Market Progress Evaluation Report

Microelectronics Initiative, No. 1

prepared by

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Final Report

FIRST MARKET PROGRESS EVALUATION REPORT OF THE MICROELECTRONICS INITIATIVE

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Acknowledgements

TABLE OF CONTENTS

APPENDICES

APPENDIX A: INTERVIEW GUIDES

APPENDIX B: THE MICROELECTRONICS INDUSTRY BY EASTON CONSULTING

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EXECUTIVE SUMMARY

The Northwest Energy Efficiency Alliance (the Alliance) is a non-profit group of electric utilities, state governments, public interest groups and industry representatives committed to bringing affordable, energy-efficient products and services to the marketplace. This Market Progress Evaluation Report (MPER) is the first evaluation report for the Microelectronics Initiative. The focus of this MPER is on two activities of the initiative. The first is a contract with Chris Robertson & Associates, LLC (CRA) that the Alliance funded from 1997 to 1999. The second is the Special Project Fund for demonstration and benchmarking projects and workshops conducted by the Alliance to reach out to Pacific Northwest (PNW) microelectronics firms.

The Microelectronics Industry is first and foremost a manufacturing industry. The decision-making processes in the industry are similar to other industries, project champions are important in project development and implementation and groups of decision-makers are the rule, rather than the exception. It is, however, different from other manufacturing industries with which the Alliance is familiar. Five characteristics have been identified that result in the need for industry-specific solutions:

1. The microelectronics industry is a global industry. Headquarters for these firms are generally in some other part of the world than the PNW. Though important facilities may be located here, they are part of a global chain of facilities that ensure products are close to markets and original equipment manufacturers (OEMs).

2. There is a preponderance of new construction as compared to existing construction. Many of the fabrication facilities (fabs) that will be requiring electricity in the next twenty years are in the planning stages today. While the growth spurt of the 1980s and '90s appears to have slowed, new fabs still are planned at the rate of about three per year in Oregon alone.

3. As a global industry, the executives and the workforce is mobile. Plant executives move all over the world, facilities staff move among different firms in their geographic area, as the semiconductor sales cycle leads to different types of facilities slowing down or speeding up production.

4. The time-to-market and competitive pressures in this industry are unparalleled in the resource and extractive industries common in the PNW. A new product must come to market ahead of others and must meet the quality specifications of the product designers, otherwise market share will be substantially lost. Thus, risks to production are viewed even more suspiciously than in other industries.

5. Like most manufacturing sectors, energy is a small proportion of total cost, only 1-3% of production costs, and is treated as a fixed cost. However, energy is 30-50% of the day-to-day operating costs of the plant, potentially creating an opportunity for efficiency investments. Plants recoup their capital investment costs after two to three years. At that point, the costs of operating the plant can become more apparent, but only if the firms are aware of these costs.

These characteristics have defined the microelectronics industry for the past 20 years. In 1997, the Alliance funded a Microelectronics Initiative to encourage the industry to commit to increased investment in energy efficiency and to manage their plants to use energy more efficiently. Two activity streams were conducted in this initiative. The first was the CRA Microelectronics Initiative, the second was a Special Project Fund managed by Alliance staff.

THE CRA MICROELECTRONICS INITIATIVE

The core hypothesis for the Microelectronics Initiative is that by working with a small number of interested players to identify and implement energy efficiency changes, the changes will spill over internally and to others in the industry through the tendency of firms to use a "copy exact" approach to design. For the CRA Microelectronics Initiative activities this hypothesis was implemented within the following parameters: that contacts would be made with a focus on executive and mid-level decision-makers for early adopter firms, irrespective of whether they are located in the PNW or elsewhere in the world.

We found the program theory promulgated by the CRA Microelectronics Initiative to be sound. It is consistent with social science theories and the effort appears to have been partially successful. CRA made a large number of contacts, facilitated a review of audits for plants of a firm outside of the PNW, conducted the project at an optimum time to gain interest by the industry, and remains a respected expert on energy efficiency opportunities for the industry. However, CRA failed to fully achieve its objectives for several reasons:

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1. The CRA effort focused on the management level and did not include a process for integrating operations-level personnel into the process.

2. The CRA effort was incompletely implemented because CRA did not control the Special Project Fund activities. The CRA Microelectronics Initiative initially planned to use the fund for projects with early adopters, irrespective of their location in the world, and to focus on a variety of demonstrations – chilled water, exhaust system, production tools, building design, etc. When the Special Project Fund came to focus on projects with a direct benefit to the PNW, the full theory could never be implemented.

3. The message that CRA brought to the industry lacked direct transferability to PNW industry firms. CRA focused on a single set of solution providers' capabilities. Not only are all microelectronics processes and facilities unique, but the message of the solution providers was perceived by workshop participants and facilities management staff in the PNW as needing additional research and demonstration to transfer to the PNW climate.

4. The issues of confidentiality and proprietary information were relatively well handled by CRA and the industry had come to trust CRA, an important success. However, as CRA continued to work with the EPA, the industry became suspicious. These suspicions grew beyond a concern about possible regulation to becoming concerns that the energy efficiency solutions CRA proposed were infeasible.

THE SPECIAL PROJECT FUND

The core hypothesis for the Special Project Fund activity stream is similar to the Microelectronics Initiative as a whole: that by working with a small number of interested players to identify and implement energy efficient changes and provide forums for information sharing (workshops) that the changes will spill over internally and to others in that industry. The parameters for implementation of this hypothesis, however, were different for the Special Project Fund. For the Special Project Fund, the contacts could be anywhere, but the projects had to show a direct benefit to the PNW. Rather than expecting "copy exact" to lead to adoption by others, the hypothesis suggested that measurement and benchmarking the information, along with targeted information dissemination, would spur adoption of energy efficient practices.

We found the Special Project Fund theory, as a market transformation theory, to be somewhat weaker than the CRA Microelectronics Initiative when viewed in the context of social science theories. The focus on measurement has not been demonstrated to be effective in the past and the expansion to include benchmarking and comparison of the metrics has yet to be conducted. Nonetheless, to date the progress indicators for the Special Project Fund are on track, but a full assessment of the theory cannot be made until the activities are completed. The evaluation identified the following indications of progress for the Special Project fund:

1. Three measurement projects will be completed and comparisons between these projects will be possible.

2. Investments in implementation of the recommendations that emerge from the projects are likely, but the scale of that investment may be less than proposed by the recommendations. Furthermore, it is unclear whether the firms will then choose to conduct on-going monitoring and attempt to use that to operate their facilities in a more energy efficient manner.

3. The Alliance has implemented two workshops, with a third planned for 2001, at which local PNW microelectronics firms hear presentations from national experts on energy efficient solutions for the microelectronics industry.

4. Firms that have not yet participated in the workshops tend to be unaware of the workshops or of what other firms are doing. Most are interested in learning about the workshops and about what other firms are doing, suggesting that dissemination in the PNW, if promoted well, could be effective.

RECOMMENDATIONS

No specific recommendations are provided to specifically address the CRA initiative, since that effort ended in December 2000. The recommendations therefore are divided into two categories. The first category concerns specific recommendations regarding next steps for the Microelectronics Initiative Special Project Fund; these are followed by recommendations for next steps in addressing the overall issue of how the Alliance can move forward with the Microelectronics Initiative.

Special Project Fund

We have identified four recommendations to consider for the ongoing activities of the Special Project Fund.

1. The Special Project Fund activities are still in process. These activities should continue and efforts should be made to conduct workshops once comparison data are available.
    - The Alliance must create a plan for how to compare and present these results.
    - Results of the comparison activity should be used to reformulate the program theory for the Microelectronics Initiative.
2. After the workshops are completed, the Alliance should conduct an evaluation of the completed model and assess response to the comparison activity.
3. The Alliance should explore working more closely with local PNW utilities to reach additional microelectronics firms and include them in the workshops.
4. Once contacts with utilities are expanded, the Alliance may be able to effectively leverage local conservation investment opportunities to provide additional demonstration and comparison data for workshops.

Future Microelectronics Initiative Activities

The context in which the first years of the Microelectronics Initiative operated has begun to change. The investment process in the industry is shifting, changes are occurring as firms consider the next generation of chips. Yet, the global nature of the microelectronics industry remains a driving force, as do the other characteristics noted above.

The evaluation found a need for more information, as well as some opportunities that can facilitate the overall goal of the Alliance to influence the way PNW facilities use energy. The following five recommendations are aimed at furthering these efforts in the current context.

1. The Alliance should conduct a full market assessment of the microelectronics industry in the PNW. Such an assessment should include

an analysis of number of firms, size of clean rooms, and consumption patterns for utilities (water, gas, electricity and air).

- In addition, if appropriate confidentiality agreements can be developed, survey efforts with firms or local utilities could be conducted to assess current level of investment in energy efficiency and plans for expansion or refitting of fabs.

- The focus to date has been on facilities. As part of the market assessment it is important to identify the relative potential for working with the industry on tools, process and facilities.

2. A market transformation program model needs to be developed that will build on lessons learned from this evaluation and from the market assessment activities to be conducted. Our sense is that the model should focus on how to facilitate the expansion of market share for the solution providers.

3. Though already suggested, an advisory committee of utility representatives and consulting engineers who work with the microelectronics firms could provide the Alliance with additional expertise during the process of developing a new program model for the Microelectronics Initiative.

4. Energy is not a high priority for the microelectronics industry. In order to have a market transforming impact on the tools, processes and facilities, it will be necessary for energy industry members to become involved with the microelectronics industry organizations such as International SEMATECH, the Semiconductor Industry Association (SIA), and the Semiconductor Industry Suppliers Association (SISA).

    - The effort by the Electric Power Research Institute (EPRI) in the past foundered on contractual issues and any new effort needs to address this up front and be led by an entity with more flexibility. Such an entity also needs to have experience working with manufacturers and with energy organizations in the midst of regulatory pressures. Our sense is that the Consortium for Energy Efficiency (CEE) is the most likely organization to meet these needs. California utilities and the Alliance could jointly initiate such an effort with CEE and perhaps attract the interest of some New England (Massachusetts and New York) and Southwestern (Arizona and Texas) utilities as well.

- In addition to working with other energy organizations, it is important for the Alliance to attend national and international meetings such as the International Semiconductor Environmental Safety and Health Conference (ISESH), SIA, SISA and others.

- We heard from industry representatives that solutions focused on reliability and cogeneration are of preeminent concern to microelectronics firms today. Market transformation opportunities may exist in these areas that will enable the microelectronics industry to increase its trust in the energy efficiency community.

5. Designers we spoke with indicate an increased willingness to work with the Alliance to explore design solutions. With two of the largest design firms for the global microelectronics industry located in the PNW, the Alliance should continue to work to reach these firms. Options include:

    - On-site workshops with the designers, in addition to invitations to participate in the workshops for firms; and

    - Providing the design firms with the opportunity to market energy efficiency projects that would meet the objectives of the Special Project Fund.

1. INTRODUCTION

INTRODUCTION

The Northwest Energy Efficiency Alliance (the Alliance) is a non-profit group of electric utilities, state governments, public interest groups and industry representatives committed to bringing affordable, energy-efficient products and services to the marketplace. The Alliance sponsors the Microelectronics Initiative, which has a variety of components. Two are the focus of this evaluation. The first is the effort by Chris Robertson & Associates, LLC, and the second is the Special Project Fund for workshop, demonstration and benchmarking projects focusing on Pacific Northwest (PNW) microelectronics firms. In this chapter we describe the various aspects of the initiative and introduce the evaluation. This Market Progress Evaluation Report (MPER) is the first evaluation report for the initiative.

INITIATIVE DESCRIPTION

The Alliance held an open solicitation for market transformation projects in the spring of 1997. In response, Chris Robertson & Associates, LLC (CRA) submitted a proposal requesting support for efforts to "identify early adopters, help them to explore advanced resource efficiency and then present their examples to other firms in the industry." As part of this effort, CRA also requested funds be available for use in supporting viable projects that could demonstrate the value of energy efficiency efforts. The crux of the proposal by CRA was to focus on early adopters, which were not necessarily firms located in the PNW. The premise was that the microelectronics industry is global and tends to follow the leaders, thus when early adopters accept a new idea, the rest of the industry will do the same thing.

The initiative was funded at $1.43 million for a two-year effort. Approximately 50% was allocated to a Special Projects fund, which was placed in reserve for allocation by Alliance staff under the direction of the Board of Directors. CRA was hired to identify and contact early adopters, and the Alliance hired a staff person to oversee the project, conduct workshops with industry representatives in the PNW and oversee the Special Projects Fund.

The history of the initiative design and development process is discussed in more detail in Chapter 3.

Figure 1

EVOLUTION OF THE MICROELECTRONICS INITIATIVE

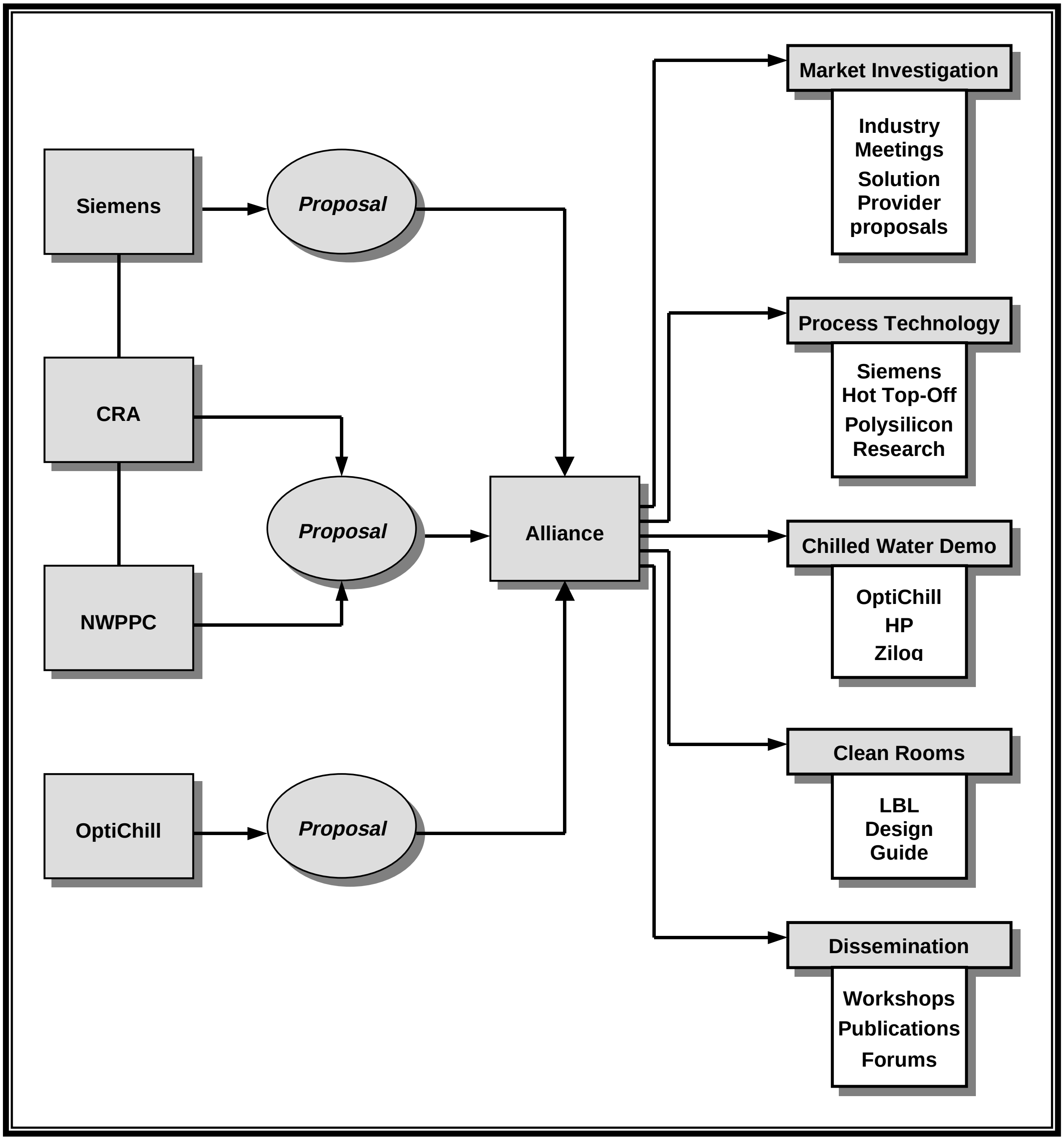

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Figure 1 displays the Alliance's involvement in different activities in the microelectronics industry as of December 2000. Specifically, the figure shows how the initiative evolved to include a spectrum of projects beyond the initial market investigation project proposed by CRA and the dissemination activities initiated by the Alliance. These include:

- Three projects for demonstration and benchmarking of energy savings opportunities in the chilled water plants at semiconductor fabrication facilities, two identified by CRA and one submitted in response to an RFP request by the Alliance;
- Co-funding for a project by Lawrence Berkeley National Laboratories (LBNL) to develop design guidelines for clean rooms;
- A research effort to understand opportunities for energy efficiency improvements in polysilicon manufacturing; and
- A separately funded venture, initially identified by CRA, but submitted independently by Siemans Solar to develop a more energy efficient manufacturing process for silicon. The Alliance hopes this project will have long-term impacts on the microelectronics industry.

METHODOLOGY OF EVALUATION

Evaluation Questions

The key questions the evaluation addresses are driven by the criteria for success and progress indicators outlined by the Alliance and published at their website.[1] These are noted below:

[1] http://www.nwalliance.org/projects/current/micro.html

Criteria for Success

Effectively influence industry practices leading to implementation in semiconductor fabrication facilities that integrates 'world class' practices for efficient use of energy and other resources in both the facility support services (HVAC, de-ionized water, process gasses, etc.) and in process tools. Provide information that will assist this industry to more rapidly adopt energy efficient practices in design and technology.

Progress Indicators

1. Identification and assessment of specific market transformation leverage opportunities in design, manufacturing technologies, and facility support systems in the microelectronics and polysilicon industries.
2. Development and assembly of information on high priority energy and resource efficiency opportunities within the semiconductor manufacturing industry.
3. Participation in meetings with industry associations, key industry meetings, and conferences to present energy efficiency strategies and opportunities for green fabrication facility collaborative projects.
4. Key industry representatives attend project workshops that discuss and promote "world class" examples of energy efficiency opportunities within the microelectronics industry.
5. Increasing awareness of energy efficiency opportunities among representatives of major microelectronics manufacturing companies and organizations within the region.
6. Implementation of energy efficiency opportunities within the microelectronics industry.
7. Several companies participate in one or more integrated design processes.

Evaluation Approach

This MPER focuses on the CRA effort, the workshops, and the special project activities between project inception in February 1998 and November 30, 2000.[2] We relied on industry research and on qualitative interviews with initiative team

[2] This report includes some footnotes regarding changes that occurred in the microelectronics industry response to the initiative between November 2000 and March 2001, when the MPER was finalized. However, these will primarily be topics addressed in subsequent evaluations.

members and contacts in the microelectronics industry. The evaluation is structured to test the hypothesis of the Microelectronics Initiative and determine whether the industry has moved to an increased focus on energy efficiency as a result of CRA's efforts, the Alliance workshops, and the Special Project Fund.

Easton Consulting developed an analysis of the microelectronics industry in 1999 that set the stage for much of the later interviews. This is provided in Appendix B. The following interviews were conducted in 1999 and 2000. In the case of industry leaders, specific contacts are not identified due to the confidential nature of their information.

- CRA Team members: Chris Robertson, Chris Robertson & Associates, LLC; Peter Rumsey, SuperSymmetry, USA; and Jay Stein, E-Source.
- Alliance and PNW energy staff: Jeff Harris, Northwest Power Planning Council (NWPPC) and Alliance; Blair Collins, Alliance; and Mark Kendall, Oregon Office of Energy.
- Microelectronics Industry contacts:[3] SEMATECH, Micron, Zilog, Wafertech, Hyundai, Hewlett-Packard, Wacker-Siltronic, Oki-Semiconductor, Fujitsu, LSI Logic, Motorola, Applied Materials, and others.
- Microelectronics design service providers: Jacobs Engineering, IDC, Inc., CH2M-Hill, Willis Energy Services, Ltd., En-WISE.

Table 1 details our sampling approach and interview status. One of the surprising outcomes of the interview process was the fact that 40% of the people we attempted to contact were either no longer with the same company or could not be reached through the phone numbers CRA had obtained.

We developed interview guides for discussions with microelectronics industry leaders. These included a general guide for discussion of industry trends and three guides for discussions with firms in the PNW who had considered a Special Project Fund: one for those with a completed project, one for those with a project in process, and one for those with no contract in place. Copies of the interview guides are included in Appendix A.

[3] Contacts' positions were primarily facilities management, though we also included a corporate vice president, a design engineer, and environmental engineers. Three of these firms are directly involved in special projects with the Alliance.

Table 1

SAMPLING STRATEGY AND INTERVIEW DISPOSITION

CONTACTS	POPULATION	ATTEMPTED INTERVIEWS	INTERVIEW STATUS
Alliance, NWPPC, State Energy Office staff	3	3	3 completed
Initiative Team Members	4	3	3 completed
CRA List of Contacts in Microelectronics Industry	56 - USA 18 - Non USA	39 - USA 0 - Non USA	10 completed 16 no longer at firm 13 not return calls
Microelectronics Firms in Pacific Northwest Listed in Quantic database	12 > 50,000 Sq. Ft. 26 < 50,000 Sq. Ft. 38 Total	12	7 completed 1 refused 4 not return calls
Firms involved with Special Project Fund	8	8	7 completed 1 not return calls

In addition to the interviews, further activities were conducted as part of the evaluation to provide the Alliance with a more comprehensive picture of the microelectronics industry. Chapter 2 presents a description of the market based on a variety of sources. However, as will become evident, additional research is still required to fully characterize the microelectronics industry in the PNW.

REPORT STRUCTURE

This first MPER for the Microelectronics Initiative includes three chapters following this introduction. Chapter 2 presents a characterization of the microelectronics industry and Chapter 3 discusses the progress of the initiative. Chapter 4 reviews the hypothesis for the initiative and examines the program theories in light of different social science theories of change. Finally, Chapter 5 draws conclusions about whether the initiative had an impact on the industry and what next steps should be taken by the Alliance in addressing this industry.

2. INDUSTRY STRUCTURE

INTRODUCTION

The microelectronics industry is a relatively young and rapidly growing industry. Beginning in 1947 with the invention of the transistor, the first major application using silicon components occurred in 1954 by Texas Instruments. Today the microelectronics industry is a global industry with a significant presence in the PNW. Intel, the largest semiconductor firm in the world, is also the largest employer in the Portland, Oregon, metropolitan area. The industry as a whole provides significant employment opportunities in Oregon, Washington and Idaho.[4]

This chapter seeks to characterize the industry structure using the following sources:

- Research conducted in the PNW in the mid-1990s.
- A research study conducted by E-Source in 1997.
- A market description developed by Easton Consulting for this contract (Appendix B).
- Research conducted by Southern California Edison for the California utilities.
- Interviews with 28 industry contacts conducted for this evaluation.
- Review of *International Technology Roadmap for Semiconductors*, published by the Semiconductor Industry of America (SIA).

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4 The largest industry in terms of employment in the PNW continues to be lumber and wood products at approximately 90,000 in 1999. Electronic equipment is a close second in Oregon (46,700 lumber and wood products, 40,500 electronic equipment) but lags further behind wood products and allied industries for the region as a whole at 73,000. Estimates are for Oregon, Washington and Idaho using state figures located at each state website; seasonal adjustments and closing dates somewhat vary.

THE INDUSTRY

Description

The microelectronics industry is a highly competitive global industry. In 2000, the industry sales record for semiconductor chips for the first time is expected to reach $200 billion, a 48% increase over 1998 sales of $135 billion.[5]

Semiconductor chips have been manufactured since the late 1950s, taking off in the 1960s with the development of integrated circuits and of storage capabilities in IC DRAM. In 1980, sales were under $20 billion and the US was the world leader in production. By 1999, the U.S. had a 33% market share of semiconductor production, and Japan 23%. Europe controls 21% of the semiconductor market and the rest of the world (including other Asian/Pacific countries) has a 23% share.

