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USING FEDERAL TECHNOLOGY POLICY TO STRENGTH THE US MICROELECTRONICS INDUSTRY

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Abstract

A review of US and Japanese experiences with using microelectronics consortia as a tool for strengthening their respective industries reveals major differences. Japan has established catch-up consortia with focused goals. These consortia have a finite life targeted from the beginning, and emphasis is on work that supports or leads to product- and process-improvement-driven commercialization. Japan's government has played a key role in facilitating the development of consortia and has used consortia promote domestic competition.

US consortia, on the other hand, have often emphasized long-range research with considerably less focus than those in Japan. The US consortia have searched for and often made revolutionary technology advancements. However, technology transfer to their members has been difficult. Only SEMATECH has assisted its members with continuous improvements, compressing product cycles, establishing relationships, and strengthening core competencies. The US government has not been a catalyst nor provided leadership in consortia creation and operation.

We propose that in order to regain world leadership in areas where US companies lag foreign competition, the US should create industry-wide, horizontal-vertical, catch-up consortia or continue existing consortia in the six areas where the US lags behind Japan--optoelectronics, displays, memories, materials, packaging, and manufacturing equipment. In addition, we recommend that consortia be established for special government microelectronics and microelectronics research integration and application. We advocate that these consortia be managed by an industry-led Microelectronics Alliance, whose establishment would be coordinated by the Department of Commerce. We further recommend that the Semiconductor Research Corporation, the National Science Foundation Engineering Research Centers, and relevant elements of other federal programs (including the Advanced Technology Program at the National Institute of Standards and Technology) be integrated into this consortia complex.

Annual funding of $1B is appropriate, with industry bearing a majority of the cost and authority of management. Where appropriate, consortia work would be assigned to government-owned laboratories and to universities. The primary sponsoring agencies of government-owned laboratories selected for consortia work would bear the full cost of their technical work.

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ABSTRACT

A review of US and Japanese experiences with using microelectronics consortia as a tool for strengthening their respective industries reveals major differences. Japan has established catch-up consortia with focused goals. These consortia have a finite life targeted from the beginning, and emphasis is on work that supports or leads to product- and process-improvement-driven commercialization. Japan's government has played a key role in facilitating the development of consortia and has used consortia to promote domestic competition.

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EXECUTIVE SUMMARY

As a preparatory step to recommending government-sponsored programs in microelectronics, especially programs that emphasize partnerships between universities, government-owned laboratories, and US industry, we have examined major US semiconductor collaborative efforts as well as the principles of collaboration in Japan. This was done in the context of merged competitiveness and commercialization models that recently evolved from the Harvard Business School and the National Academy of Engineering. Our goals were to arrive at a consensus position on what consortia should emphasize, to arrive at a funding and management compromise for collaborative work that is attractive to both industry and government, and to identify those consortia that should be established to strengthen the competitiveness of the US microelectronics industry.

Rather than focusing on business weaknesses, US collaborative efforts have sometimes emphasized areas where the US already excels: (1) research and (2) technology-enabled commercialization (science intensive, breakthrough-driven work). An exception is SEMATECH, which emphasizes development and product- and process-improvement-driven commercialization (engineering intensive, evolutionary work). US industry executives have concluded that US industry has already demonstrated strength in areas: (1) those that are close to basic research; (2) those that do not require heavy capital equipment investment; (3) those that can be initiated by individual innovation; and (4) those that have been supported by public investment in basic research, defense procurement, and environmental regulations and private investment in R&D. National collaborative efforts in these areas, if needed at all, should employ lead maintenance strategies by focusing on the creation and diffusion of basic research. In contrast, these executives observe, US industry is weak in areas where public investment has been small, risk sharing is limited, capital needs are high, extensive investment periods are required, manufacturing focus is high, and foreign governments and industry have targeted the area. Collaborative efforts are more likely to be of interest to industry when they are designed as catch-up programs in areas where US industry is weaker than foreign competition and the areas have substantial market potential. Studies consistently show the manufacturing area and its close ally, product- and process-improvement-driven commercialization, to be the areas in which the US needs to catch up. US consortia should focus on these areas.

Our early review of US semiconductor consortia revealed that early US collaborative efforts were handicapped by the absence of a national semiconductor roadmap that had been widely socialized and accepted by the US semiconductor industry. Recent roadmap development by the National Advisory Committee on Semiconductors and the Semiconductor Industry Association have resolved this. US collaborative projects have too often operated on the premise that horizontal cooperation (collaboration by companies that are in direct competition) over a wide research agenda was the key to competitiveness. SEMATECH, a horizontal-vertical consortium with upstream vertical integration into manufacturing equipment, has partially corrected the major US competitive handicap that stems from the paucity of vertically integrated semiconductor corporations. The Semiconductor Research Corporation has successfully steered US universities toward work in silicon research and is, therefore, credited with aiding the flow of university graduates who can effectively move into industry. (Accrual of benefits from their research should be regarded as a bonus.) The US government has not played a major role in establishing microelectronics consortia, but has provided 50 percent of SEMATECH's funding. US collaborative efforts have not focused on the special needs of government systems.

In contrast, Japanese collaborative programs have pursued work that is narrow in scope. They have focused on establishing the **feasibility** of emerging new products and processes, and their work has been directed toward information exchange and research coordination rather than exclusively toward cooperative research execution. In Japan, collaborative programs have promoted **horizontal competition** (competition between companies for the same product line) that led to additional R&D investment by consortia members. Therefore, they cannot be regarded as an industry subsidy. Their work agenda is in large part based on extensive surveys of technology visionaries throughout Japan. Their engineering research associations, the principal vehicles for horizontal collaboration, have an average lifetime of only 6 years. They emphasize providing a technological basis for continuous manufacturing improvement; hence, they are attentive to product- and process-improvement-driven commercialization. As an example of Japan's focus on narrow-scope, immediate needs, they formed a collaborative effort to develop special microelectronics for space applications although their need for such microelectronics has been small.

Japan's government institutions are heavily involved in collaboration with industry. They contribute funding to industry (but rarely more than 50 percent of industry costs), they serve as a catalyst, they promote the identification and transfer of foreign innovation, they offer tax benefits to those joining consortia, they provide facilities and personnel from government-owned laboratories, and they act as a think tank for Japanese consortia. Without the leadership of government institutions, Japan's consortia would likely have failed. Taking into account the costs of government manpower (rarely included in estimates of government's contribution to consortia) and tax benefits would substantially increase the estimate of Japan's government contribution to industry.

It is recommended that any US consortia (1) be established in areas where the US lags foreign competitors, (2) be established for a specific narrow purpose, (3) have a lifetime determined at their formation, and (4) promote or at least not compromise **competitive horizontal relationships and cooperative vertical relationships** (relationships between a company and its suppliers and customers). When consortia need to share facilities, they should make use of existing facilities where possible and emphasize research coordination, information exchange, and the demonstration of advancements that lead to process- and product-improvement-driven commercialization, and they should establish the feasibility of emerging new technologies. Consortia should be judged by market performance of their members and the amount of additional R&D investment they stimulate among their members rather than by technical accomplishments. Collectively and in close partnership with their member companies, US semiconductor consortia should help develop and continuously update a roadmap for US technology. As a general rule, we recommend that industry absorb the major cost of consortia management, leadership, and oversight, and that government help support the cost of technical work. The government should pay for consortia work at universities and national laboratory facilities, and industry should match that cost with at least 100 percent of in-kind work in their own laboratories.

We recommend that the US government establish and fund a national effort to support the following:

- Optoelectronics Technology Consortium
- Research Integration and Application Center
- Electronics and Semiconductor Materials Consortium
- Packaging Consortium
- Display Consortium
- Memory Consortium
- Simulation and Modeling Consortium (technology CAD)

The following existing associations and programs should be integrated into this complex:

- Microelectronics and Computer Technology Corporation
- SEMATECH
- Semiconductor Research Corporation
- Engineering Research Centers of the National Science Foundation.
- Semiconductor Projects of the National Institute of Standards and Technology Advanced Technology Program.

STRENGTHENING THE US MICROELECTRONICS INDUSTRY

In a previous study, it was concluded that the first priority for government microelectronics programs should be to help the US microelectronics industry regain its competitiveness.[1] This priority is dictated not only because private, commercial industry provides most of the microelectronics used in government systems, but because microelectronics is the key to a strong US economy. The question is how can government best help industry? Should government limit its involvement to basic research and the research and development of technology that is unique to the needs of government? Or should government help to establish collaborative efforts that will strengthen the competitiveness of the US microelectronics industry, and in turn strengthen the US economy in general? We see the latter as the answer. While an arms-length relationship between industry and government might be the ideal arrangement for market forces to direct industry's investment patterns, the reality of the matter is that government and industry are already linked in innumerable ways. Some of these are depicted in Figure 1.

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1. James E. Gover, *The Role of Microelectronics in the Military and Economic Dimensions of National Security: Reinvesting the Peace Dividend in Microelectronics*, SAND91-2785, Sandia National Laboratories, Albuquerque, NM, January 1992.

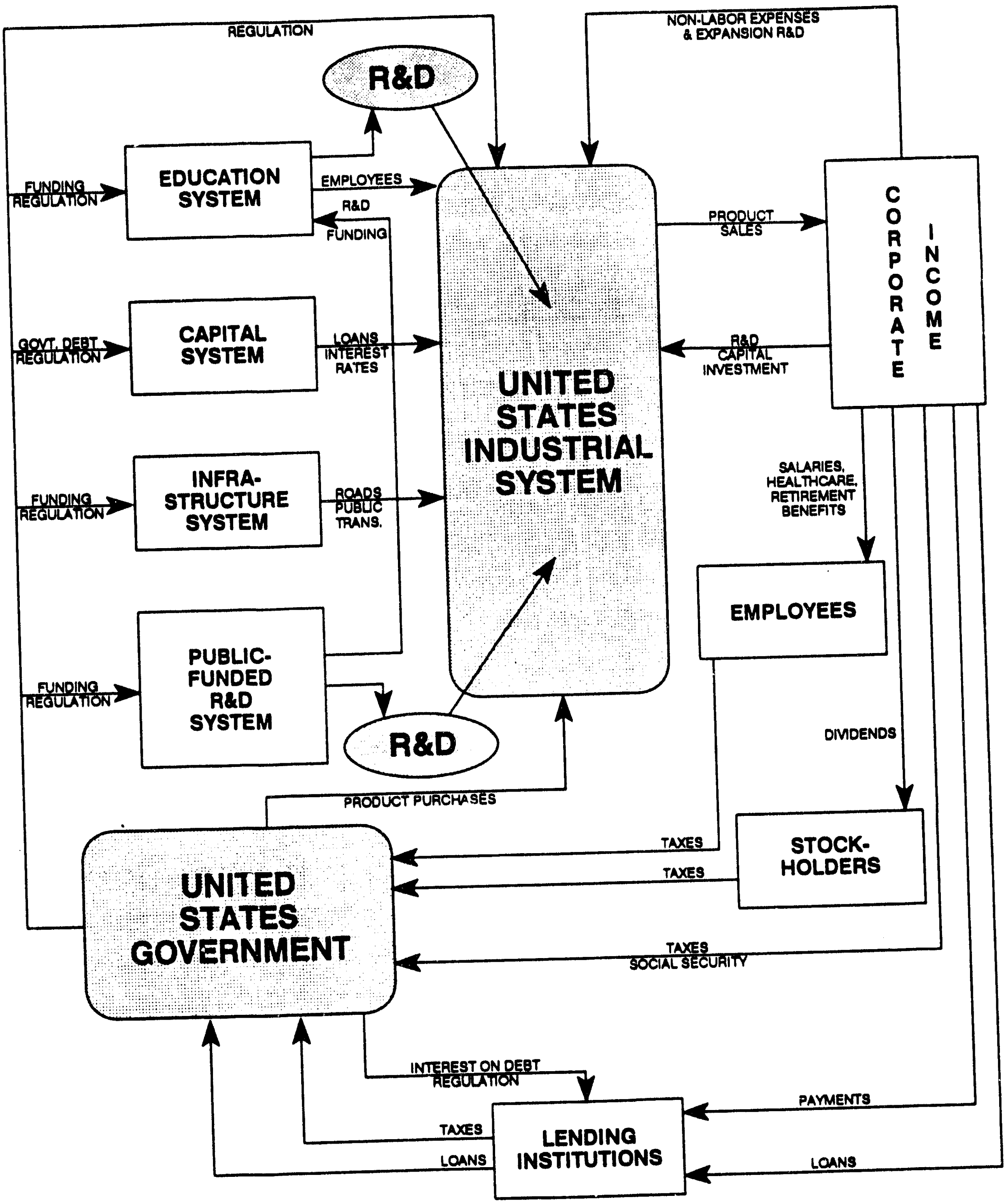

Figure 1 Government and Industry Interfaces

In this study we are searching for an effective way for the federal government to redirect some of the resources of the publicly funded R&D system. We do not argue that publicly funded R&D is as efficient or as effective as privately funded R&D; rather, we believe that if the federal government chooses to continue funding R&D, then it is appropriate that an increasing fraction of that R&D be of value to the commercial sector. In a recent study of the U.S. capital system, Professor Michael Porter, Harvard Business School, concluded that many US firms invest too little in those assets and capabilities required for competitiveness (especially intangible investments such as employee training and research and development), while wasting capital on investments with limited financial or social rewards.[2]

In a report of the National Science Board, there was a stern warning that the US is in danger of falling further behind other countries in economic competitiveness because of an eight year slump in spending for commercially relevant R&D. The chairman of the committee issuing this report, Dr. Roland Schmitt, former President of Rensselaer Polytechnic Institute, stated at a press conference that closing the current R&D gap between the United States and its chief competitors might require an increase of $25 billion in annual private and federal spending.[3] It is unlikely that this additional investment can immediately be made by the private sector. It could, however, be attained by reprogramming of the federal R&D investment.

With Japan's investment in commercially-relevant R&D having grown at 10 percent per year (until set back by their recession) in comparison to 0.4 percent for the US, it is apparent that making an increasing percentage of the federal R&D investment commercially relevant is a necessary step but only a stopgap measure. US industry must over the long run increase their investment in R&D. Note that Professor Porter's study recommended that policy makers focus on ways to encourage industry to increase their investments. However, many of his recommendations will be slow in implementation, e.g. increased public and private sector savings, whereas reprogramming of federal R&D can occur on a relatively short time scale if Congress and the President so wish. Furthermore, without major shifts of funds among various federal agencies, reprogramming of federal R&D can be made with minimal political conflict.

In this study, we develop the case for government-supported consortia that develop competitiveness and strengthen the US microelectronics industry. This recommendation is based on the success Japan has had with its consortia and the effect of that success on its national economy. In addition, examination of options for federal R&D funding shows that for those areas driven by product and process improvements, consortia are the most effective option. First, studies of US competitiveness are examined to determine the weakest areas. Because Japan's competitiveness has increased so markedly since the formation of its consortia, the principles on which its consortia are based are examined to see what the US can learn from them. The principles on which US consortia are based are then examined and compared with the

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2. Michael E. Porter, the Council on Competitiveness and the Harvard Business School, *Capital Choices--Changing the Way America Invests in Industry*, June 25, 1992.

3. *The Washington Post*, "National Science Board Warns US Must Beef Up R&D," Thursday, August 13, 1992, p D10.

Japanese experience. Criteria proposed for more successful consortia are also listed. The examination of the principles leads to a compilation of criteria to guide the development of successful US consortia that are compatible with industry's needs, and a role for government is proposed that we believe will strengthen the competitiveness of US industry. We have not dealt with legal issues surrounding antitrust matters and the ownership of intellectual property developed by consortia. We assume that the legal framework for these matters was developed when SEMATECH and other consortia were established. If antitrust issues that need further legislative attention exist, they are not addressed here. We believe that the integration and synthesis process we have used in this study has led to valid and appropriate recommendations for the microelectronics industry and that they are useful for other areas of technology as well.

REQUIREMENTS FOR CONSORTIA

CONSORTIA MUST DO MORE THAN GOOD RESEARCH

The Alvey Program, a five year, $360M government sponsored collaborative research effort in Britain that was intended to develop generic, precompetitive information technology, has recently been evaluated by two of Britain's science and engineering policy experts. These evaluations concluded that despite meeting its research goals, the Alvey Program did not help the British information technology industry. In particular, Alvey has been faulted for concentrating too narrowly on research and for having unrealistic expectations for the sharing of precompetitive research among rival companies. Alvey planners were criticized for misunderstanding the Japanese programs they were trying to imitate as well as overvaluing the strength of research alone.[4] US policymakers could be criticized for having made the same mistakes.

The overall US R&D investment has consistently exceeded that of international competitors by a factor of three to five. Even when defense-related R&D is excluded, the US invests more in R&D than any other country. In 1985 the US spent twice as much on nondefense R&D as Japan and almost five times as much as West Germany, yet both of those countries made important gains in market share in industrial sectors with the highest value-added potential.

> "The simple answer is that research, in and of itself, does not promote competitiveness--more money does not necessarily translate into market share."[5]

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4. *Science*, "Britain Picks Wrong Way to Beat the Japanese," Vol. 252, May 31, 1991.

5. Arthur D. Little, "Report to National Center for Manufacturing Sciences," *Technology Transfer: R&D to Commercialization*, April 1989, p 6.

In electronics, products of competitors are often not that different. Therefore, time-to-market, marketing, customer service, quality, price, buyer confidence in the manufacturer, and similar factors drive buyers' decisions.[6] Nevertheless, in response to international competition, the US government has often increased its research investment rather than attend to these issues. However, the requirements for competitiveness are far more complex and may not be solved by simply increasing government's investment in R&D.

Mr. Rueben F. Mettler, retired Chairman and Chief Executive Officer of TRW Inc. and past Chairman of the Competitiveness Policy Council's Manufacturing Subcouncil, has concluded that we need a far better understanding of competitiveness in a global economy. He explains that winning or losing in world markets depends on many factors including:

- the framework of policies and practices of corporations, government, and educational institutions
- management and strategy in large and small companies
- a skilled and motivated work force
- savings and investment levels
- tax policies and market access
- science, technology, and manufacturing
- product and process innovation
- quality and productivity
- marketing and distribution
- cooperation between public and private interests, and
- most particularly, **leadership and strategy from top to bottom**.

Mr. Mettler stresses the need for competitiveness solutions to be addressed in the **full systems sense** rather than as a narrow, single-issue solution.[7] The Competitiveness Policy Council identified six issues: savings and investment, education and training, technology, corporate governance and financial markets, health care costs, and trade policy as being deserving of priority attention in strengthening America's competitiveness.[8]

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6. *New Technology Week*, "Fields: We're not Going to Disrupt Operations As We Change Our Direction," May 13, 1991, p 8.

7. Ruben G. Mettler, "US Manufacturing in a Global Context," *The Bridge*, Summer 1991, p 5.

It is clear from only a cursory examination of existing federal semiconductor programs that none meet Mr. Mettler's admonition to address competitiveness in the full systems sense.

THE HARVARD COMPETITIVENESS MODEL PROVIDES A USEFUL FRAMEWORK

Professor Rosabeth M. Kanter of the Harvard Business School,[9] in an interpretation of studies by that institution, indicated that to be competitive high-technology organizations must:

- sustain core competencies
- achieve time compression for each cycle of product development
- make continuous performance improvements
- strengthen relationships, especially with suppliers and customers.

A company may strengthen their core competencies by building a knowledge base in those skills that are critical to the success of the company. Hamel explains that core competence is best understood in terms of the fundamental benefit it provides a customer.[10] If, for example, they build a product in contrast to providing a service, manufacturing is likely to be a core competence.

To strengthen core competencies, a company must collect knowledge from all available sources and they must spread and share that knowledge throughout the company. Employees must be open to learning from each other, and they must be willing to learn from outside the company. (While learning outside the company is fully accepted in Japan's culture, US companies have often considered this practice to reflect on their competence.) To fully capture the value of new knowledge that is originating from outside the company, as well as become an accepted member of the knowledge generating network, employees must be capable of generating original knowledge themselves. We believe that those US companies that manufacture semiconductors demonstrate these characteristics and, in general, have as strong, if not stronger, core competencies than their foreign competitors.

To compress time a company must be the first to market with innovative new products or they may be the first to use innovative new products and processes. Professor Fumio Kodama, Saitama University, has identified technology fusion, the blending of incremental technology

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8. Competitiveness Policy Council, *Building a Competitive America*, March 1, 1992, p 17.

9. Rosabeth Moss Kanter, "How to Compete," *Harvard Business Review*, July - August, 1990, p 7.

10. Gary Hamel, "Corporate Imaginations and Expeditionary Marketing," in *Challenging Conventional Thinking for Competitive Advantage*, The Conference Board Report, No. 1021.

improvements from several previously separate fields of technology, as a way of creating new products that revolutionize markets. (We later identify this as a form of new market-driven commercialization.) Professor Kodama emphasizes that technology fusion occurs only when the market drives the R&D agenda, the company has intelligence gathering capabilities that track technology advancements both inside and outside their industry sector, and the company has established cooperative R&D ties with a variety of companies across many different industries.[11]

Time compression also occurs by making reductions in the cycle time of products, usually by introducing incremental improvements to products and processes faster than competitors. Rapid response to customer needs and learning to do work concurrently, e.g., research, development, and manufacturing, rather than sequentially, are also ways of compressing time. We believe that US semiconductor companies lead foreign competition in time compression and with further improvements in modeling of products, processes, and manufacturing can increase their lead in this area.

Continuous improvement is the making of step-by-step incremental improvements to organizations and their products and processes. The mindset must avoid binary reasoning that classifies organizations, products, and processes as either good or bad. Rather, measures, customer feedback, training, and other mechanisms are employed to accelerate learning and always be on the lookout for improvement opportunities. It is important that goals be defined as a series of small victories, each building on the previous accomplishment. Benchmarking of competitors is necessary to determine if the rate of continuous improvement is sufficient. For most organizations implementation of a total quality management program or a zero defects management program is a key vehicle for making continuous improvements.

When a new product is introduced in Japan, according to Peter Drucker, the company introducing the product immediately pursues a tri-direction strategy for replacing it. One track organizes work to improve the product with specific goals and time deadlines--with the sum of these improvements resulting in a truly different product (product and process improvement driven commercialization). Another track is developing an entirely new product from the technologies used in the existing product (new-market driven commercialization). The third track involves the innovation of an entirely new technology to achieve functionally the performance characteristics of the original product (technology driven commercialization). According to Drucker the leading Japanese companies pursue all three strategies simultaneously under the direction of the same cross-functional team.[12]

In commercialization models we will discuss later, these three methods of commercialization are identified, respectively, as product and process improvement commercialization, new market driven commercialization, and technology driven commercialization. According to Masaaki Imai,

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11. Fumio Kodama, "Technology Fusion and the New R&D," *Harvard Business Review*, July-August, 1992, p 71.

12. Peter Drucker, "Japan: New Strategies for a New Reality," *The Wall Street Journal*, October 2, 1991.

"KAIZEN strategy is the single most important concept in Japanese management--the key to Japanese competitiveness success. KAIZEN means ongoing improvement involving everyone--top management, managers, and workers. If asked to name the most important difference between Japanese and western management concepts, I would unhesitatingly say, Japanese KAIZEN and its process-oriented way of thinking versus the West's innovation- and results-oriented thinking."[13]

It is clear to us that US industry severely lags Japan in the development of continuous improvements. Even though many in the US can talk about continuous improvement from an intellectual perspective, few have truly embedded continuous improvement into their corporate culture. Quite simply, continuous improvement is orthogonal to US culture, including US corporate culture, US educational culture, and especially, US government culture. To develop continuous improvement programs that are competitive with those of Japan will require a full decade and only then with a large commitment of resources and spirit.

It is critical for companies to establish relationships not only with their suppliers and customers but within a company and between even competing companies. These relationships facilitate the sharing of knowledge and offer opportunities for the development of win-win relationships among companies, their suppliers, and their customers. Japan's companies, because of their highly vertically integrated structures, have embedded the establishment of relationships within their corporate cultures. In many instances the few US companies that are vertically integrated partially discard the potential advantages of vertical integration by operating as separate business units that compete for corporate resources and corporate management positions. We believe that US microelectronics companies have failed to develop relationships to the extent of their Japanese competitors. However, the pace with which US companies are establishing partnerships with Japanese competitors suggests that US companies are strengthening relationships with competitors.[14]

For a collaborative effort to be useful, it must help the participating companies to improve in the areas listed by Professor Kanter. It can do this by (1) cost sharing: to accomplish high risk projects, to reduce duplication, to support university research, and to benchmark foreign technology; and (2) doing what one company alone cannot do such as setting standards and forming multi-company, vertical relationships with suppliers and customers.[15]

Dr. William G. Howard, Senior Fellow of the National Academy of Engineering, has proposed a model of competitiveness complementary to the Harvard model. In his model, he observes that competitiveness is influenced by factors both external and internal to the competing company. Many competitiveness studies have focused their attention on external factors

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13. Masaaki Imai, *KAIZEN--The Key to Japan's Competitive Success*, McGraw-Hill Publishing Company, 1986.

14. Committee on Japan, Office of Japan Affairs--National Research Council, *US-Japan Strategic Alliances in the Semiconductor Industry: Technology Transfer, Competition, and Public Policy*, National Academy Press, Washington, DC, 1992.

15. Dr. Craig I. Fields, personal communication.

such as the cost of capital, equipment depreciation schedules, the legal and regulatory environment, education, and unfair competition. Although these external factors are of great value, (for example, US companies must have access to debt and equity capital at · ıtes equivalent to those of their competitors), internal factors are even more vital. Dr. Howard's internal factors are similar to those competitiveness principles identified by Professor Kanter and include internal competence, manufacturing skill, and the effectiveness by which industrial firms translate technological innovations to marketplace advantage (commercialization).[16] In semiconductors, there is little evidence that US firms suffer from a lack of internal competence, especially as it relates to the sciences that underpin semiconductors. The deficiencies exist in manufacturing skills and commercialization as evidenced by a review of the areas of weakness identified by the Council on Competitiveness and the Computer System Policy Project (CSPP). Prior to reviewing these results, we will explore commercialization issues.

COMMERCIALIZATION, NOT RESEARCH, IS THE US PROBLEM AREA

Dr. Eugene Wong, formerly with the Office of Science and Technology Policy, has observed that since World War II, the United States has dominated in basic research in nearly every branch of science. In most areas we have dominated in the development of breakthrough technologies. For a confirmation of Dr. Wong's assertion, refer to Table I.

In the field of electronics alone, the most breakthroughs were achieved in the US. Dr. Wong has stressed that we must learn to deal with the transition from technology innovation to successful commercial applications.[17] However, we conclude later in this section, using a commercialization model of Dr. Howard and Dr. Guile, that the US has in the past been quite capable in some areas of commercialization, e.g. technology-driven commercialization and new market-driven commercialization, but lags in other areas of commercialization, e.g. product- and process-improvement-driven commercialization.

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16. William G. Howard, Jr., "The Commercialization of R&D in the US," SRC Workshop on Commercialization of R&D in the Semiconductor Industry: A Comparison of US and Japanese Practices, June 19-21, 1990.

17. Eugene Wong, "The Influence of Government Policy on the Commercialization of R&D in US Industry," SRC Workshop on Commercialization of R&D in the Semiconductor Industry: A Comparison of US and Japanese Practices, June 19-21, 1990.

TABLE I:
SUMMARY OF INTERNATIONAL TECHNOLOGY TRANSFER

Technology	Nation in Which Original Research was Performed	Nation that First Commercialized Products	Nation that became Dominant in Product and Process Improvements
Fuzzy Logic	United States	Japan	Japan
Television	United States	United States	Japan
VCRs	United States	United States	Japan
Facsimile Machines	United States	United States	Japan
DRAM Memory	United States	United States	Japan
Flat Panel Displays	United States	United States	Japan
Robotics	United States	United States	Japan
Semiconductor Materials	United States	United States	Japan
IC Manufacturing Equipment	United States	United States	Japan
Lasers	United States	United States	Japan
Computer Aided Manufacturing	United States	United States	Japan
Digital Watches	Europe	United States	Japan
Total Quality Management	Europe	United States	Japan
Anti-Skid Brakes	Europe	Europe	Japan
Compact Disk Players	Europe	Europe	Japan
Aircraft/Jet Engines	Europe	Europe	Japan
Microprocessors	United States	United States	United States
Software	United States	United States	United States
Biotechnology	United States	United States	United States
Medical Technology	United States	United States	United States
Supercomputers	United States	United States	United States

Dr. Howard and Dr. Bruce Guile have divided commercialization into four classes.[18,19]

(1) Technology Driven Commercialization (Technology Push)

Has a risky and speculative market.
Can produce extremely large and rapid business growth.
Is frequently driven by revolutionary scientific discovery.
Requires a 15 to 20 year development period.
Can make the competition's business obsolete.
Is adaptable to linear organizations (Research-Development-Manufacturing).
Requires much supporting technology development.
Occurs infrequently.
Can have short-lived advantage as market shifts to product and process-improvement driven commercialization.
Is especially the domain of high-tech start-up companies in pursuit of niche markets.

(2) Product- and Process-Improvement Driven Commercialization (Market Pull)

Is based on a concept that has already been proven in the marketplace.
Emphasizes competition in price, performance, design, quality, and features.
Emphasizes rapid, continuous improvement, through incremental innovations in product design, production, and services.
Is the bread and butter of industrial technological innovation.
Is usually the large sales stage of technology driven commercialization.
Makes use of well-developed analytical tools and experience.
Has steady project goals defined as a continuous series of small triumphs.
Has short product cycles in which change occurs rapidly.
Has low technology risks.
Has low market risks.
Moves technology to the site of its application.
Puts high emphasis on quality.
Is not adaptable to linear organizations (Research-Development-Manufacturing) but works best with project teams.

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18. Dr. Bruce R. Guile, "Profiting from Innovation," Hearing on Acceleration of US Technology Utilization and Commercialization, US House of Representatives, Committee on Science, Space, and Technology, Subcommittee on Technology and Competitiveness, May 7, 1991.

19. William G. Howard, Jr., and Bruce R. Guile, *Profiting from Innovation*, The Free Press, 1991.

(3) New-Market Driven Commercialization (Market Pull)

Requires understanding customer needs.
Selects best technology to meet customer needs by searching everywhere.
Places most value on broad technology experience.
Has technology as the primary risk.
Finds customer relationships to be critical.
Gets best results from project teams.
Is often the domain of start-up companies in pursuit of niche markets.

(4) End Game Commercialization (Market Pull)

Maintaining a core set of technological capabilities is important.
Is mature phase of product- and process-improvement driven commercialization.
Has slow growth and low margins.
Must continue to improve while competitors are treating products as a cash cow.
Gets best results from project teams.
Focus on quality must remain a high priority.
Use of benchmarking is particularly valuable.

In those industry sectors dominated by technology-driven commercialization, US corporations have generally excelled. In those sectors dominated by product- and process-improvement-driven commercialization, US corporations have generally fared less well. As shown in Table I, in most categories dominated by product and process improvement commercialization, the US did the originative research and made the initial product introduction. Although the research thrusts of US government and academic institutions suggest otherwise, by far the majority of electronics products and semiconductors (maybe 95 percent of market) conform to the product- and process-improvement-driven and end game commercialization categories. The extensive work of Ralph E. Gomory, formerly an IBM executive and now president of the Sloan Foundation, has emphasized the dominance in the electronics world of fast-paced, evolutionary innovation that is driven by market needs.[20,21,22,23,24] In his studies, Professor Martin Fransman of the University of Edinburgh has stressed that the Japanese experience in areas such as computers and electronic devices has taught the United States that the

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20. Ralph E. Gomory, "Research in Industry," *Proceedings of the American Philosophical Society*, Vol. 129, No. 1, 1985.

21. Ralph E. Gomory, "Technology Development," *Science*, Vol. 220, May 6, 1983.

22. Ralph E. Gomory and Roland W. Schmitt, "Science and Product," *Science*, Vol. 240, May 24, 1988.

23. Ralph E. Gomory and Harold T. Shapiro, "A Dialogue on Competitiveness," *Issues in Science and Technology*, Summer 1988.

24. Ralph E. Gomory, "From the Ladder of Science to the Product Development Cycle," *Harvard Business Review*, November-December 1989.

acquisition, assimilation, and creation of technical knowledge, and correspondingly the achievement of international competitiveness, require neither the mastery of basic or fundamental science nor quantum leaps in knowledge.[25]

To have value and attract serious industry participation, US collaborative efforts in the electronics chain must conduct work that leads to or promotes product- and process-improvement-driven commercialization. These efforts are more likely to be effective when they employ catch-up strategies. Even those areas that are technology-driven (maybe 2 percent of the world electronics market) can quickly move into product- and process-improvement-driven commercialization as their market develops. Despite this fact, research-driven, leap-frog, breakthrough efforts are the focus of many collaborative programs even in areas dominated by process- and product-improvement-driven commercialization. Support of technology-driven and new-market-driven commercialization is attractive to government because work in these areas is easily shown to be precompetitive and therefore, politically correct.

