workshop, written responses to 194 questions asked during the workshop, and participants' comments on how the workshop could be improved. According to SEMATECH's former Director of Facilities, most of the member companies' questions dealt with construction costs, equipment specifications, and safety and environmental issues. The most critical comments from workshop participants were that (1) the facilities tour should have been more detailed and thoroughly rehearsed, (2) more time should have been allowed for questions and answers after each presentation, and (3) printed material should have been made available to participants for review prior to the workshop so they could have been better prepared to ask questions.

According to SEMATECH officials, 6 members are planning to replicate the SEMATECH technology to upgrade existing fabrication facilities or construct new ones and all 14 members will use aspects of SEMATECH's facilities technology. A DOD National Security Agency official noted that the agency recently constructed a new fabrication facility at Fort Meade, Maryland. While plans for the fabrication facility were already approved before SEMATECH transferred its facility technology package, the National Security Agency received some indirect benefits

because the National Semiconductor Corporation, a SEMATECH member, was the construction contractor. The official stated that the National Security Agency expects to benefit from future technology transfer packages, such as a workshop on chemical-handling safety.

Comments From SEMATECH

SEMATECH

INNOVATION FOR AMERICA'S FUTURE

September 22, 1989

John M. Ols, Jr.
Director for Housing and Community
Development Issues
U.S. General Accounting Office
441 G Street N.W.
Washington, D.C. 20548

Dear Mr. Ols:

SEMATECH has reviewed the draft of the GAO report entitled Federal Research: The SEMATECH Consortium's Start-up Activities (GAO/RCED-89-217) and found the draft thorough and basically accurate in reflecting the activities and accomplishments of SEMATECH to-date. However, we do feel the following points are either missing or under-emphasized in the report:

1. Failure to recognize the fact that competitive analysis has driven SEMATECH's planning activities from the outset;

2. Failure to recognize the implications of SEMATECH's impact on the national economy since semiconductors are the foundation of the electronics industry (which employs more Americans -- 2.6 million -- than the steel, auto, and aerospace industries combined);

3. Failure to recognize the fact that SEMATECH is a unique R&D undertaking in that the Department of Defense will realize direct benefits from the SEMATECH program, but only has to pay half the price for the R&D. Also, the fact that SEMATECH achieved an industry consensus for DOD, if you will, is a very distinct benefit to DOD that goes unnoticed in the report.

4. The recommendation for the President to move quickly to name the members of the Advisory Council on Federal Participation in SEMATECH has merit. But the draft does not acknowledge the role that the National Advisory Council on Semiconductors (NACS) is currently playing in regard to SEMATECH. In fact, the NACS and the Advisory Council on Federal Participation in SEMATECH may be a

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redundancy that Congress should address. We feel the intent of Congress in establishing a joint industry-government advisory panel has been met with the establishment of the NACS. We certainly do not oppose the formation of the Advisory Council on Federal Participation in SEMATECH, but we would hope that the GAO and Congress would review the possible duplication.

SEMATECH has provided in the attachment to this letter, specific suggestions that we feel would correct and/or clarify the language in the draft report.

We appreciate the opportunity to review the draft, and we have been impressed with the professionalism exhibited by the GAO in dealing with SEMATECH. I hope the GAO, and Congress, understand that we are willing to work with you to achieve our common goals. I would hope that our point #4 above would be seriously considered since with each new entity dealing with SEMATECH we are required to take time away from our mission to explain the SEMATECH operation to each individual group.

Sincerely,

Robert N. Noyce
CEO & President

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