The microelectronics industry is still increasing in size and scope. As outlined in Appendix B, the industry is composed of firms that design, manufacture and market semiconductors to original equipment manufacturers (OEMs). There are a variety of different types of semiconductor chips: digital, analog, mixed, microprocessors, memory, logic devises, etc. Different types of fabrication facilities (fabs) are needed for each of these. Figure 2 displays the production chain for semiconductors; the firms noted in boxes have facilities in the PNW.

On the front end of the microelectronics industry are the producers of the raw materials for making semiconductors and the equipment manufacturers who create the tools needed to produce the semiconductors. On the back-end are the OEM users of the semiconductors, such as computer assemblers and wireless phone companies.

As Figure 2 shows, the companies located in the Pacific Northwest provide services at a variety of points in the production cycle. According to the Northwest Power Planning Council (NWPPC) staff, the newest growth area at the back-end of the microelectronics industry are server farms, which use semiconductor-based equipment to facilitate use of the Internet. Unlike the OEM companies, the server farms are highly electric energy intensive. They rival semiconductor fabs and clean rooms for electric energy consumption at 30-50MW a piece. Recent news articles in Portland and Seattle suggest that several server farms are likely to built in the PNW.[6]

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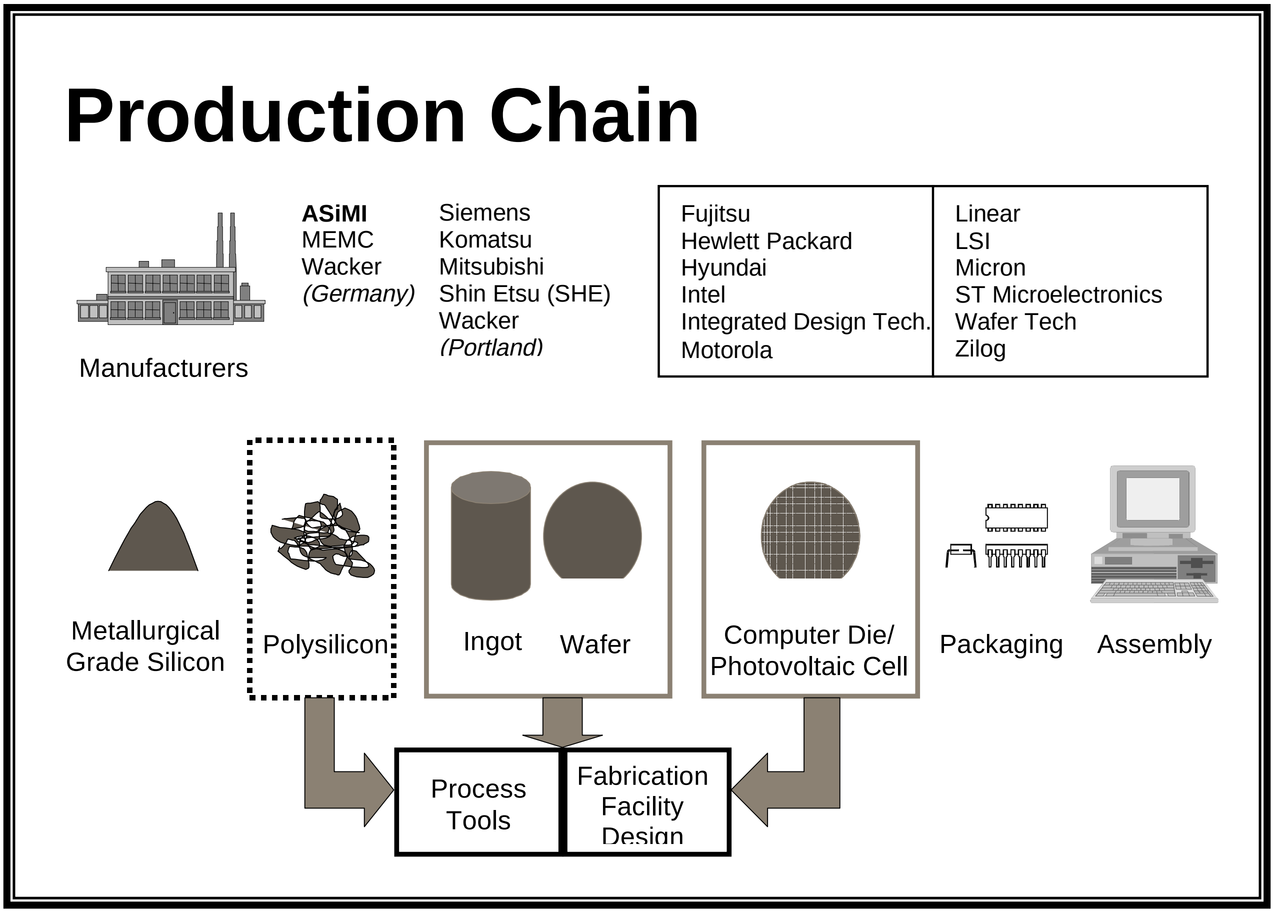
5 http://www.semichips.org...hives/gsr12042000_74.htm

6 http://www.govtech.net/news/features/feature_sept_29.phtml

Figure 2

PRODUCTION CHAIN FOR SEMICONDUCTORS



There are three important characteristics of semiconductors that drive decision-making in the microelectronics industry.

1. Probably the most important characteristic of the microelectronics industry is the requirement of the production process for clean particle-free air, water and chemicals. This need drives facility requirements for plant and process tool design.

2. The second is the issue of speed to market. Semiconductors are a constantly evolving product. Chip speeds increase about every 18 months,

according to Moore's Law.[7] There is incredible pressure to be the first firm to get the next fastest chip to market.

3. The third is competitiveness. Whoever has the first new product to market will tend to be the market leader. With everyone attempting to accomplish the same goal, a faster chip in 18 months, the competitive pressures are huge.

Growth Trends

The rapid growth of new fabrication facilities has slowed since the mid-1990s; however, growth of the microelectronics industry continues throughout the world and in the PNW. The last industry study for the PNW was conducted in 1995 by the Northwest Power Planning Council, the Bonneville Power Administration and the Oregon Office of Energy (OOE). At that time, the projected growth in demand for the industry was for 400-500 additional MW.[8] With semiconductor chip fabs being built at the rate of five per year in Oregon, that seemed likely. In 2000, according to the OOE, fabrication facilities in Oregon are being built at the rate of three per year, so growth can be expected to continue, although perhaps at a somewhat slower rate than in the mid-'90s.[9]

This rapid growth rate is one of the unusual characteristics of the microelectronics industry. Unlike most industrial sectors, especially the traditional forest products industry of the PNW, the manufacturing plants are new. Many of those that will be on-line in the next 20 years are still in the planning or conceptualization stage. In most of the other PNW industries, the plants have been in place for many years. In the vernacular of today, the fabs are for the information-based economy, while most of the rest of the industrial sector of the PNW is in the resource-based economy.

The criticality of the production process drives the need for new fabs to produce new chip designs. New facilities tend to be built for each new generation of chips, facilities built for the previous generation are then refurbished to produce the commodity products. Industry analysts predict that the costs associated with this growth model, however, are likely to outpace capital availability in the future,

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7 A descriptive law noted by Gordon Moore of Intel in 1965.

8 Northwest Power Planning Council. *Opportunities for Efficiency: NW Microelectronics Industry.* 1996.

9 It is important to note that economic conditions for the electronics industry change frequently. In fall 2000, Intel detailed substantial expansion plans for its Hillsboro, Oregon, campus. In Feb 2001, they indicated that the plans would move more slowly than expected due to the economic downturn of early 2001. *The Oregonian*, February 21, 2001, page 1, *Intel will put raises on hold, cut hiring.*

perhaps even the near future. At that time, chip speed will no longer double every 18 months and fab growth will begin to slow.

The Pacific Northwest

The PNW has been a major center for the microelectronics industry since the late 1970s. In 1976, Hewlett-Packard (HP) moved its calculator division from California to Oregon, and Intel built its first fab plant. Since then, HP has continued to expand facilities, Intel has become the largest employer in the Portland metropolitan area and the geographic area has come to be known as the Silicon Forest, as distinct from the Silicon Valley of Northern California.

According to a report by E-Source in 1998, two of the top ten semiconductor manufacturing regions of the US are located in the PNW (Portland to Eugene, Oregon, and Boise, Idaho). In addition, the Portland-Eugene area ranks in the top ten for high-tech industry clean room facilities.[10] Portland is home to several specialized design and engineering firms, including two of the largest—IDC, Inc., a joint venture of CH2M-Hill and Hoffman Construction, and Jacobs Engineering.

Current growth projections suggest that energy demand in the industrial category that includes microelectronics will surpass the pulp and paper industry by 2001 or 2002, with demand by 2015 of over 800 MW. Including server farms in this, growth could easily reach 1,000-1,200 MW—almost equal in size to the maximum capacity of the Bonneville Dam.[11]

Energy Efficiency Opportunities

There are three potential areas for energy efficiency investment at a fab: the fab facility, the production process tools, and the production process itself. Of these three, the production process is considered the most difficult to influence. The fab facility offers the most promise.

According to an EPA study of 12 fabs in 1997, about 46% of the energy consumed by fabs on a day-to-day basis is for HVAC systems (chillers, air handlers and exhaust fans). Another 35% is for production tools, and the remaining 19% is for such

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10 E-Source. *Delivering Energy Services to Semiconductor and Related High-Tech Industries: Part 1: Market Assessment.* January 1998.

11 Bonneville Power Administration. *1997 Fast Facts*. June 1998. Pp 10. For comparison, Grand Coulee capacity is 7,079 MW, Bonneville is 1,224 MW and McNary is 1,120 MW.

activities as nitrogen processing, process cooling water, water purification, lighting and other support services.[12] With these consumption characteristics, savings opportunities could be substantial.

In a presentation by Lee Eng Lock of SuperSymmetry, Ltd. in October 1995, Mr. Lee described opportunities for improved HVAC efficiency of 40-50% in a typical fab.[13] Just looking at a few components (chiller, air handler, water pumping, and cooling tower), Lee pointed out that typical designs required 1.6 kW per ton of chilled water (for an 8,000 square meter clean room operating at full load), though efficient designs could reduce that figure to 0.61 kW per ton. Moreover, argued Lee, these savings could be gained without sacrificing production quality or system reliability.

Opportunities also exist for reducing the energy consumption of production tools, though the potential value of these savings varies across tools. Some of the people we spoke with specifically mentioned that tools offer incredible opportunity because of two reasons:

1. Tools are currently designed with no specific consideration for the energy consumption of the tool in the production process. As a tool designer said, "if they had a specification for energy consumption, say some percent lower than the previous generation, that would give us something to work for. As it is, the specifications they do give us drive the design process."

2. Tools are designed and produced with specific expectations for the environment in which they will operate. The operating parameters are specified for each tool and tend to state conservative requirements for cooling and heating that will ensure that the tool operates. These specifications encourage over-design of the chilled water and air handling systems.

This opportunity, however, requires an integration of tool designs and facility designs that has not occurred.

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12 *Proceedings of the Semiconductor Energy Efficiency Opportunities Workshop*. San Jose, CA. November 13-14, 1997. US Environmental Protection Agency.

13 Northwest Power Planning Council. *Micro-Electronics Facility Efficiency Workshop: Meeting Report and Appendices 95-23.* Northwest Power Planning Council, Portland, OR. December 14, 1995.

Facilities Design Process

The semiconductor industry is extremely competitive. One of Intel's founders, Gordon Moore, predicted in 1965 that the capabilities of a semiconductor would double every 18-24 months. In the 26 years from 1971 to 1997, the number of transistors on a chip has increased more than 3,200 times.[14]

With this rate of growth, the semiconductor industry is committed to designing chips and getting them to market as rapidly as possible—a fab needs to be designed and built as quickly as possible. Facility managers and designers we spoke with indicate that cost recovery occurs within the first two years of fab operation, with the third year being the year for profit. A new production facility in 1999 can require over $1 billion in investment for the facility and tools required to achieve high product quality.[15]

Because the product quality is so critical, semiconductor plants have very stringent requirements for clean, particle-free air and water. Other than for scheduled maintenance, production lines run at full capacity around the clock for most of the year. Anything that enables or improves productivity is highly valued. This means that the tools and chemicals used in the process and the quality of the power are highly valued. Those factors that do not directly affect the process—the cost of tools, the cost of energy and water—are considered fixed, just the cost of doing business.[16] The industry tends to address these factors up front through choice of plant location. E-Source found energy rates to be second to environmental regulations in plant site selection.

The facility utility services of energy, air, water and waste are fairly commonplace, though specific tolerances required to maintain the purity of the air and water are unusual. The HVAC systems must maintain air in narrow temperature ranges and at very high levels of cleanliness. Pumps are used to produce clean particle-free water and for treating water prior to release from the facility. Water purity is so critical that cleanliness is sometimes measures in parts per trillion.[17] The process

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14 Intel "Processor Hall of Fame" http://www.intel.com/intel/museum/25anniv/hof/moore.htm

15 A counterpoint to Moore's law is Rock's law, which suggests that the capital cost of tools will double every four years.

16 Southern California Edison. *Large Customer Needs and Wants: Interim Report: The Semiconductor Industry.* Draft June 2000.

17 Water is used to clean the silicon to remove chemicals used to etch the chips. Thus, cleanliness of the water is critical before use in the process and must be carefully treated afterwards before returning to the public waste stream.

tools are energy intensive with temperatures that must be maintained within a very narrow range. Finally, the lighting levels tend to be quite high.[18]

Because of these unique requirements, specialized design firms have evolved that focus on the microelectronics industry. They offer their clients an understanding of the process requirements as well as design skills. Because time is of the essence, some firms use an approach called "copy exact" that repeats facility and process design at all facilities manufacturing the same type of chip. One firm with a copy exact approach described to us a process taking up to a year to change a design specification. However, only some of the largest firms seem to really be able to use copy exact, others do not use multiple facilities for chip fabrication or do not fully subscribe to the approach. We found three firms whose own perception was that they were attempting to do copy exact.

The facility designers must know the process, must understand how it is expected to work and must be able to rapidly produce a design that can be quickly constructed. Typical time to design is 6-12 months; depending on the size of the facility; construction is similarly short. Designers we spoke with indicated that there is little time to work on the design concept since the firms want to minimize the opportunity for their competitors to learn of their new fab.

Two designers we spoke with at two of the leading design firms, however, did suggest that times are changing. Energy efficiency is increasingly a concern among their clients. One noted that management expectations for required payback periods in 2000 had begun to lengthen toward three years. This, along with a slowdown in the need for new fabs, is creating an opportunity to spend more time incorporating energy efficiency solutions into the design process.

Industry Organizations

The microelectronics industry is highly competitive. Trade associations provide a way for companies to meet and share what information they are willing to divulge. Three of the oldest organization are:

- The Semiconductor Industry Association (SIA), which is the trade association for US semiconductor manufacturers;[19]

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18 Southern California Edison. Pp 19.

19 http://www.semichips.org

- The Semiconductor Research Corporation (SRC), which is U.S.-based and was established to coordinate educational efforts to produce a workforce that will meet the needs of the semiconductor industry;[20] and

- Semiconductor Equipment & Materials International (SEMI), which is an international trade association for the tool manufacturers who supply the equipment and supplies needed to produce semiconductors.[21]

Together SIA and SRC, along with SEMI, helped established SEMATECH in 1987. A consortium of thirteen U.S. semiconductor manufacturers created SEMATECH using matching funds from the U.S. Federal government. The purpose of the organization was to reinvigorate the semiconductor industry in the United States, and to address the increasing strength of the Japanese industry. Research conducted by SEMATECH is focused on the pre-competitive stage of semiconductor development. Following ten years of success and the cessation of federal government support, SEMATECH formed International SEMATECH in 1998.[22]

International SEMATECH is a consortium of thirteen semiconductor manufacturing companies from seven countries and has an international focus with the aim to accelerate development of the advanced manufacturing technologies needed to build the most powerful semiconductors. The organization is based in Austin, Texas, and has 600 people on staff.[23] After SEMATECH opened to international members, the Semiconductor Industry Suppliers Association (SISA), formerly SEMI/SEMATECH, was formed in 1999 to continue the effort to advance the United States semiconductor industry. One of SISA's goals is to facilitate the use of International SEMATECH research by SISA member companies.[24]

Utility company efforts to work with SEMATECH and International SEMATECH can be traced to an effort by the Electric Power Research Institute (EPRI) to jointly develop a Center for Electronic Manufacturing in 1997. The center was never opened, as the contractual agreement was never finalized. Other efforts to work with the industry have been limited and seem to be primarily singular efforts by those utilities with customers who are members of SEMATECH.

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20 http://www.src.org

21 http://www.semi.org

22 http://www.sematech.org/public/corporate/history/history.htm

23 http://www.sematech.org

24 http://www.sisa.org/index.html SISA's home page has the most comprehensive list of links to microelectronics organizations.

One of the activities undertaken by the industry is the creation of the *International Technology Roadmap for Semiconductors*, published by the SIA.[25] The Roadmap identifies goals for advances in microprocessors through a complete analysis of the steps needed to design and manufacture the product. The Roadmap is developed in the pre-competitive environment to assist all industry members to move forward. The Environmental, Safety and Health (ESH) section of the Roadmap includes goals for resource conservation for water and energy. Among these goals are many areas where research is required in the next two to ten years. These include:

- *ESH:* Reduce equipment heat discharge, recycle equipment exhaust, reduce process area size by equipment integration, develop water-cooled equipment versus air-cooled.

- *Interconnect:* Reduce energy consumption of plasma and sputtering systems, reduce RF plasma energy consumption, alternate low energy plasma systems.

- *Front End Processing:* New energy efficient thermal processes, new water and chemical heating technologies, reduce exhaust requirements for tools.

- *Lithography:* Design equipment for minimum energy use, energy-efficient designs for environmental control

- *Factory Integration:* Develop ultra-efficient factory design template, recycle equipment exhaust, recycle exhaust heat energy.

In some cases, the roadmap indicates "no known solution" to goals for reduced energy consumption. These include:

- By 2005, energy consumption overall for fab equipment and fab facility at 0.4-0.5kWh/cm^2 (2.6-3.2kWh/in^2); by 2011, 0.3-.04kWh/cm^2.[26]

- By 2002, 300 mm production fab equipment energy consumption equal to .5 times consumption of a 200 mm facility; by 2008, equal to .4 times consumption of a 200 mm facility.

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25 http://public.itrs.net/

26 The reader will note that the energy consumption goal for overall fab equipment and for the fab facility are the same. These both are production cost models. An operating cost model, might lead to different scenarios.

In a few cases, energy efficiency activities have already been sufficiently researched and development is underway, or solutions have been qualified for application. These include the following:

- *Factory Integration:* Optimize existing facilities equipment for energy consumption, implement high efficiency cogeneration systems, decrease air conditioning load by implementing mini-environments, mini-pod systems and clean dry air tunnels.

These goals provide a potential point of cooperation where the industry is seeking to transform its use of energy, but lacks the knowledge to meet its own goals.

Water conservation goals are also noted in the Roadmap. A news release from SEMATECH in October 2000 noted success resulting from audits of process water capabilities, which reduced rinse water consumption by member companies by 40% since 1997.[27] Such success in water conservation further suggests that the Roadmap may have an influence on resource conservation and might work for energy conservation as well.

Another venue for working with the industry is through the International Semiconductor Environmental Safety and Health (ISESH) conference. The 8th Conference call for papers by December 2000 was posted, with a conference planned for June 2001.[28] The conference specifically asks for papers on energy conservation. The 3rd Asian Semiconductor Environmental Safety and Health (ASESH) conference was held October 21 through November 1, 2000, and included a session on benchmarking of energy consumption.[29]

27 http://www.sematech.org/public/news/releases/wateruse.htm

28 http://www.tsia.org.tw/8th%20ISESH.htm

29 http://www.tsia.org.tw/3rd%20asesh.htm

3. INITIATIVE PROCESS

INTRODUCTION

This chapter describes the formulation of the hypothesis behind the Microelectronics Initiative. The chapter then examines the evolution of the project's steps toward implementation, from 1996 to November 2000.

ORIGINS OF THE ALLIANCE MICROELECTRONICS INDUSTRY INITIATIVE

Regional Awareness

The microelectronics industry, by the mid-1990s, was poised to become a very significant user of electricity in the PNW region.[30] In the summer of 1995, staff at the Oregon Office of Energy (OOE) administering the Business Energy Tax Credit Program began noticing that microelectronics manufacturers had been showing great interest in the PNW. The OOE program offered tax credits to corporations that invested in energy-efficiency techniques in the manufacturing process.[31] As the staff evaluated the tax credit applications, they realized that each plant would require electrical capacity of 25 to 30 MW.[32] It did not take much analysis to see that the microelectronics industry would quickly become a major source of electrical demand for the region.

The PNW had been the home of industry pioneers, such as Tektronix, Hewlett-Packard, and Intel for about 20 years. These and other companies were drawn to the region by low-cost electricity, large amounts of clean water, and a skilled labor force.[33] Cheap electricity appealed to the managers of the fabs because they used huge quantities for production equipment and for maintaining the clean and particle-free air conditions required in "clean rooms" where chips are made.[34] Water

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30 Chris Robertson, et al., *"Opportunities for Efficiency in the Northwest Microelectronics Industry,"* booklet published by the Northwest Power Planning Council, 1996 (?), p. 3.

31 The tax credit amounted to 35% of the cost of energy-efficiency measures.

32 Interview with Jeff Harris.

33 Robertson, et al., *"Opportunities for Efficiency in the Northwest Microelectronics Industry."*

34 Temperature and humidity are maintained within +/- 1%.

was critical, because it was used in chillers that kept temperatures constant in the precise manufacturing process and to clean the chips following manufacturing. Globally, the semiconductor industry announced plans in 1995 through the first half of 1996 to invest $169 billion in new manufacturing facilities.[35] Due to the positive features of the PNW, it was anticipated that perhaps $20 billion of that investment would come to the region, adding up to new electricity demand of about 600-800 MW.[36]

The Northwest Power Planning Council (NWPPC) also became aware of the rapid growth of the microelectronics industry in the region. And staff had heard presentations made by Lee Eng Lock, a mechanical engineer who had established SuperSymmetry Services, based in Singapore. An avid champion of improving energy efficiency in manufacturing facilities, Mr. Lee had developed innovative measurement and testing equipment as well as analytic software that monitored the performance of HVAC systems and industrial equipment. Questioning traditional rules of thumb in engineering practice, he used his data to redesign the facility services (e.g., HVAC, re-circulation air, and process cooling water) in several factories in Asia and Europe, and measured and documented huge energy savings.

Impressed by such claims, The NWPPC and OOE cosponsored a workshop on Microelectronic Facility Efficiency on October 20, 1995, in Portland, Oregon. Representatives of microelectronics firms as well as public and private utilities in the region attended the workshop. The key presentation came from Lee Eng Lock, who described his work in factories. Most notably, he claimed that air handling systems, pumps and chillers in his redesigned factories used so much less electrical energy than what was consumed in conventional microelectronics facilities that they quickly paid for the extra investment in the more efficient equipment. Overall, Lee claimed energy efficiency savings of 40 to 50% could be achieved.[37]

Industry Barriers

Despite the promise of increased energy efficiency, leaders of the microelectronics industry have not transformed their practices. In fact, several barriers impede rapid acceptance of the principles Lee Eng Lock and others have proselytized.

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[35] Chris Robertson, Jay Stein, Jeff Harris, and Mark Cherniack, "Strategies to Improve Energy Efficiency in Semiconductor Manufacturing," *ACEEE 1997 Summer Study on Energy Efficiency in Industry*, p. 2.

[36] Chris Robertson & Associates, *"Microelectronics Energy Efficiency Initiative Business Development Venture,"* submitted to the Alliance, July 31, 1997.

[37] Northwest Power Planning Council, *"Micro-Electronics Facility Efficiency Workshop, Meeting Report and Appendices,"* December 14,1995, pp. 4-5.

