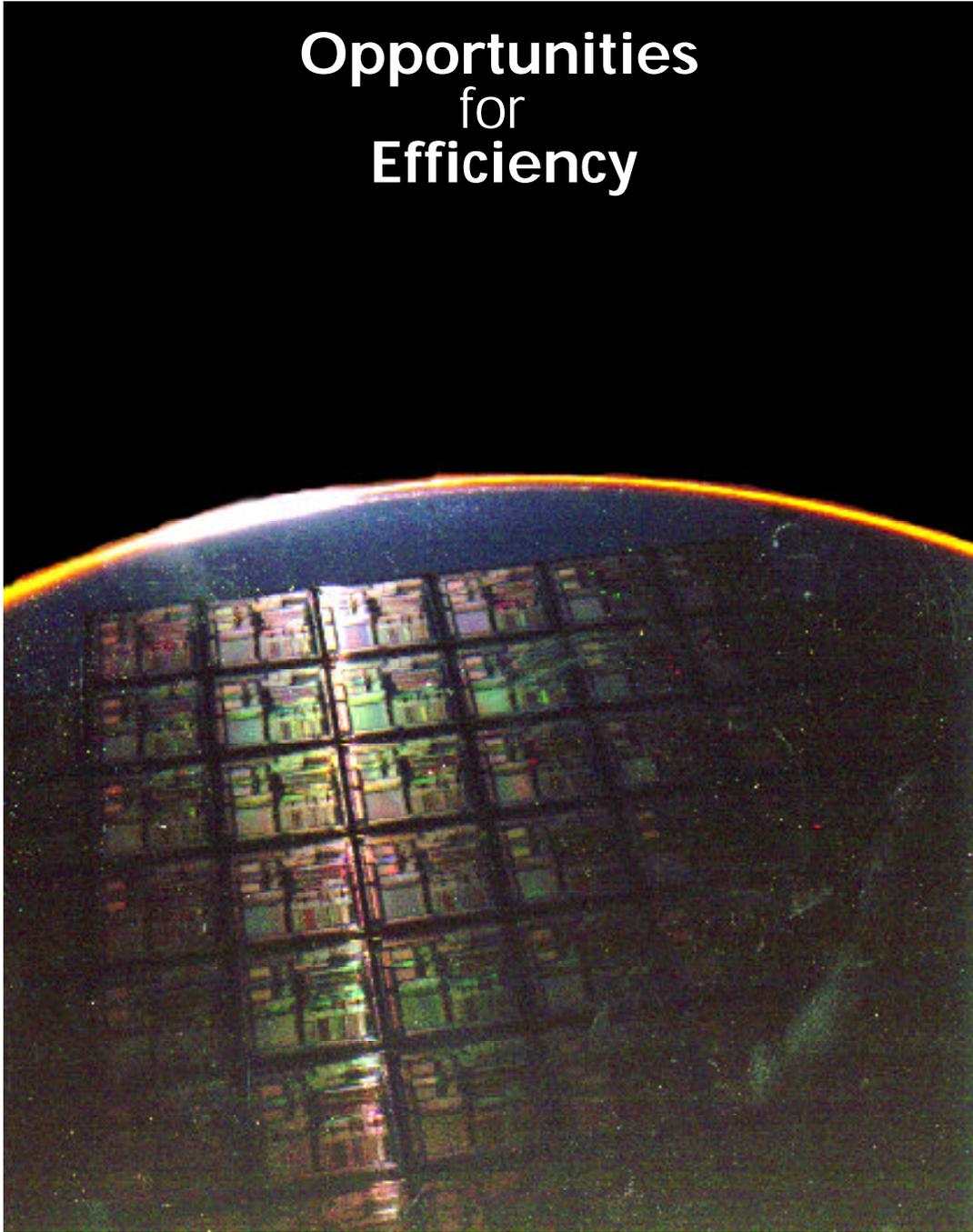


Opportunities for Efficiency



NW **Micro** Electronics
Industry

Opportunities for Energy Efficiency in the Northwest Microelectronics Industry

Prepared by

Chris Robertson, Chris Robertson and Associates

Jay Stein, E-Cube, Inc.