New-market-driven commercialization, and in many instances, technology-driven commercialization are, for the most part, in the able hands of US entrepreneurs who foster the development of start-up companies to fill these niche markets. US start-up companies are the best in the world at supporting new-market-driven commercialization. Much of the credit for this is attributable to the availability of venture capital in the US. Few nations have venture capital firms. Assuring the availability of low-cost capital and reducing government regulations to a manageable set would likely be of more value than consortia efforts to companies whose products fit new-market and technology-driven commercialization. In Japan, a nationwide system of centers to assist small businesses with manufacturing technology was established and has proved very useful. Such a system, modeled after US Department of Agriculture Extension Service Centers, could also provide assistance to US companies that emphasize new-market commercialization or technology-driven commercialization market niches as well as end game commercialization. In the event the niche market grows to a market dominated by product- and process-improvement-driven commercialization, there is evidence that start-ups suffer from many of the same weaknesses that plague US corporate behemoths. For example, the area of flat panel active matrix displays provides evidence of a technology invented in the United States but which Japan took over from US start-ups as the product line moved to product- and process-improvement-driven commercialization.[26]

These discussions lead to the model of commercialization shown in Figure 2.

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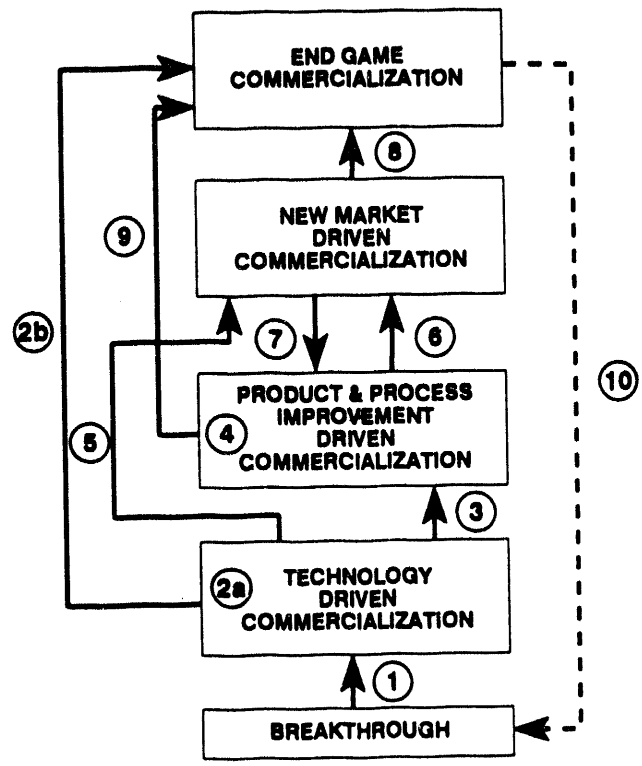
25. Martin Fransmann, *The Market and Beyond: Cooperation and Competition in the Japanese System*, Cambridge University, 1990, p 258.

26. Richard Florida and David Browdy, "The Invention That Got Away," *Technology Review*, August-September 1991, p 43.



(1) Science breakthrough leads to technology innovation

(2) Technology innovation protected by patents so that initial innovation is sustained (2a) until technology enters a mature phase (2b).

(3) Technology not protected by patents enters into competition with multiple companies.

(4) Technology advancement is improved for decades by competing firms with each improvement leading to a new product. Products can experience many cycles of improvement.

(5) Initial product innovation leads to new markets for the technology.

(6) During the improvement phases, new market opportunities are discovered.

(7) New markets can enter a product and process improvement phase.

(8) New markets protected by patents and sustained until market researches terminal phase.

(9) Eventually product and process encounter physical or economic barriers and technology enters mature phase

(10) Frustration with maturity of technology inspires breakthrough.

Figure 2 Model of Commercialization Based on Work of Gomory, Howard, and Guile

AREAS WHERE THE US IS STRONG AND COMPETITIVE SHARE COMMON FEATURES

As a first step in determining how to develop the principles that will lead to successful microelectronics programs in the US, an examination of studies analyzing strengths and weaknesses in US competitiveness along with the type of strategy that should be applied in each case is in order. In recent studies the Council on Competitiveness identified the competitive characteristics of US-based companies. Areas in which the US-based companies are already strong and competitive have these characteristics.[27]

- They are close to basic research (therefore, their commercialization is frequently technology-driven).
- They have low capital needs.
- They were initiated by individual innovation.
- They are supported by US government investment in basic research, defense procurement, and environmental regulations.

To this list we add our observation that they are in areas where intellectual property is most easily protected. Collaborative efforts in areas with these characteristics are not needed.

One may interpret these Council on Competitiveness studies to suggest that additional US emphasis on basic research is a lead maintenance strategy and would further strengthen an area in which the US is already strong. Despite the evidence coming from Japan that supports the creation of **catch-up consortia**, there is yet no clear evidence from Japan that lead maintenance, joint R&D is effective. Professor Wakasugi of Shinshu University predicts that with Japan's computer companies having caught or passed the US and Europe in technological standards, it is not guaranteed that joint computer R&D will continue to be an innovative organization in Japan.[28]

AREAS WHERE THE US IS WEAK OR NONCOMPETITIVE ALSO SHARE COMMON FEATURES

Areas in which US-based companies are weak or have lost much of their competitiveness have the following characteristics.[29]

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27. Council on Competitiveness, "Gaining New Ground: Technology Priorities for America's Future," March 1991, p 35.

28. Ryuhei Wakasugi, "A Consideration of Innovative Organization: Joint R&D of Japanese Firms," Schumpeter Conference, Siena, Italy, May 1988.

- These areas have insufficient private or public investment in the underlying technology.
- Risk sharing in technology development is inadequate among companies.
- These areas have high capital needs but companies have made inadequate capital investment.
- Extensive investments must be made in technology over a long period of time.
- Significant manufacturing focus is required to succeed.
- These areas have been targeted by foreign governments and industry.

Perhaps the best examples of areas exhibiting these features are flat panel displays and dynamic random access memories (DRAMs).

To the Council's list we add the observations that US companies have had difficulties in competing sectors where commercialization is driven by product- and process-improvements and sectors where intellectual property is not easily protected.

Collaborative efforts in these sectors must employ catch-up strategies that emphasize short term returns. In contrast to lead maintenance consortia, collaborative efforts that attend to US weaknesses and employ catch-up strategies would be of more benefit and interest to US industry. **In other words, US consortia should focus on technology development in manufacturing areas targeted by foreign governments that require lengthy and high levels of capital investment and in which the US is underinvested relative to the economic potential of the area.** After a competitive position is reached, the collaborative effort could break up or shift to a lead-maintenance strategy at reduced funding levels.

CAN GOVERNMENT-SPONSORED PROGRAMS HELP INDUSTRY COMMERCIALIZE TECHNOLOGY?

Economists believe that there is one reason for government support of commercialization by US industry--the marketplace has somehow failed. This failure could be due to government intervention in the marketplace (tariffs, restrictions of imports, funding of domestic industries, dumping of products at prices below their manufacturing costs, etc.) resulting in competitive advantage for their industries. For example, *The Economist* recently noted that nations of the European Commission in 1990 subsidized businesses $100 billion with $40 billion of this aid for manufacturing.[30]

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29. Council on Competitiveness, "Gaining New Ground: Technology Priorities for America's Future," March, 1991, p 35.

30. *The Economist*, "European Competition Policy--Aid Addicts," August 8, 1992, p 61.

Failure in the marketplace could also be due to regulatory and other domestic interferences with the free market instituted or condoned by the US government that disadvantage US industry relative to foreign competition. If a government program is to be effective in aiding commercialization, the source of the market failure must be identified and the proposed public policy change must be directed toward solving that problem.[31] Although such a strategy might seem obvious, federal programs instituted in response to a market failure do not always address the root cause of the market failure.

In addition to the above economic arguments, public investment can help harmonize the investment goals of corporations, which are, in principle, to make money for stockholders, with public needs, which are principally, high-paying jobs. Despite the widely held view that whatever is good for General Motors is also good for America, public and private interests can be orthogonal. As an example consider semiconductor partnerships between US and Japanese companies. In a recent study, the National Research Council noted that these partnerships benefit US companies by: (1) providing capital for survival; (2) by leveraging development and growth, technical, and investment resources; (3) by providing access to the Japanese market; (4) by providing freedom to focus resources on high-return activities; and (5) by offering opportunities for organizational learning. Costs or losses can accrue to the US company participating in the partnership or they may accrue to the US industry as a whole, including both upstream and downstream companies and horizontal competitors that are affected by the partnership. Costs include the transfer of highly valued enabling technology, the transfer of incremental technology, low return on expended resources, unsuccessful licensing alliances, long-term opportunity costs for semiconductors and downstream markets, technical dependence, and lost political independence.[32]

It is a legitimate responsibility of the federal government to assess the costs and benefits of these partnerships and ascertain that their overall impact on the US economy is positive. As the National Research Council explained,

> "It will be important for US policymakers, the American semiconductor industry, and other analysts to continue to monitor the mechanisms and impacts of US-Japan strategic alliances, to assimilate experience, and to consider changes in public policy and corporate strategy where appropriate. The US government and industry need to create an environment in which American firms have sufficient bargaining power in forming alliances, and the necessary information base must be developed to take full advantage of the possible benefits."[33]

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31. Mr. Mark Forman, Office of Senator Roth, personal communication.

32. National Research Council, *US-Japan Strategic Alliances in the Semiconductor Industry*, National Academy Press, 1992, pp 76-82.

33. Ibid, p 83.

One of these partnerships was formed by IBM, Toshiba, and Siemans to develop a 256 Mbit DRAM.[34] While likely to be in the interests of IBM, Toshiba, and Siemans, this agreement is not likely to be in the best interests of Intel, Phillips, and NEC. If it doesn't lead to an international 256 Mbit DRAM manufacturing cartel, it is in the best interests of the US economy because the R&D will be done in the United States and it practically guarantees IBM a source of 256M DRAMs for downstream markets. If the research and development work uses US made manufacturing equipment (made competitive through SEMATECH efforts that are partially supported by public funds), it is likely that Toshiba and Siemans will use the same equipment in their manufacturing plants. If IBM decides to market 256M DRAMS, this partnership may improve their chances for making sales in Europe and Japan. (It also improves Toshiba's chances for making sales in Europe.) If any of the three members of this partnership thought that this agreement would result in their capturing a smaller share of the world DRAM market than they otherwise could have captured, they probably wouldn't have made this sacrifice just to save $600 million in research and development costs.

Unlike consortia that because of government support may invite participation by weaker competitors, thereby leading to increased domestic competition, joint agreements like the IBM-Toshiba-Siemans partnership are made among equals. Those companies that are not already competitive in the international marketplace will not have sufficient bargaining power to be invited to reap the benefits of partnerships with technology leaders. Thus, in addition to consortia preparing companies to participate in international partnerships, they may also be used as a tool of the state to repair domestic damage done by international partnerships. If, for example, the federal government were to observe that the IBM-Toshiba-Siemans joint agreement had undesirable effects in the DRAM market, then government could revive the US Memories concept or support another initiative that brought additional domestic DRAM manufacturers into the competition. We see this flexible, real-time response of government as preferable to regulatory measures that attempt to anticipate the effects of international or even domestic partnerships and control their initiation.

Government investment may also be required to supplement industry investment, particularly in those technology areas where technology is highly competitive and rapidly changing. Watkins has argued that firms can't by themselves always make the investments necessary to provide themselves with commercially relevant technologies.

> "Markets may fail because of the negotiations and technology communications difficulties posed by complex, rapidly advancing technologies, and governments are in a unique position to overcome them. ...The coincidence of attractive economic and political prospects augurs well for the umbrella-consortia paradigm as a model for future public policies which seek to foster technological innovation and diffusion."[35]

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34. *Business Week*, "Talk About Your Dream Team," July 27, 1992.

35. T.A. Watkins, "A Technological Communications Cost Model of R&D Consortia As Public Policy," Research Policy 20(1991) 87-107, Elsevier Science Publishers B.V. (North-Holland).

Leyden and Link argue that the government has a crucial role to fill in ensuring that society's general interests in innovation are represented in private-sector decision making through a variety of programs and initiatives that reward innovation at all levels in a way that creates as few countervailing distortions as possible. They propose that government activities that fulfill this role fall into two general categories: (1) creation and maintenance of a legal environment conducive to private-sector investment in innovative activities and, (2) provision of sufficient stimuli to overcome the natural inclination of private parties to consider only their private benefits when choosing the level of innovative activity in which to engage.[36]

The American public is willing to make tax investments that result in jobs like DRAM research, development, and manufacturing provided that it is done within the United States. They are also willing to invest in basic research provided that there is a legitimate, well articulated connection to United States needs and that research benefits US manufacturers more than their foreign competitors. Vague platitudes that call for tax dollars to be spent for expanding the body of knowledge for its own sake don't sell well, particularly during an economic downturn. *The Economist* recently explained,

> "The taxpayer supports science so that it will solve problems and make inventions, not by and large because he thinks knowledge itself is a good thing."[37]

We are also reminded of another caution for government programs. Government must be careful to ascertain that public investment does not substitute for private investment. In fact, in the ideal case, public investment should stimulate more private investment because, if appropriately directed, it reduces the risk for private investment. It should be noted that few federal programs attempt to measure whether or not the federal investment stimulates additional private investment or if it, in fact, substitutes for private investment. Federal programs that directly subsidize industry incur these risks.

Having concluded that government has a legitimate but cautious role to play in commercialization, we examine the classes of research and development programs that government may establish that will impact commercialization. First we revisit commercialization using the model shown in Figure 2. Of course, research and development isn't the only mechanism government can use to support commercialization; tax and other regulatory measures may be even more important. Nevertheless, our attention is directed to research and development. The classes of research and development programs that government can support to strengthen commercialization that is driven by product and process improvements include research and development on new or improved methods of manufacturing, new or improved techniques of design, improved linkage between design and manufacturing, improved manufacturing processes, improved control of manufacturing processes, and new or improved manufacturing equipment.

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36. Dennis Patrick Leyden and Albert N. Link, *Government's Role in Innovation*, Kluwer Academic Publishers, Dordrecht/Boston/London, 1992, p 2.

37. *The Economist*, "A Survey of Science--The Edge of Ignorance," Feb. 16, 1991, p 17.

The classes of programs that government has deployed in the past to support research and development activities that are believed to benefit the competitiveness of US industry include those listed in the following:

(1) Consortia, for example, SEMATECH.

(2) Engineering Research Centers such as those established by the National Science Foundation and other applied research programs.

(3) Procurement programs in support of government missions that pull new technologies into the commercial marketplace, for example, defense procurement.

(4) Technology extension centers that assist small businesses in their use of new manufacturing and design technologies, for example, extension centers sponsored by the National Institute of Standards and Technology.

(5) Mission-driven research and development that spins-off technology that also has commercial use, i.e., dual use technology, for example, the Department of Defense, the Department of Energy, the National Aeronautics and Space Administration, etc.

(6) Technology transfer programs based on cooperative research and development agreements (CRADAs) are used to establish partnerships between corporations, universities, and federally owned laboratories. These programs rarely involve competitors participating in the CRADA. An exception is those that are linked to consortia. All federal agencies conducting R&D received CRADA funding.

(7) Basic research that leads to technology breakthroughs, for example NSF, NIH, DOE, ARPA, etc. sponsored basic research.

(8) Grants to small businesses to conduct research and development of a technology that shows commercial promise. All federal agencies sponsor small business grants.

(9) Direct funding of an individual corporation's R&D on commercial products. The Advanced Technology Program at NIST is an example.

Despite this wide array of federal programs that annually invest $75B in R&D, the federal government has not seen fit to invest in critical economic analyses of federal R&D. In fact without any quantitative framework for evaluating commercial success, political processes dominate decision making. Both ARPA and NIST are experiencing significant funding growth. Because most of this funding is divided into many small packages and spent in the private sector, it is politically popular. Its utility for economic growth has yet to be established.

CONSORTIA PROVIDE THE BEST METHOD FOR GOVERNMENT SUPPORT OF COMMERCIALIZATION DRIVEN BY PRODUCT AND PROCESS IMPROVEMENTS

The types of programs that government can develop to support commercialization depend upon the commercialization category according to the Howard-Guile model. First, we shall consider commercialization that is driven by product and process improvements. The importance of this class of commercialization is highlighted in the conclusions of Ralph Gomory and Roland Schmitt.

> "In technological areas where the United States has not been competitive, we have lost, usually not to radical new technology, but to better refinements, better manufacturing technology, or better quality in an existing product. An important point about incremental improvement is that it is built around the existing product--not around a new idea."[38]

Consortia that address all elements of the Kanter model and focus their work on strengthening manufacturing processes and design methods and, in particular, the linkage of these functions, can help those areas where commercialization is driven by product and process improvements. We see consortia that are composed of major manufacturers in an industry sector as well as their suppliers and customers as the best vehicle for rapid diffusion of information to medium and large manufacturers, an especially important need in sectors in which commercialization is driven by product and process improvements. If consortia also include horizontal companies that are lagging industry leaders, and consortia participation pulls these companies up to the standards of the industry leaders, they can serve as a vehicle for stimulating domestic competition and indirectly result in each member strengthening their core competencies. A National Academy of Science Panel chaired by Dr. Harold Brown concluded that Japanese experience suggests that publicly-funded R&D can rarely serve as a substitute for, but should more properly be seen as a complement to, in-house research. Dr. Brown emphasized that public investment may support technology adoption and dissemination as effectively as it supports technology creation.[39]

Although a consortium actually can directly strengthen the core competencies of all its members, it is difficult to argue that consortia are better than alternative programs for strengthening core competencies of the consortia members. Consortia may be the ideal vehicle for strengthening the core competencies of upstream suppliers, or consortia may be the ideal vehicle for strengthening the core competencies of its weaker members by diffusing knowledge from the stronger members. Because of their value in establishing relationships and strengthening suppliers, consortia should not be judged by their impact on the core competencies of leading competitors.

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38. Ralph E. Gomory and Roland W. Schmitt, "Science and Product," *Science*, May 27, 1988, p 1131.

39. National Academy of Science Panel chaired by Harold Brown, "The Government Role in Civilian Technology--Building a New Alliance," 1992.

Consortia can establish temporary vertical relationships and capture the value of vertical integration when it is really needed without suffering the penalties of complacency, entitlement, and destructive intra-corporate competition that sometimes accompanies vertical integration within a single corporation. Consortia can also lead to temporary horizontal relationships that can help diffuse information among domestic competitors during a period when a domestic industry base is threatened, without promoting monopoly behavior among horizontal competitors. We see consortia as having great potential for creating a win-win arrangement for the public and private sectors without favoring a select few in the industry group.

Consortia can be a vehicle for teaching the principles of continuous improvement, a necessary skill for those who are competitive in product and process improvement-driven commercialization. This teaching can be provided vertically to suppliers and customers and horizontally to competitors. Horizontal companies can especially benefit from sharing innovative ideas for implementation of quality programs, and it is easier to establish industry standards among competitors who have similar quality practices. When a manufacturer learns quality methods at the same time as their suppliers and customers, the likelihood of successful implementation is increased. We do not believe that any of the other styles of government programs has the potential to be as effective as consortia in teaching the principles of continuous improvement because other programs lack the range of industry contacts that are inherent in an industry-wide consortium.

To compress time companies must learn to do concurrently activities that they previously performed serially. Computer aided design techniques that link the design process so tightly to manufacturing that design and manufacturing can be done concurrently can aid time compression. In semiconductor manufacturing it has been traditional for semiconductor manufacturers to purchase existing manufacturing equipment and adapt it for use on their manufacturing lines. Process details are methodically developed and tweaked so that yields gradually increase as the quantity of manufactured product is increased. When semiconductor device physics models, thermal models, electromagnetic coupling models, stress analysis models, circuit design models, process models, and manufacturing equipment models have been developed with sufficient accuracy and tightly integrated, then circuit design, layout, and manufacturing process development will be performed concurrently, and the first manufacturing lot of new equipment and new designs will immediately provide yields expected during full production. Development of these analysis methods can be done in universities, government laboratories, and industrial laboratories. Therefore, we recommend that programs whose intent is to develop these tools could be funded through a variety of federal programs with the work coordinated and integrated in a user friendly way through a consortium. We do not see the consortium as a preferred mechanism for actually originating the models, but it is the preferred mechanism for managing the development, and for integration of the models into a package that meets industry-wide standards.

Of the remaining classes of government programs, the one that has the most value for supporting commercialization driven by process and product improvements is technology transfer programs that employ CRADAs to link government laboratories to industry. In the usual arrangement these programs link a single government laboratory to one or two corporations, therefore, they lack the range of horizontal and vertical companies that can be pulled together in a consortium. Furthermore, the range of problems they attack is limited by the needs of the few corporate participants. However, when a CRADA is used to link a government laboratory to an industry-wide consortium, it can achieve the breadth of corporate contacts available in the consortium. We believe that preference should be given to this class of CRADAs by government agencies.

TECHNOLOGY DRIVEN COMMERCIALIZATION CAN BE SUPPORTED BY A WIDE RANGE OF FEDERAL PROGRAMS

With few exceptions many types of federal programs are supportive of technology driven commercialization. While basic research funded by NSF, DoD, and DOE and applied work supported by NIST's Advanced Technology Program support technology driven commercialization, technology extension centers and mission-driven research and development have less potential. Whatever the programmatic arrangement, it should be determined prior to pursuit of the research and development work that US industry is willing to make the manufacturing investment required to commercialize the technology.

One of the most positive contributions government has made to new technology commercialization has been by serving as a customer for new technology through government procurement programs. Canada has had a similar experience. A study of high tech start-ups in Canada revealed that government serving as a customer was far more effective than government providing R&D financing.[40] For the most part US procurement has been through defense programs and commercialization of the new technology was not the primary intent of the program. In fact, generally new technology has been commercialized through government procurement only because there were no acceptable technological alternatives. Reversing the priority, if there is sufficient economic justification, could result in government playing an increased role in being the first customer of new technologies that have commercial potential. Consortia that are designed to strengthen upstream suppliers can provide a similar service by agreeing to purchase innovative new technologies and thereby allow the manufacturer of the new technology to justify the manufacturing investment.

CAN GOVERNMENT PLAY A CONSTRUCTIVE ROLE IN SUPPORTING CONSORTIA?

In the United States an adversarial relationship between government and industry has promoted few cooperative relationships and has resulted in strong opposition to any alternative for a constructive industrial policy or technology policy by government. Professor George Cabot Lodge of Harvard's Business School explains that this behavior is a feature of our basic ideology.

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40. Jerome Doutriaux, "High-Tech Start-Ups, Better Off with Government Contracts than with Subsidies: New Evidence in Canada," *IEEE Transactions on Engineering Management*, vol. 38, No. 2, May 1991, pp 127-135.

> "Most of the problems of our high-tech industries derive from America's traditional ideology of individualism. ...According to this ideology...government, a necessary evil, is a referee blowing its whistle now and then, but never a coach and certainly not a player. Bigness in government and in business is inherently suspect, as is cooperation between the two."[41]

For years the US government has invested more in research and development than any other government. The federal R&D investment nearly equals that of the private sector. While the federal R&D investment has been large by international standards, it has been directed toward government missions and basic research. Although technology transfer, dual use technologies, and technology spin-off from mission work have had some value in strengthening the competitiveness of US companies, that value pales in comparison to the investment potential of making this R&D directly attentive to commercial needs as its top priority. The federal investment produces basic research results that are available to the entire world. Therefore, even though this investment has great value to mankind, it does not preferentially advantage US industry. If the federal R&D investment is to be reprogrammed so that it has commercial value, it must be managed differently from mission directed work or basic research. In Tables II, III, IV, and V, we compare current government management practices for building core competencies, compressing time, making incremental improvements, and establishing relationships to those required to promote competitiveness in US industry.

Many doubt the ability of government to make these changes. As *The Economist* recently noted, despite the potential for improving efficiency of government through the use of computers, faxes, and low cost telephone service, the size of the US government continues to grow. Many US public institutions have become "top heavy."

> "Between 1980 and 1991 the number of officers in the American army grew by 7%, while the number of soldiers shrank by 3.5%. In 1965-1985 the number of non-teaching staff in school administration in the United States grew by 102% while the number of students shrank by 8%."[42]

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41. George Cabot Lodge, "It's Time For An American Perestroika," *The Atlantic Monthly*, April 1989, p 35.

42. *The Economist*, "Parkinson's Law, continued," August 8, 1992, p 16.

TABLE II:
COMPARISON OF CURRENT GOVERNMENT PRACTICES IN STRENGTHENING CORE COMPETENCIES TO THOSE NEEDED TO PROMOTE COMPETITIVENESS

CURRENT GOVERNMENT PRACTICE
Mission-Driven R&D
• Builds core competencies in government mission areas - industry value is second priority through dual use, tech-transfer, and spin-off
• Programs are defined by government with minimum industry input
• Programs lead to stronger competencies in products than manufacturing processes
• Builds an industry base that has core competencies in areas important to government missions without emphasizing commercial pursuits
• Discourages learning from other companies
• Encourages government to not use core competencies developed in the commercial market-place
• Funding distribution on the basis of constituent need leads to a lack of consistency in core competencies and gross inefficiencies in their development
Basic Research
• Builds core competencies through the development of new knowledge.
PRACTICES NEEDED TO PROMOTE COMPETITIVENESS
• Build core competencies in manufacturing and commercialization, areas U.S. industry has determined it needs to strengthen
• Support the growth of core competencies in U.S. commercial sector
• Build an industry base that has core competencies in areas important to industry's commercial pursuits that government can use to support government missions (not vice-versa)
• Invest in building core competencies through collection, interpretation, and diffusion of knowledge
• Support consortia and other programs that emphasize learning from others
• Fund to efficiently achieve industry selected core competencies

TABLE III:
COMPARISON OF CURRENT GOVERNMENT PRACTICES IN COMPRESSING TIME TO THOSE NEEDED TO PROMOTE COMPETITIVENESS

CURRENT GOVERNMENT PRACTICE
<u>Mission-Driven R&D</u>
• Budget process of starting small and growing tends to stretch program length
• Extremely difficult to kill programs - preferable to extend their duration
• Qualification, testing, and certification requirements stretch programs
• Sequential phasing of research, development, and manufacturing extends programs
• Spin-off, tech-transfer, and dual-use time scales are slow by industry standards
• Rules and regulations stretch programs
<u>Basic Research</u>
• Supports the introduction of innovative new products but does not preferentially advantage U.S. manufacturers
• Very small investment in basic research to reduce the development time of products or to discover radical new manufacturing processes
PRACTICES NEEDED TO PROMOTE COMPETITIVENESS
• Support industry in areas that industry determines to be critical
• Support roadmaps determined by industry to be compatible with industry's product cycles
• Emphasize evolutionary advancements in manufacturing to allow industry to reduce product cycle time
• Identify and eliminate government rules and regulations that interfere with rapid commercialization
• Search for innovation from around the world and diffuse the knowledge for rapid commercialization
• Emphasize concurrent engineering programs, streamlining the design process, and linking it to manufacturing
• Provide adequate initial funding to assure project success

TABLE IV:
COMPARISON OF CURRENT GOVERNMENT PRACTICES IN MAKING CONTINUOUS IMPROVEMENTS TO THOSE NEEDED TO PROMOTE COMPETITIVENESS

CURRENT GOVERNMENT PRACTICE
Mission-Driven R&D
• Programs tend to emphasize making major steps in product improvement rather than incrementally improving existing products
• Total Quality Management has not been used in government to the extent it has been used in industry
• There is little incentive for government contractors to make continuous improvements in products built for government
• Attention to design for manufacturability, cost of manufacturing, and manufacturing processes is less than that required for continuous improvement programs
• Quality is established by testing rather than robust design
• When performance specifications are met there is no emphasis on making improvements
Basic Research
• Science intensive, original breakthroughs that advance knowledge are emphasized rather than incremental steps
• Synthesis of others knowledge is emphasized less than creating original knowledge
PRACTICES NEEDED TO PROMOTE COMPETITIVENESS
• Encourage vertical consortia to provide quality training programs for suppliers
• Provide training techniques in quality methods and lean manufacturing to small business
• Encourage concurrent engineering and factory modeling
• Transfer R&D results rapidly to industry through industry management of programs and industry definition of each program, its roadmap, and its strategic plan
• Emphasize programs making incremental improvements to manufacturing processes
• Collect, interpret, and rapidly use knowledge developed around the world in the work of all programs
• Conduct R&D in a manufacturing environment

TABLE V:
COMPARISON OF CURRENT GOVERNMENT PRACTICES IN ESTABLISHING RELATIONSHIPS TO THOSE NEEDED TO PROMOTE COMPETITIVENESS

CURRENT GOVERNMENT PRACTICE
Mission-Driven R&D
• Relationship with suppliers is adversarial with government always being the customer for the work
• Vertically integrated structures and partnering are of concern because of their potential to promote monopolies
• Industry use of government-funded R&D for commercial benefit is of concern
• Most relationships are arms-length and formal because government also performs a regulatory function
• Control is preferred to empowerment
• Relationships formed in conduct of government R&D work have little commercial value
Basic Research
• Relationships established in the conduct of basic research usually are between scientists and have little commercial value
PRACTICES NEEDED TO PROMOTE COMPETITIVENESS
• Build relationships between university researchers, federal-owned laboratory personnel, and industry personnel must be a primary thrust
• Link industry with their suppliers and customers through virtual, vertical integrated structures
• Share knowledge as a primary emphasis on each program

Our 60 years of experience in government funded R&D have taught us that there is a historical basis for skepticism about the ability of government to sponsor successful programs. However, as David Osborne and Ted Gaebler have explained in their studies, when government agencies are forced to operate in a competitive environment (lean, decentralized, and innovative) in which their survival is at stake, they can learn to compete.[43] Osborne and Gaebler have compiled numerous examples of this for state and local governments. Their revolutionary work clearly shows that the issue isn't government versus the private sector, it is monopoly versus competition. Monopolistic practices in the private sector can lead to bureaucratic institutions that are as inefficient and ineffective as government agencies that operate in a monopoly environment. Of course, as Osborne's and Gaebler's work suggests, if government agencies are to become as efficient as private institutions, government institutions must be forced to compete with the private sector and government agencies must be forced to compete with each other. As Osborne and Gaebler explain,

> "Our governments are in deep trouble today. In government after government and public system after public system, reinvention is the only option left."[44]

Osborne and Gaebler have concluded that there are ten principles behind successful government.

(1) Most entrepreneurial governments promote competition between service providers.

(2) They empower citizens by pushing control out of the bureaucracy.

(3) They measure the performance of their agencies by focusing on outcomes rather than inputs.

(4) They are driven by their goals, not by rules and regulations.

(5) They redefine their clients as customers and offer them choices.

(6) They prevent problems before problems emerge.

(7) They put their energies to not only spending money, but earning it.

(8) They decentralize authority, embracing participatory management.

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43. David Osborne and Ted Gaebler, *Reinventing Government*, Addison-Wesley Publishing Company, Inc., 1992.

44. Ibid, p 331.

(9) They prefer market mechanisms to bureaucratic mechanisms.

(10) They focus not simply on providing public services; instead they catalyze all sectors--public, private, and voluntary--into action to solve their community's problems.[45]

Many have articulated the pitfalls of government involvement in research and development. Some believe that government has overestimated the value of big science projects. G. Pascal Zachary, staff reporter with *The Wallstreet Journal*, concluded that the US government became enamored with big science because of the remarkable success of the Manhattan Project. He notes that government projects that support either military or civilian goals have the following signature:

- Large-scale bureaucratic organizations that are insulated from economic markets and public referenda set research agendas.

- Facilities are dotted across many states in order to spread the wealth to satisfy legislators.

- Contractors are widely employed to mollify industries that feel threatened by government funded research.

- Political and social crises in need of solutions lend legitimacy to the researchers and their patrons.[46]

Zachary claims that federal technology policy is the prisoner of special interests whose missions have grown increasingly commercially irrelevant in the past 25 years. He advocates that the federal government establish driver projects in which a commercially relevant engineering problem is addressed. He cites candidate projects as electronics for the physically disabled, environmental sensors, flat screen displays, and the electric car as appropriate projects.[47] To his list we add advanced electronics for criminal incarceration, drug detection, and other public safety areas; electronics for health maintenance; and electronics for improved education.

Cynthia A. Beltz in reviewing the debate over high definition television cautions,

> "Rapid changes in technology and the emergence of sophisticated economic peers do challenge the United States to respond. But this response must be grounded in reasoned analysis of what is known, what is politically feasible, and what is likely to be constructive over the long haul."[48]

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45. David Osborne and Ted Gaebler, "Reinventing Government: How We Can Get More For Less From the Public Sector," Testimony before the Joint Economic Committee, March 5, 1992.

46. G. Pascal Zachary, "Where Did Big Science Take Us," UPSIDE, April 1992, p 18.

47. G. Pascal Zachary, "Time for the Big Science Spectacle to Fold Its Tent," UPSIDE, May 1992, p 90.

Linda Cohen and Roger Noll have reviewed case studies of government programs in the following areas: NASA communication satellites, photovoltaics, the supersonic transport, Clinch River Breeder Reactor, the space shuttle, and the synthetic fuels program. Of these, only communication satellites and photovoltaics were interpreted by Cohen and Noll to be successes. (Note that all of these are technology driven commercialization programs.) They identified the major pitfalls arising from these government-sponsored research and development programs and developed criteria for government support:

- Government programs should address technologies that are susceptible to market failures in private R&D decisions--failures that cannot be stimulated by general policies such as favorable tax treatment.