Perhaps the most significant barrier stems from the industry's intense competitive nature. Like the manufacturers of the products that use semiconductors, the microelectronics industry needs to produce its chips to high performance and quality standards at an exponential rate, with new generations in technologies emerging about every three years.[38]

With many competitors in each submarket, the leaders need to get their product to customers quickly in order to maintain a technological edge—even if that edge remains for a matter of weeks or months. In such a situation, facilities and design managers of companies that build fabs in periods of between 12 to 18 months tend to be hesitant to undertake innovations. They avoid risks that could delay the opening of a manufacturing plant. Such a delay could cost millions of dollars, even if the plant were opened only a few weeks late.

The time pressures of manufacturing also lead to difficulties in efficient design practice. Very often, the designers of the mechanical systems (air handling, cooling, etc.) work separately from the designers of the electrical systems, but both are under constant pressure to do their jobs quickly. Little time exists for designers to coordinate their activities and design a total system that minimizes energy consumption. The teams feel pressured instead to get their specific tasks complete so the fabs can be built quickly and reliably.[39]

Beyond these concerns, is the fact that electricity consumption constitutes only about one-to-three percent of total production costs. Compared to capital costs for the tools and building (that often exceed one billion dollars per fab), electricity bills are on the order of a few hundred thousand to a million dollars per month. Such costs do not seem significant, especially if energy-efficiency improvements might cause delays in construction.

A flip side to this barrier is the opportunity presented by looking at operating costs instead of production costs. Typically, new plants' return on investment is cleared within two or three years; after that, the costs of operating a fab are driven largely by labor and energy costs, with energy costs typically between 30-40%.[40]

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38 Robertson, Stein, Harris, and Cherniack, *"Strategies to Improve Energy Efficiency,"* p. 1.

39 Robertson, Stein, Harris, and Cherniack, *"Strategies to Improve Energy Efficiency,"* p. 4; and Robertson,et al., *"Opportunities for Efficiency in the Northwest Microelectronics Industry,"* p. 18.

40 NWPPC, *Opportunities for Efficiency*. 1995. pp. 11.

The Alliance Project

Along with OOE and NWPPC, CRA believed that the microelectronics industry would become a major energy user in the PNW. CRA had approached OOE and NWPPC in 1995 and participated in the work that led to the October 1995 workshop sponsored by Bonneville and OOE. CRA also received a small grant from Bonneville and NWPPC to perform an initial study that culminated in production of a brochure on the subject.[41]

Seeking to extend this work, CRA, OOE and the NWPPC tried to interest other organizations. They talked to managers of SEMATECH, a joint industry and government consortium which sought to improve development of semiconductor manufacturing equipment. Because of its large presence in the industry, SEMATECH acted like a de facto industry standard maker.

At the same time, CRA built up a network of relationships with several other key players in the marketplace. CRA did this partly by contributing significantly in another industry workshop in October 1996, sponsored by the Power Planning Council, BPA, and the OOE, in which Lee Eng Lock returned with data from his work to improve the energy-efficiency of fabs in Singapore and elsewhere.

After its creation, the Alliance appeared to be the most logical source of support for the work that OOE, the NWPPC and CRA were pursuing. However, obtaining a firm contract with the Alliance did not come quickly nor automatically. In a request for funding submitted at the end of July 1997, CRA proposed to continue the work he had done with the BPA, NWPPC, and OOE on identifying energy efficiency opportunities in the semiconductor and broader microelectronics industries. More specifically, he sought to communicate the value of energy efficiency opportunities in these industries through the use of workshops, professional education, and personal networking. He also hoped to create a design collaborative (or design "charette"[42]) as a way to implement novel approaches into industry planning. He also proposed to recruit companies that would be willing to participate in actual design changes for forthcoming fabs.[43]

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41 Robertson, et al., *"Opportunities for Efficiency in the Northwest Microelectronics Industry."*

42 A design charette is a public interactive design workshop focused on a single project or single design process geared toward developing a consensus design.

43 Chris Robertson and Associates, *"Microelectronics Energy Efficiency Initiative Business Development Venture,"* submitted to the Alliance, July 31, 1997.

Initially the Board members expressed a variety of concerns, both about how CRA would contact utility customers and about the effectiveness of the approach. Though convincing industry leaders was an important element of the market transformation process, the Board wanted to see more control over CRA's activities and more certainty of tangible outcomes.

Thus, the proposal was initially deferred.[44] A rewritten proposal focusing on promoting the idea of integrated design through a design charette finally won approval from the Board in December 1997.[45] Key to the revised proposal were both the targeted activity and budgeting and oversight provisions. The staff-recommended budget of $1.43 million (to be disbursed over two years) included $100,000 for evaluation of the project and $700,000 set aside in a reserve fund for special projects under the control of the Alliance executive director. Prior to authorizing the reserve funds, the director would consult with the Executive Committee members.[46] Moreover, CRA would be required to provide quarterly work plans that described what they expected to do for the next three months. Overall, according to NWPPC and Alliance staff, Board members now felt that the project would be overseen effectively.

On a day-to-day basis, the project also required supervision from the Alliance. Seeking someone who had a good knowledge of the industry, the Alliance hired a project manager who had worked at a local semiconductor facility. Thus at the point of funding, there were two major components to the Microelectronics Initiative, the CRA Microelectronics Initiative and the Special Projects Funds.

THE CRA MICROELECTRONICS INITIATIVE

Hypothesis

The CRA Microelectronics Initiative differs from what might be thought of as "classic" market transformation interventions—those that focus on the deployment of specific energy-efficient technologies and thus address the mass market, or at

44 No Board action was taken at the meeting of 29 and 30 September 1997, *"Board Meeting Minutes,"* Portland, Oregon September 29 and 30, 1997, Revised October 31, 1997. At the Board meeting of 28 and 29 October 1997, the project was deferred, with a recommendation that the proposal be rewritten. *"Board Meeting Minutes,"* Portland, Oregon, October 28 and 29, 1997, Approved February 26, 1998.

45 As envisioned in the revised proposal, a design charette could be funded in any part of the world, the charette would bring some of the leading energy efficiency designers to an early design conceptualization of a new fab with the opportunity for the Alliance to then feed the design information back to firms in the PNW.

46 *"Board Meeting Minutes,"* Seattle, Washington, 11 and 12 December 1997, Approved 26 February 1998.

least the large market of commercial building operators. It involves intensive preparatory work with a very limited number of market actors and considerable reliance on intra-industry communication. This type of transformation might be called "industry transformation."[47]

The core hypothesis suggests the possibility of working, in selected sectors such as the microelectronics industry, with a small number of interested players to identify and implement energy-efficient changes that will then spill over to others in that industry. Among the critical characteristics of a target industry are the facts that the investment cycle is extremely short and that competition among major players is intense.[48]

Accordingly, major actors in the industry will emulate and incorporate any technologies or practices that appear to provide an advantage in productivity, quality, reduced waste, ability to meet environmental standards, or costs—so long as no unacceptable changes are required in speed, production or throughput. A corollary hypothesis is that, because of the (global) competitive forces involved, the investments in energy efficiency need not be in the region (although from the Alliance perspective such investments are obviously to be preferred).

The use of this market transformation hypothesis in the Microelectronics Initiative, however, was not new to the Alliance. The Alliance is also testing the same hypothesis in another segment of the microelectronics industry. In 1996, CRA identified a project and brought it to the attention of the NWPPC. The firm submitted the project in the proposal cycle and in late 1997 the Alliance undertook a project with Siemens Solar Industries, to improve the energy efficiency and productivity in the manufacturing of silicon crystals for use in photovoltaic cells and computer chips.[49] Project leaders have seen energy savings of between 40-50%. Moreover, they have also seen productivity improvements in reduced use of resources and faster production of solar cells.[50] Siemens Solar is the only producer of silicon ingots for photovoltaics in the U.S. The manufacturing process for photovoltaics-grade silicon ingots is transferable to the microelectronics industry if

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47 Eilert, P & G. Fernstrom. (2000) "An Industry Transformation Framework for Achieving Sustainability." In *Proceedings of the 2000 ACEEE Summer Study*. Pp6.85-6.106.

48 As one contact described the industry structure detailed in chapter 2 "Product cycle is very short, tooling cycle is middle term, and facilities cycle is decades."

49 "Alliance and Siemens Solar Industries Agree to Share Cost of Demonstrating New, More-Efficient Silicon Crystal Production Process," *Business Wire* (8 April 1998), from Dow Jones Interactive.

50 Northwest Energy Efficiency Alliance, "Silicon Crystal Growing Facilities," http://www.nwalliance.com/projects/current/silicon.html (accessed 4 June 1999).

a new process can produce higher-grade silicon. The market transformation hypothesis is that as other producers of silicon ingots in the microelectronics industry realize the non-energy and energy benefits gained by Siemens by using these techniques, they will adopt similar approaches, and the process used to manufacture microelectronics-grade silicon ingots will be transformed. The Alliance board approved $1 million for this project[51] in October 1997.[52] When Board members approved the CRA project they hoped to employ similar principles to transform the microelectronics industry more directly.[53]

CRA Microelectronics Progress

CRA began their efforts in March 1998. An important aspect of the agreement between the Alliance and CRA was an agreement to respect the proprietary issues within the microelectronics industry. As such, the project manager and a staff person from NWPPC were the only ones initially with access to the monthly report.

A review of the monthly reports reveals little specificity about the initiative. Nonetheless, the monthly reports demonstrate that CRA began meeting with contacts in the industry in March and continued this process through October 1999, with the project completed in December 1999.

According to NWPPC and Alliance staff who oversaw the projects, the initial meetings were quite successful. CRA and Alliance staff were invited to attend a small industry meeting with 40 others on Clean Production, in which energy efficiency was "put on the table" as a issue worthy of consideration. CRA also attended a major industry meeting of Environmental, Safety and Health managers in the Silicon Valley and was then invited by the Rocky Mountain Institute (RMI) to participate in their efforts to work with a leading semiconductor manufacturer.[54]

These early efforts led to not only an increased awareness of the topic by leaders in the microelectronics industry, but also resulted in access to audit reports for projects conducted by Lee Eng Lock and RMI. These reports, in which proprietary data was masked, provided solid evidence of the opportunities in operating fabs.

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51 Siemens matched the $1 million funding.

52 The Alliance, *"Board Meeting Minutes,"* Portland, Oregon, 28 and 29 October, Approved February 26, 1998

53 The Siemens project evaluation is yet to be completed. The full test of the theory will be forthcoming in future years.

54 World Semiconductor Council Executive Environment Safety and Health Summit (San Francisco, 1998), Asia Pacific Economic Cooperation Forum on Clean Manufacturing in Electronics Industry (Portland, 1998), Center for Environmentally Benign Semiconductor Manufacturing (Palo Alto, 1998),

The following provides a list of the activities that occurred during the CRA Microelectronics Initiative.

- Business-to-Business presentations were conducted at Northwest companies including, Micron, Zilog, Intel, Wafertech, Hyundai, Hewlett-Packard, Wacker-Siltronic, Oki Semiconductor, Fujitsu, LSI Logic. Additional presentations held outside region including STMicroelectronics, Motorola, AMD, IBM, Hewlett-Packard, Los Alamos National Laboratory, AT&T.

- CRA published an article in *Semiconductor Fabtech* (21,000 distribution) June 1999 10th Anniversary Edition. The article describes the opportunity for improved profitability through advanced energy and resource efficiency.

- The project's work received favorable citations in two important new books published in 1999—*Cool Companies*, by Joe Romm and *Natural Capitalism* by Paul Hawken, Amory Lovins and Hunter Lovins—and in several trade press and newsletter articles.

- CRA identified project opportunities at four PNW semiconductor fabs, which were pursued under the Special Project Fund.

- The results of a series of detailed efficiency assessments at STMicroelectronics (STM—a global chip manufacturer) facilities, using CRA team members, RMI, SuperSymmetry Services, and E-Source were made available to NWPPC and Alliance staff for review and analysis.

- Strategic presentations were made at: *World Semiconductor Council Executive Environment Safety and Health Summit* (San Francisco, 1998), *Asia Pacific Economic Cooperation Forum on Clean Manufacturing in Electronics Industry* (Portland, 1998), *Center for Environmentally Benign Semiconductor Manufacturing* (Palo Alto, 1998), *Sure Power Corporation's Workshop on High Reliability Power Supply for Critical Facilities* (Boston, 1998), U.S. EPA's *Workshop on Energy Efficiency Strategies in Semiconductor Manufacturing* (Austin 1998), U.S. Asia Environment Program's *Workshop on Clean Production in Semiconductor Manufacturing* (Singapore, 1999), Lawrence Berkeley Lab's *Workshop on Energy Efficiency in Semiconductor Manufacturing* (Berkeley, 1999), U.S. DOE workshop on energy efficiency and reliability for National Laboratory and Federal energy managers (Denver, 1999).

SPECIAL PROJECT FUND

Hypothesis

The special projects component of the overall Microelectronics Initiative was originally conceived of as a means for CRA and the Alliance to fund promising projects that could further the market transformation hypothesis. When the Board of Directors separated these funds from those for CRA, the funds came under the Alliance's discretion alone. The staff person hired to oversee the fund was in the position to develop a strategy and propose use of the fund to the Board.

The initial goal was to fund design charettes to encourage integrated building design for new fabs. However, as CRA and Alliance staff talked to microelectronics firms in the PNW and in other parts of the world, they found limited interest in a design charette. CRA found one company that would consider the idea, but they had many internal decisions to make before they could move on the idea. About nine months after project inception, no company was willing to conduct a design charette. The Alliance concluded that there would be no takers and that another project approach was needed.

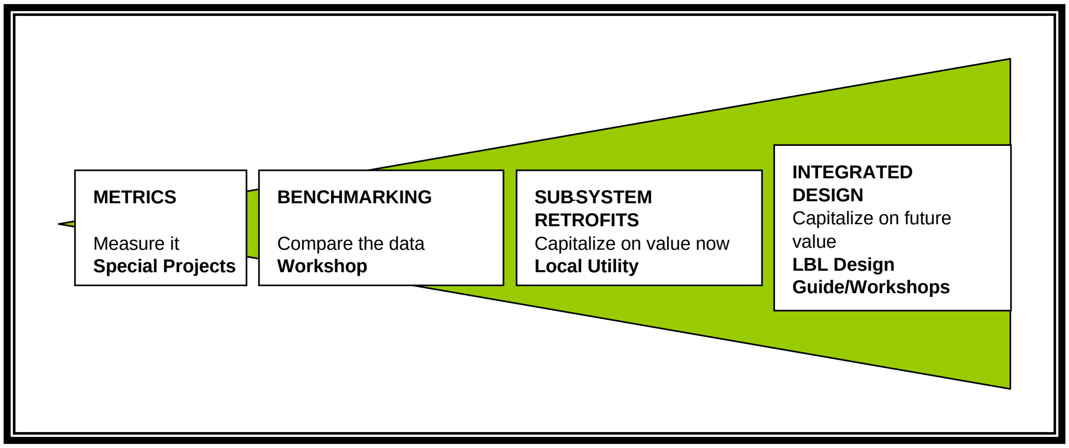
The concept that has come to be the primary driver for use of the fund is rooted in the phase: "If they measure they can manage, if they measure, they have to compare and this will increase the visibility of the cost of ownership."[55] As CRA and Alliance staff had talked to firms in the first year of the project they had heard firms say, "of course our building is energy efficiency, we just built it." The hypothesis for the Special Project Fund therefore was to focus on measurement, to show the firms that in fact there were opportunities for saving energy in their own facilities and that measurement activities would lead to change in the way energy is used in the facilities. Figure 3 displays the vision Alliance staff had for how measurement activities could lead to more integrated design of fabs.

To facilitate this approach, the Alliance sponsored two workshops with microelectronics firms in the PNW and offered to co-fund measurement projects for any regional microelectronics firm. The purposes of the workshops were information sharing, outreach to the industry, and education on energy efficiency solutions by international experts.

55 Interview with Blair Collins.

Figure 3

PROJECT INFLUENCE MODEL



As of October 2000, two measurement projects had been funded in addition to the Opti-Chill project. The measurement activities, while all focusing on HVAC and chillers, are structured differently, depending on the subcontractor proposed for the project. One of the projects primarily relies on a walk-through audit approach, one relies on a very high level of installed monitoring equipment and computer modeling, and one uses a monitoring and modeling strategy that builds on the installed facility management system (FMS), implemented at two different fabs owned by one company.

The hypothesis is somewhat different from that initially proposed by CRA. The initial CRA project envisioned using the Special Project Fund to support a variety of different type of demonstration projects anyplace in the world, if the Alliance could subsequently use the data and information to demonstrate the value of energy efficient design. In the CRA hypothesis, the Alliance might have funded a study to compare energy use across facilities using different design strategies, even if the facilities were in California or Singapore. In the hypothesis now used by the Alliance, only projects in the PNW can be funded.

Special Project Fund Progress

The two workshops held to date have attracted 37 participants. These 37 participants included presenters as well as facility representatives from eight of the

research/into/action

major semiconductor fabrication facilities in the PNW.[56] A third workshop is planned for May 2001. In addition to these workshops, the Special Project Fund is also responsible for the following:

- Three major Northwest chip manufacturers are implementing measurement projects through the Special Project Fund.
- Two major Northwest chip manufacturers entered into negotiations to implement measurement projects through the Special Project Fund, but contracts were not finalized.
- The Alliance provided partial funding for a project at Lawrence Berkeley National Laboratory to create design guidelines for energy efficient clean rooms.

RESPONSE TO THE INITIATIVE BY INDUSTRY

Testing the success of the Microelectronics Initiative is difficult for several reasons. First, the time since initiative inception is short and the vision for the two approaches will take time to come to fruition. Second, the CRA Microelectronics Initiative anticipates a sea change in attitudes and awareness, yet there are clearly multiple intervening variables that could also lead to such a sea change. Some that must be considered include: restructuring of the electric industry, electricity price shocks, cyclic conditions in the semiconductor industry, regulatory requirements due to global climate change, market positioning strategies using the environment, and possibly others. Third, the semiconductor industry is huge—any one person is likely to have an opinion, but not necessarily the pulse of the industry. Fourth, the industry is fluid, people move about, change jobs, companies rise and fall, contacts are difficult to keep track of over time. Fifth, the CRA Microelectronics Initiative has terminated, the Special Project Fund activities are still in progress with several steps yet to be implemented, and contacts made by CRA have not been continued.

Given this, we nonetheless, attempted to determine whether either of these hypotheses had had any effect on the industry, or were likely to in the near future. The following discusses each approach.

56 There are at least 38 microelectronics firms in the PNW and 12 firms are over 50,000 square feet in size (Quantic database).

The CRA Microelectronics Initiative

As noted earlier, we talked with 24 contacts in the microelectronics industry, 14 of these were located outside of the PNW and ten were located in the PNW. The contact list was generated from CRA's contact list. In talking with industry contacts outside of the PNW, we found no indication that these contacts were aware of STMicroelectronics efforts in regards to energy efficiency, nor that these contacts were familiar with CRA or the Northwest Energy Efficiency Alliance efforts. However, within the PNW, contacts were aware of STMicroelectronics' efforts, CRA and the Alliance. Most knew of, or had attended one of the three workshops sponsored by the NWPPC or the Alliance and had heard CRA and SuperSymmetry make presentations.

The design and engineering firms involved with the Alliance in the special projects often saw merit in the CRA initiative. Two discussed how their own businesses were growing and how interest in energy and willingness to invest in energy efficiency by their clients was increasing, though still slowly. One of these consultants specifically mentioned that he felt the overall approach taken by the Alliance, though difficult to prove, had contributed to the changes he was experiencing. Another designer, who is based in the PNW, was familiar with CRA but has not participated in any Alliance activities to date, although he indicated that his firm hoped to become involved with the Alliance in the next six months.

If the CRA Microelectronics Initiative is seen as a continuation of the effort begun by the NWPPC and OOE to reach out to microelectronics firms at the senior executive and management levels, then the CRA effort did continue the progress begun in the middle 1990s. NWPPC staff particularly noted that the meetings attended by CRA in 1998 were significant opportunities that had not existed prior to that time. These meetings provided an chance to contact senior executives in ways that had not been achieved before, but do those people remember CRA and the Alliance? We found no indication they did; however, energy efficiency has emerged in 2000 as an increasingly important issue at other firms in addition to STMicroelectronics.[57] We also found no indication that the contacts were maintained after initial contact, as 40% of those we attempted to reach were not available due to moves, changes in phone numbers, or jobs.

[57] While a limited sample and certainly potentially attributable to external factors, we identified a change in corporate commitment to energy efficiency for several firms by examining the 1997-2000 Annual Reports or Environmental, Safety and Health Reports placed at firm's websites. Those with specific energy efficiency objectives included Motorola, Mitsubishi Electric, Wacker-Siltronic, Intel and Hewlett-Packard, those without included Fujitsu, Zilog, Micron, and Hyundai.

Other explanations also exist for these changes in views toward energy. Though the United States government has yet to ratify the Kyoto Protocol, the issues of global climate change and the environmental impact of the semiconductor industry have the attention of management.[58] The industry is cyclical, and while there was a production downturn that coincided with the initiation of the CRA Microelectronics Initiative, the downturn subsided in 1999 and production increased at plants throughout the PNW during 1999 and 2000.[59] The energy crisis in California in the summer of 2000, and in the Midwest and Northeast in the summer of 1999 may also have had an impact.

Part of the CRA project hypothesis assumes that once an early adopter company makes a change, others will follow to keep up. We sought to test this idea and found it to be difficult to support or refute. At its most specific level, the hypothesis hinges on the notion of "copy exact."[60] Yet, we only found three firms that use some form of copy exact or “copy almost.” All other firms, as well as designers we spoke with, suggested that copy exact was not a goal for their firm and provided reasons not to do copy exact such as, “each plant does something different,” “technology keeps changing so do we,” etc. On the other hand, it was also clear from their comments that they are affected by what happens at other facilities in their company or in their industry niche. Several of the contacts discussed how changes at one facility can affect another, or how they try to keep abreast of changes in the industry. SEMATECH was cited by some as a source of information.

The CRA hypothesis is a long-term approach, the small changes that can be traced to the initiative as described in the progress discussion above, may be connected to the changes being noted here, but the links are tenuous. In addition, the CRA hypothesis was not fully executed. A component of the original hypothesis was that funding for special projects could provide examples of state-of-the-art energy efficiency design solutions, with sufficient data to be convincing to managers and owners of firms located in the PNW. The Special Project Fund has not been used for

[58] The Kyoto Protocol sets forth goals for greenhouse gas emission reduction. The Protocol has not been ratified by the U.S. Senate. However, many companies have voluntarily begun to implement efforts to achieve emission reductions. This is especially true for global companies, which have plants in countries where the Kyoto Protocol has either been ratified or is viewed as inevitable.

[59] A slow down in production was reported in January and February 2001, as the draft report was being reviewed.

[60] Copy exact is the design strategy in which a firm attempts to replicate fabrication plant design and construction in multiple locations so that the product is identical no matter where it is manufactured. The copy exact strategy also facilitates the ease of transfer of management and technical staff between facilities.

any design projects. Where such projects were conducted by CRA solution providers outside of the PNW region, the Alliance does not have access to these data.[61]

The Special Project Fund

It is important to recognize that the Special Project Fund activities are still in process. A total of five projects have been considered using the Special Project Fund, with three underway. The next steps after project funding and completion will be comparison of results using workshops and other methods. This section describes the progress of activities as of December 1, 2000.

One project with a microelectronics firm has been completed. SuperSymmetry conducted a walk-through and did it with short-term monitoring equipment on two plants' motors, chillers, pumps, cooling towers, and air handlers. They produced a report that compared the company's power usage per ton of cooling with an industry benchmark and recommended 12 projects that the company could do to reduce power consumption. Said the company's facilities manager, "We got the data that shows management the justification behind the projects I'm recommending."

Two additional projects are underway. For one microelectronics firm, En-Wise is installing permanent sensors into a chilled water system comprising three plants and under SCADA control. En-Wise developed electronic drawings of the system and made a proposal regarding the sensors to be installed. In its next steps, it will install the sensors, analyze the monitoring data that flows from them, and provide the client with energy saving recommendations and consultation. The recommendations may also enable the client to optimize production.

For another microelectronics firm, Willis Energy Services is conducting the Opti-Chill project. This project develops computer models of the client's three chilled water plants, installs monitoring instrumentation, analyzes the data, and prepares an "Opportunity Identification Report" for each plant.