Karl Vischer, Bonneville Power Administration

Jeff Harris, Northwest Power Planning Council

Mark Cherniack, Chris Robertson and Associates

Mark Kendall, Oregon Office of Energy

Carlotta Collette, Northwest Power Planning Council

Designed by Stephen Sasser, Northwest Power Planning Council

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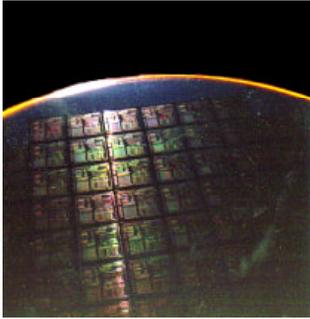
Bonneville Power Administration

Northwest Power Planning Council

Oregon Office of Energy

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- 1 -
**AN
INVITATION**

To the outside world, it sometimes seems that the microelectronics industry is expanding at the speed of microprocessors. Nearly every day, newspapers bring word of new technological breakthroughs, and new fabricating plants are quickly constructed to bring the new product line to an enthusiastic market.

In the Pacific Northwest – the “silicon forest” – this has sparked tremendous economic growth. The microelectronics industry is now the region’s biggest employer, having overtaken the wood products and aerospace industries in 1994. These are good, mostly high-paying jobs, the kind of jobs most regions are trying to attract.

But this growth can tax a region’s natural resources. Microelectronics manufacturing facilities are both water and energy intensive to operate. In fact, electricity is the biggest operating expense in these facilities. The microelectronics industry has shown great interest in the restructuring of the electricity industry because of anticipated reductions in electricity rates. Those savings are expected to amount to about 10 percent of the microelectronics industry’s total electric bill.

This report will describe savings on the order of 50 percent off electricity bills. Similar efficiencies in water use are also obtainable. And capital costs to build these new, far more efficient fabricating plants can be lower than it costs to build today’s average facility.

There are non-energy benefits to be gained, as well. More efficient HVAC systems, for example, cost about a third less than conventional systems, provide higher filter efficiencies with slower air flows and enable better contamination control. The result is better product yields.

**Who are we and
why do we care
about this?**

This report is one of the products that resulted from a study of efficiency opportunities in the microelectronics industry. The study, conducted by Chris Robertson and Associates, was sponsored by the Bonneville Power Administration, this region’s federal power marketing agency; the Northwest Power Planning Council, a resource planning compact formed by the states of Idaho, Montana, Oregon and Washington; and the Oregon Office of Energy.

These agencies called for the study because they share a concern for, and some responsibility to protect, the Northwest’s economy and its environment. The consolidated microelectronics industry, with its tremendous growth in this region, can have a powerful influence on both of these.

In the Pacific Northwest, the microelectronics industry is growing faster than any other industry. As it grows, it requires significantly larger amounts of electricity, as well as clean water and other natural resources. For example, over the next decade, this industry is projected to require between 400 and 500 megawatts of additional electricity from Northwest power suppliers. That’s about as much electricity as two new natural gas-fired power plants

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generate. We are interested in reducing this new load as much as possible through improved energy efficiency to help avoid the environmental impacts associated with energy production.

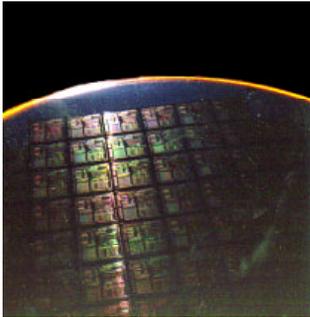
This region has considerable experience with securing the same comfort levels or better and producing the same products or more using far less electricity and other natural resources. We have learned that improved resource efficiency also improves productivity. Resource efficiency is the link between meeting the needs of a competitive microelectronics industry and the need in the Northwest for sustainable industries that bring quality jobs to our economy.