- A reasonably promising technological path should be available for developing new technology.

- Relatively inexpensive exploratory work should be conducted to investigate alternative pathways.

- Progression from exploratory work toward commercial demonstration must occur only if

  (1) greater effort at a less expensive, more exploratory stage is unlikely to produce compensating benefits in costs and performance, and

  (2) prospects for the technology must be sufficiently promising to warrant the more expensive next stage.

- The funding profile must recognize that successful program execution may require sustained expenditures over a long time; therefore those fragile political coalitions that form to gather program support for commercialization must be sustainable throughout the lifetime of the program.[49]

The Panel on the Government Role in Civilian Technology, chaired by Harold Brown, former Secretary of Defense, concluded that the guidelines for public sector support of government/industry R&D ventures should include cost-sharing provisions, project initiation and design by private firms, insulation from political concerns, a diversified set of R&D objec-

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48. Cynthia A. Beltz, *High-Tech Maneuvers--Industrial Policy Lessons of HDTV*, The AEI Press, 1991, pp 106-107.

49. Linda R. Cohen and Roger G. Noll, "An Assessment of R&D Commercialization Programs," *The Technology Pork Barrel*, The Brookings Institution, 1991, pp 365-373.

tives, and rigorous project evaluations and review.[50] Therefore, we believe that government can support consortia and other programs that facilitate competitiveness provided that certain principles are followed.

- The government agency funding the program must have a stake in its success.
- Economic metrics (market share growth, new jobs created in the private sector, total sales growth, increased industry investment in research, development, and manufacturing, etc.) must be used to determine program funding level and evaluate program success.
- Industry must determine the programs, their roadmaps and strategies, and industry must manage these programs to assure that program roadmaps are followed.
- Government (both the executive and legislative branches) must authorize, appropriate, and commit funds without specifying any more than funding processes, principles, and desired economic outcome.
- Government must be willing from the beginning to provide funds at levels sufficient to meet market demands and be willing to kill a program's funding when it is finished.
- Government must monitor industry's investment to assure that it is substantially larger than that of government and ascertain that government investment stimulates additional industry investment.
- Avoid selection of government and industry contractors based on political considerations.

All of these provisions were included in the Competitiveness Bill, S.3258, that was introduced on September 22, 1992, by Senator William V. Roth, Jr.

SEMICONDUCTORS PLAY A CRITICAL ROLE IN THE ELECTRONICS CHAIN

The electronics industry is a complex, multi-tiered structure that begins upstream with materials and equipment for manufacturing semiconductor integrated circuits. These form the hardware building blocks for the downstream electronics sectors. The electronics chain is depicted in Figure 3. In Japan, unlike the US, most of the companies that are heavily invested in downstream electronics sectors are also vertically integrated and heavily invested in upstream sectors, particularly in semiconductor manufacturing. Six vertically integrated firms produce 85 percent of Japan's semiconductors, 80 percent of Japan's computers, 80 percent of

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50. Panel on Government Role in Civilian Technology, National Academy of Sciences, National Academy of Engineering, and the Institute of Medicine, *The Government Role in Civilian Technology--Building a New Alliance*, National Academy Press, Washington, DC, 1992.

Japan's telecommunications equipment, and 60 percent of Japan's consumer electronics. In the US, approximately 80 percent of all semiconductors are manufactured by merchant firms that manufacture few or no other upstream or downstream products.

Of course, the electronics chain may be considered to be another generation downstream because the five major electronics sectors can dominate system applications of electronics. For example, Britain's Royal Navy awarded a contract to IBM for anti-submarine helicopters. The helicopter's flight controls, radars, laser countermeasures, infrared countermeasures, etc., all depend on sophisticated electronics while the basic helicopter structure is established technology. Because most of the value-added is in the electronics, an electronics company, not a helicopter company, is the prime contractor.[51]

Yuzo Takahashi, Department of Electrical Engineering, Tokyo University of Agriculture and Technology, has reviewed the history of Japan's post World War II success in developing electronic components. He notes that despite Japan being ten years behind Western competitors at the end of World War II, within 20 years they had caught and passed American component manufacturers in carbon fixed resistors, miniature vacuum tubes, capacitors, transformers, and crystal resonators. They did this not by leap-frogging US technology, but by making incremental improvements to US technology. By introducing quality methods to their design and manufacturing processes they were able to bring their operational parameters, e.g., resistance, capacitance, etc., under very tight control. The production of radio sets immediately after World War II provided the application pull for these components. Sony's development of transistor radios in the mid 1950's provided a market for both miniature versions of these components and transistors. These developments promoted the development of television sets and resulted in an average annual growth rate of consumer electronics sales between 1955 and 1960 of 60 percent.[52]

Mr. Allen Rosenstein, Chairman of the Board of Pioneer Magnetics, asserts that US component manufacturers did not voluntarily give up the consumer electronics business; rather Japan targeted consumer electronics and began with low-cost components and materials. Mr. Rosenstein further explains that Japan's companies used predatory pricing to dominate the components and materials markets; then they ate their way up the food chain to final goods. He predicts that they are doing exactly the same in computers, which will fall in a few years.[53]

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51. *The Washington Post National Weekly Edition*, "A British Contract Propels IBM Into Making Helicopters," September 9-15, 1991, p 21.

52. Yuzo Takahashi, "Progress in the Electronic Components Industry in Japan After World War II," Chapter 2 of *Technological Competitiveness: Contemporary and Historical Perspectives of the Electrical, Electronics, and Computer Industries*, edited by William Aspray, currently being reviewed for publication by the IEEE Press.

53. Mr. Allen B. Rosenstein, Chairman of the Board, Pioneer Electronics, and Professor of Engineering, University of California, Los Angeles, personal communication.

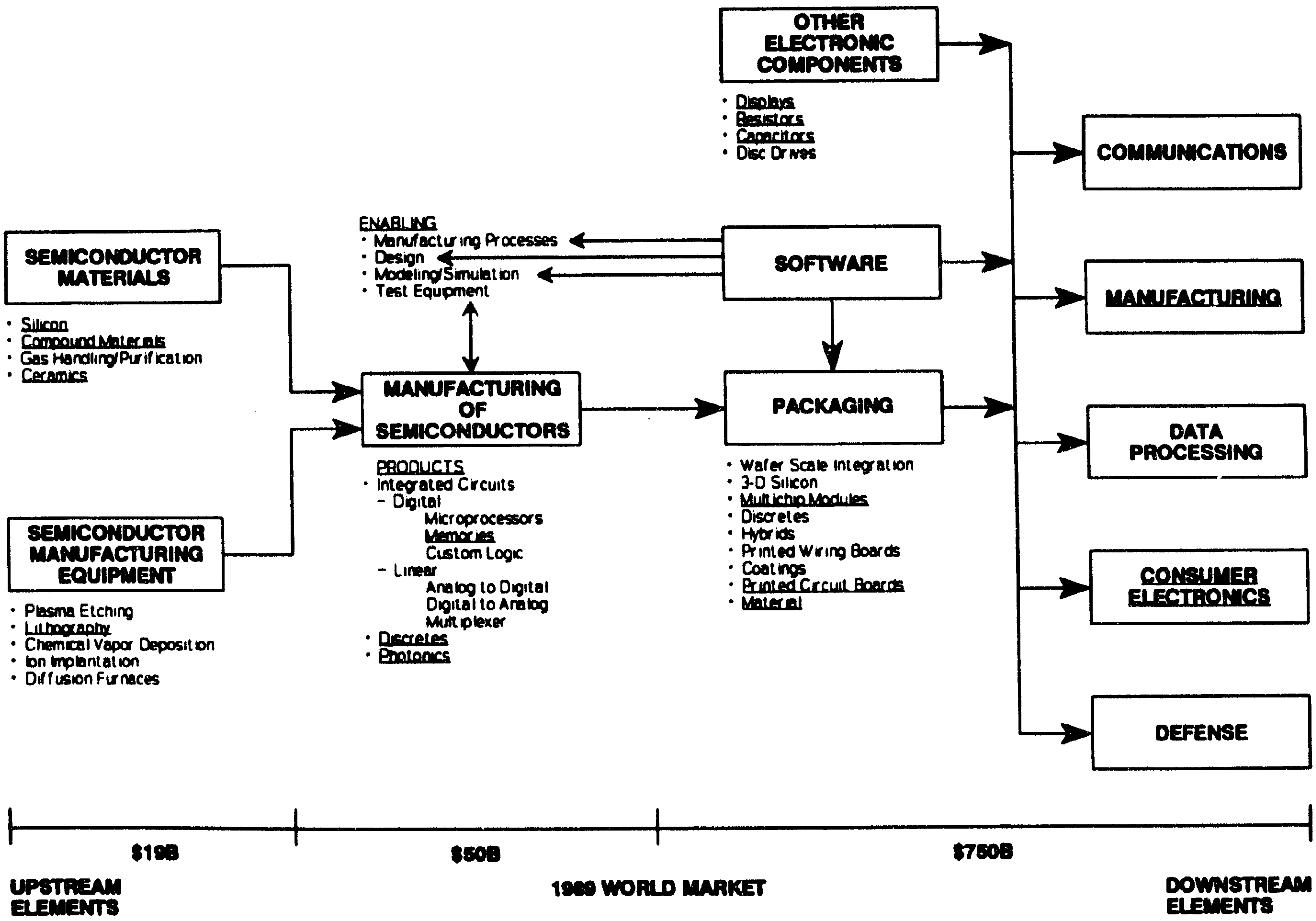

Figure 3 Major Elements of the Electronics Chain. Downstream elements are fed by upstream sectors comprising packaging, software, semiconductor manufacturing (including enabling capabilities), materials, and manufacturing equipment. Segments where US companies are having the most difficulty competing are underlined.

This capability led to Japan's dominance of consumer electronics.[54] In Figure 4, we show how this trend has continued since the early 1980's in comparison to other industry sectors that have also lost market share.

James Fallows, Washington editor of *The Atlantic Monthly*, has spent much of the last decade living in Asia and studying and writing about Japan's overtaking the US in electronics markets, particularly semiconductors. He attributes much of Japan's success in catching-up with US semiconductor manufacturers to the role of Japan's government. He argues that MITI's regulation of Japan's supply of DRAM chips was analagous to OPEC's regulation of oil supplies and was done to drive up DRAM costs.[55] Fallows concludes from his extensive research that the competitiveness problems experienced by US semiconductor manufacturers cannot be explained by the familiar reasons for industrial failure -- greedy bosses, pigheaded unions, rampant short-termism, and over regulation by the meddlesome state. He notes that the American semiconductor industry was doing everything right according to American economical theory, yet it encountered competitiveness difficulties. Fallows attributes much of our difficulties to persisting in thinking that Adam Smith's rules for free trade are the only legitimate rules. He proposes that today's fastgrowing Asian economies are using a different set of rules -- rules that the US once practiced but has now forgotten.[56]

Each sector of the electronics chain exerts both push and pull on neighboring downstream and upstream sectors. For example, by dominating consumer electronics, Japan created a local market for microelectronics that led to their domination of DRAM memory chips. *The Economist* pointed out that the country producing the best high-definition television (HDTV) displays will dominate the HDTV market and HDTV producers will buy the microchips needed to run the displays from local suppliers.[57] In fact, the semiconductor chips are likely to be an integral part of the display. If the worldwide market for HDTV reaches its peak, 40 percent of the semiconductor chip market will be used in HDTV sets. Thus, display technology pushes HDTV, which pulls microelectronics, which pushes other electronics sectors including computers. We subscribe to this bi-directional "domino" concept and believe that the United States must be strong in the upstream and midstream sectors in order to reap the full economic potential of the electronic sectors where sales are typically 10 to 15 times semiconductor sales.

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54. Consumer Electronics Sector Working Group, MIT Commission on Industrial Productivity, "The Decline of U.S. Consumer Electronics Manufacturing: History, Hypotheses, and Remedies," August, 1988.

55. James Fallows, "Looking at the Sun," *The Atlantic Monthly*, November 1993, pp 69-100.

56. James Fallows, "How the World Works," *The Atlantic Monthly*, December 1993, pp 61-87.

57. *The Economist*, "Japan Eyes a New Screen," August 31, 1991, p 69.

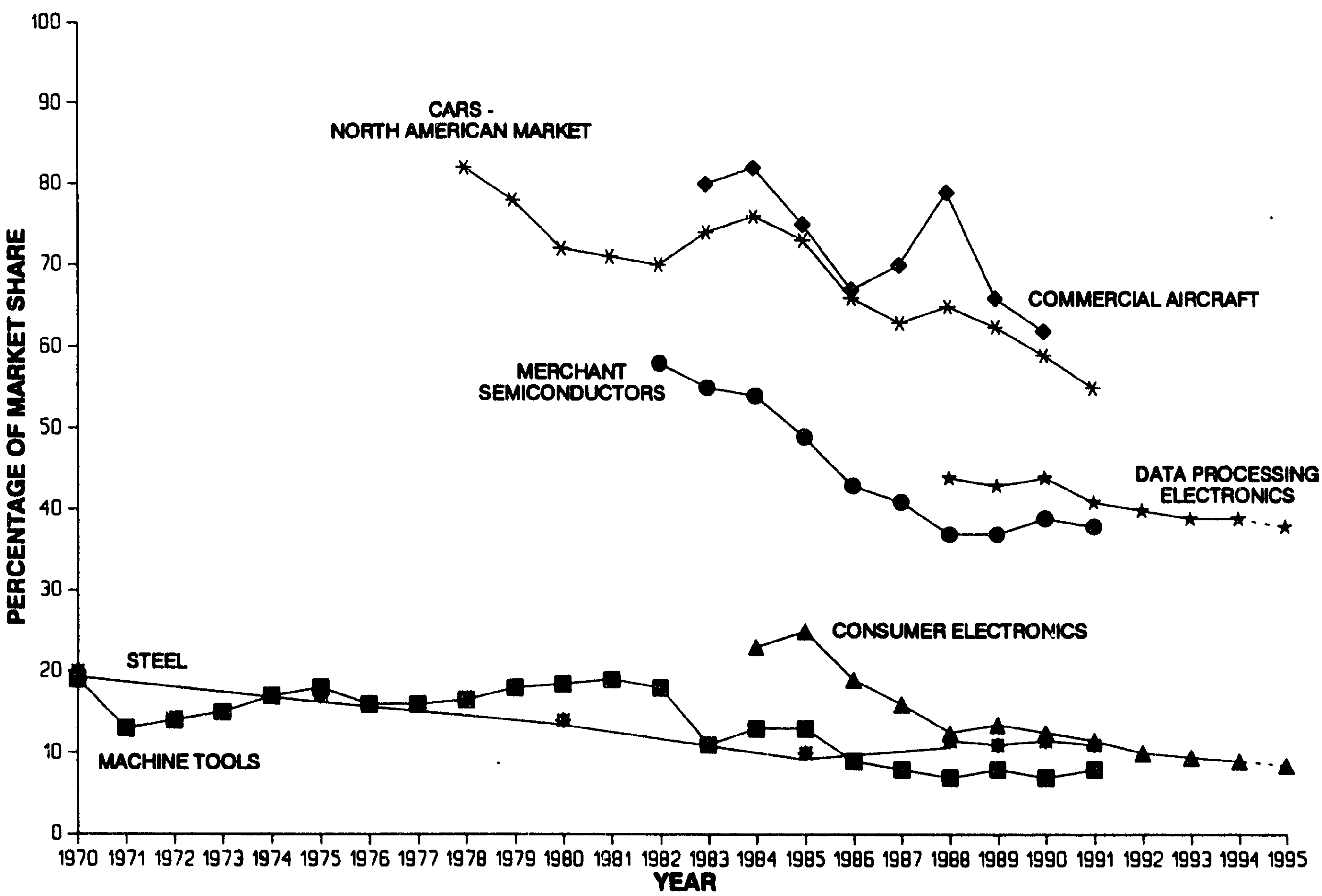

Figure 4 Market Shares of Industry Sectors Captured by US Companies. All data are world market share except where noted.

Dr. Ian M. Ross, President Emeritus of AT&T Bell Laboratories, has noted that high-volume electronics sales in consumer electronics has been the driver of high-tech electronics. The small TV has driven display technology; compact discs have driven laser technology, digital signal processors, and optical storage methods; and camcorders are driving processing power and miniaturization technology. Thus, the underlying technology base of electronics is "driven" or "pulled" by high-volume markets.[58] Dr. Andrew Grove, CEO of Intel, recently warned,

> "The companies that are beating US manufacturers in producing the enabling hardware for computers--semiconductor memories, displays, laptop computers--may well be on their way to owning those organizations that can produce the "computing utilities."[59]

Those who disbelieve the domino effect and therefore doubt the significance of loss of upstream electronics sectors are reminded that neither IBM, Motorola, Hitachi, NEC, nor any other vertically integrated, upstream component manufacturer is likely to sell state-of-the-art upstream component technology to a competitor if these sales enable that competitor to gain market share over them in a downstream electronics sector that has more market potential. (In fact, IBM, thought to be the largest semiconductor manufacturer in the United States, had, until October 1991, manufactured semiconductors only for IBM's use in downstream data processing applications.) Therefore, foreign control of these upstream sectors by vertically integrated companies provides competitive advantages to foreign companies in consumer electronics, computers and data processing, manufacturing and industrial electronics, communications, and defense electronics. Thus, control of semiconductor manufacturing equipment, semiconductor material, and semiconductor markets ultimately provides competitive advantage in the downstream electronics markets.

The Council on Competitiveness has said that

> "U.S. firms are having a hard time getting advanced technology from Japanese suppliers, according to a recent report by the General Accounting Office. Almost half of the 52 companies surveyed (by GAO) gave specific examples of Japanese companies rejecting orders for state-of-the-art equipment or parts, or delaying delivery by six months or longer. A brief delay in obtaining a part or piece of equipment can cause a company to fall a generation behind in its technological capabilities, resulting in lost market share, the report said."[60]

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58. Ian M. Ross, Statement before the US House of Representatives Science, Space, and Technology Committee, Subcommittee on Technology and Competitiveness, October 3, 1991.

59. Andrew S. Grove, "Should the US Abandon Computer Manufacturing," *Harvard Business Review*, September-October 1991, p 141.

60. Council on Competitiveness, "Challenges--Charting Competitiveness," November 1991, p 3.

Note that this is not an ethical or "level playing field" issue. It is a business issue! US companies--at least the few that are vertically integrated--have not and will not sell state-of-the-art microelectronics to customers to use in downstream applications with high profit potential, if the sale affects the ability of the US company to compete in that downstream market. For example, US semiconductor manufacturers that were selling microelectronics parts to US manufacturers of hand-held calculators quickly stopped selling microelectronics and started manufacturing calculators when they finally recognized the potential of this new business. To imagine that Japanese companies would not follow those business practices noted by GAO is irrational.

THERE ARE MANY AREAS OF MICROELECTRONICS IN WHICH THE UNITED STATES IS LOSING BADLY OR HAS ALREADY LOST

Those areas of the chain upstream from the electronics sectors that the Council on Competitiveness identified the US to be losing badly or already lost include:

- Display materials
- Ceramics for electronics
- Electronics packaging materials
- Gallium arsenide materials
- Silicon materials
- Integrated circuit fabrication and test equipment
- Microelectronic memory chips
- Multichip packaging systems
- Printed circuit board technology
- Electroluminescent displays
- Plasma displays
- Vacuum fluorescent displays
- Optical information storage

The Computer Systems Policy Project (CSPP), which represents all the major US computer manufacturers, has identified critical technologies in computing, the major part of the data processing sector, and characterized them relative to foreign competitors by categorizing them as "ahead," "lead rapidly diminishing," "behind" and "losing." Of special interest to this study are the "behind" and "losing" categories. In the following five areas of critical technologies, the US was judged to be clearly behind foreign competition.[61]

- Displays
- Manufacturing technology
- ULSI fabrication equipment and facilities

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61. Computer Systems Policy Project, "Perspectives: Success Factors in Critical Technologies," July 1990.

- Microelectronics
- Electronics packaging

Note that each of these technologies is critical to every downstream electronics sector. Under the current course and speed relative to the rest of the world, the 1995 US position in three critical technologies was projected by CSPP to be in the losing category. These were displays, ULSI fabrication equipment and facilities, and electronics packaging. (Liquid crystal displays alone are projected by analysts at Nomura Research Institute in Tokyo to be a $15B annual business by the year 2000.[62] In 1990, the world market for memory chips was $13.7B.[63]

In a survey of four dozen computer experts in the US, Japan and Europe, *Fortune* magazine ranked the capabilities of US, Japan, and Europe in the categories of microprocessor design, software, displays and printers, data networks, optoelectronics, and chipmaking equipment. This ranking revealed that the US was leading most areas, but lagged Japan in the areas of displays and printers, optoelectronics, and chip-making equipment.[64] Other studies, too numerous to cite, have reached similar conclusions.

THE US SHOULD TARGET SIX AREAS FOR CATCH-UP WORK

From the preceding authoritative studies, one can quickly conclude that the weak business areas which US collaborative, catch-up efforts in microelectronics should target include:

- Optoelectronics
- Electronics packaging
- Electronics and semiconductor materials
- Display technology
- ULSI fabrication equipment
- Memory chips

Note that these are well aligned with the seven areas of strategic electronics components identified by the American Electronics Association.[65]

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62. *The Economist*, "A Survey of Consumer Electronics," April 13, 1991, p 16.

63. *Fortune*, "Chipper Days for US Chipmakers," May 6, 1991, p 91.

64. *Fortune*, "Who's Winning the Computer Race?" June 17, 1991, p 58.

65. American Electronics Association, "Advanced Manufacturing Technology Initiative U.S. Electronics Industry Priorities," November 1993.

1. Integrated circuits
2. Printed wiring boards and multi-chip module substrates
3. Liquid crystal flat panel displays
4. Semiconductor packaging technology
5. Printed wiring board and substrate MCM assembly technology
6. High density batteries
7. Photonics

By the year 2000, the total world market for the six targeted areas will exceed $100B. More important, the nation controlling these targeted areas will have the upper hand in controlling the world electronics market which will exceed $2T. It is essential that the US regain its strength in these areas.

Collaborative efforts in these six areas must employ catchup strategies rather than lead-maintenance strategies. Thus, emphasis on long-range research should be minimal in comparison to emphasis on doing work that leads to continuous improvements in products and manufacturing methods, compressed product development cycles, and strengthened working relationships. If, for example, a consortium effort could develop highly accurate computer models of manufacturing equipment, manufacturing processes, integrated circuits, and the entire factory, then concurrent engineering methods could be developed. These would permit simultaneously developing next-generation materials, fabrication equipment for ultra large scale integrated circuits, memory chips, and high density memory chip packaging methods. Thus, time compression of many elements of the electronics chain that lead to computers, communications equipment, and other downstream elements would be aided. To accomplish this would require that each element of the chain be extremely well understood and strong cooperative vertical relationships would have to be developed throughout the chain. The development of advanced simulation and modeling tools is key to the use of concurrent engineering approaches in semiconductor process and equipment development.[66] Thus, we add modeling and simulation to our list of microelectronics target areas.

Gary Hamel, lecturer in business policy and management at the London Business School, and his research collaborators, Professors Doz and Prahalad, have explained that competing companies can benefit from collaboration provided that they adhere to the following principles:[67]

- Collaboration is competition in a different form.
- Harmony is not the most important measure of success.
- Cooperation has limits. Companies must defend against competitive compromise.
- Learning from partners is paramount.

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66. Findings of the Ad Hoc Study Group on Concurrent Semiconductor Process and Equipment Development (CSPED), for the Defense Advanced Research Projects Agency, Washington, DC, August 1991.

67. Gary Hamel, Yves L. Doz, and C. K. Prahalad, "Collaborate with Your Competitors--and Win," *Harvard Business Review*, January--February 1989, p 134.

US semiconductor collaborative R&D efforts are examined in the following sections. Competitiveness and commercialization models described earlier are employed in this examination. Lessons learned from existing consortia's experiences are identified for incorporation in future government-sponsored efforts. The success of consortia are not judged; nevertheless, recommendations for improving existing consortia are made. Prior to review of US semiconductor consortia and NSF Engineering Research Centers, Japan's consortia are examined.

HOW JAPAN'S CONSORTIA WORK

MITI's ROLE WAS CRITICAL TO THE DEVELOPMENT OF JAPAN'S ELECTRONICS INDUSTRY

To pave the comeback road to competitiveness, the US, once the teacher of high tech principles, must now become the student. We must learn from the methods that enabled companies in Japan to so successfully build the world's leading electronics industry in less than 40 years. The US has not realized the importance of Japan's Ministry of International Trade and Industry (MITI), thought by many in the US to be the ultimate example of industrial policy.

Japan's news media attribute to MITI many substantial contributions to their economy.

> "The (Japan) government's export oriented postwar economic policy has not infrequently dismayed our trading partners but it has helped to make Japanese manufacturers international leaders in electronics, cameras, telecommunications, consumer appliances, computers, and automobiles. Where Japan still lags, as in biotechnology and space science, the government is promoting interest and encouraging further research. The government has felt no need to make apologies for having helped guide corporate R&D although its strategies have sometimes exacerbated international trade friction."[68]

Mark Eaton, Director of International and Associated Programs at the Microelectronics and Computer Technology Corporation, convincingly argues that MITI and other industrial policy institutions in Japan played critical roles in guiding the Japanese economy to its achievements of the last thirty years. He sees these Japanese institutions as having assumed the role of entrepreneur on behalf of the state and as having prevented harm to Japan's essential small business community from competition between large corporations. It is clear from the analyses of Eaton and others that, contrary to the commonly held US model that private sector vitality and an active state role are mutually exclusive, MITI has demonstrated that there is no contradiction in Japan between private sector vitality and an active role for government involvement in industry.[69] In Figure 5 we show how MITI fits into Japan's government structure.

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68. *The Japan Times*, "What Constitutes Competitiveness," April 2, 1991, p 22.

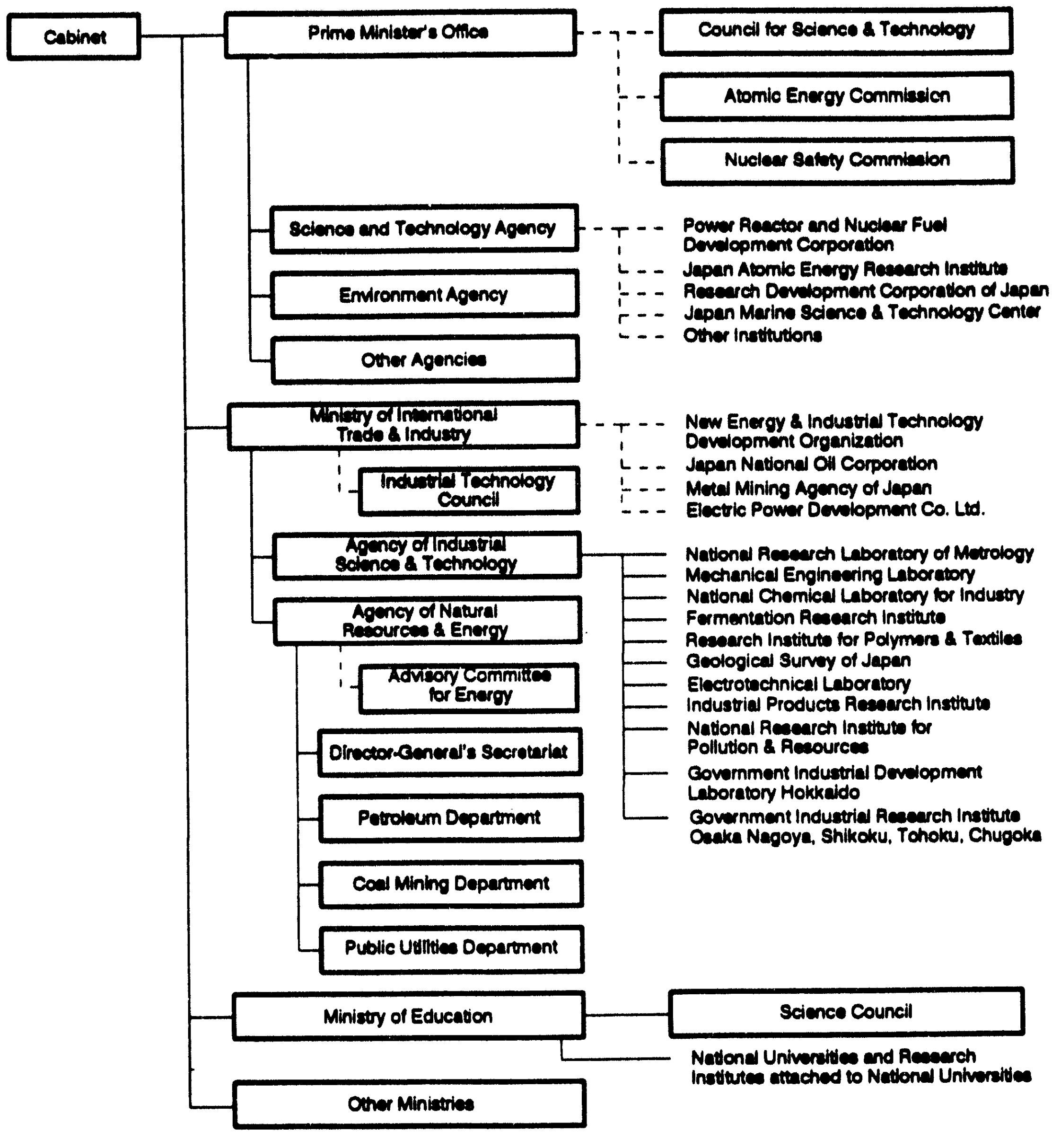

Figure 5 The Position of Ministry of International Trade and Industry in Japan's Governmental Structure

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69. Mark Eaton, "MITI and the Entrepreneurial State: The Future of Japanese Industrial Policy," unpublished draft report.

Mr. Grant Dove, when he was Chairman and CEO of Microelectronics and Computer Technology Corporation, observed that when MITI embraces a technology Japan's companies are prompted to get on the bandwagon. MITI creates momentum, which leads to new markets. Japan's consortia encourage companies to "test the waters" sooner.[70]

George R. Heaton, Jr., after completing a one year visiting professorship at the Institute for Policy Science at Japan's Saitama University, observed that Japan's government officials function more as convenors, mediators, record-keepers, and administrators than as planners of the industrial agenda.[71] **Typically, Japan's government takes action in response to industry suggestions rather than vice versa.**

Gerald Hane, currently serving as a member of the legislative staff in the US House of Representatives Science, Space, and Technology Subcommittee, has conducted the most thorough study of Japanese consortia principles by any American researcher. He spent over three years in Japan working directly with Japan's policymakers. His studies were focused on superconductivity and engineering ceramics consortia. He concluded that US models of MITI in some cases underestimate their role while other cases overstate their role. He notes that although outside sources carry the technical leadership, MITI exerts important power over firms in project formation with MITI's principal role in realizing a consortium being one of an enforcer.

> "Early leadership, the generation of ideas for research themes and the drawing of a research plan are all activities that are largely executed outside of MITI headquarters by university professors, industrial proponents, and by the national laboratory staff. MITI then reflects the expertise of these external sources of technology policy by actively promoting the activity with the industry."[72]

Hane depicts the relationship between MITI, university professors, industrial firms, and national laboratories as shown in Figure 6. By providing a combination of leadership and financing of consortia, MITI promotes diffusion of knowledge that is far more extensive than would occur in their absence. Their inclusion of relatively weaker firms in cooperative research projects aids the diffusion of knowledge into firms that otherwise would not be able to compete. MITI is also known for their vision and their ability to compensate for the short-

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70. Grant A. Dove, Plenary Session, Semiconductor Research Corporation, Washington, DC, February 27, 1990.

71. George R. Heaton, Jr., "The Truth About Japan's Cooperative R&D," *Issues in Science and Technology,* Fall 1988, p 36.

72. Gerald J. Hane, "Research and Development Consortia in Innovation in Japan," Ph.D. Thesis, Harvard University, John F. Kennedy School of Government, May 1992, pp 539-541.

sightedness and blind spots of Japan's corporations.[73] Of course, MITI is well known to employ very high quality personnel who frequently move into key industry positions when they leave MITI.