Proposals for Special Projects Funds have been submitted to two other microelectronics firms. Willis and En-Wise are the two consultants involved. The client with whom Willis is working is considering the proposal, but has it on hold. The client with whom En-Wise is working has deferred consideration of the project until at least mid-2001.

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[61] Such as one by SuperSymmetry USA that involved design and construction of a new fab in California in less time, at lower total cost and lower operating cost than another fab at the same location designed by another firm.

Alliance Offers to Firms

CRA contacts helped open the doors for several projects by creating proposals for five firms in the PNW, which led to four proposals and negotiations and two current projects. CRA initially proposed that solution providers on their team do the work. During the initial meetings, the microelectronics firms showed interest in efficiency and pursuing projects. In most cases, however, the firms perceived the initial concept as too expensive and/or too complex for their needs. The negotiations led to changes in project design based on these concerns.

Table 2 describes the results for the five firms CRA identified as having potential projects.

Table 2

SPECIAL PROJECT FUND PROJECT STATUS FALL 2000

FIRM	NEGOTIATIONS	PROJECT IMPLEMENTATION	COMMENT
One	None	None	None
Two	Deferred	None	Management changes and offshore decision-making impeded project progress
Three	Contract signed	In Process	Required majority funding of project by Alliance
Four	Contract signed	Completed	Project scope reduced from $150 to $40, a simple walk-through
Five	On Hold	None	Three proposals developed, appear to be unlikely to proceed with any

From the Alliance point of view, price, uncertainty about project benefits and the business cycle[62] have been raised as barriers to doing these projects. It is also apparent that sales cycle issues affected these projects. Microelectronics firms

62 Business cycle issues include: competing with other projects, tool build outs taking up engineering time, restrictions on capital, etc.

routinely seek a two-year pay back or less for capital projects. As the cost and complexity of a project increases, it takes more time and effort to sell the project.

As the scope of the projects evolved, the Alliance envisioned the different projects providing the opportunity to compare energy study recommendations across different measurement strategies. This became a more viable strategy when Willis Energy proposed the Opti-Chill project, a Special Project Fund project that was not generated through CRA contacts but came to the Alliance in response to the Alliance Request for Proposals in 1998. With conclusion of the contract in 1999, the Opti-Chill project became the third PNW Special Project Fund activity focused on chilled water systems.

Internal Firm Events and Attitudes Leading to the Projects

Each project has a different history that led to the firm undertaking the endeavor at this time. In addition, the project consultants each have their own unique involvement with the Alliance and its special projects.

The origins of two of the projects were traced by contacts to the work of CRA, which led to the “initial entertaining of the idea.” One project arose out of interest generated from, and contacts made at the Alliance workshop in 1999. Two projects were reported to have originated when the firms became aware that the Alliance offered the Special Project Fund. For these two projects, the contacts were not explicit about the people or events that brought the funding to the firms’ attention. Two of the firms also mentioned that their local utility played a role in initiating or moving the project forward.

We asked respondents the extent to which the Alliance’s reputation and promotion of energy efficiency in the microelectronics sector influenced their decision to consider the project. Based on our past experience attempting to trace attribution, we would expect respondents to tend to minimize the influence on their decisions of outside factors and to emphasize their own needs or preferences. It is hypothesized that such views serve the respondent by reinforcing their own sense of efficacy and minimizing their sense that others significantly influence them at times.

In fact, contacts indicated that the Alliance efforts have educated their firms and that the Alliance’s endorsement of energy efficiency in the industry has contributed to their firms’ willingness to proceed. Contacts also emphasized the importance of Alliance funding. One contact also said that the State of Oregon provided critical funding through its tax credits for energy efficiency.

One facility contact said, “About 18 months ago, I was given the assignment to initiate energy conservation activities by the site facilities manager. This assignment was driven by goals of environmental stewardship and of saving money through conservation. I didn’t have any budget, so I was actively looking for ways to leverage into programs that were available. It was the Alliance funding that made the project happen. The site facilities manager is now the overall manager for energy conservation for the whole company, so that promotion has expanded the program greatly to other sites, countries, etc.”

One contact whose firm got interested through the 1999 Alliance workshop said, “It was the industry conditions that led to the project. Things were tight. We were trying to be as efficient as possible. My boss is a very efficiency-conscious person.”

A consultant’s view about another firm was, “They were already doing energy efficiency work, but instrumentation interested them. Their own interest was the primary motivator. Secondarily, they realized that the government and the Alliance are raising the issue of energy efficiency. They wanted to participate in this program to demonstrate that they were doing energy efficiency. Not in the sense of public relations, but as an actual demonstration.”

One firm built a plant a few years ago and describes itself as extremely cost-conscious. The facility contact said, “Energy efficiency has been important to us from the start. We looked at the most efficient chiller we could get. We looked at premium motors. We looked at energy efficiency for everything. I have always been aware of energy efficiency. It was the Alliance funding that we needed to give us a boost or a jump start.”

A consultant added his interpretation of how a project came about: "They didn’t want to do the project on the basis of energy efficiency alone, even though they do have an internal push for energy efficiency. They became interested when I promoted the project on the basis of total quality management (TQM), when I said that the monitoring would let them see a failure before it happens.”

All of the firms had one or two staff who “championed” the special project and worked to get management approval. In addition, the consultants worked hard, often over several years, to make the projects happen. One consultant visited a facility six times before the contract was signed. Several of the proposals went through a number of revisions, over a period of a year or more. One contract took eight months to be signed, another took 10 months, and another was considered for 12 months, only to be deferred for another 6 months. Only one contracting process was reported as “going smoothly.”

Project Decision Making

The people and criteria involved in project decision making varied among the projects. At one firm, every step of the project from proposal to implementation design has passed through a committee. This project involves installing permanent sensors in a chilled water system comprising three plants and under SCADA control. Five facility people form the decision-making group: a network communications person, an instrumentation and controls person, a mechanical engineer, a technician for the sensors, and a technician for the chiller control system. This group was involved in the contract development and now is reviewing the consultant's proposed placement of sensors.

Said the facilities contact, "Installing sensors that will work through our communications system is breaking new ground. To get the sensing devises to communicate through the network and into the consultant's computers offsite, to negotiate who was doing what, and to document it all was an extensive effort. We were trying to be careful about what each party was doing, prior to signing, and there have been no surprises." Said the consultant "It was trial by committee."

This facilities contact identified three primary concerns of the firm during contracting. The first was the time commitment required of firm staff. Project discussions did not proceed without a billing number being established first whereby involved staff could account for their time. Second, staff were concerned about the technical feasibility of having the sensors communicate through their network. Third, staff had the concern that installing the sensors might disrupt production. Such disruption is referred to as "impacts to manufacturing" or "I to M." Of the five members of the decision-making group, the network communications person was most concerned. The technical concerns were alleviated during the contracting process through discussions with the contractors the consultant will use to install the monitoring system.

The consultant conducting this project identified a somewhat different set of concerns addressed during contracting. He reported the primary concern as that of safety to staff during installation. Secondly, he identified I to M. Lastly, he said that a unit used in the SCADA system had been discontinued by the manufacturer; consequently, the proposal necessitated a new brand of equipment whose use required approval.

The facility contact for another microelectronics firm described a much simpler decision-making process. His boss, a vice president, was a champion of the project from its inception. The energy efficiency recommendations produced by the project and endorsed by the facility manager (the evaluation contact) have the approval of the vice president and are now under consideration by the senior vice president.

The contracting concerns of this firm were the confidentiality of proprietary information and the sharing of the funding: “We determined where the metrics would be taken, and which ones. We did it in relationship to energy, not chip production rates. And the funding was negotiated.”

The consultant working with that firm identified two primary risks associated with projects such these. First, is the risk that the facilities manager might lose his job if he makes a decision that disrupts production. Second, are safety and human health risks.

Another consultant described the enormous differential between the risk of taking an action such as these projects and the risk of not undertaking such a project. “The plant engineer gets fired if a plant shuts down, whereas no one may ever know if the plant is using too much energy.” All three of the consultants said that a plant shutdown, or a certain number of plant shutdowns in a given period, are cause for firing the facilities manager.

The group whose project involves the SCADA system developed a form to assess the efficiency recommendations that the project will generate. The form describes, for each efficiency action that the group endorses, its benefits, its costs, its energy savings, and its payback. They seek investments that will pay back within three years. The engineer, a technician, and the facility contact will sign the form and recommend that the actions be undertaken. It will then go to the budgeting group, where the facility contact believes his signature will be enough to get the recommendations approved.

The facility contact for the completed project has recommended that his company pursue 9 of the 12 recommendations it received. He recommended the actions that he thinks would give the most benefit without “requiring a lot of work for the payback.” He also required actions to have an ROI of two years. One exception was an action that had a longer ROI, but solved an operational problem the company faced. The facilities manager asked the maintenance supervisor (“since he’ll have to maintain anything we put in”) and the electrician (“to see if there were any pitfalls”) to assess the recommendations as well.

The rejected recommendations “make sense as a technology, but they are not justified. They do not cost much, but the operations and maintenance costs and the effort and the risk to the fab and to production make them not worth it.” The production risk is any delay in bringing the plant back up. He identified the three activities that the company will not pursue: “To use a VFD on RO membrane pump instead of an inlet valve; to utilize acid wastewater for preheating in winter and precooling in summer; and to use waste heat from the compressors for MUAH preheat.” Said the facilities manager “I like to keep things simple.”

Views of the Alliance Process

We asked the facility and consultant contacts to comment on what, if anything, the Alliance could have done to facilitate the contracting process or to further support the projects technically or administratively. A few themes emerged.

Two contractors described the billing procedure as complex, burdensome, and distracting: “I bill the client on project milestones and the Alliance on time and materials. It gets very complicated to bill. I had to develop a matrix. And one-third of the way into the project, I was asked for an additional table. It would have been easier had I known from the outset that this information was needed.”

The second contractor said, “We were suppose to bill according to different categories. These seemed inflexible. We set up this whole billing system in response, and it’s inflexible. It has not worked out well. We had the perception that a lot of details were required on a monthly basis. This turned out not to be necessary. From a project management perspective, it’s too much detail. You lose the forest for the trees.”

Two consultants and one facility contact commented on the Alliance organizational and management skills. The facility contact said, “We had a good technical match with the project manager, but we could have used better project management about defining what the project was and keeping it on track. Keeping things moving. Breaking through obstacles. The project needs organizational skills to keep it moving. For example, making sure that when commitments are said, they are met. And when commitments aren’t met, to identify it and come up with a solution before it causes the schedule to slip. This was not a strong point and probably still isn’t.”

One contractor explained that the Alliance could have “promoted resolving the one significant problem” that came up in the project more than they did. Another contractor thought that the Alliance project manager could be more effective selling the recommendations into actual projects. “[It was] always unclear about the amount of money the Alliance could make available to the client. A meeting [about implementing the recommendations] would be useful, as would getting the utility involved.”

Another facility contact, when asked how the Alliance could better support the adoption of energy efficiency, said that his firm would receive greater benefit from funding to install efficiency measures than from funding to monitor for opportunities. “The Alliance is really pushing hard on instrumentation and monitoring, to share the results with the industry. But I would like to see them work more on system changes. The monitoring is evaluation and it doesn’t save energy in itself.”

There was positive feedback as well. Funding was identified as useful both for the measurement projects and for the hoped for implementation of the recommended projects. All of the facility contacts said that their firms would not have conducted the project on their own. They explained that they lacked the ability to analyze the data and determine energy saving opportunities and that they lacked the staff time and monitoring equipment necessary for the project.

A consulting contact suggested that the approach of the Alliance generally is working, “Seminars raise the issue and get people talking. The Alliance project manager is talking to a lot of people.”

Additional Prospects for Energy Efficiency in the Industry

The manufacturers involved with the special projects have begun to appreciate the benefits of energy efficiency. As stated, in mid-1999 one company embarked on exploring energy efficiency and now has a manger for energy conservation for the whole firm. Another company has a vice president who is very concerned with efficiency and a third company considered efficiency in all of its equipment purchases for a recently built plant. Two of the firms have described their commitment to energy efficiency in either their annual report or their ESH report for the last two years.

All of the facility and consultant contacts think that energy efficiency is becoming increasingly important to the microelectronics industry. However, as one consultant said, “Interest is growing, but the change is subtle and hard to measure.”

The facility contact who said his firm is driven by environmental stewardship and cost savings believes that these two factors are motivating others in the industry. When asked what would make energy efficiency more a priority at his firm, he answered, “Funding is always helpful for capital improvements. Anything to make energy efficiency more attractive to do.” This statement stands in contrast with the magnitude of profits generated by the industry. And yet the statement is corroborated by the remarks of the consultant that worked with this firm.

Regarding the project, he said, “The Alliance’s money was the biggest impetus. The facility’s budget for maintenance and improvements is very small.”

Two facility contacts and two consultants said that higher electricity prices would be needed to spur interest in energy efficiency. “Energy efficiency is important, but paybacks are long. Large projects with medium paybacks won’t go down.” Some noted that prices have started to rise and that some firms are recognizing that rising energy costs can be offset by efficiency gains: “Energy efficiency is an immediate solution to price increases.” Two of the consultants indicated that microelectronic firms are increasingly aware of threats to power security and reliability.

One consultant believes that the energy cost savings alone is insufficient to promote energy efficiency. He thinks that monitoring for energy efficiency also provides an opportunity for operating improvements and total quality management, and that selling the benefits of all of these is necessary to change behavior.

Another consultant believes that industry interest in energy efficiency is slowly growing. For example, he noted that one prominent designer now offers a seminar that addresses energy efficiency in the air handling systems. However, the firm to which this designer belongs has not changed its design philosophy. Similarly, designers at another firm have published an article on energy efficiency for clean rooms. Yet their firm has not changed its design approach either, although it has “started talking about it.”

On the positive side, the consultant said that the energy group at LBNL has begun a project to benchmark clean rooms. He thinks that projects such as this, as well as demonstration projects, are likely to influence industry behavior. He also mentioned that LBNL conducted a workshop that was well attended by prominent microelectronics and design firms.

He believes that change is needed both at the CEO-level and at the senior staff level within microelectronics firms. He gave the example of STMicroelectronics, which he characterized as having a CEO that is “way ahead of his staff.” Yet at other firms he knows senior facility staff who, faced with the responsibility of keeping costs down, are concerned about energy use. Sometimes the plants within a firm compete with each other for lowest operating costs. This situation provides an opportunity for energy efficiency.

This consultant sees the facility design firms as the key players for increasing energy efficiency. College-level instruction in energy-efficient design would help. He has talked with several at a prominent firm who say “we do it,” but when he visits the facilities they've designed, "I don't see it." He believes that it is important to reach International SEMATECH. However, he also thinks that the organization does not share its findings widely enough with those outside of the organization, and that it excludes fab designers.

Next Steps for Special Project Fund

The next step for the funded projects is the presentation of the results of the studies in various forums so they can be compared. The goal of the program model is that comparison will lead to firms seeing the opportunities and beginning to conduct additional measurement and investment on their own. The Alliance-sponsored workshop for 2001 will provide the first forum for these comparisons.

Nonparticipants in Alliance Workshops

The Alliance has used their workshops, as well as contacts by CRA and direct contacts from industry, to generate Special Project Fund projects. In this section we discuss the response by PNW industry contacts who have not participated in either the Alliance workshops or were not on the list of CRA contacts.

We identified the 12 largest firms in the PNW that could be considered nonparticipants. These firms each had at least 50,000 square feet of manufacturing facility in the PNW according to the Quantic database. The Alliance provided us with contact names and phone numbers for two of the firms. For the other ten firms we used directory assistance to locate a central number and asked to speak with the facility manager.

We were able to reach a facilities manager for eight of these firms, and seven of the managers were willing to participate in an interview. The responses from these individuals indicate that the Alliance efforts to reach PNW microelectronics firms have only been partially successful. It is important to recognize that we only talked with one person at each firm, others in the firm may be aware of Alliance activities. However, we did intentionally attempt to reach the same level of contact that the Alliance is attempting to reach.

Of the eight nonparticipants, four were familiar with the Alliance workshops and four were not. One who was familiar with the workshops, refused to respond to any additional questions, saying, "I know all about you guys, I am not interested."

For the remaining seven, the three who were familiar with the Alliance workshop typically had considered projects for their HVAC systems. All three had conducted at least one energy efficiency project with their local utility. All three also expressed familiarity with other projects being conducted in the PNW and by the Alliance.

For the four who were unfamiliar with the Alliance workshops, one had talked about lighting issues with their utility, but none had discussed HVAC issues. Two of these firms had internally considered projects for their HVAC systems, but none had been conducted. Two of the four firms felt they already had or would always try to design the most efficient facility. None of these four firms were aware of energy efficiency projects being conducted at other PNW firms or by the Alliance.

Of the seven contacts we spoke with, all but one was interested in learning more about projects for HVAC or for energy efficiency and the Alliance workshops. Several, but not all, noted that they preferred to be contacted by e-mail for workshops so they could forward the information to other members of their firm and to their managers for approval.

4. MODELS FOR CHANGE

INTRODUCTION

The purpose of market transformation efforts is to cause lasting changes in the market.[63] There are a variety of ways this can be done. As is discussed in Chapter 3, the Microelectronics Initiative approached the goal of creating lasting changes for the PNW microelectronics industry by a new approach. This chapter discusses the hypothesis of the initiative and the program logic models that arose to implement the hypothesis, and then examines these program models in light of different social science theories of change.

EVALUATING THE ALLIANCE'S MICROELECTRONICS INITIATIVE

The facilities producing chips for the microelectronics industry in the Alliance territory have generally been built and operated with a focus on the total cost of production, of which energy is only 2-3%. As a result, energy is treated as a fixed cost and usually addressed by trying to locate plants in areas with low-cost electric power, such as the PNW. The following characteristics tend to define how microelectronics firms think about energy:

- Fabrication plants use considerable amounts of energy, particularly for motors powering HVAC (for clean rooms) and pumping applications.
- However, energy expenditures comprise only 2-3% of the cost of chip production. Accordingly, these expenditures have received relatively little attention from industry executives and operations managers.
- In periods of heavy chip demand, consideration of new design strategies is minimized, not only to contain costs, but as a result of competitive pressure to minimize design and construction time so that the product production process gets product to market before the competitors'.

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63 "A reduction in market barriers resulting from a market intervention, as evidenced by a set of market effects, that last after the intervention has been withdrawn, reduced, or changed [p. 10]." Eto, Prahl and Schlegel, Eto, Joseph, Ralph Prahl, and Jeff Schlegel. 1996. *A Scoping Study on Energy-Efficiency Market Transformation* by California Utility DSM Programs, Earnest Orlando Lawrence Berkeley National Laboratory, Berkeley, CA.

- Once operational, industry executives tend to avoid additional changes to their facility designs, construction practices, or operations that might expose them to delays or downtime.

The CRA Microelectronics Initiative program theory was that individual, targeted educational meetings with industry decision-makers could focus the industry on the considerable benefits available from energy efficiency improvements at relatively little cost. Furthermore, these meetings could persuade industry leaders to examine the evidence, including case studies and demonstrations, that the available technology and procedures are mature enough to be implemented with little risk of failure, unanticipated costs or delay in getting the product to market.

The downturn in demand for chips, associated with the 1997-1999 Asian financial crisis, was seen as offering a particularly good opportunity for initiating these efforts with some industry leaders. That is, the downturn created a relative lull in construction, while confidence in a near-term recovery remained high. It was anticipated that as the financial crisis abated and investment increased, industry leaders would begin to incorporate their new awareness into design and construction.

An important barrier to energy efficiency investments was believed to be the "copy exact" building strategy—the tendency to replicate facility designs from one construction project to another.

The program hypothesis thought this barrier could be a mechanism for transfer of experience among manufacturers once changes are implemented. Once a few industry members adopt energy-saving designs and procedures, other industry members would likely follow suit, thus serving to transform the entire sector and move it toward efficiency. Additional spillover effects might include increased attention to energy efficiency in existing fabs as well as new facilities. Thus, one could also expect changes in operations, retrofits for efficiency, etc.

Operationally, the CRA Microelectronics Initiative activity stream focused on identifying opportunities among industry members throughout the world, arranging and facilitating meetings, educating industry members about relevant technologies and savings opportunities, and encouraging project development.[64] Table 3 displays the program logic model for the CRA Microelectronics Initiative.

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[64] CRA served as a bridge to a number of experts, not just to the Alliance. These experts, spanning a range of specialties included such firms as SuperSymmetry, Inc.; Natural Logic, Inc.; and Rocky Mountain Institute—firms characterized by CRA as "Solution Providers."

Table 3

LOGIC MODEL FOR CRA MICROELECTRONICS INITIATIVE

INPUTS	OUTPUTS	ANTICIPATED OUTCOMES	ANTICIPATED LONG TERM IMPACT
CRA connections to solution providers and the ability to reach industry personnel	One-on-one meetings, industry presentations, article in industry publication, identification and implementation of "best practice" demonstration(s) or design charette(s)	Commitments to energy efficiency by fab management, increased business for solution providers	Energy savings resulting from energy efficient design for new fabs in PNW, energy efficient retrofits for existing fabs

A second program theory emerged for the activities conducted by the Alliance in allocating the Special Project Fund. These activities focused on identifying and working with interested decision-makers to bring projects to fruition, through hosting workshops to inform PNW facilities managers, and then providing assistance in developing work plans, facilitating proposals, and funding where appropriate. The focus of the fund was measurement projects for benchmarking under the premise of: "If you measure you can manage, to manage you must compare, through comparison the cost of ownership will become clear."

The Special Project Fund program theory attempted to address the specific barrier to energy investments in which owners perceive energy as a small cost of business since it is only 2-3% of total costs. The idea was to focus on operation costs which rival the cost of labor, at 30-40% of operations costs. The measurement projects, it was hoped, would make this cost of ownership more visible to the plant management.

In addition, the Special Project Fund could also be used for other projects and was used to co-fund LBNL's efforts to develop guidelines for clean room design and to promote the efforts by sending Alliance staff to attend industry meetings in and outside of the PNW. Table 4 displays the logic model for the Microelectronics Initiative Special Project Fund.

Table 4

LOGIC MODEL FOR MICROELECTRONICS INITIATIVE SPECIAL PROJECT FUND

INPUTS	OUTPUTS	ANTICIPATED OUTCOMES	ANTICIPATED LONG TERM IMPACTS
Alliance Staff, CRA Effort, Special Project Fund, Workshops for industry	Measurement projects at multiple sites Alliance attendance at industry meetings and presentations LBNL Clean Room Design Guidelines	Comparison of HVAC metrics across multiple sites, increased business for solution providers, implementation of recommendations from the measurement studies, commitment to energy efficiency by regional firms, use monitoring to manage and operate their fabs for energy efficiency	Energy savings resulting from energy efficient design for new fabs in PNW, energy efficient retrofits for existing fabs

These two Microelectronics Initiative program theories explicitly or implicitly make a number of important assumptions. Both program models make some common assumptions. These include:

- That it is possible to find a point in the semiconductor business cycle when management will attend to opportunities for energy efficiency improvements.
- A relatively small number of manufacturers account for most of the building activity.
- Competing manufacturers do, or are willing to, share certain types of information such as energy-saving experience.
- Continued growth of the industry, evidenced in a continuing need for new fabs.

The CRA Microelectronics Initiative hinges strongly on the following additional assumptions:

- Existence of—and adaptability of—the “copy exact” building strategy.

- It is possible to identify and reach the right industry decision makers willing and capable of taking the early adopter role and to maintain those contacts.
- In the targeted companies, it is possible to identify and communicate with project champions at both the operations and executive levels and to facilitate communication between these levels.
- Since the microelectronics industry is global in scope, it would be possible to effect energy savings in the Alliance territory, even with (targeted) proselytizing and demonstration activities elsewhere.

The Special Project Fund hinges strongly on different additional assumptions:

- Efforts should show a direct benefit to the PNW.
- In the targeted companies, it is possible to identify and communicate with project champions at the operations level who will champion projects to management.
- That investment in energy efficiency solutions and additional monitoring activities will follow measurement: "If you measure you can manage, to manage you must compare, through comparison the cost of ownership will become clear."