But the microelectronics industry, focused as it is on constantly refining its products and bringing them to the marketplace faster than competing firms, has yet to exploit all the technological advances being made in the energy-efficiency of facilities, production tools or processes. This report is written with the goal of helping to change that.

The sponsors of this report – the Bonneville Power Administration, the Northwest Power Planning Council and the Oregon Office of Energy – would like to encourage the microelectronics industry to take a holistic approach to using all natural resources more efficiently. This report, however, is specifically about opportunities to use energy more efficiently. The energy-saving strategies described here have been proven or are under development. Many are being implemented in plants in Asia and in Europe. They can be used in this region, too.

Plants that require only half as much energy as competing plants have several key advantages. They have better bottom lines and so can weather industry downturns more effectively than their competitors. With lower overhead, they can produce products more profitably. And because they require only half the natural resources of competing facilities, they will be more readily welcomed by resource-conscious communities. In fact, their lower resource demands will mean that more communities will have sufficient quantities of clean water and electricity to support the plants, broadening the choice of areas in which to build. Their efficient operation will help these plants remain good neighbors.

This report is an invitation to build partnerships – to bring together the microelectronics industry, the utility and energy-efficiency industries, product manufacturers and vendors, local communities, state and federal governments, and others – to demonstrate these new efficient strategies in the Pacific Northwest.



- II -
**GROWING
AN INDUSTRY
IN THE
NORTHWEST**

The microelectronics industry has roots in the Northwest that go back many years. Tektronix, an industry pioneer and leader in the instrumentation, graphics terminal and high resolution printer business has had its headquarters in Beaverton, Oregon, for more than 20 years. Intel, now Oregon's largest employer and the world's largest producer of computer chips, designed and manufactured the 80286 chip out of the company's Hillsboro plant 15 years ago. Other industry stalwarts, such as Hewlett-Packard, also have had a long presence in the region.

Today, the Pacific Northwest's abundant clean water, low-cost electricity, skilled labor force, and targeted property tax-abatement programs have combined to push the region's microelectronics industry toward unprecedented growth. Industry forecasters concur that in Oregon alone about \$14 billion in new semiconductor facilities will be built between 1995 and 2004. Some industry analysts say investments in facilities across the entire Northwest microelectronics sector might reach \$20 billion in the same time period.

**How did we do
this study?**

The sponsors of this report funded a study to examine the following questions:

Are there significant opportunities to improve energy efficiency in the semiconductor industry?

If such opportunities exist, could strategies be identified to transform how the industry specifies, designs, and uses its tools and facilities?

Is there an appropriate role for partnerships that bring together Northwest electric utility interests, state and local governments, and others to work with the industry so it can implement these energy-efficiency strategies?

To answer these questions, the study relied on existing industry data and interviews with key individuals in the industry, as well as in government and research organizations. No new primary research was conducted.