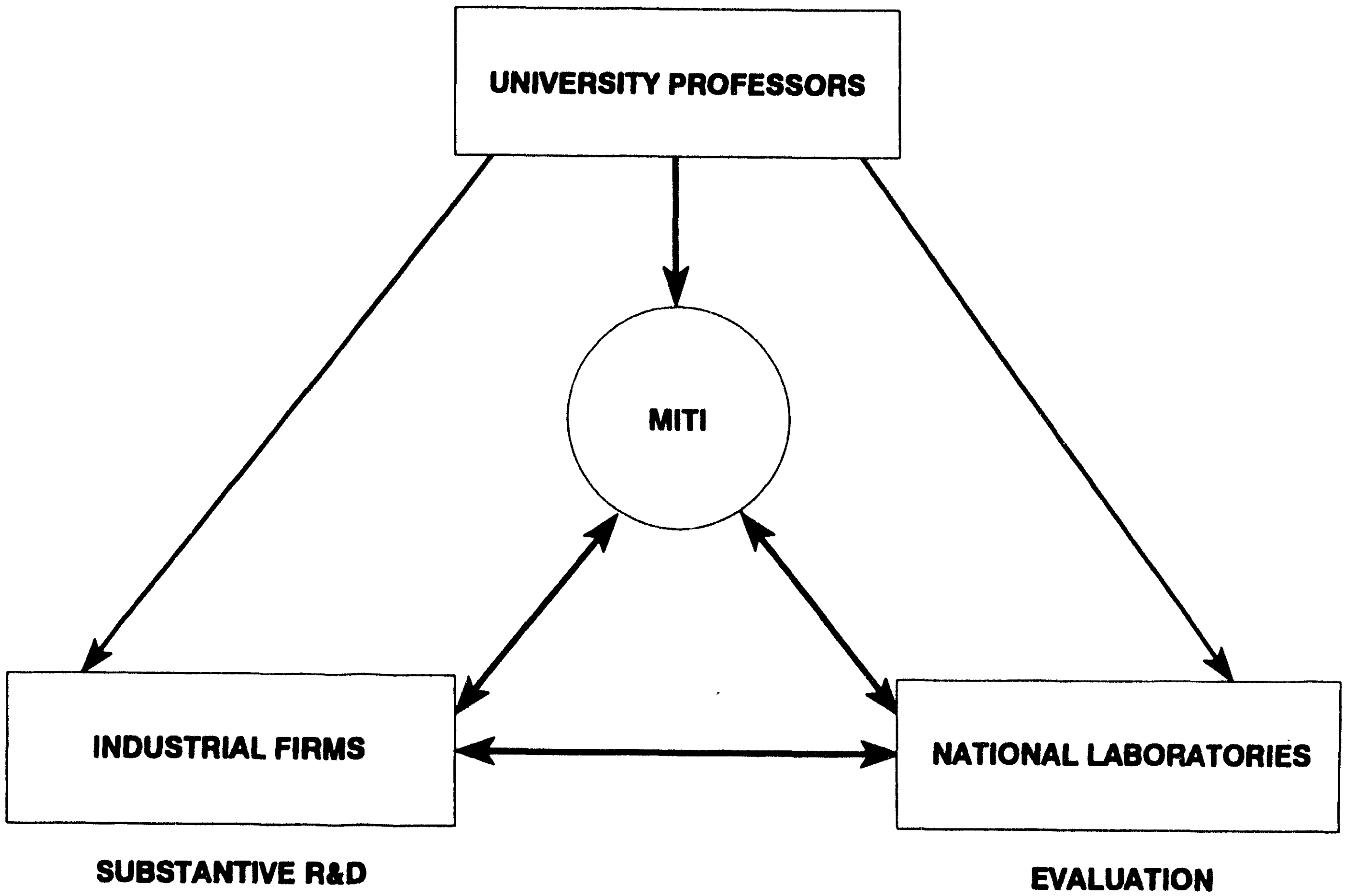

Figure 6 As Enforcer, MITI Leverages the Capabilities of Japan's National Assets and Provides Guidance and Conflict Resolution

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73. Martin Fransman, *The Market and Beyond: Cooperation and Competition in Information Technology in the Japanese System*, Cambridge University Press, 1990, p 283.

William G. Ouchi and Michele Kremen Bolton, in their extensive studies of research consortia around the world, have concluded that a so-called free market economic system that is entirely governed by markets may not always achieve the most socially desirable outcome. They suggest that new institutional mechanisms, such as consortia, may be necessary to stimulate the creation of intellectual property at socially optimal levels.[74] MITI seems to have determined, largely by trial and error, how to function in an institutionally optimum way to promote the creation of intellectual property. Although neither US industry nor our government wants a US government institution to fill MITI's role, it is clear that the US needs an organization to fill MITI's leadership function. With their recent coordination of the development of semiconductor roadmaps, the Semiconductor Industry Association (SIA) is filling this leadership void for the US semiconductor industry.[75]

While MITI has had a long history of successes, not all of their programs are judged to have been successful. Included in the latter category are: (1) attempts to force car manufacturers to amalgamate, (2) the driverless car, (3) fifth generation computer project, (4) the nuclear-powered ship, Nutsu, (5) HII rocket program, (6) cold fusion, and (7) high temperature superconductivity.[76]

It is important to not overstress the role of Japan's government in the development of Japan's electronics industries. As Odagiri and Goto explain, the policies of Japan's government would not have resulted in Japan's development were it not for the willingness and capability of the private sector.[77]

JAPAN'S OTHER GOVERNMENT AGENCIES ALSO CONTRIBUTE TO STRENGTHENING INDUSTRY

Although MITI is frequently identified as being behind Japan's industrial policy, other agencies contribute as well. For example, Japan's government institutions expend a great deal of effort to identify projects worthy of consortia interest. Technology forecasts play an important role. The Science and Technology Promotion Policy Bureau of Japan's Science and Technology Agency commissioned the Institute for Future Technology to conduct a technology forecast survey between the years of 1985 and 1987. About 3,000 technology specialists in Japan were asked 1,071 questions regarding the forecasting of technology. Respondents repre-

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74. William G. Ouchi and Michele Kremen Bolton, "The Logic of Joint Research and Development," *California Management Review*, Spring 1988, Vol. 30, pp 9-33.

75. Semiconductor Industry Association, "Semiconductor Technology: Workshop Working Group Reports," 1993.

76. *Science*, "Science in Japan," Vol. 258, October 23, 1992, p 577.

77. Hiroyuki Odagiri and Akira Goto, "The Japanese System of Innovation: Past, Present, and Future," in *National Innovative Systems*, edited by Richard R. Nelson, p 96.

sented companies (38%), academics (33%), civil service (19%), and industrial and professional association staff (10%). Questions addressed a comprehensive list of categories that are vital to Japan's future.[78]

Although one may debate the value of such a survey for the United States, in Japan such surveys have proved to be a valuable tool in underscoring the importance of scientific and technological development and identification of areas for government funding. Four such surveys have been conducted in Japan. The first was initiated in 1970.

Forward projection in Japan is exemplified by the following ten key advancements anticipated for its microelectronics program.[79]

1. Development of a logic circuit element operating at a switching speed of 1 picosecond or below. (1996)

2. Commercialization of a broad-band solid state amplifier qualified for 1,000 GHz or above. (2002)

3. Development of a three-terminal element using a light wave band (wave length of ~1 micron). (2000)

4. Development of a silicon semiconductor element with a switching speed of 2 to 3 picoseconds. (1997)

5. Application of logic circuit elements using super lattice. (2000)

6. Commercialization of a superconductive logic circuit. (2000)

7. Commercialization of large-scale integrated circuit production using synchrotron orbit radiation lithography. (1995)

8. Commercialization of technology for computer-aided design capable of designing large scale integrated logic circuits with more than 10^6 gates. (1993)

9. Commercialization of very large-scale integrated circuits with a memory greater than 100 Mbit per chip. (1998)

10. Development of super-high-integration devices with more than ten lamination layers of logic elements or memory elements. (1998)

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78. Institute for Future Technology, "Future Technology in Japan Forecast to the Year 2015 (Nijon no Gijutsu, 1987-2015)," September 1988, pp 5-6.

79. EGIS, "Japanese R&D Centers in Electronics--The Only Comprehensive English Study of Japanese Research and Development in the Electronics Industry," 5th Edition for 1988-89.

Daniel Okimoto explains that MITI's capacity to administer industrial policy is facilitated by the network of organizations that lie between state and private enterprise. He cites public corporations like Nippon Telegraph and Telephone (NTT), quasi-government organizations, special non-profit entities like the Information Technology Promotion Agency, and mixed public-private undertakings like the Japan Electronic Computer Corporation as examples of organizations that help MITI make and implement industrial policy. He notes that Japan's national research projects would be difficult to organize were it not for cooperative (engineering) research associations.[80]

JAPAN'S INDUSTRIAL POLICIES

In these discussions we have emphasized the role of Japan's government in strengthening Japan's industries. More important, however, are the underlying policies that have supported Japan's successes. MITI has been one of the agencies that helped establish and implement these policies. The Council on Competitiveness has identified key elements of these policies.[81]

- Japanese policies recognize that technological leadership is critical to national economic performance and independence.
- Japanese government-sponsored research emphasizes practical commercial applications.
- Government technology policies leverage private sector R&D.
- Industry is closely involved in the formation of science and technology policy.
- No single agency serves as technology czar (MITI spends only 13% of government's R&D budget).
- Government agencies in Japan often compete to help the private sector develop new technologies.
- Government-sponsored cooperative research projects create a "critical mass" of companies that can compete in a technology.

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80. Daniel I. Okimoto, "Regime Characteristics of Japanese Industrial Policy," in *Japan's High Technology Industries*, edited by Hugh Patrick, University of Washington Press, 1986, p 41.

81. David W. Cheney and William W. Grimes, "Japanese Technology Policy: What's the Secret?" Council on Competitiveness, February 1991.

- Japan excels at taking technology from around the world and putting it to work in Japan.

- Japan's top national priority is supporting industry, not basic research.

- Japan has initiated international research programs with other countries, but these have not yet met with great success.

Professor Wakasugi, Shinshu University, explains that it was because of government policy that joint R&D projects were so easily formed in Japan. **Joint projects were created as a mechanism for government to support an important industry sector without favoring one company over another.** Thus, consortia have been used in Japan to avoid government selection of winners and losers among their corporations. Those industry sectors in need of consortia are easily determined from world market size, market share, value-added potential, and the competitiveness status of Japan's companies working in these industrial sectors. Japan's lenient antitrust policies, tax incentives, and substantial funding have all promoted the formation of joint R&D projects.[82] In fact, it is because Japan can use consortia to assure domestic competition and avoid monopolies that they can have lenient antitrust policies.

The industrial policies in Japan have been highly evolutionary over a period of 50 years or more; Japan has experimented with a wide range of industrial policies. Those policies in place today are there because they work to the benefit of Japan's economy, not because they are attractive to ideological purists. Today's policies will be changed and improved as they begin to lose their utility. For example, Japan's government-business relationship has evolved during the 20th century from emphasizing self-control by industry to state control, and finally to emphasizing a cooperative relationship between industry and government. Preferred by big business, industry self-control can lead to control of an industry by the largest groups and it can lead to a divergence between the interests of industry and state. While state control promotes the priorities of the state, it inhibits competition, promotes inefficiency, and fosters incompetent and irresponsible management. The Soviet Union provides a recent example of this. Professor Chalmers Johnson, University of California, attributes the poor performance of Japanese industry during World War II to state control. The advantage of public-private cooperation in Japan is that it leaves ownership and management in private hands to achieve high levels of competition, while it allows the state to influence goal setting and industrial decision making to assure that the state's needs are met. Access to government financing, targeted tax breaks, risk-sharing, and other forms of government support assure industry participation in a relationship with Japan's government that industry would otherwise prefer to avoid.

According to Dr. Alan G. Chynoweth, former Vice President of Bellcore, visiting researchers from Japan hosted at Bellcore often report that their firms are not always pleased to send researchers to work at one of the MITI-supported engineering research associations and they question the benefits derived from participation. When they do participate they send fundamental researchers who are considered to be of less value than development personnel.[83]

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82. Ryuhei Wakasugi, "A Consideration of Innovative Organization: Joint R&D of Japanese Firms," Schumpeter Conference, Siena, Italy, May 1988.

83. Dr. Alan G. Chynoweth, personal communication.

In only a few areas does the relationship between the US government and US industry parallel Japan's government-industry relationship.

> "The relationship between government and business in the American national defense industries--including the unusual management and ownership arrangements for the nuclear weapons laboratories and the existence of such official agencies as the former Atomic Energy Commission and the National Aeronautics and Space Administration--is thought by Americans to be exceptional, whereas it was the norm for Japan's leading industrial sectors during high-speed growth. It is also perhaps significant that aviation, space vehicles, and atomic energy are all sectors in which the United States is pre-eminent."[84]

However, throughout the 1980s and early 1990s the US government's executive branch has shunned the establishment of ambitious government-industry partnerships to strengthen the competitiveness of industry. It has instead opted for an arm's length relationship with industry and has emphasized government support of research that is both precompetitive and generic. Of course the identification of what is precompetitive and what is not is completely dependent upon the perspective of the beholder. For example, a semiconductor manufacturer might consider a new lithography tool for manufacturing integrated circuits to be precompetitive because the tool was only beginning to be adopted by users. On the other hand, lithography tool manufacturers competing for the lithography market would identify this tool as having already entered their realm of competition.

If the US had established a National Electronics Commission, would US electronics industries have benefited? We believe these industries would be more competitive today if such an arrangement had been made. In the absence of government leadership, this role could be filled for electronics by trade associations such as the Electronics Industry Association or the American Electronics Association. Dr. Paul Krugman, Professor of Economics at the Massachusetts Institute of Technology, explains that there are two extreme views developing in the United States about how to respond to Japan's industrial policy. On the one side are free traders who naively expect Japan to suddenly adapt the trade practices of the United States. On the other side are Japan bashers who want the US to confront Japan with the threat of protectionist policies. Because Japan will not suddenly change if the bashers' position is adopted, it is likely that the United States would, in fact, be forced to implement protectionist practices that could ultimately lead to fragmentation of the world into mutually protectionist trading blocs. Professor Krugman proposes that the United States should adopt an explicit, but limited, industrial policy.

> "The US government should make a decision to frankly subsidize a few sectors, especially in the high-technology area, that may plausibly be described as 'strategic', where there is a perceived threat from Japanese

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84. Chalmers Johnson, *MITI and the Japanese Miracle*, Stanford University Press, Stanford, CA, 1982, pp 311-312.

> competition. It is possible that the costs of such a policy would exceed its economic benefits. But the downside would be limited: Federal expenditures of, say, $10 billion a year to support industrial R&D consortia would produce at least some benefits. So at worst the net cost of the program to the economy would be a few billion dollars a year--or less than one-tenth of 1 percent of GNP."[85]

On the other hand, the upside potential of Professor Krugman's recommendations is indeed compelling. Evidence of the payoff of such a policy is provided by the European aircraft manufacturing consortium, Airbus Industries. After 21 years and $26 billion (including interest) of funding by the French, British, German, and Spanish governments, Airbus has captured 30 percent of the world market share of commercial aircraft and has displaced McDonnell Douglas as second in market share to Boeing. (Of course, the world market for electronics products is over ten times that of aircraft. Furthermore, much of the competitive advantage of aircraft accrues from their creative application of electronics.) It took Airbus 20 years to show a profit, but it now has an order backlog of 990 aircraft valued at $68 billion.[86] It took Japan about 30 years from the establishment of their first Engineering Research Association to take market share in semiconductors from the United States.

JAPAN'S COLLABORATIVE EFFORTS MINIMIZE THE NEED FOR HORIZONTAL COOPERATION

According to Professor Akira Goto, Department of Economics at Hitotsubashi University and Yale University, research collaboration in Japan dates back to the early twentieth century and was important to the growth of textile and ceramic exports. Much of the early research collaboration in Japan was orchestrated by trade associations and assisted by regional public industrial laboratories.[87]

Dr. Dorothy Robyn, while a member of the staff of the US Congress Joint Economic Committee, noted that 90 percent of Japan's collaborative research involves only two firms that are typically vertically structured (maintaining a relationship with suppliers and customers). Only 20 percent of Japan's joint research is horizontal (between companies producing the same product line). Much of the horizontal research is conducted through engineering research associations (ERAs) first established in 1961. For example, a 1982 survey by Japan's Fair

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85. Paul Krugman, *The Age of Diminished Expectation--US Economic Policy in the 1990s*, The MIT Press, p 131.

86. *New York Times*, "There's No Stopping Europe's Airbus Now," June 23, 1991, Business Section.

87. Akira Goto, "Collaborative Research in Japanese Manufacturing Industries--Innovation in R&D System?" presented at Japan Economic Seminar, Harvard University, April 20, 1991.

Trade Association determined that 5.5 percent of collaborative R&D was carried out through ERAs. In Japan, horizontal alliances such as ERAs succeed only with government's sponsorship.[88] Because one-third of Japan's industrial R&D is collaborative, we have tended to view Japan's companies as a close-knit organization that routinely work together as a single unit. According to the Council on Competitiveness, some Japanese companies view large joint projects as a cost of doing business. Japanese consortia emphasize information exchange and coordination of a research agenda more than actual joint research and they have been most effective in catch-up situations.[89] By 1983 Odagiri and Goto estimate that one-half of government subsidy of Japan's industry was supplied through Engineering Research Associations.[90]

In a 1986 study, Jon Sigurdson[91] reviewed the relationship between Japan's industry and government and especially focused on how this relationship was involved in Japan's Very Large Scale Integrated Circuits (VLSI) project. Of special interest was Sigurdson's examination of ERAs, the most common instrument for government-supported inter-firm research. This examination indicated that Japan's new ventures in research cooperation have three distinct characteristics:

- All are in high technology sectors.
- All should increase the national competitive strength.
- All are concerned with the commercialization of technology and not with extending the frontiers of knowledge.

Between 1962 and 1986, Japan established seven ERAs in computer hardware (computer systems, semiconductors and optoelectronics) and seven in software technology development. Most were created in response to IBM's announcement of new computers. The goal of each of these joint projects was to develop the technology necessary to produce a computer, not to develop basic scientific knowledge. This technology was of strategic importance to each project's participants, yet it lay between firm specific product and process technology and basic or general scientific knowledge. In only three of these projects, the VLSI Technology Engineering Research Association, the Applied Optoelectronics Technology Engineering Research Association, and the Fifth Generation Computer Development Project, did the joint organization establish its own research laboratory separate from members' laboratories. Of 71 ERAs established throughout Japan's industries by 1983, only two had their own laboratories. Of the 94 ERAs established by 1989, only three had their own laboratories. Japan's six major

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88. Dr. Dorothy Robyn, "R&D Consortia," an unpublished draft paper.

89. Council on Competitiveness, "Challenges," February 1991, p 5.

90. Hiroyuki Odagiri and Akira Goto, "The Japanese System of Innovation: Past, Present, and Future," in *National Innovation Systems* edited by Richard R. Nelson, Oxford University Press, 1993, p 88.

91. Jon Sigurdson, *Industry and State Partnership in Japan*, Research Policy Institute, Lund, 1986.

computer firms (Hitachi, Fujitsu, Mitsubishi, NEC, Toshiba, and Oki) have been the major participants in all computer ERAs. R&D expenditures for Japan's major joint R&D computer projects in 1973 amounted to 18 percent of Japan's total R&D expenditure in electronics, communications, and computers. Having caught up with the US in computer technology by the mid 1980s, Japan reduced the expenditures for joint R&D in computer projects to only one percent of the R&D expenditure in electronics, communication and computers.[92]

Daniel Okimoto concluded that Japan's national research projects have made their most noteworthy contributions in the following areas:

- Extensive generation and exchange of information involving industry, government, and the financial community
- Reinforcement of close relations between government and industry
- Consensus building for technologies for Japan's economic future
- Mobilization of resources for consensus building
- Pooling of national R&D strengths
- Greater R&D spending in certain high tech industries
- Reduce industry risk and encourage the private sector to increase investment
- A means of overcoming the shortcomings of university-based research
- Leveling of technological capabilities among leading firms, thus intensifying the competition for commercial development of new products and process technology.

Okimoto notes that Japan's national research projects have contributed less in the generation of quantum advances in state-of-the-art technology than in facilitating policy processes, information circulation, budgetary allocations, technology diffusion, and market competition.[93]

Levy and Samuels explain that relations among members in Japan's horizontal consortia remain at arm's length. Researchers from competing companies rarely work together on the same technical problem. Instead, each participating company takes responsibility for a particular task of the consortium and performs the research in its own labs. The results of these

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92. Ryuhei Wakasugi, "A Consideration of Innovative Organization: Joint R&D of Japanese Firms," Schumpeter Conference, Siena, Italy, May 1988.

93. Daniel I. Okimoto, "Regime Characteristics of Japanese Industrial Policy," in *Japan's High Technology Industries*, edited by Hugh Patrick, University of Washington Press, 1986, p 55.

semi-independent efforts are often shared in a climate of conflict and distrust.[94] In the case of the VLSI Engineering Research Association, work in their central laboratory was split into six research divisions with each division staffed by only one company.[95] According to Professor Goto, the main part of the work at the VLSI and Optoelectronics ERAs was performed at member firms' laboratories rather than at the joint laboratory.[96]

Professor Michael Porter of Harvard Business School believes that cooperative research in Japan is the international exception rather than the rule. Japan's cooperative R&D projects achieve results in a different way than the term "cooperative" would lead one to expect.[97]

- Japanese firms participate in consortia to cooperate with MITI rather than each other, to maintain corporate image, and to hedge the risk that competitors will benefit from participation in the consortia.
- Company representatives constantly feed ideas to their employing companies, where they are directed toward proprietary projects.
- A firm's investment in a cooperative project is far smaller than its investment in an inhouse complementary project.

Professor Porter also believes that the most important role of Japanese cooperative research is to signal the importance of emerging technical areas and stimulate proprietary firm research, not to achieve efficiencies in R&D. Although advocates of US consortia frequently mention the value of efficiency in collaborative R&D that accrues from avoiding redundant work, efficiency seems not to have motivated collaborative work in Japan. The existence of a cooperative project in Japan has been a good lever for corporate R&D executives to use in persuading top corporate management to invest in a field.[98]

As a result of an exhaustive study of Japanese cooperative projects and surveys of Japanese executives, Martin Fransman, of the University of Edinburgh, reports that Japanese executives believe the most important benefits of national cooperative research projects to be (1) receiving funds from MITI, (2) devoting additional corporate research attention to the projects' technologies, and (3) increasing research competition between the participating companies. Access to knowledge contributed by other participating firms and access to knowledge

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94. Jonah D. Levy and Richard J. Samuels, "Institutions and Innovation: Research Collaboration as Technology Strategy in Japan," Center for International Studies, MIT, MITJSTP 89-02.

95. Ryuhei Wakasugi, "A Consideration of Innovative Organization: Joint R&D of Japanese Firms," Schumpeter Conference, Siena, Italy, May 1988.

96. Akira Goto, "Collaborative Research in Japanese Manufacturing Industries--Innovation in R&D System?" presented at Japan Economic Seminar, Harvard University, April 20, 1991.

97. Michael E. Porter, *The Competitive Advantage of Nations*, The Free Press, 1990, p 636.

98. Ibid.

from international sources were not felt to be as important. The least important benefit was the reduction of research costs by the sharing of equipment. Professor Fransman reports that as a result of Japan's national projects, between 25 percent and 75 percent additional research was undertaken,[99] with much of this being proprietary work done in individual corporate laboratories. Thus, the cooperative project stimulates investment by companies.

The concept of an ERA developed dynamically in Japan, initially generating specific technological results and then expanding to influence a whole industrial sector. The proper timing and well-directed research efforts were prime contributors to this dynamic development. Listed below are the primary features of Japan's engineering research associations.

- They are established for a specific purpose.
- Their lifetime is limited in time (typically 10-12 years in 1960s, decreasing to 6 years recently).
- They offer risk-sharing and cost-sharing.
- They speed up research and reduce overlap.
- Resources are pooled horizontally and vertically to achieve marketable products.
- They raise the technological level throughout an industrial sector.
- They provide the technological basis for continuous manufacturing improvement.
- Major companies constitute the dominant force.
- They are initiated by government laboratories, university professors, and industry.
- Some companies are keen to join an ERA; others are coerced by MITI.
- Most ERAs do not own or operate joint facilities.

The Japanese researchers Izuo Hayashi, Masahiro Hirano, and Yoshifumi Katayama, all experienced in the work of joint research laboratories, made the following observations about Japan's joint research laboratories:[100]

- They are most effective when seeking new frontiers for a future market.

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99. Martin Fransman, *The Market and Beyond: Cooperation and Competition in Information Technology in the Japanese System*, Cambridge University Press, 1990, pp 252-253.

100. Izuo Hayashi, Masachiro Hirano, and Yoshifumi Katayama, "Collaborative Semiconductor Research in Japan," *Proceedings of the IEEE*, September 1989, pp 1403-1441.

- They need to have a clear long-range target.

- They must be sufficiently strong technically to lead member companies.

- Their scope of activity should be narrow.

- They should be open to the outside world.

- They do not provide detailed technical knowledge to member companies, but provide new concepts for materials, process technologies, or devices.

- They should establish feasibility of new technologies.

- They should be confined to precompetitive research.

Note that these principles represent philosophies emerging for the 1990s in technological areas where Japan's companies are already competitive, or even lead the world. This longer range view of research collaboration is not the catch-up strategy employed by Japan's joint laboratories when they were behind the US in semiconductor technology. Japan has yet to prove its prowess in successful operation of lead maintenance collaboration; however, their history of applying KAIZEN principles to adjust consortia strategy until a successful arrangement is reached suggests that either they will find what works or they will discard the pursuit of lead maintenance collaboration.

It is interesting to note that now that Japan comfortably leads the world in commercialization, they are strong advocates of international research cooperation. MITI has invited the United States to participate in three large scale consortia in micromachining, intelligent manufacturing systems, and sixth-generation computers. Although some in the United States have considered joint US-Japan collaborative research efforts,[101] we feel that such efforts would operate to Japan's advantage because of the skills of their industries in executing product- and process-improvement-driven commercialization. That is, if research results were shared equally, Japan would commercialize innovations developed in the collaboration much faster than US companies. Therefore, we recommend that US research consortia not be open to the outside world and that US universities and government-owned laboratories not be permitted to participate in foreign-run consortia. Until the United States learns to compete in product- and process-improvement-driven commercialization, we must not make our superior research assets any more available to foreign interests than our liberal graduate education policies already dictate.

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101. National Research Council, "R&D Consortia and US-Japan Collaboration: Report of a Workshop," November 27, 1990.

GOVERNMENT FUNDING AND NATIONAL LABORATORY SUPPORT HAS AIDED JAPAN'S CONSORTIA

It is easy to see why Japanese executives place such high value on funds received from MITI. Collaborative research in Japan has become the pattern for government support of research. The ERA is the vehicle for government funding of industry. In addition to direct funding, by the late 1980s, 80 percent of Japanese government loans were extended to joint projects. Granted at low interest rates for periods up to 15 years, these loans typically exceed direct government funding of collaborative efforts. In many instances, repayment of these loans is dependent upon success of the joint projects. Not only do these loans reduce industry risk, it is in the interest of industry to downplay the success of consortia to reduce their loan obligation. Japan's firms are allowed to depreciate capital equipment used in joint projects by a full 100 percent the first year of a project. Membership fees for joint research work are losses as far as Japan's tax regulations are concerned. Registration and licensing taxes for consortia are forgiven. National laboratory facilities and the salaries of national laboratory scientists and engineers are provided by Japan's government to support consortia.[102]

In most cases, funding for ERAs is shared by government and industry. Government funding for ERAs doubled between 1977 and 1982.[103] More than 50 percent of Japan's joint projects in computers have been paid by Japan's government.[104]

> "Marie Anchordoguy, a professor at the University of Washington, reckons that between 1961 and 1981 the government (of Japan) handed out some $6 billion to computer makers."[105]

Although Japan's government is an important source of its consortia research funds, Sigurdson observes that the most important contribution being made by Japan's government is its direct catalytic effect. Business circles have placed high reliance on MITI as a think tank rather than as an authority resulting from the legal framework.[106]

Strong interactions between MITI, Japan's industries, and their national laboratories, said to be the "brains" of Japan's agencies,[107] result in their national laboratories pursuing an R&D

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102. Jonah D. Levy and Richard J. Samuels, "Institutions and Innovation: Research Collaboration as Technology Strategy in Japan," Center for International Studies, MIT, MITJSTP 89-02.

103. Ibid.

104. Ryuhei Wakasugi, "A Consideration of Innovative Organization: Joint R&D of Japanese Firms," Schumpeter Conference, Siena, Italy, May 1988.

105. *Fortune*, "Why Japan Keeps On Winning," July 15, 1991, p 84.

106. Jon Sigurdson, *Industry and State Partnership in Japan*, Research Policy Institute, Lund, 1986.

107. Ibid.

agenda that is of strong interest to industry and of high value to the competitiveness of Japan's industries. (In contrast, in the US most national laboratories are treated as contractors to federal agencies and their R&D agenda is permitted to be only incidentally related to industry needs.) Many, e.g. the National Association of Manufacturers, have called for such a relationship in the United States.[108] In contrast to the United States where national laboratories have been established to carry out specific US government missions, Japan's national laboratories were established with the specific purpose of aiding industrial technology. Dr. Masao Sugimoto, father of Japan's ERAs, argues that government laboratories should exist for solving practical engineering problems and not for academic work. His view is that researchers in Japan's government laboratories should not be like university professors who do not like to carry out practical engineering research.[109] (In contrast, some US government laboratories are engaged in basic research in direct competition with US research universities.

Japan's national laboratories not only exercise a leadership role, they are closely tied to industry. The National Research Council has pointed out that Japanese ministries all have advisory committees consisting of representatives from industry and academia. These advisory committees enable representatives from other sectors to exchange information and help set the agenda of national laboratories. Japanese corporations also send researchers to national laboratories and support contract research. Of the companies surveyed in 1988, 25 percent made use of national laboratory facilities, and of the companies worth over 10 billion yen, 40 percent used national laboratory facilities.[110] Professor Goto reports that the heads of two of Japan's ERA laboratories were from national laboratories, and many of the research staff at ERA facilities were from national laboratories.[111]

For many years Nippon Telephone and Telegraph (NTT) functioned as a government-owned, government-operated laboratory. Although NTT is said to have been privatized, Japan's government retains control over 50 percent of its shares. Daniel Okimoto has very strong regard for the work done at NTT's four large national laboratories. He notes that many NTT research specialists have left NTT to assume positions of high responsibility in the R&D divisions of Japan's companies.

> "From the standpoint of microelectronics research, these government and public corporation laboratories working in close conjunction with private industry have probably done more to raise Japan's technological capabilities than any national project completed as of 1985.... NTT's groundwork in the development of the 64K RAM, the 256K RAM, and

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108. National Association of Manufacturers, "Technology Policy Recommendations," 1990.

109. Jon Sigurdson, *Industry and State Partnership in Japan*, Research Policy Institute, Lund, 1986, p 16.

110. National Research Council, *Learning the R&D System: National Laboratories and Other Non-Academic, Non-Industrial Organizations in Japan and the United States*, National Academy Press, 1989.

111. Akira Goto, "Collaborative Research in Japanese Manufacturing Industries--Innovation in R&D System?" Japan Economic Seminar, Harvard University, April 20, 1991.

> the 1M ROM...has helped Japanese companies carve out large chunks of world markets. Certainly, Japanese producers could not have become competitive so quickly without NTT."[112]

Despite the fact that US government owned laboratories spend far more on R&D than Japan's national laboratories, US laboratories are focused on government missions and treat support of US industry as a lower priority. Therefore, they probably currently have less competitiveness value than Japan's national laboratories. However, because of their size, the capabilities of their staff, and their facilities they have far more potential than Japan's government laboratories. Nevertheless, this potential is largely underutilized for supporting competitiveness work.

In a US DOE-commissioned study of the Japanese government's role in R&D, G. J. Hane noted that the consortia portion of funding for Japan's national laboratories goes to experiments, facilities, and equipment costs. Salaries of researchers are paid from the laboratory's separate personnel budget.[113] Thus, funds invested at Japan's national laboratories on behalf of consortia are highly leveraged. In contrast, until 1993 funds invested by SEMATECH at Sandia National Laboratories, Oak Ridge National Laboratory, and the National Institute of Standards and Technology were required to cover the full cost of any work done for SEMATECH, including personnel salaries and overhead. The SEMATECH projects are now initiated under CRADA's with cost sharing.

In a recent study Hane concluded that Japan's universities and public laboratories are becoming increasingly significant in collaboration with firms, assisting both core and diversifying firms in technology-base training.[114] The United States has experimented very little with using national laboratories for technology training of industry, and US universities prefer to provide education, not training, in science, not technology.

The Very Large Scale Integrated Circuit (VLSI) ERA is frequently cited as successfully aiding Japan's semiconductor industry. Two parallel projects were carried out with very little coordination between them. One was carried out by MITI, the other by NTT. The latter focused on the applications of microelectronics to telecommunications. Although the NTT portion of the VLSI ERA is regarded to be successful, no major innovations occurred. Nevertheless, the NTT overall project helped to raise Japanese microelectronics to a common high-technological level and ensured vigorous competition among Japanese companies.[115] Many regard NTT's efforts to have had far more impact than MITI's program.

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112. Daniel I. Okimoto, "Regime Characteristics of Japanese Industrial Policy," in *Japan's High Technology Industries*, edited by Hugh Patrick, University of Washington Press, 1986, p 55.

113. G. J. Hane, "Government-Promoted Collective Research and Development in Japan--Analysis of the Organization Through Case Studies," PNL-7315/UD-400, June 1990, p 3.6.

114. Gerald J. Hane, "Research and Development Consortia in Innovation in Japan," Ph.D. Thesis, Harvard University, John F. Kennedy School of Government, May 1992, p 537.