SOCIAL SCIENCE THEORIES OF CHANGE

There are many theories of how businesses make decisions and how new ideas and concepts are adopted. In this section we discuss two theories: industrial decision-making, and two strains of diffusion theory.

Industrial Decision Making

Peters, J.S. et al. (1996) reviewed the literature on industrial decision-making and identified several important features that are worth noting here.

- Industrial firm decision-makers tend to avoid failure rather than strive for success.
- In most industrial firms there is a chain or group of decision-makers rather than a single individual.

- Industrial decision-making is a function of individual as well as group assessment of expected project usefulness to the firm.
- Industrial firm upper management will tend to ignore or not make decisions without there being a project champion at the firm who is able to sell the project "up the line."
- Decisions can be influenced by addressing the perceived benefits, costs and risks to firms and to the individual decision-makers.
- The seller must understand the position of the individual contact within the organization and then should stress the non-energy benefits of the project to both the individual and the firm.
- Since industrial decision-making is done by a group of individuals, contacts should not be limited to the project champion but should include others in the decision-making chain.
- Tailoring the project to the firm's time requirements is critical to project success.[65]

Diffusion of Innovation Theories

Before further examining the program logic models in light of the industrial decision-making theory, there is another theory that is worthy of consideration: the theory of diffusion of innovations.[66] There are two specific strands of this theory that are of interest here.

The first is the theory of diffusion as it applies specifically to the high-tech industry. Geoffry Moore postulates the following variant of the diffusion theory.[67] Essentially, the competitiveness of the high tech industry and the promise of Moore's law (as in Gordon Moore, that chip speeds will double every 18 months) drives the entire

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65 Peters, J.S., R.E. Way, & M. Seratt. (1996) *Energy Investment Decision Making in Industrial Firms.* Energy Services Journal, 2(1), pp.5-17.

66 Rogers, E.M. (1962,1971,1983,1995) Diffusion of Innovations. Free Press. The theory describes how innovations are adopted by successive groups of individual adopters, each with unique characteristics that lead them to adopt at either early, middle or late relative to the introduction of the innovation. The diffusion of innovations typically follow an "s" curve with slow early stages followed by more rapid adoption in the middle and then a tapering off at the later period.

67 Moore, G. (1991). *Crossing the Chasm.* Harper Business, New York. Moore, G. (1995). *Inside the Tornado*. Harper Business, New York.

industry to attempt to capture the crest of the each wave of technological change. The discussion of the industry structure in Chapter 2 is consistent with the theory of diffusion in the industry as described by Geoffry Moore.

The primary dilemma in the industry is that innovation tends to attract early adopters who are very technologically sophisticated, but if the firm is to increase market share, the innovation must "jump the chasm" to gain acceptance by the average user. If one succeeds, then the firm will be caught in a "tornado" of growth and change to meet the new demand. These characteristics of innovation diffusion for the industry make it possible for unknowns to succeed almost from out of nowhere, and keeps the leading firms on their toes always trying to stay ahead of the unknowns.

This process also drives the competitiveness and secretiveness of the industry, as well as the need for rapid design and construction of new fabs and the need for a flawless process, with no interruptions. These actions enable the firm to capture profit as soon as possible.

Another variant on diffusion theory is that postulated by Gladwell in the *Tipping Point*.[68] The tipping point is about how small actions can make a big difference and lead to what Gladwell calls an epidemic, or the rapid adoption of an idea, innovation, product or message. Gladwell points to three factors that strongly influence epidemics. These are:

1. The law of the few, which defines the transmission agent, the one who promotes the idea message or product.
2. The stickiness factor, which defines the quality of the product, message or idea.
3. The power of context, which defines the circumstance or environment in which the transmission occurs.

The law of the few refers to the fact that an individual can influence large numbers of others to pursue a certain action. This occurs either because she is good at connecting people (a connector), is good at brokering information among different people (a maven), or is good at selling (a salesperson). The person may be good at two of these characteristics, or only one. But being really good is important to spreading the message.

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[68] Galdwell, M. (2000). *The Tipping Point.* Little Brown & Company. Boston.

The stickiness factor refers to the idea that the message, or the product, or the idea has to be good. It actually has to make sense and it has to be able to keep being good as the idea spreads or the innovation is adopted.

The final law is context. With the right person and the right message, there still needs to be the right time and place for the idea, product, or concept to spread to others. The power of context suggests that when and where the message is stated is important to whether or not it will be picked up and whether the idea will spread.

Lessons Learned from the Theories

Summarizing the lessons that emerge from these social science theories, it seems reasonable to conclude that a single person or agency can have a significant effect on the Microelectronics industry if:

- The person or agency understands the environment in which energy efficiency decisions are made;
- Has a method or a technique that is reliable and proven;
- Addresses the non-energy benefits to the individual plant managers and to the executive decision-makers of the company; and
- Catches the industry at the right time to gain their attention.

MICROELECTRONICS IN LIGHT OF THEORIES OF CHANGE

Taking these theories, we examined the assumptions that drive each of the program logic models. What becomes apparent is that each of the program logic models adhere to some of the components of these theories of change, but ultimately, the next opportunities probably emerge by rethinking the program logic to meet the challenges posed in 2001, rather than in 1997.

Assumptions Held By Both Program Models

Both models hold the following assumptions:

- That it is possible to find a point in the semiconductor business cycle when management will attend to opportunities for energy efficiency improvements.

- A relatively small number of manufacturers account for most of the building activity.

- Competing manufacturers do, or are willing to, share certain types of information such as energy-saving experience.

- Continued growth of the industry, evidenced in a continuing need for new fabs;

Assessment: These are critical assumptions regarding the context in which energy efficiency can be expected to become important to industry. The Alliance Microelectronics Initiative appeared to be well-timed in 1997/98 because the Asian financial crisis created a lull in activity such that facilities managers could listen to the message.

The lesson from this experience is that while the lull in the business cycle did create a good time to make contacts, it did not create a good time to implement. Once the business cycle turned in 1999, projects became more fundable but facility managers had to focus on production and efficiency projects still could not get priority. With such frequent fluctuations in the industry, adaptive management needs to be fully built into the program model.

A potentially critical context has emerged with the 1999 Roadmap discussed in Chapter 2. The need to reduce energy consumption to meet global climate change and resource conservation goals has attained high importance in the industry. The fact that a few companies dominate both the industry and the industry organizations that develop and implement the Roadmap continues to be an important context for research and development.

The assumption that manufacturers do or are willing to share certain types of information is an assumption that is still being tested. The assumption seems problematic in light of Geoffry Moore's description of change in the high-tech industry. Sharing of information may be more difficult to accomplish unless it is within the prescribed industry-facilitated environments such as SIA, SISA, SEMI, International SEMATECH, or ISESH. These organizations have experience finding ways to share information without affecting competition. Though firms have been willing to sign contracts with the Alliance, the issues of proprietary data were major problems in contract signing. Additionally, while energy efficiency may be a relatively noncompetitive issue, the risk of being the only firm that is working on energy efficiency and thus forgoing efforts in some other area are substantial. There are no individual benefits or firm benefits that can be readily achieved except within a more industry-wide context.

One issue not well understood at the outset of the project, but affecting both models is the required time to close the deal. CRA and the Alliance staff together were unable to finalize any project proposals for the Special Project fund in the first two years. Yet the Opti-Chill project surfaced on its own as a result of the Alliance RFP process. The Opti-Chill project was a project waiting to be done that the Alliance and CRA did not identify. Willis Energy had been trying to sell the project to their client for a while and just needed some funding (in fact a lot of funding) to help. The lesson in retrospect seems to be that any project in the microelectronics industry will take a long time to close.

CRA Microelectronics Initiative Assumptions

The CRA Microelectronics Initiative holds the following additional assumptions.

Assumption: Existence of—and adaptability of—the "copy exact" building strategy.

Assessment: We found mixed support for the notion of full "copy exact." Perhaps three firms can be considered to adhere to or attempt to adhere to copy exact. More prevalent than a copy exact requirement was a focus on minimization of risk in any way possible. Copy exact is one strategy for minimizing risk, but the need to minimize risk in general is an even more overwhelming concern and one that all firms are concerned with. Thus the notion that a single firm would adopt energy efficiency and pursue a copy exact strategy that others might follow does not appear to offer opportunity for change in the industry. This need to reduce risk is common in industrial decision-making. While the microelectronics industry may take this to an extreme, the concern drives the need noted in the industrial decision-maker theory to ensure that the individual and group all see the benefits of an idea for the firm.

Other Assumptions:

- It is possible to identify and reach industry decision-makers willing and capable of taking the early adopter role and to maintain those contacts.
- In the targeted companies, it is possible to identify and communicate with project champions at both the operations and executive levels and to facilitate communication between these levels.

- Since the microelectronics industry is global in scope, it would be possible to effect energy savings in the Alliance territory even with (selected) proselytizing and demonstration activities elsewhere.

Assessment: The notion of approaching executives and project champions in targeted firms is consistent with the industrial decision-making model. However, there is a divide between facility managers and executives that often takes multiple contacts to overcome. The CRA initiative did not prescribe multiple contacts. As we found in our attempts to reach a sample of CRA contacts, volatility in the industry means contacts will move on and it will take a lot of effort to maintain them. The notion of being able to identify and reach industry decision-makers willing to take an early adopter role is consistent with the industry structure described by Geoffry Moore. Also, consistent with Moore would be the recognition that the early adopter might be located in other parts of the world, not in the PNW.

Special Project Fund Assumptions

The Special Project Fund program model specifically holds the following assumptions:

- Efforts should show a direct benefit to the PNW.
- In the targeted companies, it is possible to identify and communicate with project champions at the operations level who will champion projects to management.

Assessment: This is an approach consistent with a regional focus, but not with the implications of Geoffry Moore's theory or the theory of decision-making in firms. Since all PNW Microelectronics firms have corporate headquarters located outside of the region, the necessity of reaching the full group of decision-makers as described in the industrial decision-making theory suggests that a focus on the PNW will result in a slower process of adoption than if contacts are also global and projects are less focused on the PNW.

Other Assumption:

- That investment in energy efficiency solutions and additional monitoring activities will follow measurement: "If you measure you can manage, to manage you must compare, through comparison the cost of ownership will become clear."

Assessment: This assumption is problematic, for two reasons: First, given the global nature of the industry there is no reason to believe that recommendations will be implemented in the region. As one of the Special Project participants stated, though their only U.S. fab is in the PNW, application of the recommendations could be made at any of their fabs worldwide, whether or not they are made at the PNW fab.

Second, in the 1980s and '90s utilities spent considerable funds conducting audits for customers in the hope that once the information was available customers would invest in energy efficiency on their own. These audit programs by and large, while resulting in some savings, did not produce the level of savings planners had expected. In the case of this program model, the market transformation hinges on firms choosing to invest in efficiency solutions and also choosing to manage their plants differently after the measurement and the comparison activities are completed. While the comparison activity adds a new component to the audit approach, there may be problems with this as a transformation activity. The firms do not identify measurement as the tool they need, rather funding, expertise and capability are needed because their budgets are constrained to not invest in non-production related activities, even if measurement tells them it is good idea.

Analysis

In light of the theories of change, it appears that the Special Project Fund with its focus on measurement at PNW facilities may have less potential to influence the global microelectronics industry market for energy efficiency than the more broad-based program logic of the CRA Microelectronics Initiative. The Special Project Fund, however, is still in process.

There are also concerns with the effectiveness of the CRA Microelectronics Initiative. There appears to be a great deal of merit in the hypothesis given the time in which the CRA Microelectronics Initiative operated. However, the timing and context for the next phase of any market transformation effort has changed and the next steps need to take advantage of these changes. More of the same will not necessarily be effective. Furthermore, the position that copy exact could lead to widespread adoption of innovation in building design, does not appear valid.

CRA appears to have followed the connector and maven approach for transmitting information about energy efficiency. This approach can work if the connector has an incredible set of contacts and is able to connect people to one another and if the connector is good at getting people to listen to what he has to say. CRA had an excellent set of solution providers and was able to connect these providers with some of the people who could use them, they also succeeded in getting people to include them in meetings and presentations.

CRA also needed to have a "sticky" message. In talking with designers and industry facility contacts the message was interesting but it did not hold up well in all situations. Some of the contacts we spoke with specifically thought that solutions proposed by Lee Eng Lock were too specific to humid climates to be transferable to the PNW without more investigation. Some contacts were frightened by the possibility that the EPA would regulate fabs to the design criteria suggested by Lee Eng Lock. As CRA notes in their final report: this closed doors and created suspicion in an industry that likes to try and avoid regulation.

As the next chapter will discuss, the Microelectronics Initiative should build on the work conducted to date, but the next activities need to be reflective of the current context, need to reach the full range of contacts who can influence the decision and need to ensure the message will be acceptable.

5. CONCLUSIONS AND RECOMMENDATIONS

INTRODUCTION

In this section we present conclusions about the Microelectronics Initiative starting by restating the key characteristics of the industry and then discussing our assessment of the Microelectronics Initiative activities. Following the discussion of our conclusions, we present some recommendation for next steps.

CONCLUSIONS

Industry Characteristics

The Microelectronics Industry is first and foremost a manufacturing industry. The decision-making processes in the industry are similar to other industries: project champions are important in project development and implementation and groups of decision-makers are the rule, rather than the exception. It is, however, different from other manufacturing industries with which the Alliance is familiar. Five characteristics emerge that result in the need for industry-specific solutions:

1. The microelectronics industry is a global industry. Headquarters for firms are generally in some other part of the world than the PNW. Though important facilities may be located here, they are part of a global chain of facilities that ensure products are close to markets and OEMs.

2. Many facilities are in the planning stages today. While the growth spurt of the 1980s and '90s appears to have slowed, new fabs still are planned at the rate of about three per year in Oregon alone.

3. As a global industry, the executives and the workforce is mobile. Plant executives move all over the world, facilities staff move among different firms in their geographic area as the semiconductor sales cycle leads to different types of facilities slowing down or speeding up production.

4. The time-to-market and competitive pressures in this industry are unparalleled in the resource and extractive industries common in the PNW. A new product must come to market ahead of others and must meet the quality specifications of the product designers, otherwise market

share will be substantially lost. Thus risks to production are viewed even more suspiciously than in other industries.

5. Like most manufacturing sectors, energy is a small proportion of total cost, only 1-3% of production costs, thus energy is treated as a fixed cost. However, energy is 30-50% of the day-to-day operating costs of the plant, potentially creating an opportunity for efficiency investments. Plants recoup their capital investment costs after two to three years. At that point, the costs of operating the plant could become more apparent, but only if the firms are aware of these costs.

These characteristics have defined the microelectronics industry for the past 20 years. In 1997, the Alliance funded a Microelectronics Initiative to encourage the industry to commit to increased investment in energy efficiency and to mange their plants to use energy more efficiently. Two activity streams were conducted in this initiative. The first was the CRA Microelectronics Initiative, the second was a Special Project Fund managed by Alliance staff.

The CRA Microelectronics Initiative

As discussed in Chapter 4, the program theory promulgated by the CRA Microelectronics Initiative is generally sound. It fits the industry decision-making framework and the two variants of the diffusion of innovation theory. The effort appears to have been partially successful. CRA made a large number of contacts, facilitated review of audits for plants outside of the PNW, conducted the project at an optimum time to gain interest, and remains a respected expert on energy efficiency opportunities for the industry. However, CRA failed to fully achieve its objectives for several reasons:

1. The CRA effort focused on the management level and did not include a process for integrating management and operations level personnel into the process.

2. The CRA effort was not completely implemented because CRA did not control the Special Project Fund activities. The CRA Microelectronics Initiative initially planned to use the fund for projects with early adopters, irrespective of their location in the world, and to focus on a variety of demonstrations—chilled water, exhaust system, production tools, building design, etc. When the Special Project Fund came to focus on projects with a direct benefit to the PNW, the full theory could never be implemented.

research/into/action

3. The message that CRA brought to the industry lacked direct transferability to PNW industry firms. CRA focused on a single set of solution providers' capabilities. Not only are all microelectronics processes and facilities unique, but the message of the solution providers was perceived by workshop participants and facilities management staff in the PNW as needing additional research and demonstration to transfer to the PNW climate.

4. The issues of confidentiality and proprietary information were relatively well handled by CRA and the industry had come to trust CRA, an important success. However, as CRA continued to work with the EPA, the industry became suspicious. These suspicions grew beyond a concern about possible regulation to become concerns that the energy efficiency solutions CRA proposed were infeasible.

The Special Project Fund

As discussed in Chapter 4, the Special Project Fund theory as a market transforming theory is weaker than the CRA Microelectronics Initiative when viewed in the context of social science theories. The focus on measurement has not been demonstrated in the past and the expansion to include comparison of the metrics has yet to be tested. To date the progress indicators for the Special Project Fund are on track. Based on our interviews it appears that:

1. Three measurement projects will be completed in 2001 and comparisons between these projects will be possible.

2. Investments in implementation of the recommendations that emerge from the projects are likely, but the scale of that investment may be less than proposed by the recommendations. Furthermore, it is unclear whether the firms will then choose to conduct on-going monitoring and attempt to use that to operate their facilities in a more energy efficient manner.

3. Two workshops, were implemented, with a third planned for 2001, at which local PNW microelectronics firms hear presentations from national experts on energy efficient solutions for the microelectronics industry.

4. Firms that have not yet participated in the workshops tend to be unaware of the workshops or of what other firms are doing. Most are interested in learning about the workshops and about what other firms are doing, suggesting that dissemination in the PNW, if promoted well, could be effective.

Though the indicators show progress, a full assessment of the theory cannot be made until the activities are completed.

Project Progress Indicators

The Alliance established criteria for success and progress indicators for the Microelectronics Initiative. The following provides an assessment of progress as of December 1, 2000.

Criteria for Success

The Alliance set out criteria for project success and seven progress indicators.

Criteria: Effectively influence industry practices leading to implementation in semiconductor fabrication facilities that integrates "world class" practices for efficient use of energy and other resources in both the facility support services (HVAC, de-ionized water, process gasses, etc.) and in process tools. Provide information that will assist this industry to more rapidly adopt energy efficient practices in design and technology.

Assessment: The criteria for success does not identify an expected timeframe for accomplishment. A timeline should be included. Based on the findings of this MPER, the criteria for success timeframe should be viewed as five to seven years from project inception in 1997.

Based on comments from designers and facility managers, there does appear to be increasing awareness of energy efficiency opportunities in the microelectronics industry. However, this trend appears to be driven significantly by external factors such as energy prices and interest in greenhouse gas emission reductions. Sorting out the effects of a two-year effort by CRA and the Alliance is likely to be impossible.

Progress Indicators

1. Identification and assessment of specific market transformation leverage opportunities in design, manufacturing technologies, and facility support systems in the microelectronics and polysilicon industries.

   Assessment: The CRA initiative and the Special Project Fund efforts both actively worked to identify and assess specific market transformation leverage opportunities in the microelectronics and polysilicon industries. The Alliance is continuing this effort with facilities in the PNW.

2. Development and assembly of information on high priority energy and resource efficiency opportunities within the semiconductor manufacturing industry.

   Assessment: The CRA initiative provided a report on opportunities for polysilicon manufacturing and provided the Alliance and Northwest Power Planning Council with access to audits from a leading semiconductor manufacturing company of several fabs located around the world. Additional research efforts could possibly be conducted to identify tools opportunities and process opportunities and how to work with the Semiconductor Industry of American to address issues identified in the *International Technology Roadmap for Semiconductors*.

3. Participation in meetings with industry associations, key industry meetings, and conferences to present energy efficiency strategies and opportunities for green fabrication facility collaborative projects.

   Assessment: CRA and the Alliance have participated in several meetings with key industry leaders, which CRA identified in the first year of the initiative. The Alliance continues to attend key industry association meetings.

4. Key industry representatives attend project workshops that discuss and promote “world class” examples of energy efficiency opportunities within the microelectronics industry.

   Assessment: Representatives from eight of the 38 PNW microelectronics firms have attended Alliance workshops targeted to the microelectronics industry. Presentations at these workshops have been made by "world class" experts in energy efficiency for the industry.

5. Increasing awareness of energy efficiency opportunities among representatives of major microelectronics manufacturing companies and organizations within the region.

Assessment: Interviews with contacts at firms that have not attended the workshops indicates that they have minimal awareness of energy efficiency opportunities or of work being conducted at other firms in the region. The Alliance has not identified how to reach these other firms.

6. Implementation of energy efficiency opportunities within the microelectronics industry.

   Assessment: Measurement projects are underway at two firms and one project is completed. None of the firms has implemented any measures as of December 1, 2000, however, all three indicate that they expect to implement at least some of the recommendations.

7. Several companies participate in one or more integrated design processes.

   Assessment: One company expressed interest in participating in an integrated design process, however they were not able to commit to the project. No other firms have expressed any interest in participating and the Alliance no longer focuses on this concept approach.

RECOMMENDATIONS

No specific recommendations are provided for the CRA initiative, since that effort ended in December 2000. The recommendations therefore are divided into two categories: the first is specific recommendations regarding next steps for the Microelectronics Initiative Special Project Fund; these are followed by recommendations for next steps in addressing the overall issue of how the Alliance can move forward with the Microelectronics Initiative.

Special Project Fund

We have identified four recommendations to consider for the ongoing activities of the Special Project Fund.

1. **The Special Project Fund activities are still in process. These activities should continue and efforts should be made to conduct workshops once comparison data are available**. In order to ensure that the comparison efforts are effective, the Alliance must create a plan for how to compare and present these results. The Alliance can learn from

the CRA experience that simply having a presentation by an expert will not necessarily be viewed as transferable to PNW firms.

2. **After the workshops are completed, the Alliance should conduct an evaluation of the full model and assess response to the comparison activity of the initiative by microelectronic firms in the PNW and their sister locations**.

3. **The Alliance should explore working more closely with local PNW utilities to reach additional microelectronics firms and get them to attend the workshops**. Account executives have contacts at firms for energy purchases. Executives at utilities may have contacts with executives at local plants. Contacts need to be facilitated at all levels of the organization if energy efficiency investments are to occur. There are firms in the PNW still unaware of the Alliance activities. Working with utility contacts may bring more firms to the workshops.

4. **Once contacts with utilities are expanded, the Alliance may be able to effectively leverage local conservation investment opportunities to implement recommendations that arise from the measurement studies**. This could help address the barriers associated with risk to production that tend to limit willingness to invest in the recommendations. One vehicle for this type of activity would be to create an advisory committee of local utility contacts and consulting engineers who work with the Alliance to consider opportunities to facilitate market transformation activities and leverage local conservation activities for the microelectronics industry.

Future Microelectronics Initiative Activities

As noted in previous chapters, the context in which the CRA initiative operated has changed. The investment process in the industry is shifting; changes are occurring as firms consider the next generation of chips. The 1997 project model may not be applicable today. Yet, the global nature of the microelectronics industry remains a driving force, as do the other characteristics previously noted.

The evaluation found a need for more information as well as some opportunities that can facilitate the overall goal of the Alliance to change the way PNW facilities use energy. The following five recommendations are aimed at furthering these efforts in the current context.

1. **The Alliance should conduct a full market assessment of the microelectronics industry in the PNW**. Such an assessment should include an analysis of the number of firms, size of clean rooms, and consumption patterns for utilities (water, gas, electricity and air). The data should be used to look broadly at the industry to fully segment the industry presence in the PNW with respect to different activities (OEM, fabs, tools, DRAM, server farms, software, etc.) This level of analysis can be accomplished by analyzing information in either the Quantic database currently owned by the Alliance or in data from some other source.

    - In addition, if appropriate confidentiality agreements can be developed, survey efforts with firms or local utilities could be conducted to assess the current level of investment in energy efficiency and plans for expansion or refitting of fabs.

    - The focus to date has been on facilities. As part of the market assessment it is important to identify the relative potential for working with the industry on tools, process and facilities.

2. **A market transformation program model needs to be developed that will build on lessons learned from this evaluation and from the market assessment activities to be conducted**. Our sense is that the model should focus on how to facilitate the expansion of market share for the solution providers. One option could be to directly work with the consulting engineer solution providers and have them market the Special Project Fund opportunity to microelectronics firms, rather than having the Alliance and firms like CRA do this marketing.