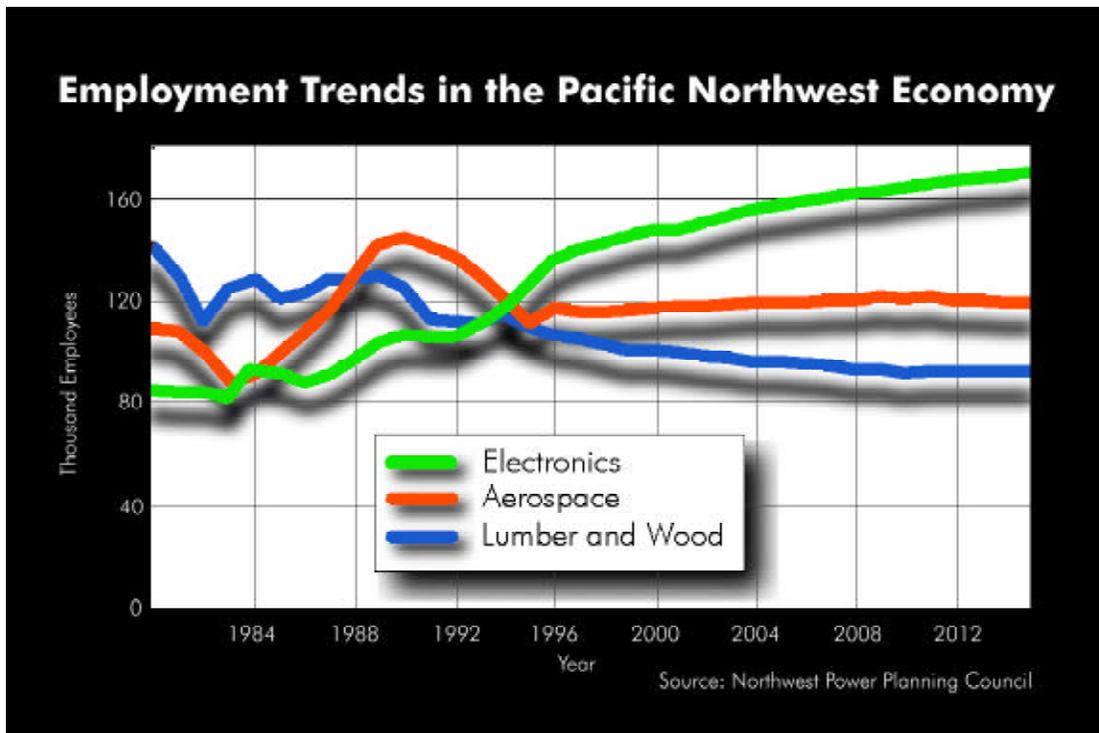
Not only are a large number of new plants being located in this region, but there is also a very large existing industry base in a number of key production segments. About half of the silicon ingot production capacity in the United States is located in the Northwest. Moreover, the Portland metropolitan area is home to several of the largest design and engineering firms specializing in chip fabricating plants.

Taken together, the existing microelectronics industry, combined with recent and projected industry growth, is creating fundamental changes in the economy of the Pacific Northwest. The consolidated microelectronics industry already employs more people in the Northwest than any other industry, including traditionally dominant industries, such as wood products, agriculture and aerospace.

Structure of the microelectronics industry

The microelectronics industry can be viewed as a chain of several major production steps. The Northwest is fortunate to have most of these steps well represented by companies operating in this region. To better understand the opportunities for efficiency in the industry, a brief description of its structure follows.

Elemental silicon feedstock is refined into a material known as “polysilicon,” which is then melted in a furnace where a single crystal silicon ingot is produced. The ingot is then sliced into thin wafers that are polished and treated before being sold to chip producers. Roughly half of all U.S. silicon crystal and wafer production is located in the Pacific Northwest, including companies such as Wacker Siltronic, SEH America and Mitsubishi Silicon America.





In the next step in the process, chip manufacturers take the polished wafers, create integrated circuits on the wafer surface, then slice the wafer into individual chips. These chips are tested, assembled and packaged for sale to circuit board manufacturers and electronic original equipment manufacturers (OEMs). The Northwest is home to a number of the world's largest producers of microcomputer chips, memory chips and application-specific integrated circuits (ASICs). Companies such as Intel, Micron and LSI Logic all have significant portions of their global production located in the Northwest.

The original equipment manufacturers and circuit board manufacturers then sell into the market for finished consumer goods. Other prime buyers include defense and aerospace companies. Again, the Northwest has a number of key domestic and foreign manufacturers of electronics equipment, including Hewlett-Packard and Tektronix. In addition, the Northwest is home to some very key beneficiaries of the end-products of

this industry, including the aerospace and software industries, which are best represented by the giants Boeing and Microsoft in the Seattle area.