115. Council on Competitiveness, "Japanese Technology Policy: What's the Secret," February 1991, p 15.

A sample of Japan's government-supported microelectronic R&D programs is tabulated in Table VI. Note the substantial funding received by NTT in support of Japan's highly acclaimed VLSI project.

Odagiri and Goto note that since 1960 there has been a downward trend in Japan's government subsidy of industry R&D decreasing from 8% of industry's investment in 1960 to 2.6% of industry's investment in 1983.[116]

TABLE VI:
A SAMPLING OF RECENT JAPANESE MICROELECTRONICS CONSORTIA[117]

Project	Companies	Technical Focus	Time Frame	Government Funds
MITI VLSI	5	VLSI Manufacturing	1975-1979	$112M
NTT VLSI	3	VLSI Devices	1975-1979	309M
New Function Elements	12	VLSI Devices & Mfg.	1981-1990	140M
Supercomputer	6	High Speed Devices	1981-1989	135M
Optoelectronics	13	Optical Semiconductors	1979-1986	80M
SORTEC	13	Synchrotron Lithography	1986-1996	62M
Optical ICs	13	Optical Semiconductors	1986-1996	42M

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116. Hiroyuki Odagiri and Akira Goto, "The Japanese System of Innovation: Past, Present, and Future," in *National Innovation Systems* edited by Richard R. Nelson, Oxford University Press, 1993, p 76.

117. Janet J. Brown, "Consortia: High-Tech Co-ops," *Byte*, June 1990, p 270.

Although less well known than the consortia listed in Table I, "hardened ICs for use under extreme conditions" was one of four cooperative research activities established under the Research and Development Association for Future Electron Devices.[118] The other three areas were superlattice devices, three-dimensional ICs, and bioelectronic devices. Twenty-four companies in Japan are members of this association. Because Japan's space agencies were unable to procure US-manufactured radiation-hardened ICs at a fast enough rate, the project to harden ICs for extreme conditions was started in order to assure a source of environmentally rugged integrated circuits for use in Japan's satellite programs.[119] In 1981, when this project was started, Japan's researchers had no experience in radiation effects in microelectronics. By 1990, at the IEEE-Nuclear and Space Radiation Effect Conference, four state-of-the-art papers were presented by Japan's scientists representing government laboratories, universities and industry.[120] By forging an organized cooperative working relationship between Japan's semiconductor industry, its government laboratories, and its universities, MITI has helped Japan develop a strong capability in radiation-tolerant integrated circuits. A research, development, and manufacturing consortium in environmentally rugged integrated circuits has not been established in the United States.

JAPAN'S PROFESSIONAL SOCIETIES AND TRADE ASSOCIATIONS ARE COMPETITIVENESS RESOURCES

Although MITI's policies promote the diffusion of information throughout Japan's industries, its professional societies also play important roles. Some describe Japan's professional societies as providing the glue that holds together Japan's universities, national laboratories, and industries. They contribute to communication at the national level, aid cooperative research, and play a decisive role in shaping inter-firm research agendas.[121] Fumio Harashima, 1990 Secretary of the IEEE and Professor of Robotics at Tokyo University, views Japan's national professional groups in electrical engineering generally to be more technically advanced than the Institute of Electrical and Electronics Engineers (IEEE).[122] The United States does not have a national professional society in electrical engineering to fill a role similar to that of Japan's domestic professional societies.

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118. Shuku Maeda, "Activities of the Research and Development Association for Future Electron Devices," *IEEE Proceedings*, September 1989, p 1420.

119. Tateo Goka, Tsukuba Space Center, National Space Development Agency of Japan, personal communication.

120. *IEEE Transactions on Nuclear Science*, December 1990, Vol. 37, No. 6, pp 1732, 1953, 2026, 2071.

121. Jonah D. Levy and Richard J. Samuels, "Institutions and Innovation: Research Collaboration as Technology Strategy in Japan," Center for International Studies, MIT, MITJSTP 89-02, p 14.

122. Dr. Fumio Harashima, personal communication.

Japan's industry associations are heavily engaged in technology forecasting, technology feasibility studies, and international travel to search for information for their members. They typically have close working relationships with Japan's government agencies and are the source of many of MITI's ideas for national research projects. Each association is supervised by a MITI organization. Industry associations are critical to the effectiveness of industry-government cooperation in Japan. In the US, industry associations spend most of their time lobbying for changes in government regulations.[123] The Semiconductor Industry Association has recently shifted to providing leadership for the US semiconductor industry by coordinating the development of roadmaps.

We conclude this discussion of Japanese consortia by noting that even the harshest critics of Japan's consortia concede that they develop technology early that would eventually be developed anyway. They just develop it soon enough for Japan to reap the economic rewards. The model of competitiveness presented early in this report identifies time compression as an important competitiveness attribute. The timeliness of incremental innovation can be as important as the original discovery that started the technology.

THE PRIMARY FEATURES OF JAPAN'S CONSORTIA ARE EASILY SUMMARIZED

- MITI and other government agencies provide leadership, identify projects with economic potential, forecast technology innovation, provide funding, and keep government sponsored R&D focused on the development of technology with economic relevance.

- Japan's industrial policies emphasize national technology leadership, the use of technology developed around the world, commercial technology applications rather than basic research, leveraging private sector R&D with government R&D funding, and cooperative government-industry relations. Maintenance of a highly competitive domestic environment is an important component of Japan's industrial policy.

- Most of Japan's collaborative efforts involve two vertically structured firms. Horizontal alliances of multiple companies are generally arranged through engineering research associations (ERAs) and are promoted by government funding. Work in horizontal consortia is split into tasks pursued by individual companies. There is little requirement for cooperation among competing companies. The formation of central research laboratories is rare; it is preferable that work be done in members' laboratories. Success of Japan's consortia has so far been limited to catch-up situations.

- Japanese consortia have emphasized research coordination and have served to stimulate additional proprietary research among their members. Preference has been given to the establishment of numerous consortia, each tasked with a clearly defined, narrow purpose,

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123. *Challenges*, Council on Competitiveness, "Japan Industry Groups Play a Key Role in Tech Research," July 1991, p 8.

and targeted with a finite life. The number of members of Japan's consortia is severely restricted. Preference is given to members who do not have strong competing interests unless these conflicts are overshadowed by a perceived common threat. Japanese consortia have emphasized work relevant to commercialization and they have compressed the development time for technology.

HOW US CONSORTIA WORK

THE PRINCIPLES OF US CONSORTIA DIFFER FROM THOSE OF JAPAN'S CONSORTIA

Experts do not all agree on what the role of consortia should be in the United States. Grant Dove believes that consortia are best suited for five functions.[124]

- Leveraging R&D dollars and talent to develop emerging technologies that are new, generic, long-range, and high risk.
- Effectively using resources to accelerate the pervasive adoption of new technology.
- Developing the infrastructure required for US competitiveness in a particular technology.
- Solving industry problems that support a broad customer base.
- Serving as an instrument for implementing US government competitiveness policy.

Professor Michael Porter, as a result of his extensive studies of international competitiveness, advocates a more limited role for cooperative research. As he sees it, there are only three principal arguments for cooperative research.[125]

- Independent research by a number of firms is wasteful and duplicative.
- Economics of scale in R&D are reaped through collaborative effort.
- Firms acting individually will underinvest in R&D because they cannot appropriate all the benefits.

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124. Grant A. Dove, Plenary Session, Semiconductor Research Corporation, Washington, DC, February 27, 1990.

125. Michael E. Porter, *The Competitive Advantage of Nations*, The Free Press, 1990.

Note that neither Mr. Dove nor Professor Porter emphasizes the promotion of domestic competition and the diffusion of research by consortia despite the fact that these functions have been emphasized in Japan and proved productive. Furthermore, the vertical relationships established through cooperative R&D can be of more value than the technical output of cooperation. Coming much closer to the Japanese model is the conclusion of the Council on Competitiveness that any R&D effort that is effective, not necessarily just collaborative efforts, must satisfy the conditions listed below.

- R&D projects must be formulated with an understanding of market needs and must link scientists and engineers to customers and markets.

- The funding and results of precompetitive research, which thrives on information sharing, should be diffused throughout the industry.

- Vigorous competition, a desirable element in proprietary research and product development, must be present.

Dr. Howard and Dr. Guile observe that consortia partnerships can be attractive when the costs of technology development strain the resources of single companies. However, they emphasize that consortia partners must be prepared to invest in consortia at levels that go well beyond direct support of the joint effort.

> "Successful participants in technology consortia, for example, are those who establish an internal shadow cadre to track the activities of the joint effort."[126]

In the electronics industry, an industry not currently driven by basic research, the gap between the point at which basic research ends and proprietary product development begins is wide. The Council on Competitiveness proposes that for those technologies with this wide gap, substantial cooperation on precompetitive, generic technology is needed. Strategic consortia involving industry, government, and academia are recommended by the Council to stimulate the necessary research.[127]

The concept of precompetitive research suggests that before some point in the evolution of technology from research toward products, research provides no competitive advantage. As stated by Martin Fransman,

> "In some cases the concept of precompetitive research is misguided. If research is to be judged to be worth undertaking by a for-profit company, it must be expected, even with uncertainty, to eventually yield

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126. William G. Howard, Jr., and Bruce R. Guile, *Profiting From Innovation*, Free Press, 1991, p 100.

127. Council on Competitiveness, "Gaining New Ground: Technology Priorities for America's Future," March 1991, p 38.

competitive advantage. From this point of view, the notion of pre-competitive research in for-profit companies is a contradiction in terms."[128]

Furthermore, as we earlier explained, what is precompetitive research and what is not depends entirely on the perspective of the person making the judgment.

The notions of generic research or generic manufacturing concepts are also not very satisfying. As Dr. Andrew Grove, CEO of Intel, has explained,

> "Leading-edge products cannot be created and produced with generic manufacturing technologies...You cannot develop high performance microprocessors with generic semiconductor technologies."[129]

It is especially important in government-sponsored collaborative programs that precompetitive, generic research not become a euphemism for irrelevant research. Making industry active in establishing and directing government's research agenda in support of industry-led consortia would prevent such irrelevancy.

Because United States institutions have always been the world leader in high technology, US consortia have tended to emphasize a lead maintenance research agenda rather than an information exchange and research coordination agenda. In their defense, there is little recognition in the United States for scientists who collect, interpret, and disperse information and coordinate research sharing. US scientists are driven to create, not synthesize. We seem to have implicitly proceeded as if the US competitiveness problem in microelectronics and electronics was an R&D problem. Part of the misunderstanding of SEMATECH's work (and there has been much of this) stemmed from their choice to not focus exclusively on research and the solution of technical problems, but to also emphasize the formation of vertical upstream working relationships and establishing of quality programs. The lack of vertical upstream working relationships is an inherently weak feature of the US electronics chain, yet it is a basic feature of the model of competitiveness as interpreted by Professor Kanter (presented earlier in this report.

The importance of vertical linkages, particularly their contribution to the economics and efficiency of information flow, is not well understood by those taught the 1945 philosophy of Vannevar Bush, who followers believed that as long as scientists were free to pursue the truth wherever it may lead, there would be a flow of new scientific knowledge to those who can apply it to practical problems. The Vannevar Bush philosophy was developed during a period when the United States ran a technology monopoly and was clearly the world's high tech leader. This view suggests that commercialization is not an issue, but rather it will automati-

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128. Martin Fransman, *The Market and Beyond: Cooperation and Competition in Information Technology in the Japanese System*, Cambridge University Press, 1990, p 282.

129. Andrew S. Grove, "Should the US Abandon Computer Manufacturing," *Harvard Business Review*, September--October, 1991, p 141.

cally be developed by companies eagerly searching for pearls of wisdom from scientists. The Vannevar Bush follower position has failed to be effective as a lead maintenance strategy and it is impotent as a catch-up strategy.

President Bush stated a view that pays more attention to commercialization than the idealistic perspective of the followers of Vannevar Bush.

> "If America is to maintain and strengthen our competitive position, we must continue not only to create new technologies but **learn to more effectively translate these technologies into commercial products.**"[130]

US consortia need to pay more attention to the structure of Japanese consortia, especially to their emphasis on manufacturing and work that leads to product- and process-improvement-driven commercialization. US consortia should make the formation of vertical relationships a major area of attention and should promote horizontal competition rather than cooperation. Collaborative efforts must employ catch-up strategies and focus on areas dominated by product- and process-improvement-driven commercialization, if they are to have measurable impact on US industry.

Masami Fujino of SBCI Securities in Tokyo, predicted that three features were essential for vertically integrated companies that will be competitive in consumer electronics in the future.

> "First, they simply have to produce their own semiconductor chips. Second, they must have the know-how for making computers and telecommunications equipment as well as consumer products. And third, they must have strong and cooperative management linking the technical, production, and marketing departments, along with a clearly defined plan detailing where the company intends being in five years time... The global supremacy of Japanese makers stems from the close links between their various operations plus their well-defined, far-sighted strategies."[131]

Companies can establish a "virtual" vertically integrated structure by developing relationships through consortia with upstream and downstream companies in the electronics chain.

Dr. Craig Fields has observed that while consortia look good in concept, in practice they often fail. Unrealistic time scales for accomplishing projects, the tendency of member companies to change their plans, financial problems of member companies, and members' priorities on internal projects have made it difficult for consortia to achieve success. Dr. Fields notes that it is not R&D but time-to-market, price, quality, and incremental improve-

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130. President George Bush, "Remarks at the Presentation Ceremony for the National Medals of Science and Technology," November 13, 1990.

131. *The Economist*, "A Survey of Consumer Electronics," April 13, 1991, p 4.

ment that contribute to business success.[132] Thus, a consortium whose thrust is exclusively R&D will gradually strengthen the core competencies of their members, but their members may not be more competitive.

REVIEW OF US CONSORTIA

Until US industry masters commercialization driven by product and process improvements, discoveries coming from new technology driven programs will have as much, if not more, return to foreign economies than to the US economy. Therefore the purpose of this section is to review existing consortia and NSF-ERCs to determine if any of these types of activities can serve as a model for government-sponsored programs that assist industry to regain its competitiveness in microelectronics. Our goal is not to be critical of existing consortia and ERCs, all have made monumental contributions to shifting industry attitude and practices as well as to evolution of national policy,[133] but to learn from past experiences and use this to influence government policies and new legislation that impact the competitiveness of US industry.

US semiconductor consortia and the National Science Foundation's Engineering Research Centers (NSF-ERCs) are evaluated based on two criteria. The first is their emphasis on helping their customers improve their competitiveness. The second is their emphasis on work that can lead to improvement in commercialization skills of their customers. Because (1) world semiconductor market is currently dominated by product- and process-improvement driven commercialization, and (2) this is the area of commercialization where US companies have had the most difficulty competing, consortia and ERCs are evaluated based on their emphasis on work that leads to product and process improvements. While these measures may not fit a universal framework for success, they are far better than the vague requirements that cloak support for special interests that often drive US government sponsored programs.

BELLCORE SUPPORTS THE REGIONAL TELEPHONE COMPANIES[134]

When the US government and AT&T reached agreement on the breakup of the Bell System as it existed in 1982, Bellcore was created to perform technical functions on behalf of the seven independent Regional Companies and to serve as a single point of contact for national security and emergency preparedness. The technical focus of Bellcore is on telecommunica-

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132. Craig I. Fields, Presentation at National Academy of Science, 1991.

133. William G. Howard, Jr., personal communication.

134. Alan G. Chynoweth, former Vice President of Bellcore, has reviewed for accuracy the data presented in this section.

tions R&D, standardization, and establishing generic requirements for the local exchange and exchange access needs of the Regional Companies. Bellcore is forbidden by the breakup agreement (Modification of Final Judgment-MFJ) from performing development of telecommunications products for manufacture. This includes network elements (switches and transmission equipment) as well as customer premises equipment.[135]

As the world's largest R&D consortium, Bellcore has 8500 employees, with about 5500 employed as professional personnel in Technical Services. Their annual budget is $1.2 billion. Bellcore's activities are split between (1) work that is generic to all the Regional Companies and funded equally between them, and (2) specific projects that are electively supported by one or more of the Regional Companies. About one-half of Bellcore's technical personnel are devoted to the development of software systems. Bellcore's Applied Research Areas has approximately 500 technical employees and a budget of $150M. About $30M of this is targeted to semiconductor-related R&D (less than 3% of Bellcore's total budget).

Bellcore's semiconductor R&D is directed toward supporting high-bandwidth transmissions systems; therefore it emphasizes research on solid-state optical devices and high-speed electronics. Areas of emphasis include gallium-arsenide/gallium aluminum-arsenide (GaAs/GaAlAs) patterned quantum-well lasers, submicron silicon bipolar technology, enhancement/depletion mode GaAs technology, submicron GaAs depletion-mode FET technology, high-speed CMOS switching and multiplexer-demultiplexer chips, narrow-linewidth high-speed tunable semiconductor lasers, GaAs heterostructure FETs, quantum-well emission transistors, integrated optoelectronics, and high-speed optics.

The greatest disadvantage of Bellcore's semiconductor work arises from the MFJ, which prohibits them from the design of products for manufacture, even by another company. Thus, Bellcore is pushed away from technology issues most relevant to manufacturing.[136] As a result, in contrast to their software operations which have continually increased, the size of Bellcore's semiconductor R&D has generally remained constant, primarily serving the experimental prototype device needs of internal customers. Thus, we see that although Bellcore's semiconductor effort excels in leading-edge research, the MFJ prohibits it from fulfilling the other requirements of Professor Kanter's competitiveness model. Since by law Bellcore cannot be tied to manufacturing, it cannot directly contribute to each cycle of product development after research or experimental prototype development phases; and it cannot continue to improve products, since it may not produce any in the first place.

Although Bellcore cannot engage in manufacturing oriented activities, the research it performs does have an impact on network equipment through Bellcore's Generic Requirements, Technical Analysis, and Quality Assurance activities in support of equipment procurement by Bellcore's owners. Since Bellcore has no manufactured products market position to protect, it is very active in the area of cooperative research with other firms. These cooperative relationships benefit Bellcore (and ultimately Bellcore's owners) by providing paths for the transfer of

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135. A.A. Berg and A.G. Chynoweth, "Semiconductor Research at Bellcore," *Proceeding of the IEEE*, Vol. 7, No. 9, September, 1989.

136. *Washington Technology*, "Bellcore R&D Goes to Waster as Courts Restrict Technology," February 21, 1991, p 4.

advanced telecommunications technologies into the vendor community at large. To date, and as filed under the National Cooperative Research Act of 1984, Bellcore has entered into over 50 such bilateral cooperative research relationships with firms worldwide.

Bellcore's new president, George Heilmeier, has introduced changes to make Bellcore a more important force in improving the competitiveness of their members. Changes include streamlining the decision-making process, avoiding research for research's sake, improving quality, choosing seven priority programs for strategic direction, and developing closer ties with phone company marketers.[137]

THE MICROELECTRONICS AND COMPUTER TECHNOLOGY CORPORATION HAS SERVED AS AN ADVANCED CENTRAL RESEARCH FACILITY[138]

With their cooperative venture, the Very Large Scale Integrated Circuit (VLSI) project, Japan succeeded in advancing their semiconductor manufacturing. Therefore, when they announced creation of their Fifth Generation Project to develop an intelligent computing system, the US computer industry was alarmed. In response, ten US companies founded the Microelectronics and Computer Technology Corporation (MCC) in 1982. At the present time, 56 companies are members of MCC. Of these, 22 own shares that convey certain intellectual property and governance rights. Members provide annual funding of $60M to $65M. MCC's mission under their past president, Mr. Grant Dove, was to accelerate the creation, delivery, and commercialization of advanced microelectronics and computer technology by providing its participants with useful, timely, and competitive research results.[139] Dr. William G. Howard, Jr., credits MCC with being the precursor to the 1984 Cooperative R&D Act that loosened consortium antitrust constraints[140] by stiffening the requirements for treble damage anti-trust settlements.

MCC has functioned as a central research laboratory for its member companies. About 85 percent of its work is done at MCC; 15 percent of its work is done under contract to universities or other companies. MCC has 440 workers. Of these, 85 percent are MCC employees and 15 percent are from member companies. Major research programs are in the areas of advanced computing technology, software technology, computer-aided design for complex circuits and systems, packaging and interconnects, electronic application of high-temperature superconductors, optical storage technology, and parallel processing. While MCC's work on

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137. *Business Week*, "Pumping Up the Baby Bells' R&D Arm," August 15, 1991, p 68.

138. This section was reviewed for factual correctness by Dr. Craig I. Fields, CEO and President of MCC.

139. Grant A. Dove, "Cooperative Research at MCC: A Focus on Semiconductor-Related Efforts," *Proceedings of the IEEE*, Vol. 77, No. 9, September 1989, p 1365.

140. William G. Howard, Jr., personal communication.

software, CAD tools, and packaging are relevant to strengthening product and process improvement driven commercialization, most of their work appears to support technology driven commercialization.

Because of MCC's long history, an examination of its experience as a consortium to determine lessons for other U.S. consortia and future government programs is worthwhile.

Even though MCC's first CEO, Admiral Bobby Inman, directed MCC toward long-range research, some MCC member companies apparently expected short-term return. MCC's computer-aided design program has been a target of MCC critics. This program has been criticized for developing computer-aided (CAD) tools that private companies were also developing for commercial sales, for choice of programming language, and for developing CAD tools for use on work stations that industry was abandoning.[141]

> "Some company participants sought CAD algorithms for use in their proprietary CAD software. Others expected bulletproof, finished tools for internal use in designing their products...Thus, many of MCC's difficulties arose over its inability to define common efforts that all the members could openly support."[142]

Although MCC has been much maligned for CAD shortcomings, their CAD program had many technical successes and some of these were transferred to member companies.[143]

The research record of MCC is impressive, but MCC has in many cases been ineffective in the transfer of technology to member companies. To study this problem and identify ways to improve technology transfer at MCC, Dr. David V. Gibson and Dr. Raymond W. Smilor, IC^2 Institute, used surveys, interviews, and archival data. Their work suggested that communication interactivity, cultural and geographical distance, technology equivocality, and personal motivation are the key variables central to technology transfer processes within and between organizations.[144] Dr. Gibson and Dr. Smilor have articulated actions that may be taken by the consortia management and staff and the shareholders to facilitate technology transfer.[145]

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141. Michael R. Leibowitz, "U.S. Consortia: How Do They Measure Up?" *Electronics Business*, January 22, 1990, p 48.

142. William G. Howard, personal communication.

143. Marv Daniel, personal communication.

144. David V. Gibson and Raymond W. Smilor, "Key Variables in Technology Transfer: A Field-Study Based Empirical Analysis," *Journal of Engineering and Technology Management*, 8 (1991) 287-312, Elsevier, p 287.

145. Raymond W. Smilor and David W. Gibson, "Technology Transfer in Multi-Organizational Environments; The Case of R&D Consortia," *IEEE Transactions on Engineering Management*, Vol. 38, No. 1, February, 1991.

A review of their work and other studies[146,147,148,149] of successful transfer of technology throughout the world reveals the dominant themes to be:

- Customer need and market forces must influence the direction of research
- Cooperative working teams spanning research to manufacturing, preferably working together in a shared facility, aid the process remarkably.
- Extension of research work is usually required to establish product manufacturability or process utility and gain serious industry attention.
- Communications, the primary means of technology transfer, must be facilitated by all practical means.[150]

MCC's CEO and president, Dr. Craig Fields, is implementing extensive project planning with identification of intermediate deliverables for long-term projects. Dr. Fields is being especially attentive to the development of a technology transfer strategy that is in place at the start of each project. He is also expediting technology transfer by sending MCC staff to work at member companies and by increasing the size of member company staff that work at MCC.[151] In addition, MCC is both aggressively licensing results to lower tier vendors which become suppliers for MCC's member companies, and spinning off companies from MCC, which similarly become suppliers for their members. Thus, under Dr. Field's leadership MCC is developing vertical relationships between member companies and their suppliers and customers.

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146. M. S. Ounjian and E. B. Carne, "A Study of the Factors Which Affect Technology Transfer in a Multilocation Multibusiness Unit Corporation," *IEEE Transactions on Engineering Management*, Vol. 34, No. 3, August 1987.

147. Robert S. Cutler, "A Comparison of Japanese and U.S. High Technology Transfer Practices," *IEEE Transactions on Engineering Management*, Vol. 36, No. 1, February 1989, p 21.

148. R. Whisnant, R. Lucik, A. Griffin, K. Barbour, B. Beatty, and D. Rogers, "SRC Study of Technology Transfer In Japan," *SRC Report*, April 19, 1988.

149. W. F. Finan, and J. Frey, "The Effectiveness of the Japanese Research-Development-Commercialization Cycle: Engineering and Technology Transfer in Japan's Semiconductor Industry," *SRC Report*, August, 1989.

150. James E. Gover and Charles W. Gwyn, "Integrating Microelectronics Research: A Strategy to Help Win the Microelectronics Race," *Sandia National Laboratories Report, SAND-0820*, January 1982, p 44.

151. Council on Competitiveness, "Full Speed Ahead at MCC," *Challenges*, September, 1990, p 4.

Since moving to MCC, Dr. Fields has conducted an extensive review of US consortia including all of those described in this report. He explains that consortia can improve R&D efficiency by reducing duplication of effort; conduct high-impact/high-risk R&D that otherwise would not be done; scan, fund, harden, integrate, and transfer foreign technology; and share expensive test equipment. He asserts that consortia must have a clear mission, be able to do a wide variety of activities ranging from process and product development to scanning information sources, and especially do things differently from university and corporate laboratories. Dr. Fields advocates that consortia staff should be from member companies and that they must plan to operate for a fixed term during which they will be subjected to competitive pressures.[152]

MCC has excelled at its major mission of conducting high quality research that its members are supposed to use to strengthen their core competencies. It has also helped develop the core competencies of MCC's member suppliers. But MCC has had difficulty in getting its research advances transformed into manufactured products or new manufacturing processes. MCC has not strengthened the ability of their members to make continuous improvements in products and processes due to loose coupling of MCC research to production and MCC's concentration on producing major advances in a wide array of areas. This loose coupling to their members' manufacturing lines has also inhibited their ability to help their members compress the cycle time of their products. Until recently, MCC's work has been concentrated on new technology commercialization rather than product- and process-improvement driven commercialization. As noted earlier, MCC has helped their members strengthen their relationships, especially with suppliers that MCC has helped develop.

Dr. Fields explained,

> "MCC is now orienting its work more toward process than product technology, directly aimed at time to market, price and quality; and performing that work in an evolutionary incremental mode rather than a revolutionary 'leap frog' mode. I include here not only technology proper, but also standards, e.g. for CAD and CIM, and applications."[153]

THE SEMICONDUCTOR RESEARCH CORPORATION MANAGES UNIVERSITY RESEARCH[154]

The Semiconductor Research Corporation (SRC) was formed by eleven member companies in 1982. Of the original founding companies, seven were semiconductor companies and four were computer companies. The purpose of the SRC is to establish a university-based,

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152. Craig Fields, presentation at Panel Discussion on Industrial Competitiveness in Electronics, Gaithersburg, MD, February 26, 1991.

153. Craig I. Fields, personal communication.

154. Data presented in this section were reviewed for accuracy by Dr. James Freedman, Vice-President, SRC.

goal-driven program of research and education in silicon integrated circuits. Today SRC has 28 members, 4 associate members including two of DOE's national laboratories, 26 affiliate members, and 7 US government participants representing the Army, Navy, Air Force, the Department of Commerce, and the National Science Foundation. SRC's annual budget of nearly $35M is provided by dues of member companies (both private companies and government-funded organizations) and SEMATECH. In 1990 the US government provided about 4 percent of SRC's research budget through SEMATECH with only about 4% coming from membership fees paid by government funded organizations. SRC's staff consists of approximately 40 technical, administrative, and support personnel. These staff are supplemented by personnel in residence at SRC from member companies and by mentors from member companies or government agencies. Residents serve as SRC program managers, and members provide technical assistance to university students.

Prior to establishment of SRC, the academic community had generally moved from conducting research on silicon to emphasizing compound semiconductors, an area rich in publishing opportunities although of much less economic significance than silicon. A major reason for creation of SRC was to provide a steady stream of students graduating with research experience in silicon integrated circuits and materials. SRC programs currently support over 600 graduate students, or about 25 percent of US Ph.D. students in electrical and electronics engineering. However, because of loss of market share by the US microelectronics industry, US industry in recent years has had difficulty in absorbing all SRC supported graduates. This has led to additional pressure on SRC to produce research results that have short-term impact on US industry.

SRC-sponsored research includes microstructure science (improved processing, materials, equipment, and mathematical modeling of processes and devices), manufacturing science (yield and reliability improvement, packaging, and manufacturing processes), and design sciences (computer tools, systems, and methodologies for integrated-circuit design). Professor William G. Ouchi, U.C.L.A. Graduate School of Management, explains SRC's emphasis to be on leaky technology, or technology weakly appropriable by the inventor and consequently difficult for one company to justify researching on its own.[155] The research goals of SRC are to accelerate by two years over a ten-year period the development of integrated-circuit technology in their member companies.[156] Thus, a stated primary goal of SRC is to assist their members in compressing time; however, their time compression goal is not attached to a specific product or to a specific cycle of that product. It is also clear from examination of SRC's selection of projects that they are supporting work that can lead to product and process improvements; however, their project selection, while appropriate for education purposes, may well be too comprehensive for a $30 million research program seeking short term results.

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155. William G. Ouchi, "The New Joint R&D," *Proceeding of the IEEE*, Vol. 77, No. 9, September 1989.

156. Ralph K. Cavin, Larry W. Sumney, and Robert M. Burger, "The Semiconductor Research Corporation: Cooperative Research," *Proceedings of the IEEE*, Vol. 77, No. 9, September, 1989, p 1328.

SRC utilizes a wide variety of technology transfer methods such as publications, presentations, topical conference sponsorship, workshops, and technology transfer courses at universities. As SRC officers have pointed out, despite their emphasis on technology transfer, they, like MCC, have had difficulty linking the innovators and the users of research.[157] SRC officials are currently exploring with the DOE the establishment of a microelectronics research integration center at Sandia National Laboratories for the purpose of university researchers validating their SRC sponsored research in a manufacturing environment. Such an institutional arrangement has been recommended to SRC by a panel of university researchers.[158] This basic concept, if proven successful by SRC and Sandia, can be expanded to accelerate the transfer of research innovations in microelectronics made throughout the world to US industry.[159]

By using university research strengths, SRC can help their members maintain core capabilities both through their research and by providing a steady stream of new graduates for industrial employment. However, because SRC's research results are not developed in an industrial environment, SRC has had difficulty moving their work to industrial manufacturing. Even though SRC's overall research goals, if achieved, will compress the time in which their members achieve their technology plans, it is impractical for SRC to impact each of their member's product development cycles. Again, the fragile linkage between SRC researchers and their members has made it impractical for SRC to help their members make continuous improvements. Clearly, SRC work has improved the working relationship between the members' R&D personnel and university researchers, but it has not emphasized strengthening their members' relationships with either their suppliers or their customers. SRC's choices of projects are exactly those that support product- and process-improvement driven commercialization. If, however, the SRC were to compromise their education goals and narrow the range of their projects to a single area, the likelihood that their research would directly impact the competitiveness of their members would be increased.

SRC has filled an extremely important leadership role in helping establish SEMATECH, assisting the National Advisory Committee on Semiconductors in fulfilling their work for the U.S. Congress, and working with the SIA to establish the national semiconductor industry roadmap.[160] It is also clear that because of SRC efforts, university research is far more relevant to industry's needs than it would otherwise be. SRC's research program has clearly

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157. Ralph K. Cavin, Larry W. Sumney, and Robert M. Burger, "The Semiconductor Research Corporation: Cooperative Research," *Proceedings of the IEEE*, Vol. 77, No. 9, September, 1989, p 1328.

158. N. A. Masnari, T. J. Sanders, D. V. Kerns, R. J. Gutman, and L. A. Akers, "University Access to Insertion Manufacturing Facility for Effective Acceleration of Research and Technology Transfer," presented at SRC Summer Study, August 28, 1991.

159. James E. Gover and Charles W. Gwyn, "Integrating Microelectronics Research: A Strategy to Help Win the Microelectronics Race," Sandia National Laboratories Report, SAND-0820, January 1982, p 44.

160. Semiconductor Industry Association, Semiconductor Technology: Working Group Reports, 1993.

produced results more than worthy of their modest annual investment. However, a $30 million to $35 million annual investment in university research will not solve the problems of the US microelectronics industry.

THE ENGINEERING RESEARCH CENTERS OF THE NATIONAL SCIENCE FOUNDATION BLEND ENGINEERING AND SCIENCE

The National Science Foundation has created Engineering Research Centers (ERCs) at universities throughout the United States to advance fundamental knowledge in engineering and improve the preparation of engineers for the practice of engineering. The propelling force for ERCs came from universities and the NSF, not US industry.[161] There are currently 18 ERCs located at nineteen universities. The NSF expects the ERCs to integrate engineering research and education, bridge traditional boundaries and approaches, and transfer technology to industry. At least eight of these are doing work that is relevant to microelectronics. NSF funding of the ERCs has averaged approximately $2 million annually, less than the $2.5 million to $5 million recommended by the National Academy of Engineering when the ERCs were evaluated in 1983. NSF funding is about one-half of the ERC's budget; industry funding ranges between 9% and 61% of the budget of individual centers and averages about one-third of their budget. Remaining funding is provided by university, state, and local sources.