3. **As mentioned above, an advisory committee of utility representatives and consulting engineers who work with the microelectronics firms could provide the Alliance with additional expertise during the process of developing a new program model for the Microelectronics Initiative**.

4. **Energy is not a high priority for the microelectronics industry. In order to have a market transforming impact on the tools, processes and facilities it will be necessary for the Alliance to become involved with the microelectronics industry organizations such as International SEMATECH, SIA, and SISA**. Such involvement will enable firms to learn of the expertise available and the importance of energy issues, and will facilitate the development of

technologies and design and construction practices that meet the goals for reduced energy consumption.

- The effort by EPRI in the past foundered on contractual issues and any new effort needs to address this up front and be led by an entity with more flexibility. Such an entity also needs to have experience working with manufacturers and with energy organizations in the midst of regulatory pressures. Our sense is that the Consortium for Energy Efficiency (CEE) is the most likely organization to meet these needs. California utilities and the Alliance could jointly initiate such an effort with CEE, and perhaps attract the interest of some New England (Massachusetts and New York) and Southwestern (Arizona and Texas) utilities as well.

- In addition to working with other energy organizations, it is important for the Alliance to attend national and international meetings such as ISESH, SIA, SISA and others. This will continue the process begun by CRA of developing contacts, demonstrating an interest in the microelectronics industry by energy efficiency professionals, and keeping abreast of ongoing developments in the field.

- Another benefit of working with the industry in industry forums will be the ability to identify solutions that meet the industry's needs. We heard that solutions focused on reliability and cogeneration are of preeminent concern to microelectronics firms today. Some of these solutions can reduce peak demand requirements, level demand, and improve efficiency of the facility. Market transformation opportunities may exist that will enable the microelectronics industry to increase its trust in the energy efficiency community.

5. **Designers we spoke with indicate an increased willingness to work with the Alliance to explore design solutions. With two of the largest design firms for the global microelectronics industry located in the PNW, the Alliance should continue to work to reach these firms.** Options include:

    - On-site workshops with the designers in addition to invitations to participate in the workshops for firms.

- Provide the design firms with the opportunity to market energy efficiency projects to their clients that would meet the objectives of the Special Project Fund.

APPENDICES

APPENDIX A

Interview Guides

Appendix A: Interview Guides

MICROELECTRONICS PROJECT EVALUATION
DISCUSSION GUIDE #1
MAY 9, 2000

Key questions: Awareness of CRA Activities; Reasons for Acceptance or Rejection; Degree of Support for "Copy-Exact" Hypothesis; Likelihood of Further Activities in PNW, decision making process in firm

Framework Notions: Peters et al. on industrial decisions; Tipping Point: Crossing the Chasm

Date ______________________________

Name ____

Company ____

Position/Title ____

Number of years with company ____

For those in the manufacturing sector

1. How critical are energy use and demand charges to respondent's business? (Pct of operating costs, etc.)

2. In what ways, if any, has the firm attempted to reduce energy-related costs in any of the following areas:

    - Manufacturing processes?

    - O&M of the fabs?

    - Design of the fabs?

3. What are the reasons for and against investing in such activities? (Probe for barriers, non-energy benefits and costs, etc.)

4. What is the decision making process for investments to improve the facility?

    - What are your firms current priorities between investments for
      cost saving
      production improvements
      health & safety requirements
      environmental benefits
      regulatory requirements

    - What would you say is the current investment focus

- How is the current business climate affecting your company?

- How does this differ from the situation of 2-3 years ago?

- What are your expectations for the next year or two?

5. Where are these decisions made for the company?

- What different teams/levels of the company are involved in different investment decisions?

- What is your company's preferred investment criterion: payback, ROI, IRR, etc. Does this vary by type of investment?

- Who does technical analysis, financial analysis and final decision-making? Does this vary by type of investment?

- Is there a maximum investment allowance permitted for different levels without additional review?

Probe here the “copy-exact” hypothesis.

- How readily can the engineers, managers, or consultants working at one of your facilities design and implement a process, operational change, or equipment modification that is not used elsewhere in the company? (Probe for specific barriers, where the decisions are made, reviewed, or vetoed, etc.)

  – What are the real and perceived risks of such changes? Would it be fair to characterize the company as risk-averse or willing to take risks? (Probe for which areas of design, mfg, etc. fit in each category, if the respondent says, "It depends.")

  – What does it take to get something through? Probe for champions, endorsers, economic/competitive context, type of change involved, etc.

  – If such a change is accepted, how readily is it copied elsewhere in the company?

  – How does the company react to news about process or equipment innovations in other companies? How readily are those accepted? What does it take? What is the relative importance of personal contacts and discussion, seminars, demonstration projects, journal articles, etc.? What other mechanisms for technology transfer are important contributors? Which of the media or relationships mentioned does the respondent consider most trustworthy? Why?

  – (At some point, it may be necessary to simply say, "I've been told that this industry follows a 'copy-exact' model. Is that true in your experience? Where does it actually apply and where does it not apply:")

- If respondent agrees that his/her company does seem to support the hypothesis, probe for which facilities are the most likely candidates for change—and what distinguishes those facilities from others (newness or age; managers involved; federal, state, or local regulatory atmosphere; etc.

    – If this venue is overseas or in another part of the U.S., how likely is it that the innovation will be picked up in the PNW?

6. Are you aware of any recent initiatives or activities with energy-saving potential that might apply to the industry?

    - If so, what are they?

    - What has he/she heard? (Probe for awareness of CRA, SuperSymmetry, ST Microelectronics, E-Source activities, etc.)

        – If aware, how did the respondent become aware?

        – Does this sound reasonable, useful for his/her company? Why/why not?

        – What follow-up on his/her part? Probe for specifics. Interested? Why/why not? Likely to take next step(s)? Why/why not? Probe for specifics.

7. If respondent is not aware or only slightly aware of such efforts, would he/she be interested in learning more?

8. If respondent/company has been directly involved with Chris or the Alliance, follow here with their assessment of the process thus far.

   - How did they decide to become involved?

   - Who made the decision?

   - What were the crucial benefits and costs considered?

   - Specifics as to the objectives, implementation steps.

   - How well did the enrollment process go? (Ease; speed bumps; serious difficulties; how improve?)

   - What stage are they in?

   - Results to date?

- As expected/better/worse?

- Likelihood of innovation moving from one fab to another?

INTERVIEW GUIDE
MICROELECTRONICS VENTURE
CONTRACTOR INTERVIEWS

Date ______________________________

Name ____

Title ____

Company ____

Phone Number ________________________ E-Mail ____________________________

Overview

1. Can you please describe the project with _________?

2. What benefits does the project offer?

   - Have the expected benefits changed over time for any reason?

3. What is the project's current status?

   - When do you expect it will be completed?

- Has the schedule been extended, or is this the originally planned completion date? (If extended, why?)

- Is there anything that you anticipate might delay the project's completion from this point?

4. How long did it take to develop the contract and get it signed?

- How did this compare with your expectations? {If it exceeded expectations, probe why.}

{Probe for who are the decision makers, what departments/perspectives they represent, they level in the company}

{Probe for market barriers, such as:

- Schedule of getting new products to market (one day sooner outweighs a year's savings from ee);
- Risk of changing something that is not broken (corporate culture); standard design practices
- First costs versus operating cost (1st cost is benchmarked; operating costs are not tracked in useful way, eg by component)
- Lack of feedback from operational plants
- Perception that energy is small, unchangeable cost (no benchmarking of energy costs);
- Lack of knowledge of costs, savings, reliability, performance
- Lack of knowledge of firms who can design/execute an ee plant

- Lack of knowledge of alternative technologies
- Fragmentation of the design process, compartmentalized budgets (electrical and mechanical systems have separate design budgets); architect's design dictating mechanical space
- Liability insurance (increases when standard practices not followed)
- Size limitations for code compliance

History

5. How did you first learn that the Alliance might be interested in funding a project such as this? Where (context) in which heard? When (Year, month/season)?

   - Who told you?

6. Did you work with Chris Robertson on this project at some point or currently? (Probe for roles and activities)

7. What were your company's key concerns in the contracting process to conduct this project?

   - How were those concerns resolved?

8. Is there anything that the Alliance might have done differently that would have made the contracting process easier for your firm?

- Anything they could have done to make any part of the process easier for your firm? (anything that could improve its administrative relationship with you; any technical aspects)

Conclusion

9. Why do you think their company was ready to proceed (or to consider the project) at this time?

- Was there someone at their company who championed the project, who kept advocating for it?

- Do you think it was their own interest in energy efficiency that initially led to them entertaining the project, or was it the Alliance's promotion of energy efficiency?

- How important do you think the Alliance's backing was (or the fact that the Alliance was promoting energy efficiency in the microelectronics industry) in their decision?

10. Do you think energy efficiency a growing issue for the microelectronics industry?

    - If so, why?

    - When would you mark the start of the increased interest?

11. What would have to happen for energy efficiency to be a higher priority in the microelectronics industry, or what needs to be done to make this happen?

12. Are firms concerned with competitive issues that might limit their participation in the Alliance's project?

INTERVIEW GUIDE
MICROELECTRONICS VENTURE
NONPARTICIPANT PROJECT INTERVIEWS

Date ______________________________

Name ____

Title ____

Company ____

Phone Number ________________________ E-Mail ____________________________

I would like to talk with you for about 5 minutes, about energy use by microelectronics firms in the Northwest. The Northwest Energy Efficiency Alliance also known as NEEA or the Alliance, is a nonprofit organization sponsored by the regions public and privately owned electric utilities. The Alliance has conducted two workshops in Portland on energy use in microelectronics firms, one in January 1999 one in May 2000.

1. Are you familiar with either of these workshops?

2. Have you ever talked with your local utility, the Alliance, or Chris Robertson Associates about doing a project to affect the energy efficiency of your air handling system, make-up air, or chillers -- your HVAC system?

    - If yes, who did they talk with, did they do anything, are they planning to?

3. Has your company ever considered doing a project to understand the energy used by your HVAC systems or to improve the energy efficiency of your HVAC system?

   - If yes, can you tell me when or if the project was implemented and generally whether you felt it was successful or not?

4. Are you aware of any projects being conducted at other microelectronics companies in the region (Oregon, Idaho and Washington) focused on energy efficiency of their HVAC system?

   - If yes, What have you heard about these projects?

   - If no, would you be interested in learning more about these projects?

(if they say yes, tell them a workshop is planned for 2001)

Conclusion

5. Do you think your company might be interested in discussing a project with The Alliance in the future? (Probe: what type of project, when might it occur, what would be the key issues for a project to actually happen.)

INTERVIEW GUIDE
MICROELECTRONICS VENTURE
IN-DISCUSSION PROJECT INTERVIEWS

Date ______________________________

Name ____

Title ____

Company ____

Phone Number ________________________ E-Mail ____________________________

Overview

1. Can you please describe the project?

   - What benefits were you expecting from the project as conceived?

2. What is the status of the project?

   - Why has a contract not been signed yet? What are your company's key concerns?

- Who (department, roles) are raising objections?

- Do they doubt the benefits will materialize, or do they see risks to the project, or...

{Probe for who are the decision makers, what departments/perspectives they represent, they level in the company}

{Probe for market barriers, such as:

- Schedule of getting new products to market (one day sooner outweighs a year's savings from ee);
- Risk of changing something that is not broken (corporate culture); standard design practices
- First costs versus operating cost (1^{st} cost is benchmarked; operating costs are not tracked in useful way, eg by component)
- Lack of feedback from operational plants
- Perception that energy is small, unchangeable cost (no benchmarking of energy costs);
- Lack of knowledge of costs, savings, reliability, performance
- Lack of knowledge of firms who can design/execute an ee plant
- Lack of knowledge of alternative technologies
- Fragmentation of the design process, compartmentalized budgets (electrical and mechanical systems have separate design budgets); architect's design dictating mechanical space
- Liability insurance (increases when standard practices not followed)

- Size limitations for code compliance

- Is anyone countering these objections? Is there someone—perhaps you—who is a champion for the project, who keeps advocating for it?

3. When do you expect the contract will be signed?

- When do you expect the project will be initiated?

4. Is there anything that you anticipate might scuttle the project at this time?

- Would the project likely be taken up again at a later date?

- Would a different foray into energy efficiency be undertaken?

5. Are other facilities in your organization aware of this project? What are their reactions? (what role/dept and level of staff)

History

6. How did you first learn that the Alliance might be interested in funding a project such as this? Where (context) in which heard? When (Year, month/season)?

   - Who told you?
   - What did you hear?
   - {If relevant:} What got your company to the workshop?
   - Was it more your company's interest in energy efficiency or the Alliance's promotion of energy efficiency that initially led to entertaining the project?
   - Was it important to you that the Alliance was promoting energy efficiency in the microelectronics industry? Did their backing make a difference in your decision-making?

7. Did you work with Chris Robertson or your local utility on this project at some point or currently? (Probe for roles and activities of each)

8. Is there anything that the Alliance might have done differently that would have made the contracting process easier for your firm?

   - Anything they could have done to make any part of the process easier for your firm? (anything that could improve its administrative relationship with you; any technical aspects)

9. Had you or your company ever considered doing this type of analysis on your own? (Probe for why they did not, or why, if they did consider it, they did not do the analysis on their own)

Conclusion

10. Is energy efficiency a growing issue for your company? If so, why?

    - Why do you think there was some initial interest in your company at this time?

    - What would have to happen for energy efficiency to be a higher priority in your company or what needs to be done to make this happen?

    - How about for the industry?

11. Do you see any competitive issues that might limit companies participating in the Alliance's project?

INTERVIEW GUIDE
MICROELECTRONICS VENTURE
IN-PROCESS PROJECT INTERVIEWS

Date ______________________________

Name ____

Title ____

Company ____

Phone Number ________________________ E-Mail ____________________________

Overview

1. Can you please describe the project?

- What is its current status?

- When do you expect it will be completed?

- Has the schedule been extended, or is this the originally planned completion date?

- Is there anything that you anticipate might delay the project's completion from this point?

2. How long did it take to develop the contract and get it signed?

- How did this compare with your expectations? {If it exceeded expectations, probe why.}

3. What benefits were you expecting from the project as conceived?

- Do you have any doubts about this now, or are you still as confident as you were at the outset?

4. What did you plan to do with the information from the project? Who has expressed interest in it, or who do plan to show it to (departments, level)?

5. How will you decide what to implement and what not to implement?

{Probe for financial and other criteria}

{Probe for who are the decision makers, what departments/perspectives they represent, they level in the company}

{Probe for market barriers, such as:

- schedule of getting new products to market (one day sooner outweighs a year's savings from ee);
- Risk of changing something that is not broken (corporate culture); standard design practices
- First costs versus operating cost (1^{st} cost is benchmarked; operating costs are not tracked in useful way, eg by component)
- Lack of feedback from operational plants
- Perception that energy is small, unchangeable cost (no benchmarking of energy costs);
- Lack of knowledge of costs, savings, reliability, performance
- Lack of knowledge of firms who can design/execute an ee plant
- Lack of knowledge of alternative technologies
- Fragmentation of the design process, compartmentalized budgets (electrical and mechanical systems have separate design budgets); architect's design dictating mechanical space
- Liability insurance (increases when standard practices not followed)
- Size limitations for code compliance

6. Are other facilities in your organization aware of this project? What are their reactions? (what role/dept and level of staff)

- Is there interest in replicating the study at other facilities?

- How will these facilities decide whether to conduct a similar project?

- Will there be any interest in incorporating some of the findings into future plants?

History

7. How did you first learn that the Alliance might be interested in funding a project such as this? Where (context) in which heard? When (Year, month/season)?

    - Who told you?

    - What did you hear?

    - {If relevant:} What got your company to the workshop?

    - Was it more your company's interest in energy efficiency or the Alliance's promotion of energy efficiency that initially led to entertaining the project?

- Was it important to you that the Alliance was promoting energy efficiency in the microelectronics industry? Did their backing make a difference in your decision-making?

8. Did you work with Chris Robertson or your local utility on this project at some point or currently? (Probe for roles and activities of each)

9. What were your company's key concerns in the contracting process to conduct this project?

   - (Probe:) Who had these concerns: department/role?

   - How were those concerns resolved?

   - Why was your company ready to proceed at this time?

   - Was there someone—perhaps you—who championed the project, who kept advocating for it?

10. Is there anything that the Alliance might have done differently that would have made the contracting process easier for your firm?

- Anything they could have done to make any part of the process easier for your firm? (anything that could improve its administrative relationship with you; any technical aspects)

11. Had you or your company ever considered doing this type of analysis on your own? (Probe for why they did not, or why, if they did consider it, they did not do the analysis on their own)

Conclusion

12. Is energy efficiency a growing issue? If so, why?

- What would have to happen for energy efficiency to be a higher priority in your company or what needs to be done to make this happen?

- How about for the industry?

13. Do you see any competitive issues that might limit companies participating in the Alliance's project?

14. Would you recommend others in your company or in your industry conduct similar projects? Why or why not? What would you say are its strong points and weak points.

INTERVIEW GUIDE
MICROELECTRONICS VENTURE
COMPLETED PROJECT INTERVIEWS

Date ______________________________

Name Brian Hansen

Title ______________________________

Company Zilog

Phone Number 208-465-6939 E-Mail ______________________________

Overview

1. Can you please describe what Supersymetry did for your company?

I want to first discuss the outcome of the project and then go into the decisions and events that led to it.

Project Experience

2. What was your expectation for how long the project would take?

   - Did it take more or less time than expected? Why?

3. What benefits did you gain from the project?

   - How do these benefits compare with your expectations? (aspects that exceeded, that fell short)

4. What did you do with the information from the project?

   - Who has seen it (departments, level)? What has been their reactions?

5. At this point, are there recommendations that you are implementing or plan to? (What?)

   - Any recommendations that you have decided you will not implement?

   - Any recommendations that you are still debating?

6. How have you decided what to implement and what not to implement?

   {Probe for financial and other criteria}

{Probe for market barriers, such as:

- Schedule of getting new products to market (one day sooner outweighs a year's savings from ee);
- Risk of changing something that is not broken (corporate culture); standard design practices
- First costs versus operating cost (1st cost is benchmarked; operating costs are not tracked in useful way, eg by component)
- Lack of feedback from operational plants
- Perception that energy is small, unchangeable cost (no benchmarking of energy costs);
- Lack of knowledge of costs, savings, reliability, performance
- Lack of knowledge of firms who can design/execute an ee plant
- Lack of knowledge of alternative technologies
- Fragmentation of the design process, compartmentalized budgets (electrical and mechanical systems have separate design budgets); architect's design dictating mechanical space
- Liability insurance (increases when standard practices not followed)
- Size limitations for code compliance

{Probe for who are the decision makers, what departments/perspectives they represent, they level in the company}

7. Are other facilities in your organization aware of this project?

- Have they seen the findings? What are their reactions? (what role/dept and level of staff)

- Is there interest in replicating the study at other facilities?

- How will these facilities decide whether to conduct a similar project?

- Is there any interest in incorporating some of the findings into future plants?

8. Now that you've done the walk-through with Supersymetry, do you think that the project they initially proposed would be beneficial?

History

9. How did you first learn that the Alliance might be interested in funding a project such as this? Where (context) in which heard? When (Year, month/season)?

- Who told you?

- What did you hear?

- What got Zilog to the 1998 workshop?

- Was it more Zilog's interest in the energy efficiency or the Alliance's promotion of energy efficiency that initially led to entertaining the project?

- Was it important to you that the Alliance was promoting energy efficiency in the microelectronics industry? Did their backing make a difference in your decision-making?

10. Did you work with Chris Robertson or your local utility on this project at some point or currently? (Probe for roles and activities of each)

11. What were your company's key concerns in the contracting process to conduct this project?

- (Probe:) Who had these concerns: department/role?

- How were those concerns resolved?

- Why was Zilog ready to proceed at this time?

- Was there someone—perhaps you—who championed the project, who kept advocating for it?

12. Is there anything that the Alliance might have done differently that would have made the contracting process easier for your firm?

    - Anything they could have done to make any part of the process easier for your firm? (anything that could improve its administrative relationship with you; any technical aspects)

13. Had you or your company ever considered doing this type of analysis on your own? (Probe for why they did not, or why if they did consider it, why they did not do the analysis on their own)

Conclusion

14. Is energy efficiency a growing issue? If so, why?

    - What would have to happen for energy efficiency to be a higher priority in your company or what needs to be done to make this happen?

    - How about for the industry?

15. Do you see any competitive issues that might limit companies participating in the Alliance's project?

16. Would you recommend others in your company or in your industry conduct similar projects? Why or why not? What would you say are its strong points and weak points.

APPENDIX B

The Microelectronics Industry

… By Easton Consulting

THE MICROELECTRONICS INDUSTRY

TABLE OF CONTENTS

EXECUTIVE SUMMARY

The microelectronics industry has become one of the most important business segments in the global economy in a very short period of time. It has also become a prominent user of energy as its fabrication plants are heavy users of electricity and other natural resources. To understand the implications of energy use in the manufacture of semiconductor chips, it is important to understand the unique characteristics of the microelectronics industry.

While the origins of the industry date to fifty years ago, the last three decades have seen the rapid emergence of a quick moving industry. Semiconductors came to replace vacuum tubes as the electronic component of choice by the 1950s. The design, manufacture and marketing of chips in the U.S. has gained particular prominence on the West Coast, in California's Silicon Valley and Oregon's Silicon Forest.

Worldwide, the industry sold $135 billion in chips in 1998 with most production taking place in Japan and the U.S. The largest firm -- Intel -- had sales of over $22 billion during 1998. While the major manufacturers are distributed globally, U.S. chipmakers have migrated to the Pacific Northwest, where economic conditions -- such as cheap energy and abundant natural resources -- supported the development of the industry.

The manufacturing process is very complex and involves several different steps, including the design of the chip, the preparation of the wafer, the imprinting and integration of transistors on the chip, and final testing. This process is incredibly capital intensive, with considerable investment in fabrication plants and semiconductor equipment. Fabs cost from $1 to $2 billion and their construction follows the technological advancements of the industry. An emerging trend is the "fabless" chipmaker that designs and markets chips, but outsources the manufacturing function to a third party.

The economics of the industry follow "Moore's Law," which is a maxim that chips will double in speed every eighteen months. The rapid pace of innovation and the expensive manufacturing process makes success in the industry difficult. Also, the business is very sensitive to chip supply and manufacturer demand economics. At times, demand projections become too ambitious and create oversupply conditions that lead to weak prices and difficult conditions for chipmakers. In addition, the industry is highly subject to global economic cycles and may reduce or delay spending to avoid oversupply.. This capital intensive process leads to a "boom/bust" cycle. Since the products have low marginal costs, manufactures are able to cut prices significantly, which can make recovering fixed investments in research & development and plants & equipment difficult. Yet despite constantly falling prices and short product life cycles, most manufacturers are able to post double-digit revenue and profit growth over several business cycles.

ORIGINS OF THE INDUSTRY

The birth of the semiconductor and the microelectronics industry took place at Bell Telephone Laboratories in 1947 with the invention of the transistor. Bell scientists John Bardeen, Walter Brattain and William Shockley found a means for addressing the limitations that vacuum tubes presented. In the first half of the 20^{th} century, vacuum tubes were the critical electronic components used in electrical products. The essential function of the tubes was to perform the dual tasks of switching and amplification. However, the tubes posed several problems based on their design -- they were large and unwieldy, fragile and unreliable, and hot and energy hungry.

THE FIRST STAGE

Following the invention of the transistor at Bell Labs, the next milestone occurred at Texas Instruments (TI), which in 1954 manufactured the first transistor based on silicon components. The word "semiconductor" became a commonly used term to refer to devices that control electronic signals by conducting electrical currents or blocking their passage. As TI introduced its transistor, other companies also began to develop integrated circuits, including Shockley Semiconductor, which was formed in 1955. Another significant company that emerged during this time was Fairchild Semiconductor, which was formed by Gordon Moore, Robert Noyce and six other Shockley employees. The "Traitorous Eight" set up shop in 1957 near their ex-employer in an area of California that would eventually become known simply as "Silicon Valley." By 1959, both TI and Fairchild had announced their first versions of integrated circuits.