A closely related industry that uses some of the same manufacturing technology is the photovoltaic ("PV") power systems industry. This industry uses the same semiconductor equipment and processes to grow single crystal silicon ingots, which are sliced into wafers and then manufactured into photovoltaic cells. The photovoltaic industry's growth rate in the next few years may substantially exceed the growth rate of the traditional microelectronics industry. Projections describe global photovoltaic demand ramping up from a current production level of around 100 megawatts per year to between 1,000 and 5,000 megawatts per year in the next decade. The photovoltaic industry in the Pacific Northwest is primarily represented by Siemens Solar Industries, the largest volume manufacturer in the world.

Key Industry Corporations in the Pacific Northwest

The Pacific Northwest is unique in the range of companies manufacturing products in almost all sectors of the industry. Major companies include the following:

Polysilicon — Advanced Silicon Materials, Komatsu Silicon

Silicon Crystals/Wafers — Komatsu Metals, Mitsubishi Silicon America, SEH America, Siemens Solar Industries, Wacker Siltronic

Process Materials

Suppliers — Fujima Abrasives, Tokyo Ohka Kogyo, Toshiba Ceramics, Toyo Tanso,

Semiconductor

Manufacturers — Adaptive Solutions, Advanced Power Technologies, Fujitsu, Hewlett-Packard, Hyundai Electronics, Integrated Device Technology, Intel, Lattice, Linear Technology, LSI Logic, Micron, OKI Semiconductor, Sharp Microelectronics, Tektronix, TriQuint

End Users — Epson, Fujitsu, Hewlett-Packard, Interactive Systems, Intel, NEC America, Planar, Sequent, Sharp, Tektronix, plus many others

Semiconductor Production Tool Manufacturers

— Production tool manufacturing is not centered in the Northwest, but local vendors and distributors of major companies include: Applied Materials, Genus, Lam Re-

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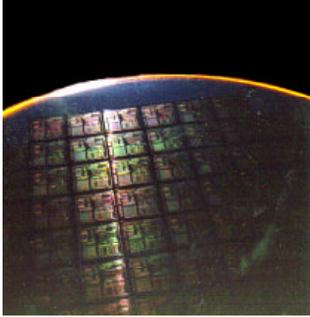
Resource impacts of industry growth

Although traditionally viewed as a light industry, the microelectronics industry's demands on the energy, water and other natural resource infrastructures of local communities are increasing rapidly. In particular, as the capital investment in semiconductor manufacturing plants has grown, so has the energy intensity of these plants. New facilities can cost more than a billion dollars and consume from 30 to 50 megawatts of peak electrical capacity.

The increase in water usage has been equally dramatic. New wafer and integrated circuit manufacturing plants can consume *millions* of gallons of water every day; enough to serve communities of several thousand households. A plant in Eugene, Oregon, applied for permits to consume up to 10 percent of Eugene's entire municipal water supply, when the plant's three construction phases are completed. Eugene has responded by accelerating plans to increase the capacity of the city's water system.

Additional inputs to wafer and chip manufacturing processes include high-purity graphite and quartz products. These products are in tight supply, and they also require large energy inputs to manufacture. As the microelectronics industry grows, so do the industries supplying these inputs. Large quantities of high-purity gasses, such as nitrogen and hydrogen, also are required and must be manufactured in energy-intensive processes of their own.

So, while the Northwest has welcomed the growth of the microelectronics industry, there has been growing concern regarding the impacts on the region's energy, water and other resources.