Although several criteria are used by NSF as a basis for selection of ERCs (research and research team quality, international competitiveness, education, industrial involvement and technology transfer, management, and university commitment) the quality of researchers at the ERC has been the most important selection factor.[162]

There appears to be a general consensus that ERCs have had a positive impact on engineering education by promoting cross-disciplinary research on campus and introducing engineering students to the highly interdisciplinary nature of engineering practice. Dr. Bowen of the Harvard Business School and Dr. Compton of Purdue University have observed that several ERCs have been particularly successful in tackling the synthesis aspect of engineering that is so critical to design and production. They note that ERCs have been active in establishing synthesis as a new academic paradigm.[163]

Dr. Philip Shapira, when working for the Office of Technology Assessment conducted case studies of four ERCs. He observed that industry representatives were pleased with the quality of research coming from these centers; however, ERC faculty were critical of the quality of industry involvement in their work and the short term interests of their industry contacts.[164] As Professor John Deutch of MIT explained, even in manufacturing oriented

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161. William G. Howard, Jr., personal communication.

162. United States General Accounting Office, "Engineering Research Centers: NSF Program Management and Industry Sponsorship," GAO/RCED-88-177, Washington, DC, August, 1988.

163. Memorandum from H. K. Bowen and W. Dale Compton to R. F. Mettler, Chairman, Manufacturing Subcouncil, Competitiveness Policy Council, "Education and Training for Manufacturing," September 3, 1992.

programs such as MIT's Leaders for Manufacturing Program, a collaboration between MIT's schools of engineering and management and 12 companies, emphasis on quick payoff (a feature demanded by product- and process-improvement driven commercialization that is synchronized with product cycles) can hamper creative collaborations between universities and industry.[165] Mr. David Osborne, noted for his research on making government institutions responsive to public needs,[166] has concluded that technology transfer from university-industry research centers is restricted because the universities define the research agenda with little involvement from industry.[167]

While the ERCs have great potential for strengthening the core competencies of those corporations that participate actively in their research, it is impractical for an ERC to interact with a very wide segment of the US microelectronics industry. Interaction with industry through a third-party broker such as SRC could be more efficient and perhaps effective than numerous, single corporation contracts. David Osborne recommends the creation of technology transfer organizations which look for promising research, take it to firms that might be interested, and broker a marriage between innovator and prospective user.[168] (The responsibilities of the research integration facility that SRC is discussing with the DOE could be expanded to provide this service.) ERCs have little potential for helping industry compress time, strengthen relationships with suppliers and customers, and make continuous improvements.

To have significant impact in an industry as large as semiconductors (by the year 2000 the world market is likely to exceed $250 billion and the R&D investment will likely be between $20 billion and $40 billion), any credible, government-funded, catch-up effort that will impact the short-term competitiveness of the US industry would have to be over ten times as large as an individual ERC and have access to a world-class microelectronics facility well-equipped by industry standards and extraordinarily well-equipped by university standards. Thus, the very modest funding levels of ERCs make it most unlikely that they will have significant impact on commercialization driven by product and process improvements.

The ERC program has more potential for impacting the competitiveness of the US microelectronics industry by promoting research and thinking that is orthogonal to today's industry practices. The NSF should simply define technology driven commercialization as the target of their ERC work. These are the areas where universities have a long-standing tradition of success. For example, Dr. Raymond Smilor, Dr. David Gibson, and Dr. George Kozmetsky, IC^2 Institute, have noted that of 103 small and medium-sized technology based com-

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164. Philip Shapira, "The National Science Foundation's Engineering Research Centers: Changing the Culture of US Engineering?" prepared for the Office of Technology Assessment, US Congress, March 1989.

165. John M. Deutch, "Getting University-Industry Relations Right," *Technology Review*, May/June 1991, p 65.

166. David Osborne and Ted Gaebler, *Reinventing Government*, Addison-Wesley Publishing Co., Inc., 1992.

167. David Osborne, "Redefining State Technology Problems," *Issues in Science and Technology*, Summer 1990.

168. Ibid, p 59.

panies in existence in Austin in 1986, 53 (or 51%) indicated a direct or indirect tie regarding their origin to the University of Texas at Austin. Without doubt, the excellence of US entrepreneurs in new market driven and technology driven commercialization is often attributable to the excellence of US research universities. Smilor, Gibson, and Kozmetsky note that the University of Texas has contributed to the development of the Austin technopolis by achieving scientific pre-eminence; creating, developing, and maintaining new technologies for emerging industries; educating and training the required work force and professions for economic development through technology; attracting large technology companies; promoting the development of home-grown technologies; and contributing to improved quality of life and culture.[169]

SEMATECH IS IMPACTING THE COMPETITIVENESS OF THE US SEMICONDUCTOR INDUSTRY

In 1987 the US semiconductor industry and the US government recognized that the US loss of semiconductor manufacturing leadership had dire consequences for the national economy and military security. A unique experiment in American industry-government cooperation was formed and named SEMATECH (SEMiconductor MAnufacturing TECHnology, Inc.) and given the national mission of quickly restoring the US world leadership in semiconductor manufacturing. On August 7, 1987, SEMATECH was incorporated with 14 high-tech companies representing 80% of the national capacity for semiconductor manufacturing.

SEMATECH began as a misunderstood cure-all program for a critical industry. Many believed SEMATECH to be the US solution to Japan's dominance of DRAM technology. Others viewed SEMATECH to be the source of industry's latest processing technology. Some believed that SEMATECH would solve all the problems of the US semiconductor industry. However, SEMATECH's annual operating budget forced the consortium to focus on a small part of the overall problem. As Dr. James Morgan, CEO of Applied Materials, Inc., a supplier to the semiconductor manufacturing equipment industry, has been attributed with saying:

> "The expectations (of SEMATECH) are somewhat unrealistic. A hundred million dollars a year in federal funding won't solve the industry's problems; it's just a toe dipper."[170]

The actual goal of SEMATECH is to improve the state of US semiconductor manufacturing technology, especially improving the current generation of equipment and the equipment that will come into widespread use within 5 to 8 years. To do this, SEMATECH has been re-

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169. Raymond W. Smilor, David V. Gibson, and George Kozmetsky, "Creating the Technopolis: High-Technology Development in Austin, Texas," *Journal of Business Venturing 4*,pp 49-67, 1988, Elsevier Science Publishing Co., Inc.

170. *Forbes*, "The Realist," May 13, 1991, p 116.

quired to develop advanced processes to challenge and exercise next generation manufacturing equipment. However, their emphasis has been on manufacturing technology, not the products, including DRAMs, made with that equipment. Therefore, SEMATECH is a horizontal consortium focused on strengthening upstream suppliers for their member companies; thus, SEMATECH may be described as a horizontal-vertical consortium. Horizontal cooperation is relatively easy to achieve because SEMATECH's focus is not on their members' products; rather it is on their suppliers of manufacturing equipment.

The semiconductor manufacturing equipment sector is divided into five major segments: lithography, plasma processes, chemical vapor deposition, rapid thermal processes, and ion implantation. Although Japan's equipment companies have gained market share in all five segments, they are approaching domination of the lithography area. Lithography is the equipment area that is key to manufacturing integrated circuits with smaller and smaller feature sizes. Because of this SEMATECH's largest R&D program has been in lithography with $145 million of their budget having been spent on improving lithography equipment.[171]

The US semiconductor equipment manufacturing industry is a complex network of over 150 entrepreneurial, generally small firms, whose individual genius lies with a few key personnel. They are frequently strong in the sciences of their business but generally less skilled in engineering and management practices. Their limited capital resources do not permit investment in long range R&D. In contrast, most of their Japan based competitors are affiliated with Japan's keiretsu and are, therefore, established for the long term. Prior to the establishment of SEMATECH, the relationship between the US semiconductor manufacturing equipment industry and the semiconductor manufacturers was much like other vertical relationships in US industry: combative, confrontational, competitive, and generally dysfunctional.

SEMATECH is funded annually at $200M, equally split between member companies and the US government through DARPA and the DoD. SEMATECH's staff of 700 consists of roughly one-third scientists and engineers from member companies and two-thirds SEMATECH employees. Member company staff generally serve 2 year assignments at SEMATECH. Extensive use is made of R&D contracts with semiconductor manufacturing equipment producers and with federal and national laboratories, and SEMATECH funds 11 University Centers of Excellence for specialized semiconductor research.

It is well recognized that SEMATECH has been a major success. An editorial in *The Washington Post* recently reported,

> "SEMATECH has apparently broken down the isolation in which a lot of the machine-makers worked and has drawn them deeply into their customers' plans. The big semiconductor companies are now developing long-term relationships with their suppliers instead of regarding them as potential competitors. SEMATECH has accelerated the movement toward computer-integrated manufacturing and is developing common standards in a field where compatibility is essential."[172]

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171. United States General Accounting Office, Briefing Report to the Chairman, Subcommittee on Defense, Committee on Appropriations, U.S. Senate, *Federal Research - SEMATECH's Technological Progress and Proposed R&D Program*, GAO/RCED-92-223BR, July, 1992, p 3.

The General Accounting Office has concluded,

> "SEMATECH appears to be on schedule for achieving its overall technological objectives of demonstrating the capability to manufacture 0.35 micron semiconductors using only US equipment by the end of 1992."

VLSI Research has estimated that US companies that make semiconductor manufacturing equipment increased their market share ahead of Japanese companies by taking 48.8% of the world market in 1992.[173] Dataquest reported that US semiconductor manufacturers increased their world market share from 34.9% in 1990 to 36.5% in 1991.[174] Many of these improvements are attributed to SEMATECH. The shift in the yen-dollar exchange rate has also aided the sale of US manufactured semiconductors as has pressure by US government officials for Japan to open markets to the sale of US-built semiconductors. Perhaps the most convincing evidence of SEMATECH's success is that US semiconductor manufacturers are now purchasing US made manufacturing equipment. In a new Intel plant 60% of the equipment is US made instead of the 70% Japan made as was originally predicted by Intel.[175] Motorola plants are now buying 88% US made equipment.

SEMATECH has supported the US semiconductor industry in all four of the areas of the Kanter competitiveness model. According to their member companies, as reported to GAO, SEMATECH has strengthened the **core competencies of their members** by:

- Reducing Japan's semiconductor manufacturers' average probe yield advantage over US manufacturers from 19% in 1987 to 9% in 1991.
- Developing a standard model for calculating the cost of ownership for equipment.
- Developing a standard method for qualifying the performance of equipment against specifications.
- Developing generic equipment performance specifications.
- Developing disciplined methods for reducing particles and reducing contamination.
- Designing the factory of the future for flexible manufacturing of integrated circuits.

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172. *The Washington Post*, "When Industrial Policy Works," August 29, 1992.

173. *The Washington Post*, "SEMATECH's Critical Juncture," August 28, 1992, p B1.

174. GAO report, p 11.

175. *Business Week*, "Chipping Away At Japan," December 7, 1992, p 120.

- Improving the efficiency of manufacturing methods.

The GAO study also reports that SEMATECH has strengthened the **core competencies of their members' suppliers** by:

- Improving the reliability of existing manufacturing equipment by reducing its down time.

- Assisting them in the development of next generation manufacturing equipment such as tungsten deposition and etch tools, advanced lithography steppers, and high density plasma etch equipment.

SEMATECH's Partnering for Total Quality Program has helped the suppliers of semiconductor manufacturing equipment make **continuous improvements** to their equipment by teaching them the principles of quality management methods including quality concepts, statistical methods, and reliability engineering as well as by developing and testing total quality management programs specifically tailored to the needs of the company. SEMATECH's work is leading to much more uniform total quality management practices throughout the US semiconductor manufacturing industry.

Almost every assessment of SEMATECH reports that their most valuable contribution has been the establishment of long term **relationships** between their member companies and their suppliers of manufacturing equipment. The relationships between semiconductor manufacturers that SEMATECH has facilitated is leading to improvements in industry cost analysis, testing, software, and manufacturing equipment standards and helping the industry improve their strategic planning.

SEMATECH's work has also led to **time compression** by their members. NCR reported that new technology was introduced into its manufacturing process 9 to 12 months sooner because of SEMATECH. Standardized methods of equipment qualification and characterization are reducing the time required for equipment and facility start-up. Standardization of equipment specifications reduced SVG's development time for a manufacturing subsystem by 9 months. SEMATECH's CIM and flexible manufacturing programs will lead to major compression of time by reducing the average time needed to fabricate semiconductors and improve yields.

THERE ARE ADDITIONAL OPPORTUNITIES TO IMPROVE US MICROELECTRONICS WITH CONSORTIA

GOVERNMENT MICROELECTRONICS WOULD BENEFIT FROM A CONSORTIUM

None of the existing US research consortia (e.g., SEMATECH, SRC, and MCC) currently addresses government needs for unique and ruggedized parts that while as technologically advanced as commercial technology, differ from those needed by the commercial sector (e.g., high reliability parts that provide radiation hardness; electromagnetic pulse, shock and vibration resistance; high-temperature operation; very-high-density packaging; and operation in hostile environments.) A government-sponsored collaborative program should deal with this issue. Such an activity could result in this specialized technology being moved much closer to commercial state-of-the-art and probably do so at costs less than current expenditures by the US government. Even though US military systems were impressive in their Desert Storm performance, they were less sophisticated than those used in Japan's latest CD players and home video cameras. Shintaro Ishihara claims that 92 of the 93 foreign-made semiconductors used in US Desert Storm military equipment were made in Japan.[176]

US CONSORTIA SHOULD FOCUS ON HOW TO MAKE THEIR MEMBERS MORE COMPETITIVE

It is clear that most US consortia do not focus on **all** of the elements necessary for maximum competitiveness in high-technology industries. Much work remains to be done. Despite US pre-eminence in research, US consortia have tended to emphasize a research agenda rather than work that supports product- and process-improvement-driven commercialization and manufacturing. (There are indications, however, that new CEOs are moving MCC and Bellcore away from their earlier long-range research emphasis.) Preoccupation with precompetitive, generic research, while politically attractive, could lead to proliferation of irrelevant research, an already abundant commodity. Commercialization issues must be center stage in microelectronics and electronics consortia work. In some cases lead maintenance strategies are being implemented in areas where catch-up strategies are needed. By striving for all four elements of the Harvard competitiveness model and emphasizing product- and process-improvement driven commercialization, proactive government-sponsored consortia can perform each of the functions from research to improved manufacturing techniques to prototype production that demonstrate the feasibility of new concepts. Government-sponsored programs can strengthen government-industry relationships, assist consortia in technology transfer to their members, add value to university research, apply to government needs the latest technol-

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176. *Newsweek*, "A Japan That Can Take Credit," July 15, 1991, p 27.

ogy developed at consortia, improve semiconductor manufacturing equipment, develop and transfer emerging technology to electronics start-up companies, and develop special technologies needed for defense and environmental monitoring. Opportunities exist throughout the semiconductor industry chain for government-sponsored programs to strengthen US competitiveness as well as provide for government's special microelectronics needs.

ADDITIONAL VERTICAL RELATIONSHIPS SHOULD BE ESTABLISHED

Despite SEMATECH's success in linking manufacturing equipment to semiconductors, the industry still suffers from the absence of vertical linkage between other upstream sectors as well as between semiconductors and downstream electronics sectors. Michael Borrus, director of the Berkeley Roundtable on the International Economy points out that it was the absence of vertical linkage between components and consumer electronics that led to the downfall of the US consumer electronics industry because it depended on foreign suppliers for resistors, capacitors, and picture tubes.

> "American firms ceded control over the pace and direction of product and process innovation to foreign competitors."[177]

Further strengthening of US microelectronics can be gained by forming tighter linkages and establishing formal means of coordination among the various consortia.[178] The electronics sectors, perhaps through the Electronics Industry Association or the American Electronics Association, should provide the leadership for development of national roadmaps in other electronics sectors as the SIA has done for semiconductors.

WITHOUT NATIONAL LEADERSHIP US CONSORTIA WILL NOT ACHIEVE THE EFFECTIVENESS OF THOSE IN JAPAN

It is clear that the leadership provided by Japan's government agencies and national laboratories is critical to the success of their consortia. However, it would not be appropriate for this arrangement to be exactly imitated by the US because neither industry nor government wants such an arrangement. An alternative structure that would provide national leadership could be forged from an industry-led initiative coordinated by the Department of Commerce or another federal agency designated by Congress. This initiative, authorized and commissioned by the US government, would periodically work with the SIA to update roadmaps for semiconductor technology and identify and manage consortia that would support industry in the im-

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177. Michael Borrus, "Chips of State," *Issues in Science and Technology*, Fall 1990, p 42.

178. Dr. William G. Howard, National Academy of Engineering, personal communication.

plementation of development work required to achieve the goals. These actions (initially led by the National Advisory Committee on Semiconductors) have evolved through the Semiconductor Industry Association with much assistance and cooperation from SEMATECH, SRC, US industry, US government agencies, and government-owned laboratories. These organizations under SIA sponsorship have developed a technology roadmap for the semiconductor industry which provides the basis for progress in materials and bulk processing, environmental safety and health, interconnective lithography, process integration, chip design and test, equipment modeling and design, process and device structure and computer aided design, packaging, and manufacturing facilities and manufacturing systems.

In the past these various efforts have suffered from the lack of central coordination and in many instances existing consortia and national committees appear to have competed for the role of industry spokesman. As a result these activities have often appeared as parochial, led to public confusion, and made it difficult for the President and Congress to involve government in a supportive way. The current arrangement is somewhat informal and lacks the permanence that national planning work of this importance demands. Industry coordination, leadership, and oversight of microelectronics consortia could be provided through a Microelectronics Alliance with much of the specific work of each consortium funded by government. Financial support for that work done at government-owned laboratories could come from reprogramming of funds from the Executive Agency that sponsors a particular laboratory.

SEVERAL CONSORTIA ARE NEEDED TO STRENGTHEN THE US SEMICONDUCTOR INDUSTRY

Catch-up consortia should focus on electronics packaging, electronics and semiconductor materials, display technology, fabrication equipment for ultra large scale integrated circuits, memory chips, simulation and modeling, and optoelectronics. The National Advisory Committee on Semiconductors developed a plan called Micro Tech 2000 that, by the year 2000, would develop the semiconductor technology that is required to move US memory technology three years ahead of that predicted by Moore's Law. This plan has been revised and updated to contain roadmaps for manufacturing equipment, materials, computer-aided-design and simulation, economic modeling of manufacturing lines and markets, packaging, and testing in the SIA roadmap. Although SEMATECH is currently working on fabrication equipment, we recommend that consortia be established in each of the other areas.

In addition, we propose that another consortium be established to focus on the collection, integration, and dissection of research innovations from around the world (including US universities); filtering of this information to identify useful knowledge; adding value as needed to attract industry interest or transfer the knowledge to another consortium for the purpose of their adding value; and distributing of these value-added innovations to the US semiconductor industry. In some instances, additional laboratory or manufacturing demonstrations will be required before sufficient interest by industry can be obtained to complete the technology transfer. For example, a team of university leaders in electrical engineering have identified for Semiconductor Research Corporation (SRC) the value to US industry of universities having access to a manufacturing facility that would allow university researchers to validate their research in a manufacturing environment. Access to a research insertion manufacturing facility would strengthen the relevance of university research in processing technologies and tools, diagnostics and control, CAD software, and novel devices and circuits while also accelerating the transfer of university research to US industry before it is gathered by foreign competitors.[179] SRC is currently negotiating with the Department of Energy and Sandia National Laboratories to establish such a facility at Sandia.

US CONSORTIA SHOULD BE FUNDED BY INDUSTRY AND GOVERNMENT

The US government alone could provide funding for these consortia with investment of less than 5 percent of the "Peace Dividend," expected to grow to several 10's of billions of dollars. Alternatively, federal funding could be provided by revenue from a federal excise tax on all electronics systems sold in the US that make use of semiconductor technology, or federal funding could be provided by a federal luxury tax on consumer electronics products, similar to taxes on tobacco and alcohol products.

THESE CONSORTIA SHOULD BE CLOSELY LINKED

It is recommended that a national semiconductor consortia infrastructure that satisfies the needs just described be created as shown in Figure 7. Note that we are not proposing each of these as a single facility; in fact, Japan's experiences suggest that a distributed system is generally preferable. As far as is practical, we recommend that technical work be conducted at laboratories owned by the US government and that funding for these laboratories be provided by their parent Executive Agency. However, selection of the government laboratory to use for specific consortia work would be totally in the hands of industry personnel and would lie outside the sphere of political influences of Executive or Legislative bodies of the US government.

The Research Integration and Application Center, described and proposed in Appendix A, would focus on the collection and synthesis of research information from around the world that supported the activities of the other consortia.[180]

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179. Professors N. A. Masnari, T. J. Sanders, D. V. Kerns, R. J. Gutmann, and L. A. Akers, "University Access to Insertion Manufacturing Facility for Effective Acceleration of Research and Technology Transfer," presented at SRC Summer Study, August 28, 1991.

180. James E. Gover and Charles W. Gwyn, "Integrating Microelectronics Research: A Strategy to Help Win the Electronics Race," SAND91-0820, Sandia National Laboratories, Albuquerque, NM, January 1992.

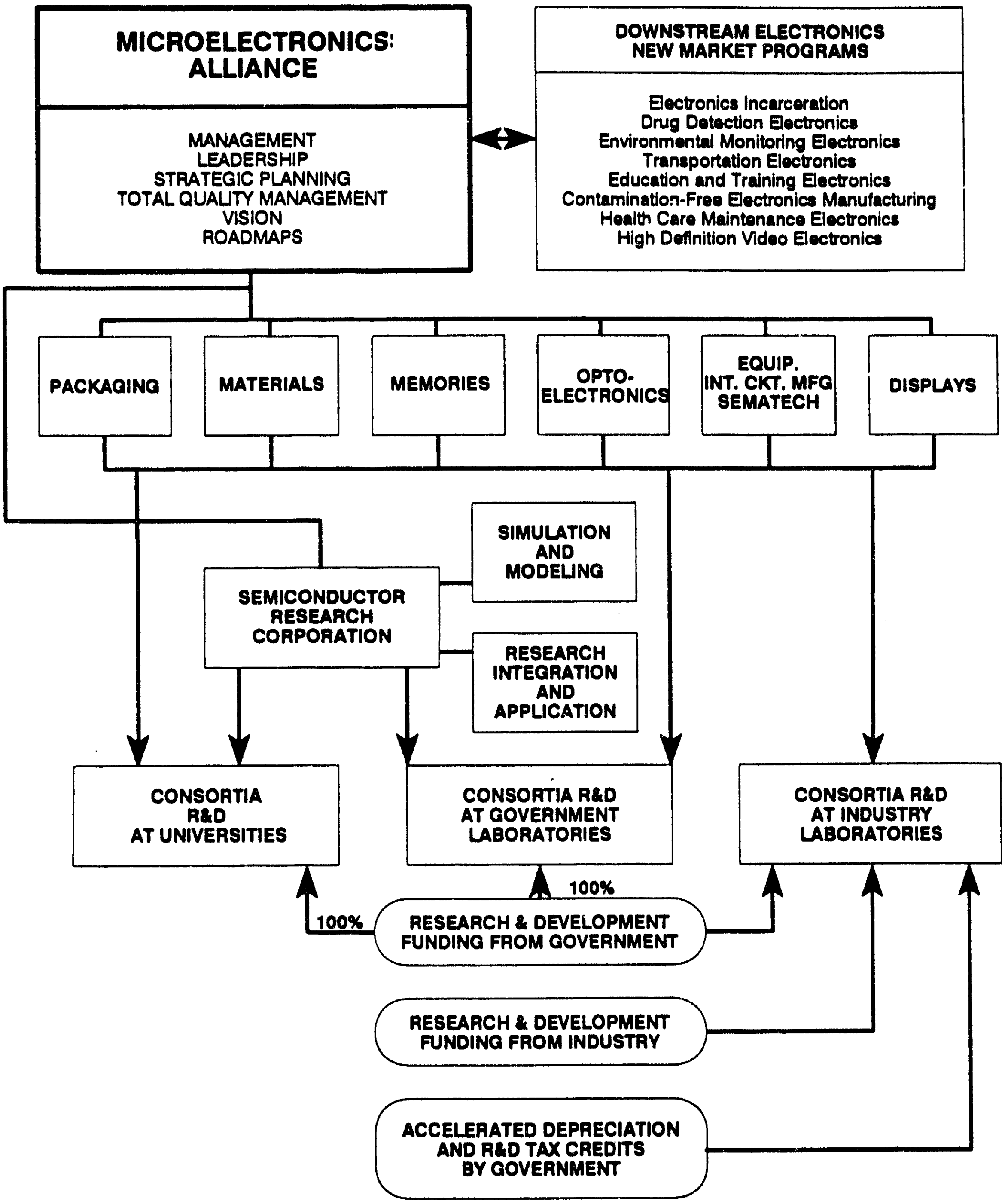

Figure 7 Organizational Structure Proposed for the Microelectronics Alliance to Manage the Recommended Consortia Complex

All of the funding for the Microelectronics Alliance as well as **all the funding for management** of each consortium would come from industry. Work of each consortium done at government-owned laboratories would be paid with government funds by reprogramming of existing budgets. Government and industry would negotiate a funding split for that work performed at an industry-owned laboratory. Industry funding by individual members would be (1) directly proportional to total "equivalent sales value" of semiconductors manufactured around the world by the member and/or total "equivalent sales value" of semiconductors purchased by members for use in electronic systems and (2) inversely proportional to the fraction of these total sales or purchases manufactured in the United States. Upper limits to corporate funding would be set to avoid excessive influence by a single corporation and lower limits would be set to restrict the number of members to a manageable set. Corporations whose owners manufacture more than 50 percent of their products outside the US would not be eligible for membership. We suggest that the consortia complex, exclusive of the downstream electronics consortia, should be funded at a total level of $1B/yr. Thus, the US semiconductor R&D investment would be increased by 25 percent. This investment should be sufficient to have measurable impact on the competitiveness of the US microelectronics industry. Only the Microelectronics Alliance and SRC would be treated as "permanent" institutions. We are not prepared to recommend how this funding would be split among the various consortia. These recommendations would be made by the Microelectronics Alliance.

NUMEROUS PRINCIPLES ARE RECOMMENDED FOR MANAGEMENT AND OPERATION OF THESE SEMICONDUCTOR CONSORTIA

The following principles for establishing US consortia sponsored by the US government are recommended. These are synthesized from competitiveness and commercialization models, the experience of the US and Japan with consortia, and the opinions of those who have studied consortia.

- Preference should be given to establishing consortia for a specific, narrow purpose. They would have a finite life targeted at the time they are formed. Each consortium member should have a graceful and successful exit strategy identified when its joins.[181]

- Consortia should target areas where the US lags foreign competition and they should emphasize work that supports product- and process-improvement-driven commercialization in their implementation of a catch-up strategy.

- Consortia should especially target the low-sales, upstream end of the electronics chain: equipment, materials, and components. This would prevent foreign competitors from using predatory pricing and a protected home market to gain control of the upstream

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181. Dr. Bruce Guile, National Academy of Engineering, personal communication.

domestic supply and manufacturing base that could be used to control downstream electronics sectors.

- Consortia should focus on practical technology including product- and process- feasibility, and leave science advancements to universities and other institutions traditionally focused on basic research.
- Consortia should emphasize research coordination and information exchange, especially in emerging technology of high interest to their members.
- Consortia should promote **competitive** horizontal relationships and **cooperative** vertical relationships.
- Consortia that require joint facilities should use existing state-of-the-art facilities whenever practical and they should minimize capital investment to reduce the impact of closure when their job is done.
- If consortia requiring joint facilities are located at government-owned institutions, their facility, capital equipment, and operating costs should be borne by the US government. Conversely, if industry prefers that a joint facility be located at an industrial site, then industry may bear 100 percent of facility and capital equipment costs; however, depreciation schedules for this equipment should be accelerated. In the latter case, operating costs should be shared with government.
- To be effective, consortia work must be synchronized with the product and process cycles of their members.
- Consortia that receive federal funding should emphasize the establishment of industry-government-university partnerships that increase the payoff from federal investment in universities and government-owned laboratories.
- Consortia should collectively develop a vision for a technology roadmap and develop a plan and strategy for realization of that roadmap by US companies. This roadmap should be made public in order to stimulate competition and promote government support.
- Consortia's success should be measured by how much the industry they are supporting improves its competitive position in the international marketplace and by the rate at which their members **increase** their R&D investments. These additional R&D investments should be given favorable tax treatment. Consortia that do not lead to increased market share and increased corporate R&D investment should be closed.
- Funders of consortia must be patient. The European Aerospace manufacturing consortium, Airbus Industries, required 20 years to realize a significant market impact.

APPENDIX A.

MICROELECTRONICS RESEARCH INTEGRATION AND APPLICATION CENTER

AIIM

Association for Information and Image Management

1100 Wayne Avenue, Suite 1100
Silver Spring, Maryland 20910

301/587-8202

Centimeter

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 mm

1 2 3 4 5

Inches

1.0 1.1 1.25 1.4 1.6 1.8 2.0 2.2 2.5 2.8 3.2 3.6 4.0 4.5 5.0 5.6 6.3 7.1 8.0 9.0 10

MANUFACTURED TO AIIM STANDARDS
BY APPLIED IMAGE, INC.

2 of 2

Executive Summary

In the decade of the 1980s the semiconductor-based electronics industry became the most important industry in America. However, by the end of the decade, U.S.-based and -owned manufacturers had lost market share to foreign-owned or foreign-based manufacturers in practically every electronics sector. At the same time, U.S. industry's R&D investment continued to exceed that of their competitors, and the U.S. government's R&D dwarfed that of foreign governments. This imbalance posed a disturbing question. The rate of which Nobel prizes and foreign students are crossing our borders suggests that our research and advanced education infrastructure are in order. So what is defeating us in the world microelectronics arena? *If we're so smart, why aren't we winning the electronics race?*

We find the publicly funded research infrastructure strong in R&D but weak in transferring that R&D into the commercial sector. One of the U.S.'s weaknesses in maintaining a lead in the world electronics market is slow transfer of technology. This works to the detriment of U.S. industry and allows countries such as Japan to be the first to develop applications of U.S. research. We conclude that if the U.S. could turn university and federal laboratory research to the competitive advantage of the U.S. electronics industry, it could substantially swing the competitive balance in the favor of the U.S. To make that transition we note that in many, if not most, cases value must be added to the research to make it attractive to industry.

As a major contribution to turning our rapid loss of world market around, we propose that the United States create a government-funded Microelectronics Research Integration and Application Center to bring together R&D and industry representatives in a single facility to focus on transferring microelectronics R&D from our universities and federally funded laboratories to the commercial sector. We further propose that the Microelectronics Research Integration and Application Center must surpass the speed with which Japan and other foreign countries transfer the United States' R&D to their own commercial sectors.

The Problem: U.S. research preeminence *alone* has not provided U.S. electronics industries with a competitive advantage.

During World War II, the U.S. emerged as a world leader in science and technology, and federal funding for R&D began to grow.

Before World War II, the U.S. built a strong industrial base on the strength of scientific discovery in Europe. During World War II, the U.S. further expanded this capability to support our war effort and that of our allies. The ability of U.S. industry to rapidly manufacture military products was perhaps our strongest defense resource. At the end of the war, the U.S. was the only world power to emerge with its manufacturing industries intact; we held an international industrial monopoly.

Recognition that scientific discovery was critical to major inventions of the 1940s—nuclear power, nuclear weapons, and solid state electronics—made it easy to conclude that science was the driving force for technology innovation.[1] Thus, a new paradigm was born. Great research and development laboratories were created at universities and in federal agencies with funding from the federal government.

As the U.S. began to develop a strong scientific and technological infrastructure, interest in advancements outside the United States diminished. According to Taizo Yakushiji, professor of international relations at Saitama University, history shows this to be a risky strategy.

> "Britain began its downhill slide in the 19th century when it failed to learn from improvements made on textile technology stolen by upstart American makers. Today, he says, U.S. manufacturers are not studying their overseas competitors carefully enough."[2]

Federal funding of R&D grew from approximately 25 percent of the total U.S. R&D investment before World War II to as much as 65 percent of the U.S. R&D investment after World War II. Today federally funded R&D is almost 50 percent of the total U.S. R&D investment. The federal government has as much impact on R&D as do market forces,[3] and the two aren't always aligned.

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1 J. P. McKelvey, "Science and Technology: The Driven and the Driver," *Technology Review*, January 1985, p 38.

2 *Fortune*, "To Be a Leader in Technology You Must Share It," January 14, 1991, p 34.

3 Barry Bozeman and Michael Crow, "the Environments of U.S. R&D Laboratories: Political and Market Influences," *Policy Sciences* 23:25-26, 1990.

Federal support of research by universities also grew after World War II.[4] Today our universities spend $13B each year on research, and federally owned laboratories spend $21B on research and development.[5,6]

U.S. universities have used federal research funding (only 6.6% of university research is directly funded by industry) to help them become the envy of the world. University research programs have made our graduate schools attractive to students from around the world.