The next watershed event in the industry took place in 1968, as Moore and Noyce left Fairchild and formed Intel. One of their key hires at the new company was Andrew Grove, who acted as Director of Operations. Moore's venture at Intel progressed rapidly and, it can be said, led to the emergence of today's microelectronics industry in the early 1970s. At that point, the first generation of "storage IC DRAM" was developed. At the time, the DRAM (also known as RAM) capacity was 1K. This capacity has quickly grown (doubling every 18 months according to "Moore's Law") through successive generations of chips. Following the development of DRAM semiconductors, the industry followed with the emergence of the microprocessor and "Erasable Programmable Read-Only Memory (EPROM).

PACIFIC NORTHWEST

While the microelectronics industry found its beginning in Silicon Valley, much of the activity takes place today in the "Silicon Forest." This area covers a small piece of the Pacific Northwest, with much of the focus on the state of Oregon. In particular, the Silicon Forest refers to Portland's western suburbs and the large number of giant semiconductor fabrication plans that exist along Interstate 5.

The beginnings of the Silicon Forest can be traced back to Tektronix Inc., which is an instrument maker that was founded in 1946. As Silicon Valley firms developed new products, they turned to the state of Oregon in the north and created new plants in order to take advantage of favorable economic conditions, including cheap energy, abundant natural resources (such as water) and low labor costs. The nearby Pacific Rim location helped to create the initial demand in the region, but the real growth took place after 1976. In that year, Hewlett-Packard (HP) moved its calculator division from California to Oregon and Intel built its first fab plant in the area. To this day, HP's presence in the state is significant.

But Intel's presence has had even greater significance. It is the largest employer in the Portland metro area and provides a large boost to the local economy. The historic growth of the firm bodes well for the community. Presently, Intel is planning to invest $3 billion on two new fab sites in order to provide manufacturing facilities for the next generation of P7 microprocessors. As the largest and most respected chipmaker in the world, Intel has attracted other chipmakers (including Asian-based firms, such as Fujitsu and Hyundai) to the Silicon Forest. Growth of the chip business has grown substantially in the 1990s through a new spurt in fab construction.

Part of this spurt can be traced to government intervention. The state of Oregon increased its ties to the microelectronics industry by creating the Oregon Strategic Investment Program (OSIP) in 1993. The government recognized the competition between states for the presence of large corporate technology facilities. Many competing states were offering economic incentives to entice development of fabs in their locales. In order to help Oregon's economy, the government responded by offering to cap the taxable value of a new capital construction project at $100 million. For chipmakers and their massively expensive plants, this is a considerable break that alleviates property tax expenses.

In recent years, growth in the Silicon Forest has been challenged by a wave of public concern over the potential environmental hazards presented by semiconductor plants. Chemical spills -- such as the one that occurred at Fujitsu's Gresham, Oregon plant in July 1995 -- have raised the concern that leaks threaten the well being of local communities. These issues may limit the number of new plants that are created in the Silicon Forest in coming years.

THE SEMICONDUCTOR MARKET

SIZE & GROWTH

According to Cahners In-Stat Group, worldwide semiconductor sales were $126 billion in 1998. The Semiconductor Industry Association reports slightly higher numbers, with 1998 sales of pegged at $135 billion. Figure 1 provides historical and predicted semiconductor sales numbers. The SIA reports that since 1990, sales have grown at an compounded annual growth rate of 13%. DRAM sales have moved faster than the rest of the market and have improved at an average annual rate of 19% during the last eight years.

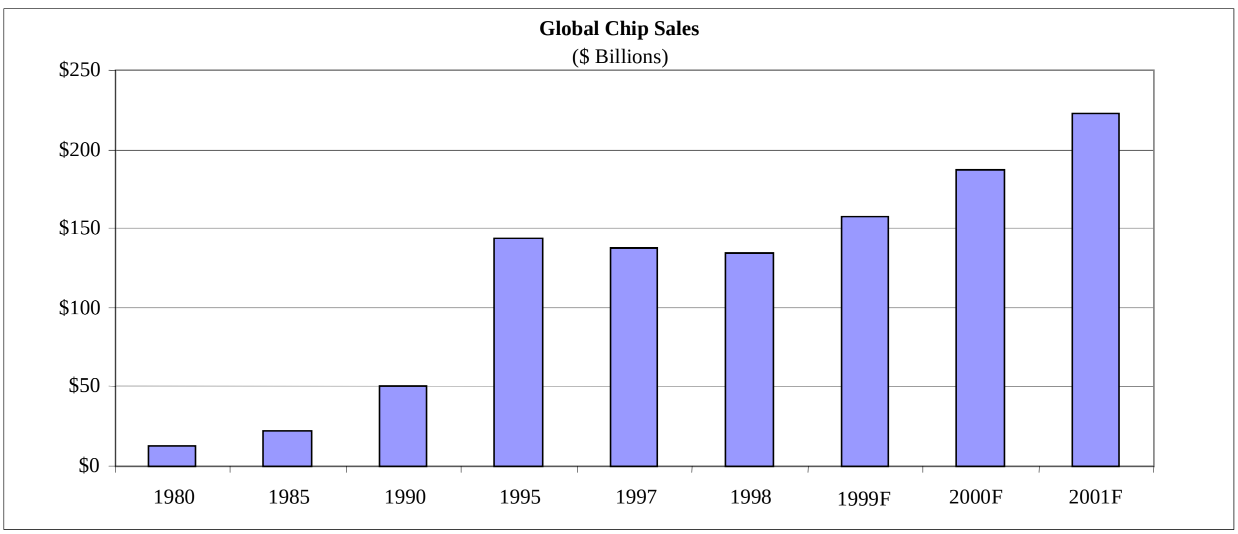

Figure 1

Source: SIA, World Semiconductor Trade Statistics; Forecasts by International Data Corp.

END MARKETS

Manufactured semiconductors are sold primarily to original equipment manufacturers (OEMs) by internal sales forces and independent distributors. North America is the leading region in terms of chip consumption, as shown in Figure 2. Japan's share of global chip consumption has dropped considerably over the last eight years as original equipment manufacturers in other parts of the Asia/Pacific region have seen an increased presence on the world stage.

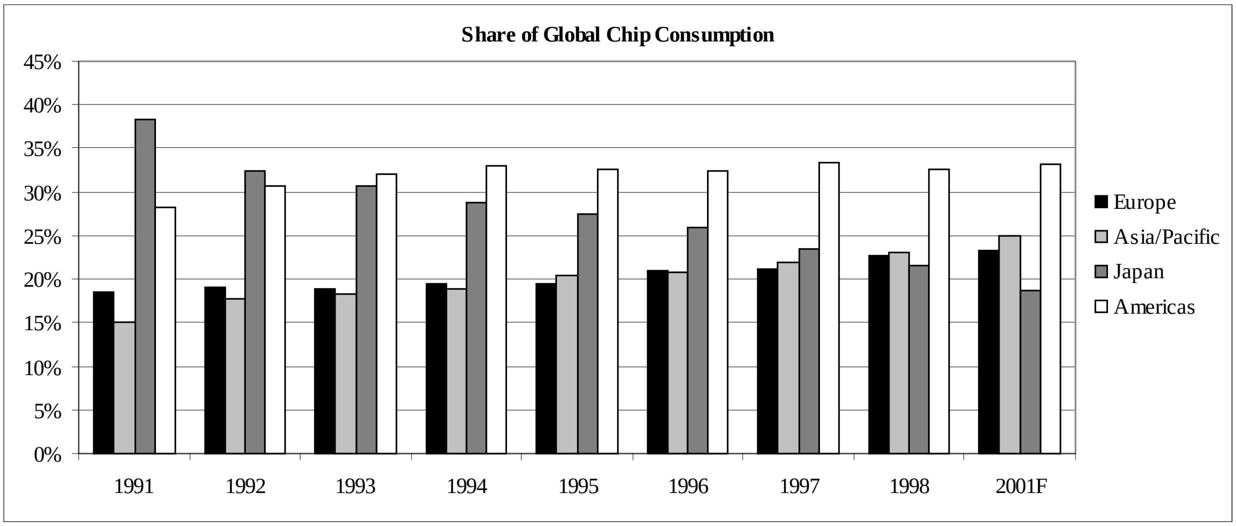

Figure 2

Source: SIA, World Semiconductor Trade Statistics; Forecasts by International Data Corp.

MARKET PARTICIPANTS

The U.S. microelectronics industry is composed primarily of firms that design, manufacture and market semiconductors to original equipment manufacturers (and occasionally directly to personal computer users). There are many smaller firms that design or market semiconductors, but outsource the manufacturing function to other entities. Figure 3 lists the top twenty firms based on worldwide semiconductor sales.

The leading U.S. based firms include Intel, Motorola, Texas Instruments, Lucent Technologies, IBM, AMD and National Semiconductor. According to the Semiconductor Industry Association, the U.S. and Japan are the dominant locales in the industry with 33% and

23% market share, respectively. Europe controls 21% of the semiconductor market and the rest of the world (including other Asia/Pacific countries) has a 23% share.

Worldwide Semiconductor Sales					
Rank			1998	1997	%
1998	1997	Company	($ millions)	($ millions)	change
1	1	Intel	$22,092	$21,120.0	4.6%
2	2	NEC	$7,527	$9,249.0	-18.6%
3	3	Motorola	$7,300	$8,034.0	-9.1%
4	6	Toshiba	$6,125	$7,392.0	-17.1%
5	5	Texas Instruments	$6,000	$7,560.0	-20.6%
6	4	Hitachi	$5,455	$7,586.0	-28.1%
7	7	Samsung	$4,567	$5,933.0	-23.0%
8	8	Philips	$4,502	$4,451.0	1.1%
9	10	ST Microelectronics	$4,248	$3,970.0	7.0%
10	12	Siemens	$3,867	$3,475.0	11.3%
11	9	Mitsubishi	$3,720	$4,100.0	-9.3%
12	15	Lucent Technologies	$3,202	$2,760.0	16.0%
13	13	IBM	$3,197	$3,310.0	-3.4%
14	11	Fujitsum	$3,125	$3,867.0	-19.2%
15	14	Matsushita	$2,684	$2,876.0	-6.7%
16	17	Advanced Micro Devices	$2,556	$2,356.0	8.5%
17	16	National Semiconductor	$2,140	$2,521.0	-15.1%
18	19	Hyundai	$1,801	$2,015.0	-10.6%
19	18	Sharp	$1,745	$2,099.0	-16.9%
20	20	Sony	$1,720	$1,854.0	-7.2%
Top 20 Total			$97,573	$106,528.0	-8.4%
Total Market			$125,612	$137,203.0	-8.4%

Figure 3

Source: Cahners In-Stat Group

INTEL

Because of its large size and strong reputation, Intel is considered the bellwether of the industry. Under the guidance of Andy Grove, Intel has become the dominant force in the microprocessor market and commands an 85% share. Through its "Wintel" alliance with software developer Microsoft, Intel chips have become the standard in personal computers despite continual challenges by low-cost producers.

Intel is an aggressive competitor and has won every recent battle in the marketplace. Several firms have sought to eat into Intel's dominance. Motorola appeared to present a challenge with its PowerPC chip available for use in Apple Computers. But significant business and consumer acceptance never materialized. Intel managed a battle against Digital Equipment Corporation, which sued Intel for patent infringement; Intel countersued and used its market position to place Digital in a no-win situation. Intel eventually settled the dispute by buying Digital's chip production operations. Intel is also continually challenged by late generation microprocessor clones by companies such as Advanced Micro Devices (AMD) and National Semiconductor. While the impact on Intel's market share has been small, competition results in pricing pressure and limits the revenue potential of older Intel products. Intel can still sell the newest and fastest processors at high prices, but its profits in the low-priced PC market are small.

OTHER PLAYERS

While Intel dominates the microprocessor market, the competitive playing field is more dynamic in other semiconductor markets. One of the market segments that holds the greatest growth potential is digital signal processors (DSPs). These chips convert analog signals (such as light or sound) into digital signals and are primarily used in cellular phones and PC modems. These "mixed signal" chips have high margins and have led many manufacturers to covet this space. Texas Instruments is the current front runner, but Lucent, Motorola and Analog Devices are gaining ground.

In the memory segment, Japanese, Taiwanese and South Korean manufacturers dominate the DRAM market with a combined 80% share. Samsung is the leader with Toshiba and Hitachi close behind. The leading U.S. chip manufacturers are Micron Technology, IBM and Motorola. (Intel does not participate in this segment.)

THE PRODUCT

The term "semiconductor" covers a wide range of electronic products. By definition, semiconductors have electrical properties that blend attributes of conductors and insulators. The main function of these electronic components is to conduct, transfer and amplify electricity between electronic circuits. Two categories of semiconductors are discrete semiconductors and integrated circuits (ICs). The discrete semiconductor has a single-function and a single electronic component, such as a diode or transistor. Discrete devices have 13% of the market. ICs have multiple-functions and include thousands of tiny transistors to create sophisticated electronic circuits on a rigid surface (such as silicon) known as a chip. These circuits and interconnected switches control electronic currents in specified patterns.

END MARKETS

Semiconductors are used in virtually all electronic goods. Most manufactured chips are used in computers and data processing equipment. Consumer electronics -- including televisions, audio and video equipment -- is the second largest market. Semiconductors are also used in communications equipment (such as cellular phones), automobiles, aircraft, home appliances, industrial controls, satellites, missiles and calculators. Figure 4 summarizes the end market shares of market of semiconductors in 1998.

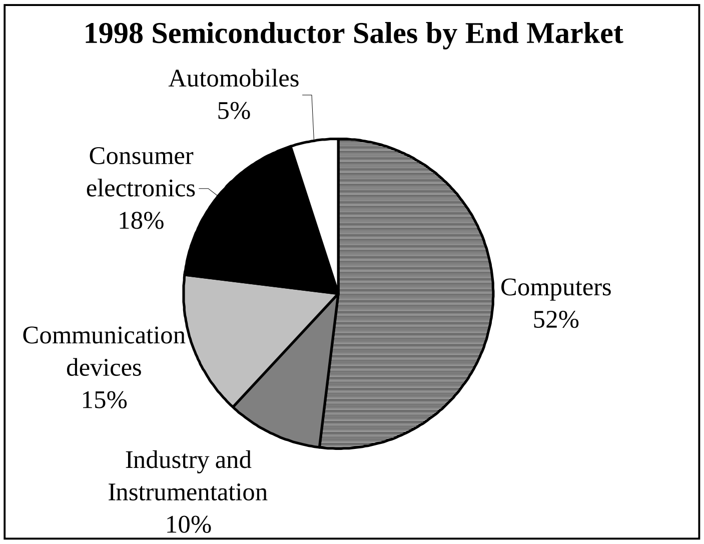

Figure 4

Source: Semiconductor Industry Association

TYPES OF SEMICONDUCTORS

Semiconductors perform a wide range of functions, but can be described in two general classes. Figure 5 shows end market shares and sales by semiconductor types.

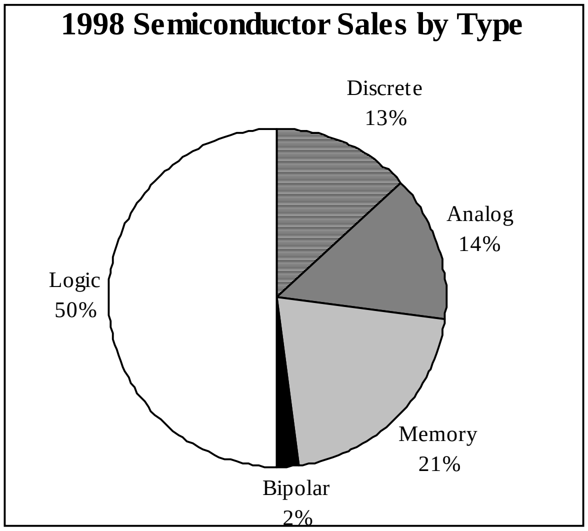

Figure 5

Source: Forward Concepts

Analog semiconductors (or linear circuits) process continuous information such as speed, pressure, temperature, light, sound, and voltage, that is collected from a physical source.. Analog devices generally measure or amplify analog signals, convert analog signals to digital data, or vice versa. Some types of analog chips include amplifiers, voltage regulators, interface circuits, and data converters and are used in automobiles, communication devices, industrial and medical instruments and video products.

The more commonly used chips are *digital semiconductors*. These chips store and process information in binary form or “bits” (i.e., “1”s or “0”s). They perform arithmetic operations or logical functions by manipulating binary signals (on/off switches). Computers, for example, operate in this digital mode. There are three main types of digital chips.

Microprocessors

Microprocessors are the “brains” in computers and represent 42% of the integrated circuit market in terms of dollars. They are commonly known as central processing units (CPUs) because they control the data processing function. The best known example of a microprocessor is Intel's Pentium chip, which is the most commonly used semiconductor in personal computers. Microprocessors can also be found in electrical devices other than computers, such as consumer electronics and telecommunications products.

Memory

Memory chips are designed to store data and programming code or instructions. They command a 37% share of the integrated circuit market. A number of different products fall under the digital memory category. *Volatile* memory products can be used in temporary applications, such as cutting and copying text in a word processing document. However, they need to be refreshed or saved or they will lose information once power is turned off. The most common type of volatile memory is called dynamic random access memory (DRAM). DRAMs allow for very high-speed data storage and retrieval. Currently, the most common memory capacity of a DRAM component is 64 Mb.

Another common volatile memory product is static random access memory (SRAM). This is a type of read/write memory in which electrical refreshment is not required, but the chip still retains many volatile properties.

Non-volatile memory products retain information even after power is turned off. They are used in long-term memory applications and are erasable and programmable. *ROM* (Read Only Memory) devices permanently store repeatedly used information, such as tables of data and characters for electronic displays. *EPROM* (Erasable Programmable ROM) devices allow stored information to be erased through exposure to ultraviolet light permitting new information to be re-programmed into the device. *EEPROM* (Electrically Erasable Programmable ROM) products provide the convenience of selective erasure of information through electronic impulses rather than exposure to ultraviolet light. *Flash memory* is an IC whose entire contents can be bulk erased simultaneously. It shares the advantage of other nonvolatile memory in that it retains information when power is off. Its ability to repeatedly and rapidly erase and re-program information makes it competitive with DRAMs or disk drives for storing data. Although flash devices are more expensive, the market is growing rapidly.

Logic Devices

About 21% of ICs are logic chips, which perform mathematical calculations. These semiconductors handle the mathematical treatment of formal logic by translating “AND,” “OR” and “NOT” functions into a switching circuit, or gate. The basic logic functions obtained from gate-circuits form the foundation of computing machines. Logic devices are designed to be customized and programmed according to the needs of the OEM. This category includes gate arrays, standard cells and programmable logic devices (“PLDs”). Also included are application specific integrated circuits (ASICs), which are semi-custom devices that allow a customer to connect standard elements in a prescribed fashion.

MANUFACTURING PROCESS

The creation of a semiconductor is a multi-step process. In general, the capital-intensive process by which sand is reduced to silicon wafers that ultimately become a microchip consists of five basic phases.

Design

The design stage is the beginning of the development process. Depending on the level of complexity of a chip, the "circuit" design phase can take several months and up to a year. Most chipmakers rely on a computer-aided design (CAD) system to program the chips with the appropriate transistors, resistors, capacitors, etc. The CAD system provides quality control by detecting potential problems in temperature, voltage or timing. The system also evaluates how the chip will potentially operate and can simulate performance. Key firms that develop CAD systems include Cadence Design Systems and Synopsys, headquarters for both of which are located in Silicon Valley. (A branch office of Synopsys is located in Portland.)

The next aspect of the design phase is the creation of a composite drawing that is over 400 times larger than the actual chip size. The design has several layers that are color-coded to represent a pattern of circuitry for future manufacture. Eventually, the individual circuit lines will be reproduced at a molecular size that is more than 100 times thinner than a strand of human hair.

Wafer Preparation

After the design stage, chipmakers concentrate on the wafer fabrication phase. The key component is a thin, circular silicon wafer, which are generally six or eight inches wide. A first and continual step for wafers is cleaning and inspection. Manufacturers must ensure that microscopic particles do not contaminate a wafer undergoing fabrication. Thus, semiconductors are always manufactured in a clean room that contains highly specialized air filters.

Imprinting Circuits

After the silicon wafer is cut and cleaned, the manufacturer moves to the next crucial stage -- imprinting circuits. Here, the chipmaker builds consecutive layers of complex circuitry on top of the wafer through processes known as chemical vapor deposition (CVD) and physical vapor deposition (PVD). Several other chemical and physical processes are needed to bring the chip closer to completion. For example, masking and diffusion are key steps. Masking involves the transfer of intricate patterns by exposing unmasked portions of the wafer to light. Then, during diffusion, electrically charged particles are implanted into the silicon to alter its electrical characteristics. This forms negative and positive conducting areas, creating a pathway through which electricity can flow. Chipmakers may imprint circuits at levels of up to twenty times or more according to the patterns established during the design phase.

Integrating Circuits

After the layers of circuitry are imprinted on a chip, the manufacturer needs to make the appropriate circuits electrically active. The manufacturer can put the chip through a diffusion process whereby dopant[69] atoms are introduced to the wafer's surface through a complex heating process. Alternately, the manufacturer can engage in ion implantation where dopants are literally shot into the wafer surface.

Assembly and Testing

In the final stage, a layer of glass-like material is applied to protect the semiconductor from contamination and damage. Each circuit on the wafer is tested for functionality (electrical, environmental, and structural integrity) by electronic probes, which can run more than 10,000

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69 A dopant is a material used to change the conductance of the semiconductor material.

checks in less than a second. The wafer is then sliced into individual chips (called “die”) which undergo further microscopic inspections before shipping. Chips are sold to original equipment manufacturers that eventually sell finished electronic goods to the business and consumer market.

It is important to note that quality control is very important in semiconductor production. Most chipmakers use "in-line monitoring" as a way to test for defects at the time of production. Throughout the manufacturing process, statistical process control (SPC) methods are utilized to ensure that each step of the process stays within operating parameters. In this way, quality is "built in" through real-time control, analysis and adjustment of the process variables.

PROCESS IMPROVEMENTS

Because the semiconductor manufacturing business is very capital intensive, all players need to take steps to improve productivity. For manufacturers, the focus is on the production process and improvements that can extend the life of fixed costs assets -- namely fabs.

The primary concern of manufacturers is to put more and quicker transistors onto smaller chips at lower costs. The issue here is lowering the costs through improvements in process technology. One of the big steps the industry is looking towards is the expansion of the silicon wafer's diameter from a 200-millimter standard to a 300-millimeter standard. This represents a change from an 8-inch wafer to a 12-inch wafer. While the industry will need to sink some expense into the replacement of manufacturing equipment, the change will increase production efficiencies significantly. The larger wafer will provide 220% more usable silicon. This new size will allow the industry to reduce prices at the same 25% to 30% rate that prices have declined at over the last 30 years.

While wafer sizes are increasing, the size of the elements on an individual chip are decreasing. A key aspect of product innovation has been to reduce the circuit "linewidths" to allow a greater number of circuits to be placed on a chip. Currently, the linewidth measurement is shrinking from 0.35 microns to 0.25 microns. The electrical components will take less space and will require less energy to function.

The dual innovations of larger wafer sizes and smaller linewidths should ensure the continued production of ever cheaper chips for the foreseeable future. Former Intel CEO and chairman Andy Grove has predicted that by 2011, Intel will be able to ship a microprocessor that contains one billion transistors and operates at 10 GHz. The chip will have linewidths of 0.07 microns and will be able to calculate over 100 billion operations per second.

FABS

"Fab" refers to a semiconductor fabrication facility. Currently in the U.S., there are approximately 200 chip plants. The number of new plants built globally each year is shown in Figure 6. Chipmakers must make continual investments in new plants and equipment in order to keep pace with rapid improvements in chip design and manufacturing technology, such as that discussed earlier. As new technologies are introduced, semiconductor equipment needs to be replaced with a new generation of equipment. And when technology leaps are particularly significant, new fabs are required. Fabs are expensive. In 1984, a typical chip plant cost $10 million to build, but fifteen years later, a top production facility can cost at least $1 billion. The most advanced and biggest plants can cost nearly $2 billion.