- III -
**EFFICIENCY:
THE FIRST STEP
TO
SUSTAINABILITY**

The Northwest's electricity policy over the last 15 years has been shaped by the belief that conserving energy, through efficiency improvements, can be more cost-effective and environmentally responsible than building new power plants to meet new demands. The same is almost certainly true of water supply. Our interest is that new and existing microelectronics manufacturing facilities are as efficient in their use of electricity and other resources as is cost-effective. Although there are many obstacles to accomplishing greater efficiency in the industry, the industry has several characteristics that could make efficiency improvements widely achievable:

- The industry is concentrated in just a few dozen semiconductor manufacturers, and a few hundred key tool manufacturers and suppliers. These firms have great opportunities to coordinate their efficiency efforts through their associations, conferences, consortia and research and development facilities.
- New generations of chip technology are scheduled to be developed every three years. Each new generation requires new production tools and new fabrication facilities. Consequently, each new generation affords an opportunity to design for resource efficiency.
- The industry's conservatism in factory designs and manufacturing processes could work in favor of efficiency. Once an efficient design is built, tested, and proven, others plants can copy that design.
- Industry overcapacity in a number of segments has slowed new construction temporarily in the Pacific Northwest, as it has elsewhere. This creates a brief window of opportunity in which energy-efficiency opportunities can be explored and implemented in those plants that are planned but not yet built.

search, Varian and many others. Some specialty tool manufacturers do have their headquarters here, including Electro Scientific Industries.

Consulting Engineering and Construction Firms — Major Portland area firms with global industry accounts include: Hoffman Construction, Industrial Design Corporation and Jacobs Engineering Group, Inc. Industrial Design Corporation and Hoffman have formed a subsidiary design/build company called TDC Construction.

What's in it for you?

One of the world's largest microelectronics companies, SGS-THOMSON Microelectronics of Italy, has a new company policy about resource efficiency. It was summarized by the company's director of corporate environment strategies, Fabio R. Borri, in his report, "Environment: A New Industrial Parameter." "We consider that environmental performance is a basic ingredient for product quality and company reputation; the business benefit is that managing for natural resource efficiency and clean processes is one of the greatest engines of productivity improvement." SGS-THOMSON's efficiency motto is: "Ecology is Free."

The fact is, ***ecology pays***. Better designed facilities, tools and processes can cost less, not more, to build and operate. According to Lee Eng Lock of Supersymmetry Services, a more efficient HVAC system costs about 30 percent less than conventional systems, is more reliable, and has less wear and tear on components due to lower pressures and slower airflow. Lee maintains that this design improves filter efficiency, which could reduce particle contamination – a key concern in the microelectronics industry. The likelihood of reduced contamination from improved filter efficiency needs further study and documentation.

Designs that incorporate total resource efficiency also have a tendency to ***save time and improve productivity***. For example, new lighting technologies use a single, very-efficient light source that can be "piped" to "outlets" in other areas, including clean rooms. These technologies provide uniform, high-quality illumination, but the lighting source is located outside the clean room environment. Substantial improvements in lighting efficiency are possible using concentrated daylight or new lighting sources, such as sulfur lamps. At the same time, having the light source located outside the clean room reduces down time by

eliminating clean room lamp replacement routines. The result is higher productivity at the plant.

Leaner operations also are more likely to ***survive industry cycling***. In periods of excess capacity, for example, the plants with the highest operating costs will tend to be taken out of production first. Plants that continue to operate through peaks and troughs, because they run efficiently, are among the most prized assets of any corporation and any community.

Ultimately, it may be that ***local communities benefit*** most from industrial efficiency. While it's true that most communities will compete to attract large, stable employers, the high water and energy demands of conventional microelectronics fabricating facilities could narrow the selection of communities with sufficient resources. Such resource constraints could limit corporate expansion. Companies that can demonstrate their environmental responsibility will be welcome throughout the world.

EFFICIENCY OPPORTUNITIES IN MICROPROCESSOR FABRICATING PLANTS

Among the most expensive of modern industrial systems, large, new microprocessor fabricating plants, called "fabs," cost on the order of \$1.0 to \$1.5 billion each. Industry observers suggest a third of the capital cost is for the clean room and supporting facilities, and the remaining two thirds pays for production tool systems and equipment. As plant sizes grow and become more complex, they require more new energy services. The average cost of typical new fabs that were looked at for this report came to \$1.2 billion, and projected energy use at the plants ranged from 30 to 50 megawatts.