Equally impressive are the research capabilities of federal laboratories. The research output (both quality and quantity) of our government-owned laboratories far exceeds that of any other nation's government laboratories. Our national laboratories have been called the "jewels in the crown" of the nation's research establishment.[7] Others have proclaimed that the United States has created and nurtured the finest research and development establishment in the world through its combination of government, university, and industrial laboratory systems. It has been noted that the federal laboratories, in particular, embrace an astonishing breadth and depth of science and technology—the best to be found— and that this knowledge base represents one of our most valuable national assets.[8]

Federal funding improved the R&D, but that is no longer enough to give the U.S. a competitive advantage.

Yet the research products of universities and federal laboratories have apparently not provided U.S. electronics industries with a competitive advantage. If these proclamations of excellence are correct, why aren't we winning the electronics race? Transfer of these research results into active industrial use is seemingly a missing key ingredient.

Part of the explanation for our inattention to technology transfer or the movement of research to industrial application may be attributed to the scientific community's reverence for excellence in science and the comparatively low regard for manufacturing. According to President Bush,

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[4] D. Shapley and R. Roy, *Lost at the Frontier*, ISI Press, 1985.

[5] *Business Week Special—1989 Bonus Issue, Innovation in America*, "Business Goes to College," p 50.

[6] Congress of the United States, Office of Technology Assessment, "Making Things Better—Competing in Manufacturing," March 1990, p 38.

[7] *Inside Energy*, "Watkins Asks New Panel to Explore Post-Cold War Mission of Labs," May 7, 1990, p 3.

[8] Testimony of The Honorable D. Allan Bromley, Director, Office of Science and Technology Policy, Executive Office of the President, before the Committee on Commerce, Science, and Transportation, United States Senate, Washington, DC, May 23, 1990.

"In the 1945 report that led to the founding of the NSF, the National Science Foundation, Vannevar Bush—no relation—wrote, 'As long as scientists are free to pursue the truth wherever it may lead, there will be a flow of new scientific knowledge to those who can apply it to practical problems.' ...If America is to maintain and strengthen our competitive position, we must continue not only to create new technologies but learn to more effectively translate these technologies into commercial products. In this way, we (U.S. government) can help leverage the R&D of the private sector helping whole industries advance in any increasingly competitive global market."[9]

Japan has gained the competitive advantage by importing scientific discoveries and then emphasizing development and manufacturing technology.

In the 45 years since the end of World War II, Japan, with emphasis on development and manufacturing technology, has caught up with and is in the process of overtaking the U.S. in science-intensive, high-technology electronics industries. The U.S. continues to lose market share in every sector of electronics except software and medical electronics. Japan's industries have flourished largely on the strength of science and technology innovations outside their borders. Japan has practiced the pre-World War II U.S. paradigm by building a strong industrial base from the transfer of scientific discoveries made in the U.S. and Europe to Japan.

In identifying the next steps for federal action, Lewis M. Branscomb, of the John F. Kennedy School of Government, Harvard University, has proposed investing in human resources, federally funded R&D focused on the downstream phases of the innovation cycle, building a stronger industrial base of dual use technologies, and a changed U.S. attitude toward the technical achievements of others.

"In comparison with Japanese companies, Americans suffer extensively from the 'not invented here syndrome.' ...A good diffusion strategy (for technology) gives as much emphasis to importing knowledge and adapting it for use as it does to accessing home-grown knowledge."[10]

Japan's domestic rivalry, management practices, and dedication are other major contributors to their competitive advantage.

While effective technology transfer is vital for competitiveness in today's high technology climate, we do not claim to explain competitiveness as only a technology transfer issue. As the historian John Lukacs explains, the loss of World War II served to inject cohesion, discipline, and will into Japan, in contrast, the victors began to lose power as they were

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9 President George Bush, "Remarks at the Presentation Ceremony for the National Medals of Science and Technology," November 13, 1990.

10 Lewis M. Branscomb, "Toward a US Technology Policy," *Issues in Science and Technology*, Summer 1991, p 53.

lulled into waning national cohesion, discipline, and will, and the consequent effects were seen in education, legal, commercial, and political institutions.[11]

Michael Porter of the Harvard Business School believes that competition between Japanese companies also helps account for Japan's economic surge:

> "The harsh domestic rivalry among Japanese companies—not government, not cheap labor, not exports—has been the key to that nation's success."[12]

Others identify low capital costs or domestic markets that resist imports as the primary driver for Japan's economic growth. Henry Kissinger attributes Japan's success to their leadership.

> "In his White House memoirs, former Secretary of State Henry Kissinger concludes that since 1945 Japan has been better led than any other major country. Over this period, he writes, Japanese leaders simply proved to be more 'farsighted' and 'intelligent' than their counterparts. ...Wise leadership has brought Japan to its current pinnacle."[13]

Robert M. White, former Under Secretary for Technology, United States Department of Technology, offered another perspective.

> "A recent study carried out for the National Science Board based on IRI members, showed that they regard management practices as the major reason for our inability to compete."[14]

James Fallows, Washington editor of the Atlantic Monthly, explains that four themes account for Japan's success.[15]

- A clear government commitment to develop technology that has economic potential
- Government's competency and legitimacy
- The social contract of the Japanese
- The financial structure of post-war Japan.

It is particularly interesting to note that none of the scholars and national leaders who have studied Japan's industrial prowess and none of the endless myriad of ignored U.S. competi-

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11 John Lukacs, "The Stirrings of History," *Harpers Magazine*, August 1990, p 41.

12 Michael E. Porter, "Why Nations Triumph," *Fortune*, March 12, 1990, p 95.

13 Charles William Maynes, "Coping with the '90s," *Foreign Policy*, Spring 1989, p 42.

14 Robert M. White, Presentation to IEEE-USA National Government Activities Committee Colloquium on the IEEE-USA Legislative Initiative, October 20, 1990, Washington, DC.

15 James Fallows, Panel Discussion on Industrial Competitiveness in Electronics, Gaithersburg, Maryland, February 26, 1991.

tiveness studies attribute Japan's success to basic technological superiority. Further, none of the studies identify research deficiencies in the U.S. as a contributor to our diminished competitiveness. Yet, every time the competitiveness issue surfaces, there is a rush of research proposals. As Edward J. Doyle, IEEE-USA Competitiveness Committee, has emphasized:

> "U.S. competitiveness is a complete issue. It involves manufacturing technology, design methodology, cost of capital, antitrust laws, public education, societal characteristics, industrial policy, and government-sponsored R&D."[16]

Unfortunately, no one has yet sorted out these in a quantitative way so that a priority list of policies may be established.

Japan's government has promoted corporate competition in manufacturing rather than intellectual competition among research institutions. In doing this they have sacrificed Nobel Prizes and scientific prestige for the sake of their economy. We believe most U.S. taxpayers are willing to make this sacrifice.

> "Does science lead to technology? The country with the most Nobel prizes in science per head—Britain—is notoriously slow at commercializing inventions and has been for nearly a century. Japan, to this day, stands as living proof that brilliant technological inventiveness can exist in a country with a lacklustre tradition of basic science."[17]

The Economist noted that,

> "In a recent issue of Nature, of the 15 first authors of papers announcing original results, 11 were from America, and one each was from Scotland, Germany, Australia, and Russia."[18]

There is no doubt that U.S. research institutions have excelled in the creation of original results. Only England competes with the U.S. in this area. However, neither England nor the U.S. has turned this capability to economic advantage.

We need to find a way to turn U.S. university research to the competitive advantage of U.S. industry.

Many leaders of U.S. universities have spoken out on the danger of relying solely on science. Harold Shapiro, President of Princeton University, observed:

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[16] Edward J. Doyle, Presentation to IEEE-USA National Government Activities Committee Colloquium on the IEEE-USA Legislative Initiative, October 20, 1990, Washington, DC.

[17] *The Economist*, "A Survey of Science — The Edge of Ignorance," February 16, 1991, p 17.

[18] *The Economist*, "A Survey of Science — The Edge of Ignorance," February 16, 1991, p 5.

> "What may not be in our best interest is the belief that superiority in science alone—at the expense of everything else—will ensure this country's economic strength. ...It is very, very seldom that a monopoly on science alone has produced a tremendous spurt in sustained economic and social dividends."[19]

Paul Gray, President of MIT explained,

> "Research universities in the United States have long played a central role in coming up with many of the basic new concepts that have shaped our society, but turning these concepts into processes or products has usually been a long and expensive procedure requiring years of further analysis and development. ...These days it's often not the innovation but the implementation that brings success in the marketplace. In addition to considerable vision, it takes years of applied research, much money, and a great deal of patience. ..."[20]

Rowland W. Schmitt, past President of Rensselaer Polytechnic Institute has pointed out that the U.S. science community must better demonstrate that its work is instrumental to the nation's goals.

> "We must take seriously the priorities on critical technologies spelled out by DoD, the Department of Commerce, the Council on Competitiveness, and others."[21]

In an interview published in *Harvard Business Review*, George M. C. Fisher, President and CEO of Eastman-Kodak, explained:

> "The United States has an inherent advantage over Japan in science. ...In engineering, ...the advantage goes to Japan: the disciplined process, the collegiality at all levels, the willingness to subjugate the interests of the individual to the good of the company. ...The discipline of the Japanese culture favors them on technology execution."[22]

U.S. industries, perhaps in part because of short-term pressures, have accrued few competitive advantages from the fruits of electronics research conducted outside their walls. In fact, our foreign competitors who are oriented to the long term frequently make more effective use

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19 Harold T. Shapiro, "A Dialogue on Competitiveness," *Issues in Science and Technology*, Summer 1988, p 42.

20 Paul E. Gray, "Advantageous Liaisons," *Issues in Science and Technology*, Spring 1990, p 43.

21 Roland W. Smith, "Fulfilling the Promise of Academic Research," *Issues in Science and Technology*, Summer 1991, p 44.

22 Bernard Avishai and William Taylor, "Customers Drive a Technology-Driven Company: An Interview with George Fisher," *Harvard Business Review*, November-December 1989, p 112.

of our published research than we ourselves make. Recognizing the necessity for innovation, Japan has taken bold steps to aid the movement of research from U.S. universities to Japan's industries (Figure 1). Of the 274 companies funding MIT, 18 are Japanese companies.[23]

They have endowed 21 of MIT's 211 professorial chairs. Eleven Japanese companies fund Caltech, and ten fund Columbia.[24] Japanese companies have established R&D centers near our most prestigious universities to capture their research. Kobe Steel has opened R&D facilities near North Carolina State and Stanford University; NEC has an artificial intelligence laboratory near Princeton University; Hitachi Chemical has a biotech lab at the University of California, Irvine; and Shiseido has a biology research center at Harvard.[25] Other Japanese companies with research centers near top U.S. universities include Canon, Ricoh, ASCII Corp., and OKI American, Inc.[26] Of the 250 members in MIT's Industrial Liaison Program, 53 are Japanese firms and 45 are European firms. Members gain access to MIT academic services as well as research valued at $300M, of which 80% was publicly funded.[27]

At Stanford, Japanese corporations have endowed six permanent chairs and one visiting professorship in business and engineering at an average cost of $1.2M. By working through Stanford's affiliation program, Japanese corporations have established informal relationships with specific faculty. For example, NEC has this working arrangement with several computer science professors.[28]

Michael Porter of the Harvard Business School has also pointed out the value of research for gaining a competitive advantage and observed that foreign firms are pursuing U.S. university programs:

> "American university research represents an important potential source of competitive advantage for U.S. companies. Despite the benefits of proximity, however, American companies often seem to lag behind foreign firms in taking advantage of it."[29]

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[23] Personal Communication, Eric C. Johnson, Director, MIT Office of Corporate Relations.

[24] *The Wall Street Journal Report: Technology the Final Frontier*, "Harvesting the American Mind," November 14, 1988, p R6.

[25] *Business Week's Innovation, The Global Race*, "A Shopping Spree in the U.S.," June 15, 1990, p 87.

[26] *Los Angeles Times*, "Ideas? Japanese Buy American, Raising Hackles," July 22, 1990, p D1.

[27] Ibid.

[28] *Forbes*, "The New Face of Japanese Espionage," November 12, 1990, p 96.

[29] Michael E. Porter, *The Competitive Advantage of Nations*, The Free Press, 1990, p 727.

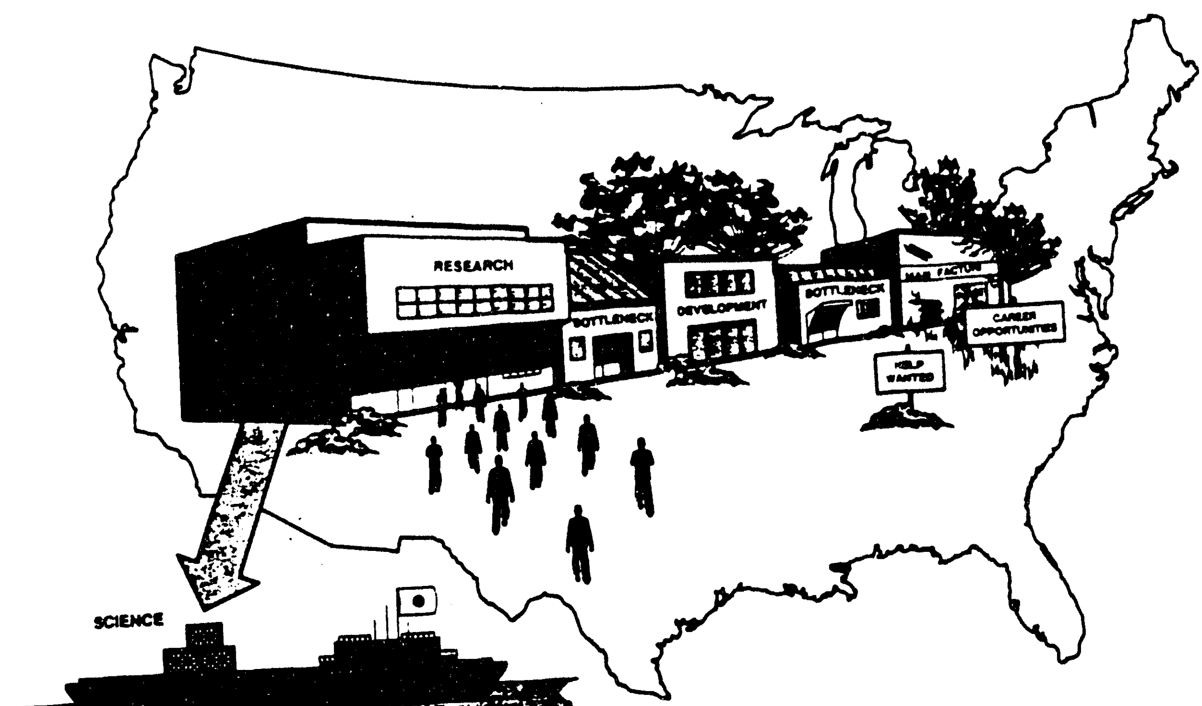

Figure 1. Recognizing the necessity for new knowledge, Japan has taken bold steps to aid the movement of research from U.S. research institutions to Japanese industries.

Arno Penzias, Vice President of Research at AT&T Bell Labs, has noted that Japanese businesses actually invest more money in U.S. universities than they invest in Japanese universities.[30] Thus, Japan's companies have been able to purchase what used to be a major advantage of the U.S.—innovative, creative research.

Numerous U.S. leaders have expressed concern about the movement of research from universities to foreign powers. John C. Redmond, President of GTE Laboratories, pointed out,

> "A case can be made for the development of a policy for technology transfer between research universities and U.S. firms that would favor U.S. companies over their foreign competitors."[31]

Erich Bloch, former Director of the National Science Foundation, has expressed a strong position on this issue.

> "I would argue that foreign competitors are not paying the full costs of U.S. academic research, and that, therefore, the American public is not receiving a full return on its long-term investment."[32]

The U.S. has developed the research resource base required to sustain us as the world's electronics technology leader, but we have yet to discover how to convert this knowledge base to full and at least temporarily **exclusive** U.S. use so as to quickly capture its economic potential in U.S. industry. Data trends suggest that unless we learn how to do this, our world market share in electronics products will continue to erode.

Mindy L. Kotler, President of Search Associates, has studied Japan's methods of information gathering and made the following observation.

> "In Japan, information and information gathering are viewed as an important commodity and activity. ...It is increasingly popular in the U.S. to equate information with power. Nevertheless, in practice Americans rarely value it in that sense. Information is seen as simply a collection of facts and data, of disparate news and statistics. ...The American tradition is one of information openness. ...Today's Japanese information-gathering machine is a multi-billion-dollar industry. Information is used (in Japan) not only to explain but to reduce uncertainty and to plan strategy."[33]

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[30] Arno Penzias, "The Japanese Are Not Superhuman," *Forbes*, March 20, 1989, p 126.

[31] John C. Redmon, "Forum — Letters to Editor," *Issues in Science and Technology*, Summer 1990, p 13.

[32] Erich Bloch, "Forum — Letters to Editor," *Issues in Science and Technology*, Summer 1990, p 12.

[33] Mindy L. Kotler, "Information Strategy: The Japanese Advantage," Testimony before the Technology and Competitiveness Subcommittee of HSST, U.S. House of Representatives, April 30, 1991.

Ms. Kotler points out that in Japan information gathering is holistic. That is, technical facts are interpreted in the context of the researchers, their work environment and management structure, and their research goals. It is Ms. Kotler's opinion that much of the $300 million spent by Japan in the U.S. on what some term as lobbying is actually information gathering rather than corporation representation. This includes extensive participation in U.S.-based think tanks.

Rather than complain about Japan's practices, we suggest that we in the U.S. need to recognize the value of information and institute an effective information gathering network for science and technology innovations. The science and technology community, in particular, needs to learn the skills of using information synthesis to produce knowledge. Unfortunately, for so long U.S. technical journals have emphasized the necessity for originality that scientists and engineers have come to view gathering of information generated by others as a second class function. While the U.S. legal profession is largely based on information collection and synthesis, these methods have not penetrated U.S. science and technology.

What should have been obvious from the very beginning is just now being understood—that is, productivity and competitiveness are dependent not solely on technological innovation but also on the collection of these innovations, their synthesis, and incorporation through rapid **technology transfer** into industrial processes and commercial products.[34]

Robert Reich, Secretary of labor, observed:

> "The U.S. government is relying on ambitious research projects to spur commercial competitiveness. Instead it should speed the commercialization of new technologies wherever they may be developed. ...The problem lies in the inability of American companies...to transform discoveries quickly into high-quality products and into processes for designing, manufacturing, marketing and distributing such products."[35]

Others have made similar observations.

> "The country (U.S.) must...fundamentally alter its approach toward science and technology. U.S. policies...have tended to concentrate more on the generation of new knowledge than on the adoption of product or process innovations based on that knowledge."[36]

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[34] J. S. Yudhen and M. Black, "Targeting National Needs—A New Direction for Science and Technology Policy," *World Policy Journal*, Vol. VII, No. 2, Spring 1990, p 252.

[35] Robert B. Reich, "The Quiet Path to Technological Preeminence," *Scientific American*, October 1989, pp 41-42.

[36] Richard M. Cyert and David C. Mowery, "Technology, Employment, and U.S. Competitiveness," *Scientific American*, May 1989, p 60.

The challenge facing our nation is how to speed the conversion of research to industry products so that we can reap the economic rewards faster than foreign competitors. In particular, we must develop a mechanism to tap the federal investment in research and development at universities and federal laboratories. As Congressman George Brown pointed out:

> "The United States is producing a wellspring of government-sponsored research, but few in America are drinking from the well."[37]

Many have identified weaknesses in the U.S. system. Dr. Allan Bromley noted:

> "Other countries are outperforming the United States in transforming research discoveries into high-quality products and into processes for designing, manufacturing, marketing and distributing those products."[38]

Dr. Bromley also suggested that federal laboratories can help our industries, particularly the small and mid-sized industries:

> "...The coupling between federal laboratories and industry is weak, especially with small- and mid-sized companies that could benefit most from federal assistance, and too often, an attitude of mutual distrust exists that inhibits any effective cooperation between industry and government."[39]

Despite the fact that there seems to be a consensus among leaders and analysts that the U.S. doesn't suffer from a lack of research, but rather from the engineering application of research, there is much momentum, lobbying strength, and vested interest in the research community to maintain the status-quo or simply increase federal funding for research. It is clear that change will indeed come slowly in the absence of dramatic mission shifts among federal agencies.

Institutional deficiencies partially contribute to the U.S. competitiveness question. Too many of our federally funded R&D institutions and the legislative and executive organizations that fund and oversee these institutions have obsolete strategies and policies. Among these is the implicit assumption pioneered by Vannevar Bush that technology transfer automatically occurs when high quality research is done—an assumption that history has disproved. Such outdated and ineffective strategies must be replaced with more productive ones.

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[37] Congressman George E. Brown, Jr., "Profitable Technology from Uncle Sam," *High Technology Business*, February 1989, p 26.

[38] Testimony of the Honorable D. Allan Bromley, Director, Office of Science and Technology Policy, Executive Office of the President, before the Committee on Commerce, Science and Transportation, United States Senate, Washington, DC, May 23, 1990.

[39] Ibid.

Japan's success in technology transfer is clearly not entirely due to their success in monitoring U.S. university research and standards organizations. Charles H. Ferguson of MIT has identified two other methods that Japanese companies have successfully employed to transfer technology from the U.S.[40]

- Become a source of components and hardware to U.S. competitors. Insight into competitors' strengths and weaknesses is gained, and leverage to pressure U.S. firms to license their designs to Japanese companies can result.
- Japan's vertically integrated firms make equity investments in U.S. startups.

As the Japanese are gaining economic momentum, they are creating a strong research base that they will eventually use to their advantage.[41] The Council on Competitiveness recently conducted a study of Japan's technology policies and how these impact Japan's success in competitive industries. Among their findings was,

> "Japan has been increasing its emphasis on basic research, but its top priority is still to support industry. Much basic research in Japan remains research that is basic to industry's future rather than basic in the U.S. sense of being without foreseeable applications."[42]

Most of Japan's R&D is done in industrial labs, where access to the information is easily controlled. **Unless the U.S. learns to better leverage research institutions around the world, particularly our universities, to the advantage of U.S. industry, Japan, through effective use of their research institutions, will dominate all those high-tech industries with significant economic potential by the turn of the century.**

Key to the U.S. regaining and maintaining the competitive advantage is rapid transfer of precompetitive, generic research and enabling technology from research institutions throughout the world to U.S. electronics industry faster than it is transferred to foreign industry.

Problem Analysis: Removal of bottlenecks and redirecting areas of emphasis can benefit transfer of precompetitive, generic electronics R&D from research to manufacturing.

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40 Charles H. Ferguson, "Computers and the Coming of the U.S. Keiretsu," *Harvard Business Review*, July-August 1990, p 66.

41 Sheridan M. Tatsuno, "Japan's Move Toward Creativity," *The G-A-O Journal*, Summer 1990, p 13.

42 Council on Competitiveness, *Challenges*, February 1991, p 5.

The traditional linear path from research to development to manufacturing may be depicted as shown in Figure 2, where development is split into advanced development and engineering development.[43]

The advanced development stage is sometimes omitted, either because of lack of industry capability or by misplaced focus.

Many medium- to small-sized companies lack an advanced-development, precompetitive, preprototype capability, and larger companies may be so focused on engineering development and manufacturing that they underemphasize advanced development.

To arrive at a product ready for sale, the development products must have undergone repeated testing and examination under actual use conditions. The manufacturing process and design parametrics must be defined. Early reliability information must be developed largely through testing and studying preproduction lots, and preliminary assessment must be made of the yield of manufacturing processes. Without these, the investment required for manufacturing is excessive risk for industry buy-in.

Few U.S. companies (except for the largest, such as IBM) are well staffed in the advanced development arena. It is in this advanced development stage that ideas are tested and critically examined to determine their potential. For companies lacking this capability, ideas and information must be moved from research to engineering development without having progressed through an advanced development, preprototype stage. The risks in omitting this stage are great, but successful industries who cautiously make this step are criticized for short-term thinking and risk aversion. An advanced development phase is preferred, but not always affordable, even in the U.S. semiconductor industry where industrial investment in R&D is 9.3% of sales.[44]

After a radically new product is introduced, competitiveness in high-tech industries is sustained by introducing incremental improvements into each new product cycle. Start-up companies find it especially difficult to prepare for product cycles that follow their initial product introduction. Thus, even though a start-up with a radical new product may experience early success, sustaining this success through the introduction of products that are improved versions of the last generation may be difficult. Financial collapse or buy-out can result. Second- and third-cycle products may come directly from engineering development or manufacturing, but eventually more dramatic steps involving the research and advanced development steps must be involved. This process is depicted in Figure 3.

These cycles utilize research, advanced development, engineering development, and manufacturing stages in a variety of combinations. Competitive industries have short cycle times and large improvements between successive cycles.

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[43] Personal Communication, Dr. James F. Freedman, Vice President, Research Integration, Semiconductor Research Corporation.

[44] *Business Week—1990 Bonus Issue, Innovation*, "The Global Race," June 15, 1990, p 205.

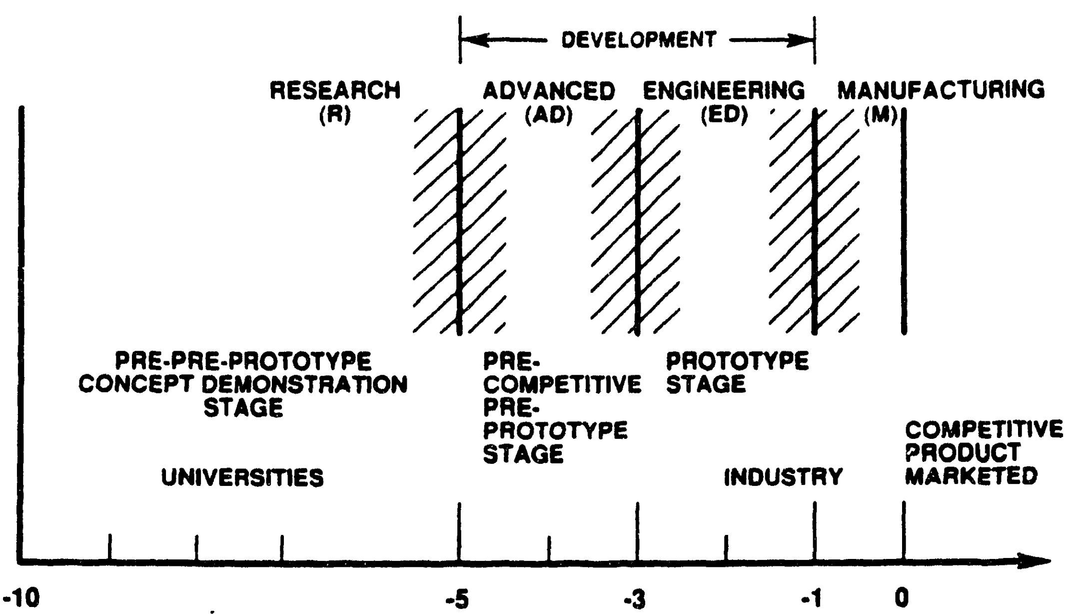

Figure 2. As an idea evolves through a linear system it can pass through several developmental stages, beginning with research and ending with manufacturing.

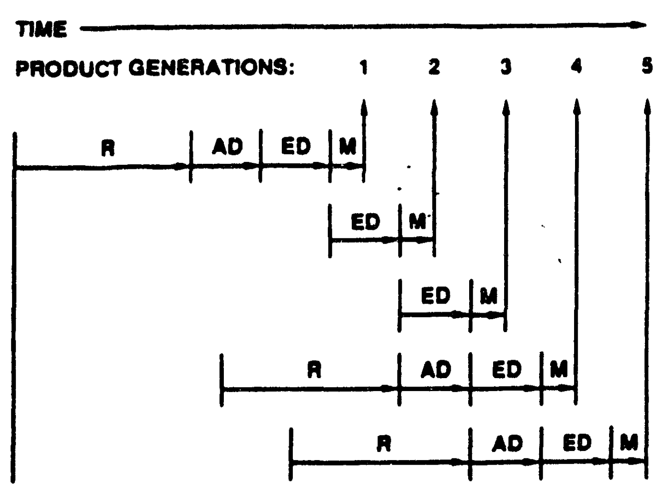

Figure 3. After a product is initially introduced (product generation 1) it undergoes numerous cyclic incremental improvements (product generations 2, 3, 4, ...).

The more competitive and fast-moving the technology, the shorter the product cycles and the more critical the role of research. Its **timeliness** is especially critical. Great ideas at the wrong time in the product cycle have no utility unless they are still useful for the next cycle. In the most competitive industries, research contributions may be necessary for each product cycle.

Amy Lowen Manheim of GAO's National Security and International Affairs Division has reviewed the transfer of government-sponsored technology to the private sector.

> "Rarely are government efforts to transfer a given technology to the private sector made at a sufficiently early stage in that technology's life. ...Technology is the knowledge, the information, that underlies applications. For this kind of "naked" technology to be transformed into a commercially successful product, it must first be "clothed" in consumer's needs."[45]

Connor Peripherals, a U.S. electronics company that manufactures hard-disk drives, has become the fastest growing major manufacturer in the U.S. by making frequent product improvements in small steps. Connor uses nonstop innovation to keep rivals—including Japanese rivals—at bay.[46]

In highly competitive industries, such as microelectronics, manufacturing equipment, manufacturing processes, and produce improvements must take place concurrently rather than serially. In highly competitive, fast-paced industries, the product cycle length may be shorter than any of the preparatory stages of research, advanced development, engineering development, and manufacturing. In this case, a project team must be working on second- and third-cycle improved versions of the product even before the first product cycle is completed.

Parallel, rather than series, development is required for rapid technology transfer.

William J. Spencer, former Xerox Group Vice President for Research and currently CEO of SEMATECH, has examined how ideas are moved from the research laboratory to the delivery of products to customers.

He contrasts the old linear system's serial model of product delivery, in which the functions of research, development, design, manufacture, marketing, sales, and service are conducted sequentially, to the parallel model of product delivery, in which these functions are conducted concurrently.[47] His models are depicted in Figure 4. Note that not only is the serial process too slow, it has few opportunities for customer feedback.

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45 Amy Lowen Manheim, "The Need for a Strategic Marketing Plan for U.S. Technology," *The G-A-O Journal*, Summer 1990, p 21.

46 *Fortune*, "America's Fastest Growing Company," August 13, 1990, p 48.

47 William J. Spencer, "Research to Product: A Major U.S. Challenge," *California Management Review*, Vol. 32, No. 2, Winter 1990, p 45.

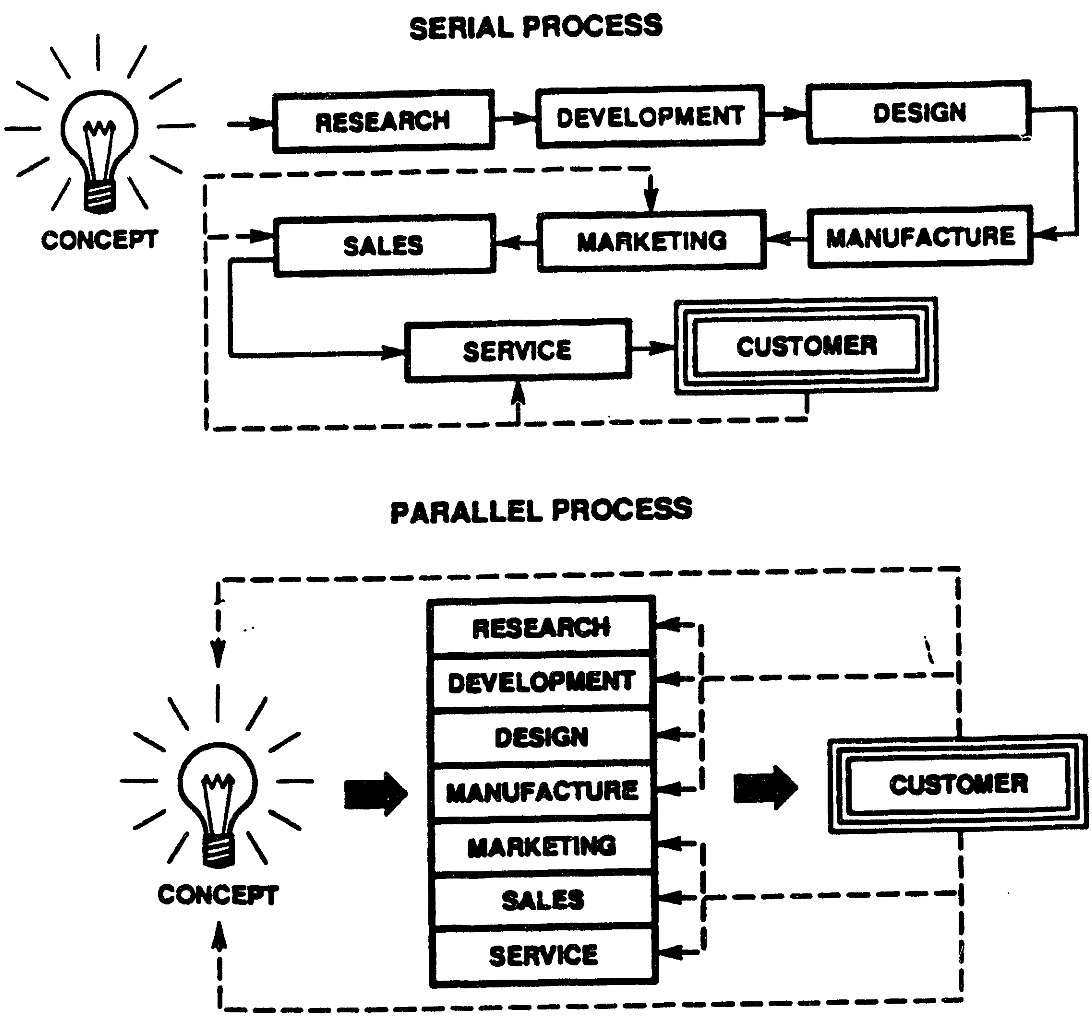

Figure 4. In order for companies to develop products quickly, gain share in existing markets, and then develop major new markets, the serial mode of product delivery must be collapsed and replaced with product development done in parallel. Customer feedback (dashed lines) is critical throughout the process.