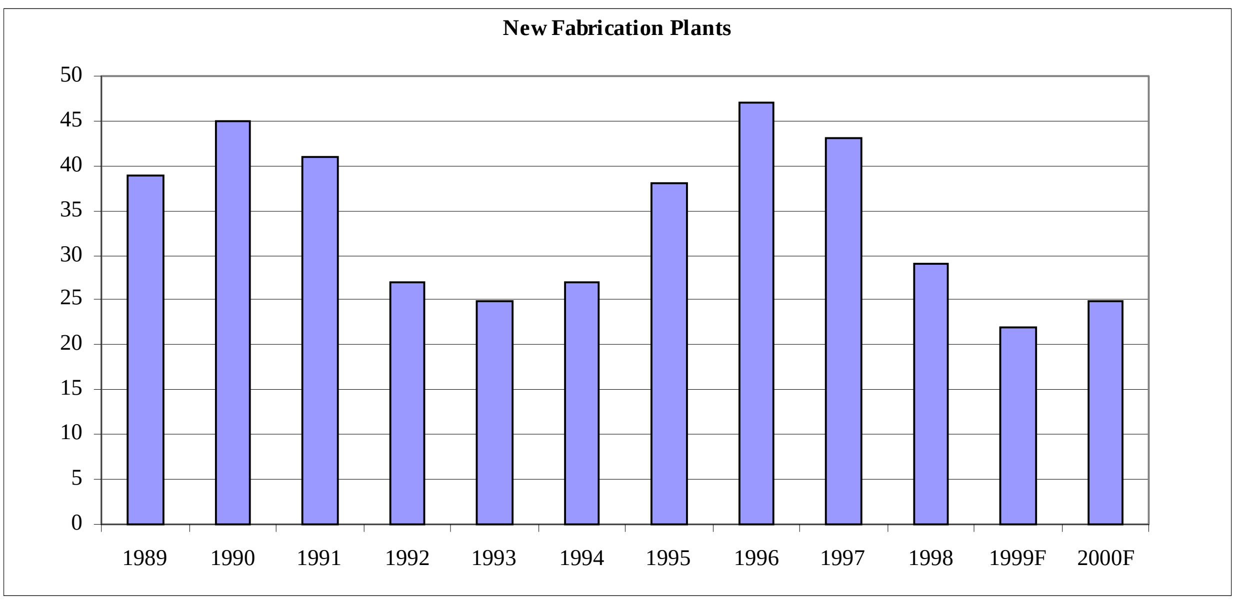

Figure 6

Source: Dataquest

According to "Moore's Second Law," the cost of a manufacturing facility doubles every generation of chips. SEMATECH -- an industry trade group for semiconductor equipment manufacturers -- predicts that the cost of a new fab could reach $10 billion by 2015. This would make a semiconductor plant the most expensive facility type in the world. Despite their high costs, most fabs have short lives and become obsolete after a few years. While chip makers are often able to retool their production lines to improve the manufacturing process, building a new fab becomes economically feasible when significant technological advances occur and massive tooling changes are necessary. The introduction of a 300-millimeter wafer size is an example of such a change.

Even with the brutal economics of fab costs and longevity, manufacturers must continue to make investments. The pace of technological evolution is so fast that demand for "old" chip technology drops soon after the introduction of a new generation of chips. Semiconductor manufacturers need to be on the cutting edge. There is also an incentive to build new fabs in order to create higher profit margins through process improvements. And lastly, the semiconductor manufacturers that are the first to bring a fab into production mode will be able to capture both market share and profits.

According to *Electronic Business*, most chip manufacturers wait until Intel has committed to build the next generation of fabs. For example, the industry has been looking to switch to 300-millimeter fab technology. But small players in the industry would not commit capital resources until Intel announced that it would support the new standard. The impending switch to larger wafers will be the cost over $20 billion according to SEMATECH and will be the most expensive upgrade in the chip industry's history.

Overall, according to the Semiconductor Industry Association, U.S. companies spend on average of 14% of sales revenues on capital equipment and facilities and an additional 12% on research & development. The level of capital expenditures has essentially remained flat over the last four years, but the market appears to be on the cusp of a three-year growth period according to the Semiconductor Industry Association. This growth is driven by a correction in inventory levels. Figure 7 on the next page details capital spending by global semiconductor manufacturers and illustrates the impact of the Asian financial crisis on the industry.

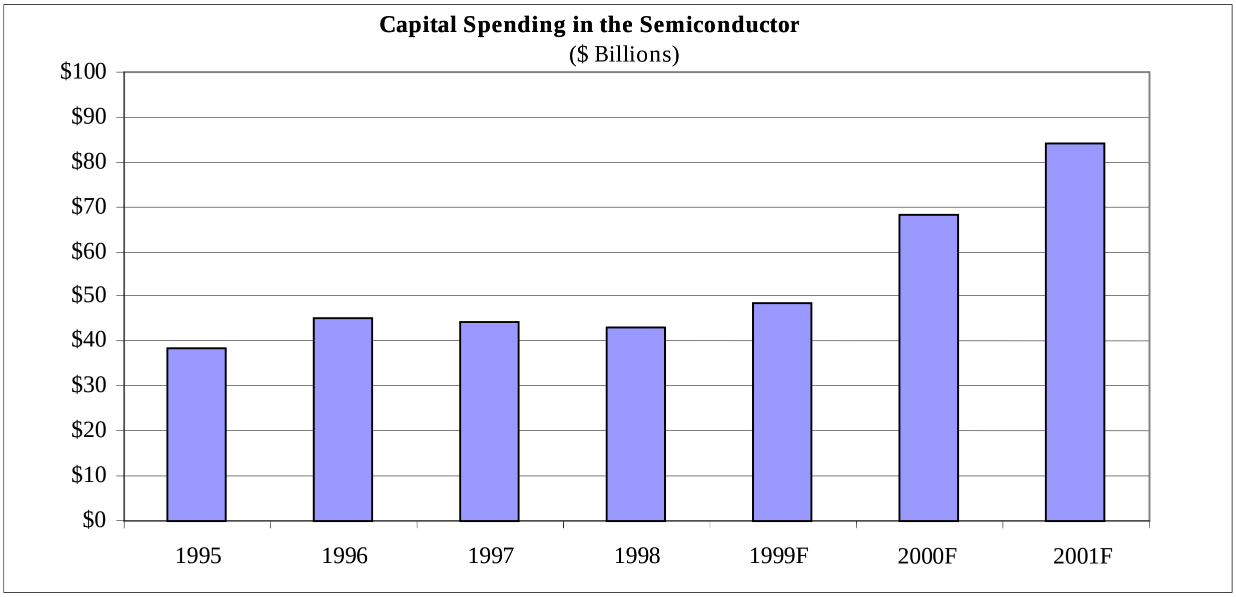

Figure 7

Source: Semiconductor Equipment and Materials International

THE SEMICONDUCTOR EQUIPMENT MARKET

The equipment industry, which supplies the instruments and tools that are used to design and manufacture semiconductors, is of great importance to the chipmakers. About 70% of the cost of developing a new fab is spent on semiconductor manufacturing equipment. This industry is dominated by several big players, as the combined sales of the top 10 firms comprise 60% of the market. The biggest U.S. players are Applied Materials, Lam Research and KLA-Tencor. The largest Japanese firms are Tokyo Electron, Nikon and Advantest. In 1998, global sales of semiconductor equipment were approximately $26 billion.

As a supplier to chipmakers, equipment makers experience the good and bad of economic cycles to an even greater extent than the chipmakers themselves. Demand often fluctuates and causes high variability in earnings. The trade association Semiconductor Equipment and

Materials International provides a closely followed indicator called the "book-to-bill ratio" which provides insight on the semiconductor industry's short-term economic direction. The ratio is simply global orders divided by global sales for North American semiconductor equipment manufacturers during a trailing three-month period. If the ratio is greater than 1.0, near-term sales in the industry are likely to be higher.

Figure 8 shows how cyclical the semiconductor business has been in the late 1990s.

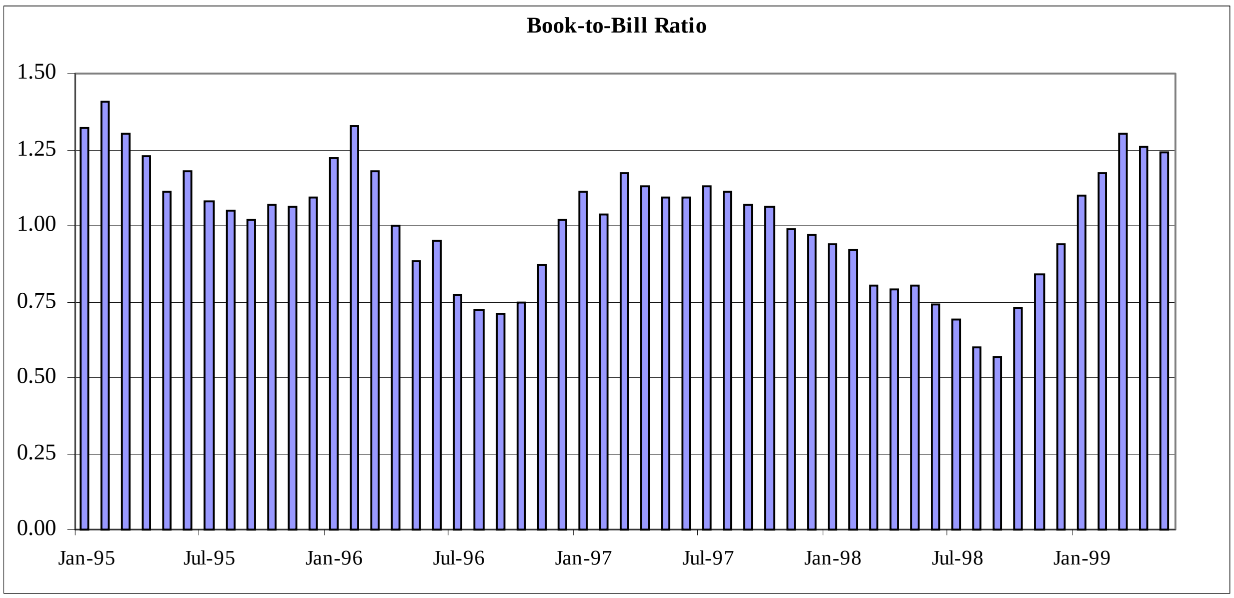

Figure 8

Source: Semiconductor Equipment and Materials International

MANUFACTURING OUTSOURCING

One of the key developments in the last two decades of the semiconductor industry is the emerging trend of outsourcing manufacturing operations. Some firms have decided to focus management skill on designing and manufacturing chips, such as Level One Communications, C-Cube Microsystems Inc., S3 Inc., ESS Technology Inc. and Xilinx Inc. These "fabless" firms relied on contract manufacturers or foundry partners to produce the semiconductors. Thus, fabless firms do not own any semiconductor fabrication equipment or facilities. This provides some advantages and disadvantages versus the traditional, fully integrated development model.

Fabless entities enjoy higher profit margins and stronger free cash flows because less capital is tied into physical equipment and buildings. These firms are generally able to spend more money on research & development, specifically on chip design. Fabless companies generally create the most innovative chips. But for many fabless companies, the downside of the business model takes place when the industry is experiencing rapid growth. When demand is strong, foundry space can be limited. This makes chip procurement both difficult and expensive for a fabless firm. The leading foundry for fabless semiconductor companies is Taiwan Semiconductor Manufacturing Corp. The leading U.S. players are IBM and Bell Micro. The foundry business is expected to grow throughout the next decade and some researchers forecast that over one third of all semiconductor production will result from outsourcing.

INDUSTRY ECONOMICS

The semiconductor industry is intensely competitive and moves quickly. The pace of the business is perhaps unlike any other because of the constant technological innovations that propel the industry. While other traditional business sectors generally use price increases to help achieve growth, the microelectronics industry functions in a constant state of rapid deflation. The industry is able to fight through deflation by means of new product introductions. In addition, decreasing production costs through shrinking transistor sizes and improved throughput has allowed the industry to contain expenses. In aggregate over several business cycles, the semiconductor business has strong revenue growth and is highly profitable.

The most distinguishing characteristic of the industry is that it is capital intensive. According to the U.S. Census Bureau, the average U.S. manufacturer invested 3% of sales in capital goods. For the U.S. semiconductor industry, the ratio is approximately 14% and sometimes even higher. This high level of investment is reflected in the short lives of semiconductor industry equipment, which has an economic depreciation rate of over 30% per year, according to the SIA.

Relative to the high fixed cost nature of the industry, chipmakers' energy expenditures represent a relatively insignificant cost. According to the Annual Survey of Manufacturers, the U.S. semiconductor industry spent nearly $500 million on energy needs in 1998. With U.S. semiconductor sales at approximately $45 billion, energy costs are just 1.1% of chip sales.

However, viewing the cost of energy related to the variable cost structure of the semiconductor business demonstrates that electricity expense can be significant. The cost of goods sold as a percentage of sales for chipmakers is approximately 30% to 50%, based on recent financial statements of Intel and National Semiconductor, respectively. Thus, energy costs are from 2% to 3% of the variable cost of manufacturing a chip. For most fabs, this relates to a monthly electric bill from $500,000 to $1 million, according to Silicon Valley Power. Besides energy cost, manufacturers are also concerned with energy reliability. The loss of power in a fab would likely result in damaged inventory that can not be replaced. Since the cost of replacing these goods is high, it is likely that chipmakers are more concerned with reliability than cost.

In 1999, the semiconductor industry finally awakened from a three-year slumber. The weakness had been a result of overcapacity in the marketplace and a soft pricing environment. These problems were exacerbated by the Asian crisis in 1997 and 1998. Problems with the Asian financial economy -- devaluation of currencies, declines in the stock market and the collapse of some banks -- seeped into other industry sectors, including technology. In 1998, unit sales of PCs dropped 2.5% in Japan and 1.3% in other parts of Asia. In monetary terms, the drop was even steeper.

Chips are essentially commodities and follow the economics of a traditional supply/demand relationship. Chipmakers had reduced capital spending in recent years to help alleviate the acute oversupply condition.

Yet product life cycles of semiconductors and products in the end market continue to shrink. The life cycle of a personal computer can be as short as six months. Innovations in some consumer goods, such as cellular phones, are introduced at a rapid pace as chips and their host devices get smaller and smaller.

Some industry experts believe that the chip industry is finally maturing and that participants will have to extend the time between new chip and product introductions in order to recoup the investments of earlier innovations. Because of the need for massive capital investments with uncertain (yet quick) payback cycles, new entrants are not likely to emerge. Instead, consolidation may be a theme over the next few years as participants seek to capture the economies of scale that are persistent in this manufacturing business. For example, Hyundai Electronics and LG Semicon merged in 1998 to create the world's biggest maker of memory chips. Most players already engage in horizontal partnerships with other chipmakers and vertical partnerships with OEMs. In Asia in particular, electronics giants such as Toshiba and Fujitsu have launched joint ventures based on shared technologies. By sharing costs, the levels of capital investment will likely diminish in coming years.

It is important to note that the industry is highly globalized. Participants must sell to both domestic and foreign markets in order to recoup investments. With thin profit margins, manufacturers' fortunes are tied closely to the global economy. In order to survive, semiconductor makers need to create products that appeal to a wide spectrum of OEMs throughout the world.

INDUSTRY ASSOCIATIONS

The key players in the industry have formed several associations to address business dynamics in the marketplace. The Semiconductor Industry Association is the leading U.S. association representing semiconductor manufacturers. The association seeks to maintain U.S. leadership in the semiconductor market and contains more than 80 member companies. The SIA addresses issues related to trade practices and technology advancements. It also places an emphasis on environmental protection and worker safety & health through research programs.

The SIA expanded its role in 1987 when it formed a consortium called "SEmiconductor MAnufacturing TECHnology" or SEMATECH. The organization is focused on technology development through a partnership with the U.S. government in order to protect and expand the leadership of the U.S. in the semiconductor industry. The non-profit's development programs address all phases of the manufacturing process. Some of SEMATECH's development programs include initiatives in design systems, front end processes, assembly and packaging and manufacturing methods.

The semiconductor equipment makers also maintain a strong presence through Semiconductor Equipment and Materials International (SEMI), a global trade association. Created in 1970, SEMI embraces the development of free trade and open markets. The organization helps members improve marketing opportunities through easier access to customers and government entities. The association provides information and resources that allow members to successfully market their products on a global basis.

MOORE'S LAW

An examination of the semiconductor industry's economics would not be complete without mentioning "Moore's Law." Gordon Moore suggested in 1965 that in every 18 month period the power of semiconductors would double. Thus, pricing of chips would drop by 50% every 1.5 years. Surprisingly, Moore's Law has accurately described the industry over the last 35 years. Both transistor density and microprocessor performance have followed the maxim.

But it is important to note that the immutable forces of nature may eventually make Moore's Law obsolete. Researchers will need to explore the atomic structure of matter in order to build smaller and smaller transistors. The field of nanotechnology, which examines the use of atoms and molecules on chips, will gain prominence in the next decade according to industry experts.

A CYCLICAL AND VOLATILE INDUSTRY

By the mid-1990s the semiconductor industry had become one of the most explosive segments of the economy. The history of the semiconductor industry is cyclical, with semiconductor products having short life-cycles caused primarily by rapid technology innovations and resulting in pricing pressures.

To some extent, chip demand is related to the overall, worldwide economic cycle and the corresponding business and investment trends. During recessions, businesses cut capital spending on equipment such as personal computers, which is the most important demand driver for semiconductor manufacturers. In addition, consumers will spend less on electronic devices, such as cellular phones and video games, during times of economic weakness.

While the economy creates some of the ups and downs in the semiconductor industry, the chip cycle is tied more to the balance of supply and demands for chips based on inventory levels. The industry is known for very long lead times in design and production. This forces OEMs to order chips far in advance of the introduction of the product to the market. Electronics manufacturers need to anticipate demand and make sales projections, which chipmakers use to determine production. But because demand forecasts are imprecise, it is very difficult for semiconductor firms to anticipate market dynamics and keep inventory and supplies in balance. This makes planning difficult and intensifies the joy and pain of the industry's booms and busts. If there is an oversupply of chips, a weak pricing environment will emerge. Conversely, a limited supply will lead to high profits and high margins for semiconductor manufacturers.

The impact of these cycles is demonstrated by the semiconductor equipment industry, which is a supplier to chipmakers. In 1998, chip-making equipment manufacturers saw new sales orders nearly disappear. At the worst point, SEMI reported that three-month average new equipment orders were just $471 million. This represented a drop of 70% from $1.6 billion during the comparable period a year earlier.

The DRAM market is another example of a segment that has experienced high volatility in recent years, as Figure 9 demonstrates. Massive oversupply of chips and the resulting price reductions resulted in dramatic declines in revenue figures. In 1995, DRAM sales were $41 billion. Three years later, sales had diminished to $14 billion as the price of a 16-megabit DRAM fell from $12 to $2.50 in the space of one year. The Semiconductor Industry Association predicts growth over the next three years, but the volatility and potential for significant declines remains.

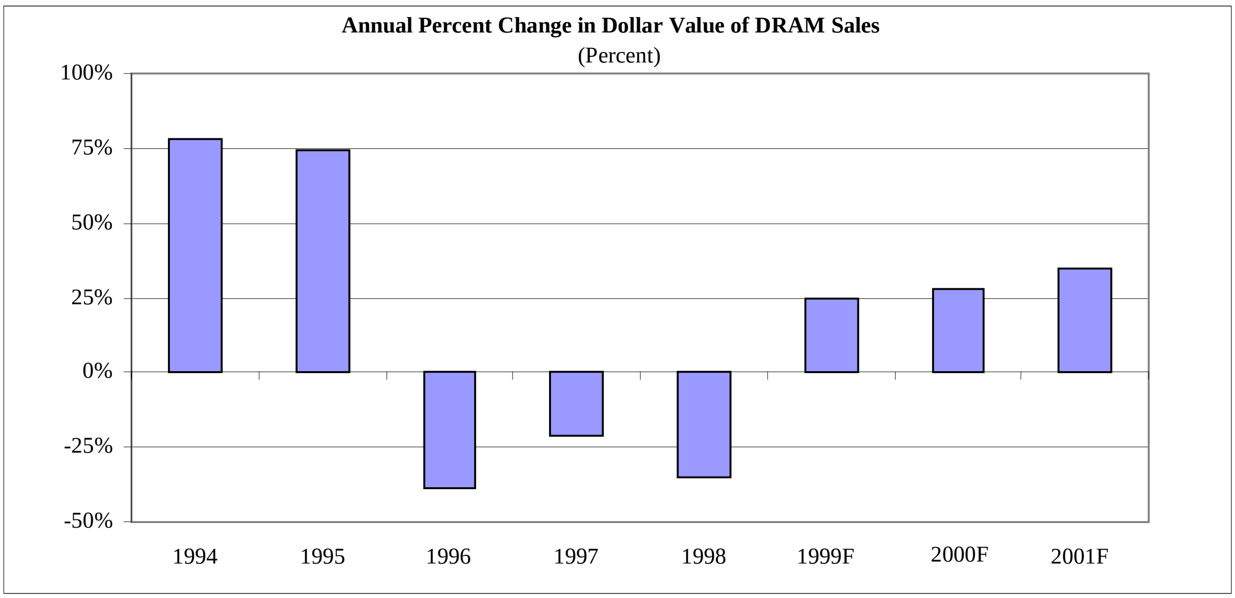

Figure 9

Source: SIA, World Semiconductor Trade Statistics

After three years of sales declines, the SIA predicts double-digit growth in most integrated circuit segments as shown in Figure 10. To achieve this growth, several anticipated events -- such as true mass market adoption of PCs -- need to occur. Otherwise, the semiconductor industry will have to weather another low growth period and wait in anticipation of an eventual boom.

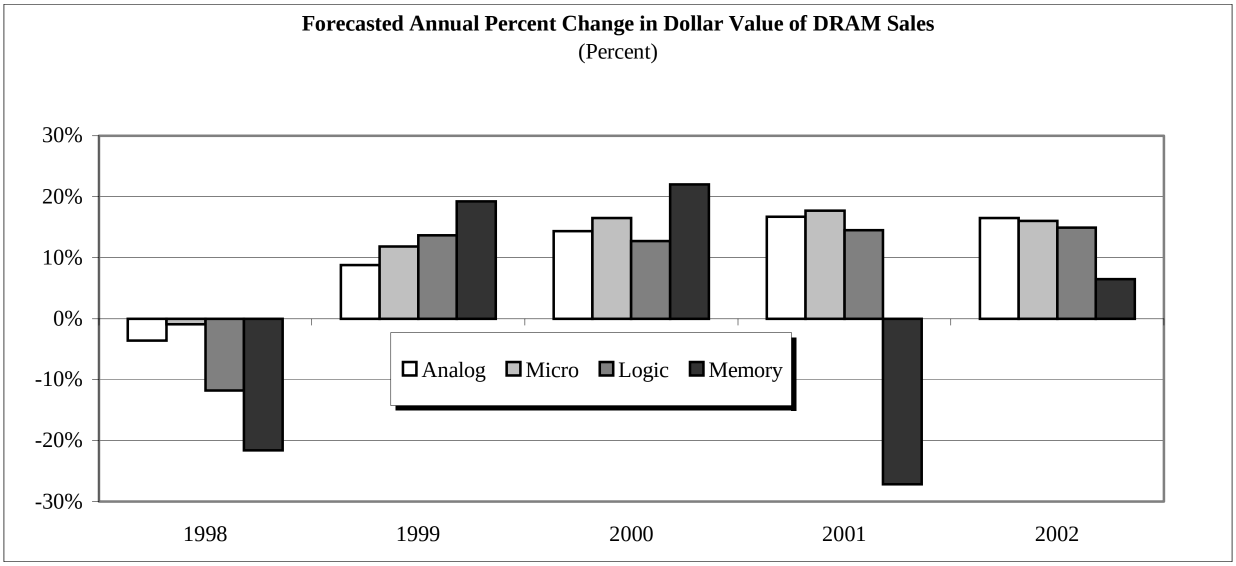

Figure 10

Source: Semiconductor Industry Association

THE MICROELECTRONICS INDUSTRY

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