The \$14 billion in new facilities planned for Oregon could represent approximately 400 to 500 megawatts of new electrical load to be served. Over the next decade, microprocessor fabricating plants in the entire Northwest could require 600 or more megawatts of new energy supplies.

Fabs impose large, relatively constant, long-term electric loads on utility systems. This electricity represents a significant portion of the facility operating cost of a

What is the microelectronics industry doing to improve energy efficiency?

Historically, this industry has not emphasized energy efficiency, but that appears to be changing. The industry, through its research consortium, SEMATECH, and several engineering firms and manufacturers are moving energy efficiency to a higher priority. For example:

- The SEMATECH Environment, Safety and Health (ESH) Program initiated and is sponsoring an international facility energy audit and benchmarking program.
- SGS-THOMSON Microelectronics, whose corporate motto is

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Table 1
Operating Costs of Three Fabrication Facilities

	Facility A		Facility B		Facility C	
Clean Room Area	372,000 sq. feet		81,000 sq. feet		60,000 sq. feet	
Financial Metrics	\$K	%	\$K	%	\$K	%
Electricity	21,890	41.5	3,468	30.4	2,477	32.1
Water	1,423	2.7	510	4.5	694	9.0
Natural Gas	2,481	4.7	391	3.4	57	0.7
Salary and Benefits	15,105	28.7	3,740	32.7	2,363	30.6
Other*	11,810	22.5	3,315	28.9	2,133	27.7

*Central plant, structures, ultra-pure water, chemical services, gas services, custodial, grounds landscaping, trash, hazardous waste.

Most of the electricity used in these facilities goes to HVAC systems, production tool systems, supporting utility services and lighting. Industry estimates indicate that roughly 40 percent of all energy used goes to production tools, another 25 to 30 percent to the heating, cooling and ventilation systems, and the balance to supporting utility services. Lighting is estimated to use only a few percent of the total energy used at the plant.

Source: SEMATECH data, 1996

"Ecology is Free," has adopted an internal environmental management and audit scheme with the intention of becoming the "greenest" chip producer in the world.

■ *Several firms in the facility design and construction field are exploring energy-efficient designs.*

■ *Several semiconductor manufacturers have initiated senior management reviews of the role of energy efficiency.*

■ *At least one design firm (Supersymmetry Services) has integrated energy efficiency into an integrated systems approach to clean room design and has built facilities that have won international awards.*

■ *In Portland, Oregon, two firms (LSI Logic and Fujitsu) have agreed, as a condition of property tax abatements under Oregon's strategic investment program, to implement "exemplary environmental management plans" that include energy, water and resource efficiency components.*

■ *In the semiconductor industry transition from 200 to 300 millimeter wafers, the industry has defined design protocols to improve resource efficiency of the next generation of manufacturing tools.*

■ *Cypress Semiconductor Corp. and Hewlett-Packard have recently become "Climate Wise" partners in the voluntary climate change effort initiated by President Clinton.*

fabricating plant. Table 1, (adapted from SEMATECH data with permission) illustrates operating cost data from three different fabs. The three differ in size, ranging from 60,000 to 372,000 square feet. Electricity costs are the single greatest facility operating cost component in two of the three plants, eclipsing both labor and materials costs. In the largest fabricating plant, which corresponds to the scale of a typical new fabricating plant, the electric bill was about \$22 million per year, more than 40 percent of total operating costs ("operating cost" excludes the capitalized cost of land and buildings). Electric bills greater than \$1 million per month are common for large fabs.

Efficiency example: Improving clean room HVAC efficiency

In a workshop sponsored by the Northwest Power Planning Council, opportunities to integrate efficiency in the design of new fabricating plant HVAC systems were reported to save 70 percent or more of total HVAC energy use, with reductions in capital cost of up to one third. Similar results were reported by the Lawrence Berkeley National Laboratory in a recent study of research facilities in California. Benefits from this integrated design approach go well beyond reduced energy costs. Energy-efficient design can also improve reliability, while reducing wear and tear on other components, such as filters, fans, pumps and motors. The improved reliability and reduced wear translate directly into less down time and lower operating costs. Perhaps most significant to the industry, the lower pressures and slower airflow resulting from this design approach can improve filtration efficiency, which in turn can result in improved yields due to reduced particle contamination.