The transfer of technology from research laboratories to commercial manufacturing is difficult even when the research laboratory is owned by the manufacturing company. The chemistry of technology transfer is so subtle that only a few U.S. companies, like Hewlett-Packard and DuPont, have mastered the process.[48]

> "Just as quality and manufacturing excellence were key to competitiveness in the 1980s, superior commercialization (the ability to bring sophisticated technology-based products to market faster and more often than competitors) will be crucial in the 1990s."[49]

Recipients of research seldom believe that the researcher has adequately demonstrated the practical technical feasibility of his work. A severe expectation gap exists between research and manufacturing. Usually the research contributor and the engineering receiver have very different ideas about the appropriate hand-off point. If the receiver doesn't have the right personnel and adequate resources to extend the work beyond the point where the giver wants to hand it off, the receiver may not be interested. This difference in view can serve as a severe bottleneck to technology transfer.

> "Rarely is a technology transferred that doesn't require more development or technology improvement work on the part of the recipient. ...An effective method of transferring technology involves direct transfer of professionals."[50]

Bottlenecks that impede the development of technology to the point of application must be overcome.

The demonstration of a new technical concept is of little practical value without corresponding development activity up through its point of application.

In Figure 5 we symbolically depict inhibitors to technology transfer as bottlenecks.

Numerous studies have been conducted to determine how to facilitate and overcome bottle necks to technology transfer. Bottlenecks include inadequate investment in manufacturing procedures, physical isolation of research, development, and manufacturing personnel; lack of a common language and motivation between research, development, and manufacturing personnel; lack of technical breadth in personnel across all disciplines; lack of modern facilities and equipment (particularly in fast-moving, high-tech sectors) to test the practicality of new ideas; not-invented-here syndrome; and numerous other cultural and institutional factors. These studies conclude that the transfer of knowledge within a corporation is

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[48] *Fortune*, "Turning R&D in Real Products," July 2, 1990, p 72.

[49] T. Michael Nevens, Gregory L. Summe, and Bro Uttal, "Commercializing Technology: What the Best Companies Do," *Harvard Business Review*, May-June 1990, p 154.

[50] Committee on Science, Space, and Technology, House of Representatives, "Technology Policy and Its Effect on the National Economy," December 1988, p 53.

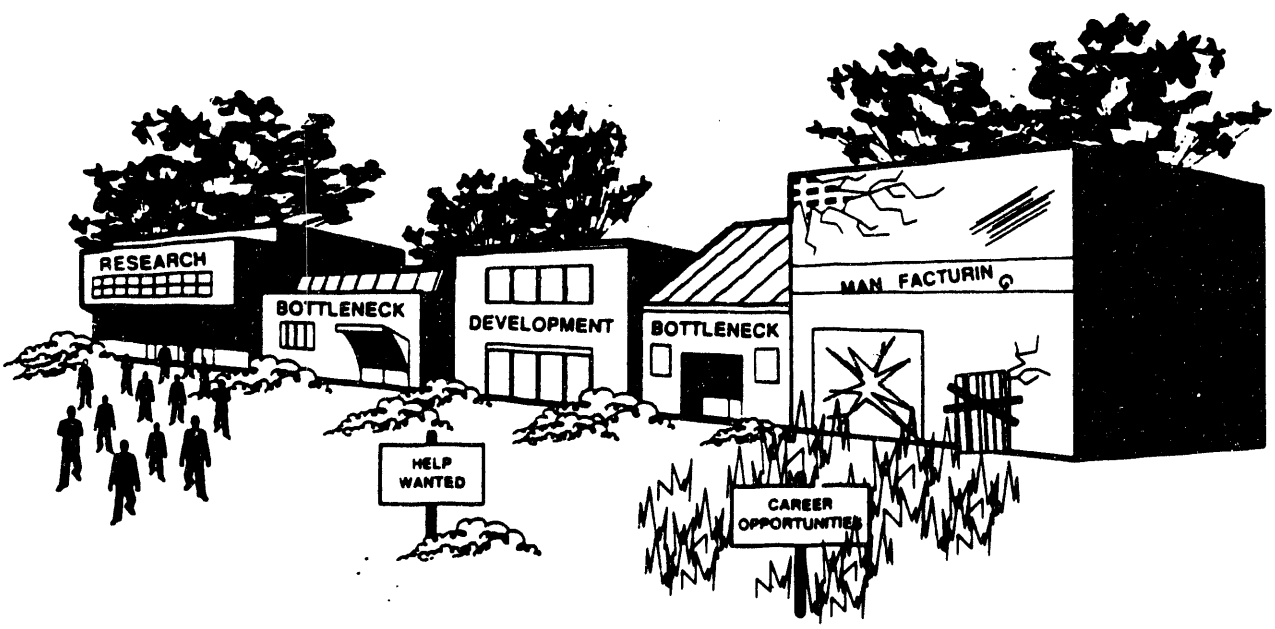

Figure 5. Many impediments make the transfer of knowledge from research to manufacturing a difficult process.

strongly dependent on corporate factors, including business strategy; corporate cultural practices; technical differences between staff, especially research and manufacturing staff; management practices; and the timeliness of the transfer.[51]

The best environment for technology transfer is a highly interactive communication between manufacturing, development, and design personnel in a shared facility.

The best environment for technology transfer between two organizations occurs when the two organizations operate as a team with a common goal and a common progress metric. Organizations competitive in electronics employ this strategy while still maintaining strengths in numerous technical specialties. This means that **the receiving organization must be involved from the start with the formulation of research objectives that are driven in large part by assessment of market potential.**

Technology transfer occurs through the process of communication, not simply through the passing of hardware. Whatever facilitates communication and cooperation between manufacturing, development, and design personnel will facilitate technology transfer. Marketing personnel must communicate market potential to researchers, and R&D personnel must discuss technology potential with manufacturing and marketing personnel. This highly interactive communications process is promoted when manufacturing industry engineers and university researchers work together as a team in a shared facility.

Tom Peters has emphasized the importance of colocation in promoting the development of cooperative teams that are able to communicate.

> "Walls of concrete and plaster are very important—and inimical to teamwork. Numerous studies chronicle the astonishing exponential decrease in communication that ensues when even their walls or a few dozen feet of segregation are introduced. Hence all team members must 'live' together. It's as simple as that. Want factory people and engineers to talk? Put them in the same room, with no dividers."[52]

> "At present, Japan seems to be unique in its industry-wide ability to move advanced technology rapidly and effectively from the laboratory to the market. ...What appears to work best is the establishment of teams of researchers, engineers, designers, manufacturing specialists, and even marketeers, early in the life of a technology or product."[53]

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[51] M. L. Ounjian and E. B. Carne, "A Study of the Factors Which Affect Technology Transfer in a Multilocation Multibusiness Unit Corporation," *IEEE Transactions on Engineering Management*, Vol. EM-34, No. 3, August 1987.

[52] Tom Peters, "Thriving on Chaos," *Perennial Library*, Harper & Row Publishers, 1987, p 263.

[53] Congress of the United States, Office of Technology Assessment, "Holding the Edge—Maintaining the Defense Technology Base," April 1989, p 103.

Robert S. Cutler, with sponsorship by the National Science Foundation, compared U.S. industrial researchers and Japanese industrial researchers in their use of new technologies resulting from university research.[54] His studies concluded that

> "Japanese engineering researchers work in teams to carry through a particular project, from the initial research stage, through development, to prototyping, and even on to production and marketing. ...In the U.S. by contrast, a university researcher typically does the fundamental work and then publishes his or her findings in the journal literature. From these publications in the open literature, another researcher...carries it (the research) through the applied research phase and again publishes the results. ...In this (U.S.) process, however, users' requirements are rarely cited or integrated into the research design, as often is the case in Japan."

The unidirectional, linear process described by Dr. Cutler that is used to transfer U.S. research results to manufacturing may eventually work, but the process is too slow to give U.S. industry a competitive advantage. It is especially sluggish in highly competitive, fast-moving industries such as electronics.

Michael Porter of the Harvard Business School explains the need for tight linkage between the researcher and the user.

> "Whatever the institutional setup for conducting R&D, it works best in those settings where research institutions have tangible connections to industry."[55]

Federal agencies have struggled with how to do technology transfer. For example, the former Secretary of Energy pointed out,

> "Efforts to utilize the technologies and capabilities residing in DOE facilities to provide assistance to the private sector in improving our industrial competitiveness must be made more efficient and effective than in the past."[56]

The expectations of members of the U.S. Congress have been heightened by their first-hand observation of technology transfer in Japan. For example, Senator Bingaman observed,

> "To facilitate the adoption and insertion of new technologies into products, Kyocera has the researchers who develop a technology move with the technology as it goes into production. The Senior Managing Director, our host at

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[54] Robert S. Cutler, "A Comparison of Japanese and U.S. High Technology Transfer Practices," *IEEE Transactions on Engineering Management*, Vol. 36, No. 1, February 1989, p 21.

[55] Michael E. Porter, *The Competitive Advantage of Nations*, The Free Press, 1990, p 635.

[56] Admiral Watkins, "Setting the Course for Technology Transfer at the Department of Energy," *Secretary Energy Notice*, SEN-30-91, January 23, 1991.

> Kyocera, explained that researchers and managers are far apart mentally, so it is important to manufacture newly-developed products near the R&D center to ensure that there is cooperation between research and production. Mitsubishi Electric also stresses the connections between R&D and production and moves researchers and R&D engineers into a plant with a new technology."
>
> "I was also struck by the emphasis on manufacturing and process R&D, which appeared to receive equal if not greater emphasis than basic technology R&D and component research. This was most evident in the 'third sector' corporations, public-private consortia for the development of specific technologies, but was also true of the R&D centers we visited."[57]

Researchers at McKinsey & Company have studied U.S., Japanese, and European companies to understand the difference between leaders and laggards in commercializing technology and the links between improved commercialization and competitive success.

> "Superior commercializers...strive to build on extensive network connecting R&D, manufacturing, sales, distribution, and service, and they **organize around products, markets, or development phases rather than functions.** For them cross-functional teams are standard practice. ...Improvement (in commercialization) starts with top management setting the right priorities along with ambitious goals. Then...build cross-functional skills and...remove obstacles to quick decisions and actions on commercialization projects."[58]

Roland Schmitt, past President of RPI, emphasized the importance of teamwork in technology transfer.

> "The best technology transfer is not a hand-off from one player to another but a team effort. ...The problem is that when you start thinking of technology transfer as a separate process of its own, removed from R&D, you've already lost the game. The user and the performer of targeted R&D need to have established a relationship before there is anything to transfer. What you need is not technology transfer but technology teamwork."[59]

The teamwork process stimulates rapid technology transfer. The transfer process for technology is expedited when all members of the team "sit at the same table" and speak a common language. However, rarely do manufacturing engineers and research personnel speak the same language, or even share the same motivations. When they do work together,

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[57] Senator Jeff Bingaman, "Trip Report of Visit to Japan," November 11-21, 1990.

[58] T. Michael Nevens, Gregory L. Summe, and Bro Uttal, "Commercializing Technology: What the Best Companies Do," *Harvard Business Review*, May-June 1990, pp 162-163.

[59] Roland W. Schmitt, "Technology Transfer," presented at Conference of the Technology Transfer Society, Portland, Oregon, June 29, 1988.

though, the results can be remarkable. For example, in the famous Manhattan Project, scientists and engineers representing universities and industry worked together at Los Alamos under the leadership of General Groves to apply nuclear physics research conducted around the world to develop nuclear weapon prototypes. They did so faster than Germany at a speed seldom equaled in history. The Manhattan Project demonstrated the principles articulated by Schmitt.

The Semiconductor Research Corporation (SRC) has investigated the process of technology transfer from universities, where they sponsor research, to their member companies. They have yet to find a process that is entirely satisfactory.

> "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...Other innovative ideas are needed...A challenge faced by the SRC...is to develop mechanisms for industrial evaluation of university results... Often, transfer of information in either direction is extraordinarily difficult and requires a major effort on the part of the recipient."[60]

The SRC has found that they can collect great quantities of information and pass it to their member companies. However, their members already suffer from information overload. What the member companies are seeking is information sifted and transformed into useful knowledge related to their technology development roadmaps.

The SRC has also studied technology transfer in Japan.[61,62] Highlights of Japanese methods include:

- Establishment of information gathering and sharing networks, including extensive conference attendance and visits to U.S. university research programs
- Japanese technical societies and R&D associations assist in technology transfer, with partial government funding for R&D associations
- Technology planning
- Maximization of people-to-people contacts
- Joint efforts by design and production personnel
- R&D staff rotation to production
- Government sponsorship of joint R&D projects[63]

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60 Dr. Larry Sumney, President, Semiconductor Research Corporation.

61 R. Whisnant, R. Lucik, A. Griffin, K. Barbour, B. Beatty, and D. Rogers, "SRC Study of Technology Transfer in Japan," *SRC Report*, April 19, 1988.

62 W. F. Finan and J. Frey, "The Effectiveness of the Japanese Research-Development-Commercialization Cycle: Engineering and Technology Transfer in Japan's Semiconductor Industry," *SRC Report*, August 1989.

63 J. Sigurdson, "Industry and State Partnership in Japan—The Very Large Scale Integrated Circuits (VLSIC) Project," Research Policy Institute, Lund, 1986.

It is also interesting to note that Japan's university personnel do much of their research at industry or national laboratory facilities and do their work cooperatively with industry personnel. Generally, institutional arrangements in Japan are designed to favor industry but are done in a way to promote domestic competition.

In all studies of successful transfer of precompetitive R&D that we have reviewed, the dominant themes that emerge are:

- Customer need and market forces must influence the direction of research.
- Cooperative working teams spanning research to manufacturing, preferably working together in a shared facility, aid the process remarkably.
- Extension of research work is usually required to establish product manufacturability or process utility.
- Communications, the primary means of technology transfer, must be facilitated by all practical means. We believe that a third-party technology transfer broker can serve as a catalyst to expedite the movement of research to manufacturing.

Our views are consistent with the ideas of David Osborne, a writer and consultant, who identified the variety of tacks that can be taken to improve the prospects of commercializing research.[64]

- Insist upon *face-to-face* interaction between academic and business researchers in any joint program.
- Create intermediary organizations that bring researchers and users together.
- Create separate technology transfer organizations which look for promising research, take it to firms that might be interested, and broker a marriage between innovator and prospective user.

In the following sections we propose to integrate these concepts to synthesize a partial solution for the U.S. microelectronics competitiveness problem. We believe the concept to be generally applicable to other fields as well.

The Solution: Synthesize what works for technology transfer into a single facility for microelectronics.

The U.S. needs to create a microelectronics research integration and application center devoted to technology transfer.

The publicly funded research institutions in the U.S. need to be made a much more valuable asset for U.S. economic growth, and we must capture research innovation in foreign institutions. America's research institutions can, and must, learn to give U.S.-based electronics industries a competitive advantage. to do this, we **must rapidly transfer precompetitive, generic research** and **enabling technology** from research institutions

[64] David Osborne, "Refining State Technology Programs," *Issues in Science and Technology*, Summer 1990, p 59.

throughout the world to U.S. electronics industry faster than it is transferred to foreign industry.[65]

We recommend creating a Microelectronics Research Integration and Application Center (referred to as the Center) to accelerate the transfer of ideas and technology from research laboratories around the world to industry. At the Center teams representing (1) university and federal laboratory researchers, (2) microelectronics industry manufacturers, and (3) host laboratory personnel whose functional capabilities span research to manufacturing will work cooperatively to move research toward commercialization.

The primary functions of the center will be to collect, integrate, extend and add value to research and to integrate it with development, design, manufacturing, and market knowledge in a single work environment.

> "Lewis M. Branscomb, former Chief Scientist for IBM Corp., cited the need today for a comprehensive information infrastructure, an important element of which would be an efficient system for diffusing and sharing knowledge."[66]

Arnoud De Meyer, Associate Dean of the MBA program at the European Institute of Business Administration in France, while on sabbatical leave at the Keio University, Yokohama, Japan, researched the issue of communications in R&D. He noted,

> "An essential element of an R&D engineer's work is the gathering, diffusion, and creative processing of information. Many studies about R&D have shown that the productivity of an R&D engineer depends to a large extent on his or her ability to tap into an appropriate network of information flow. ...Engineers do read. But they limit their reading mainly to textbooks...or trade journals. ...Several studies...have verified this core finding."[67]

The Center will collect, sift, diffuse, and share knowledge relevant to industry goals and add value by demonstrating the utility of new ideas through the preprototype stage to support U.S. industry in achieving practical microelectronics products and processes. We depict the impact of the Center on narrowing the gap between research and manufacturing in Figure 6.

The Center will assist in the parallel implementation of research, development, design, manufacture, marketing, sales, and service mentioned earlier. We depict the role of the Center in bridging the functions of research, development, design, and manufacture.

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65 *IEEE Spectrum*, "R&D Notes," October 1990, p 25.

66 Ibid.

67 Arnoud De Meyer, "Tech Talk: How Managers Are Stimulating Global R&D Communication," *Sloan Management Review* Spring 1991, Vol. 32, No. 3, p 49.

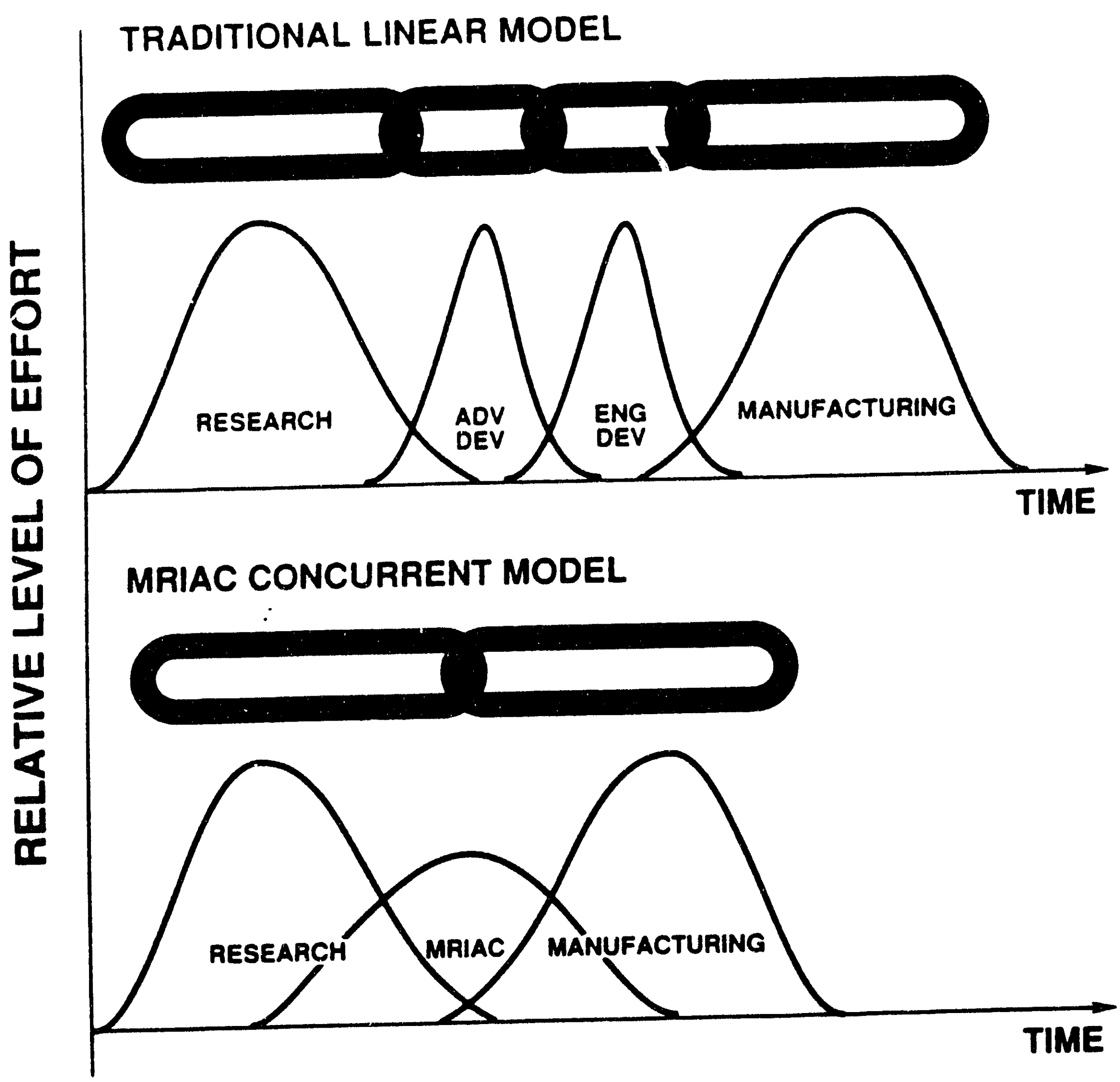

Figure 6. In the simplified representation of the traditional flow of information from research to marketing, those industries without strong advanced development capabilities capture very little research. With the Microelectronics Research Integration and Application Center (MRIAC) in place, this deficiency will be corrected and research will be transferred to manufacturing on a much shorter time scale.

The Center would bridge the bottlenecks to technology transfer as depicted in Figure 7.

Staff would be assigned to specific areas of technology transfer.

Staff at the host laboratory will be assigned to work with representatives of U.S. semiconductor companies to understand their development and manufacturing problems. Relevant research issues will be identified. Information from specific companies will be treated as proprietary and will not be shared with another company. As a result of these assignments, the staff at the Center will develop a thorough understanding of problem areas and research needs.

Other staff at the Center will be assigned to specific technical areas in which they have considerable experience and a national reputation. Each area will have been judged to be of high priority to the U.S.-based semiconductor industry. The staffs' responsibility on these assignments will focus on full awareness of worldwide research activities in the assigned areas. It will be expected that these staff set up and conduct workshops and other information exchanges among U.S. researchers to discuss how research in specific areas could impact the design or manufacturing of new or existing technology. The staff in each area will be expected to establish working relationships with world-leading researchers in that area.

Within the Center the host staff representing industry needs and research innovation will merge their understanding of problems and solutions and will develop unique connections between industry manufacturing personnel and researchers. As these associations are formed, a member of the host laboratory staff will be assigned the responsibility to bring together the relevant researcher and manufacturing engineer to merge need and innovation. If the industry representative is interested but wants more technical evidence, the MRIAC staff will be prepared to work with the researcher to further develop their work to the point deemed appropriate by industry.

It is expected that the Center's staff and researchers will sometimes identify research innovations that are of no interest to industry because of low market potential. Every effort will be expended to connect this work with an entrepreneur who is interested in manufacturing and marketing the technology. Thus, we envision that the Center will spin off numerous start-up companies that will continue to use the Center's facilities for R&D purposes, particularly during their early years.

Project management would be used.

The Center would be established as a separate project-oriented center-of-excellence organization that would use personnel and facilities that already exist in the microelectronics organization of the host laboratory. We depict the organizational structure in Figure 8.

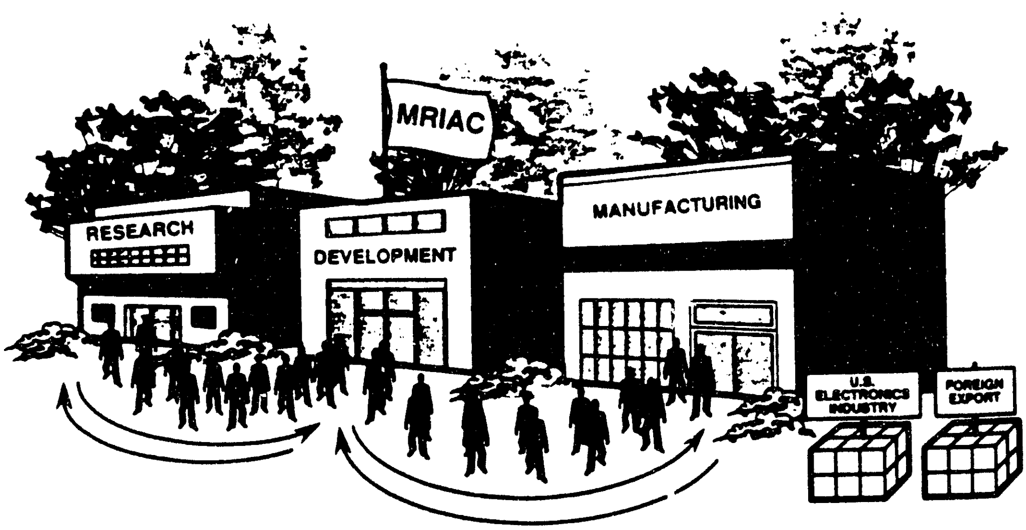

Figure 7. The Microelectronics Research Integration and Application Center will help remove the bottlenecks to technology transfer by bringing researchers and manufacturing engineers together in a shared facility. Further, it will stimulate the export of manufactured products rather than research innovation.

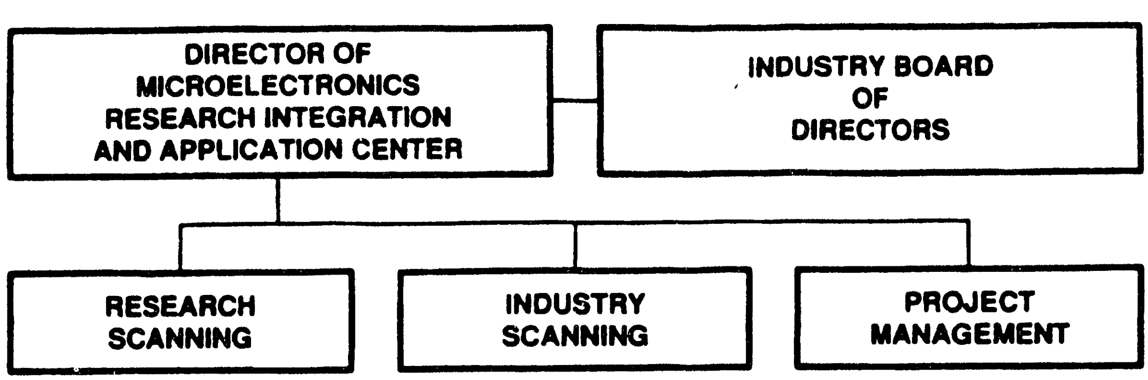

Figure 8. To rapidly transfer technology, the Microelectronics Research Integration and Application Center must be structured along project lines. The organization must emphasize the scanning of research laboratories for innovation and the scanning of industry for problems.

Support organizations' line managers will provide the resources, day-to-day technical direction, and support facilities; project managers will provide program planning, scheduling, customer liaison, and cost control. Project management reports to the Director of the Microelectronics Research Integration and Application Center, who in turn receives direction from an industry board.

This board will establish guidelines for operation and select those areas of technology transfer that the Center is tasked to emphasize. In addition to regular meetings between industry and Center personnel, engineering staff at the Center and industry will exchange and document ideas and analyses by use of a common computer network.

The staff selected for the research and industry scanning processes should exhibit entrepreneurial and innovative capabilities. They must be prepared to make purposeful and organized searches for new product ideas or processes and manufacturing changes and to analyze opportunities that these changes offer for economic innovation. This involves implementing a diagnostic discipline and a systematic examination of areas of change that typically offer entrepreneurial opportunities.

The organizational structure of the Center must accommodate industry interfaces ranging from the CEO to individual staff, single company and industry consortia, university professors and students, entrepreneurs, government laboratory and service personnel. The host organization must be capable of managing a diverse set of projects and must protect information ranging from company-sensitive or proprietary to government-classified while maintaining a cooperative working environment. Because of the diverse range of projects, time constraints, and cost restrictions, strict program management methods must be followed.

A wide range of personnel experience and a large knowledge base must be readily available to solve the diverse issues that the Center will address. This expertise includes semiconductor device and IC design, manufacturing and test, analytical and modeling skills, special skills in chemistry, robotics, device physics, metallurgy, heat transfer, special applications, etc.

Projects would be identified as critical by the U.S. microelectronics industry leaders.

In his studies of international competition, Michael E. Porter of the Harvard Business School has concluded that cooperative projects can be beneficial provided that certain conditions are met. These are:

- Projects should emphasize basic project and process research, not subjects closely connected to a company's proprietary sources of advantage.
- Projects should constitute only a modest portion of a company's overall research program in any given field.
- Projects should be indirect and channeled through independent organizations to which most industry participants have access.
- Organizational structures like university labs and centers of excellence reduce management problems and minimize the risk of rivalry.

- The most useful projects often involve fields that touch a number of industries and that require substantial R&D investments.[68]

In view of the fact that the Center is intended to foster cooperation between universities, government, and industry while maintaining and stimulating competition among U.S. industrial firms, we advocate implementation of Porter's conditions in selection of cooperative projects for the Center.

Project areas would be selected from a list developed by industry and prioritized by the Board of Directors. Projects would be selected based on priority, their need for basic work, length, availability of resources and co-funding, potential commercial impact, and identification of an industry partner. Although some projects may be long-term, preference would be given to projects having near-term benefit (less than 12 months).

The major areas of focus would include understanding foreign competitors and their manufacturing equipment, processes, and products for:

- semiconductor materials, devices, and circuits
- zero-effluent, contamination-free manufacturing
- manufacturing process modeling, simulation, design, and control
- packaging of integrated circuits
- lithography and other methods of manufacturing.

The Center would improve the competitiveness of U.S. semiconductor manufacturers by solving manufacturing problems of a generic nature and by reducing cycle time for introducing new technology. Specifically, the Center would provide facilities, materials, personnel, work space for visiting industrial and university personnel, test equipment, and design support. Technology transfer activities will emphasize areas identified as critical by industry leaders, not government.

Funding for the Center would be by government.

Government funding for the Center would be divided into four categories: (1) personnel, materials, processing, etc., costs associated with individual projects; (2) pass-through contract costs for special technology development, installation of specific manufacturing capabilities and costs associated with relocation of university personnel for temporary assignments and extensions of specific university projects having high-payoff potential; (3) general administration; and (4) advanced research. Each of the costs would depend on specific projects.

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68 Michael E. Porter, "The Competitive Advantage of Nations," *Harvard Business Review*, March-April 1990, p 88.

If a federal program such as MRIAC can succeed in turning university and federal laboratory research into a competitive advantage for U.S. industry, we would expect renewed interest by industry in funding university research, particularly small science research.

At the present time U.S. industry only provides 6.6 percent of U.S. university research funding, and most of this funding is concentrated in the most outstanding universities. Even at MIT, which has a tradition of research excellence, industry only provides $35M of their $300M research budget. Most state universities have little or no linkage with industry. We must strengthen or create that linkage and stimulate industry funding of university research by providing a wider exposure of universities to industry.

We must make available to university researchers and their graduate students world class semiconductor manufacturing facilities that few universities can afford so that university professors can test their ideas for microelectronics innovations through the prototype stage.

The Center must contain up-to-date facilities.

As a minimum, the Center must contain the following:

1. A state-of-the-art microelectronics fabrication/production facility supporting both silicon and compound semiconductor technologies
2. Experienced research and engineering personnel, knowledgeable in semiconductor device development and manufacturing
3. Support for materials and chemical analysis
4. Extensive test and characterization equipment and expertise
5. Extensive computer facilities to support a range of analytical, modeling, and simulation capabilities
6. Easy facility access and adequate office and laboratory space for visiting personnel.

The Center must be held accountable.

In addition to measuring the performance of the Center based on the standard program management metrics of cost, schedule, and milestones, success will be measured and growth will be closely tied to industry feedback and participation. If the Center fails to attract industry participation, it will die.

The continuous and rapid improvement of the U.S. microelectronics industry would be a basic goal of the Center. It must lead to increasing world market shares by U.S.-based electronics industries. If it fails to accomplish this, the Center should be closed.

Although not the primary objective, the U.S. government will receive immeasurable return on its investment by having a government-owned facility experience the dramatic growth in capabilities that would surely accrue from strengthened working relationships with the U.S. semiconductor industry. We believe that after five years both government and industry will regard their returns on investment from the Center as their best investment and that success by the Center will encourage increased industry investment in university research programs.

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