Some of the best examples of these efficient designs are those practiced by Lee Eng Lock of Supersymmetry Services, a company that specializes in the design of high-efficiency, clean room HVAC systems. Lee's designs routinely operate at 0.7 kilowatts per ton of cooling capacity, including all system components, compared to conventional industry practice of 1.2 to 2.0 kilowatts per ton, or more.

In existing factories, retrofit opportunities are less dramatic, but savings, based on estimates as well as experience, can still be significant. Lee estimates that savings of 30 percent to 60 percent of the energy used in HVAC systems are realistic. Two examples from fabs in the Northeast United States support this estimate for existing facilities:

A company with a large clean room participated in the New England Electric System Chiller Initiative Program to improve its HVAC system when it was revamping to eliminate CFC refrigerants. The company improved energy efficiency in the HVAC system by one-third, and improved productivity because it was then able to remain in production through the summer. The productivity gain is worth more than the energy savings, and this facility has expanded production as a result.

Almost \$3 million in annual energy savings were achieved in Lucent Technologies, Allentown, Pennsylvania, fabricating plant with a \$14 million annual energy bill. These savings were discovered and documented in the course of an operations and maintenance audit.

Supporting utility services — e.g., deionized water, vacuum, exhaust, compressed air, gas delivery, etc. — can all be improved through better design, equipment and controls, recycling, heat recovery and other efficiency techniques. Savings in these systems can add to the savings cited above, with opportunities in both new construction and retrofit of existing facilities.

EFFICIENCY OPPORTUNITIES IN TOOLS AND SUPPORTING UTILITY SYSTEMS

Semiconductor plants contain a complex array of subsystems, including support utilities, production tools and related components. All of the mechanical, thermal and electrical subsystems, and related equipment, are candidates for efficiency improvements.

Production tools are expensive. Each tool can cost from \$1 million to more than \$3 million and can require \$250,000 or more to configure for operation. Tools and their supporting utilities use 50 percent to 70 percent of the energy consumed by a typical semiconductor fabricating plant. Generally, once it is operating, a tool is left on except for maintenance. Tools are significant drivers of cooling loads, and when combined with the outdoor air needed to make up the exhaust from these tools, they account for the majority of cooling capacity that must be designed into the fabricating plant HVAC system.

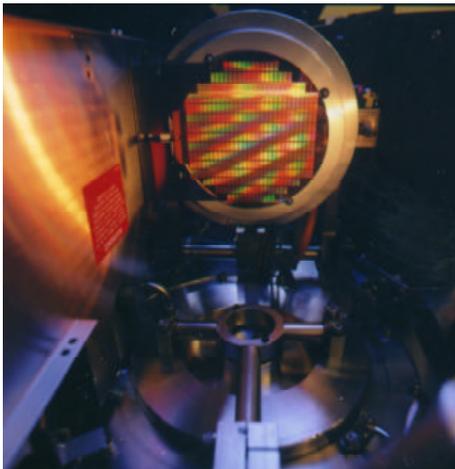
Despite the amount of energy tools require, energy efficiency typically has not been an area of focus for tool manufacturers. Components that are built into the tools generally are selected to minimize first cost, not life-cycle cost.

Efficiency examples: Tools and supporting utility systems

The energy-efficiency industry is well acquainted with components typically used in manufacturing tools, including motors, fans, pumps, heaters, compressors, plumbing, ducts, controls and heat exchangers. It should be possible to bring together energy-efficiency experts with tool manufacturers and tool users to minimize the life-cycle cost of operating production tools. Ways to improve tool efficiency include the following examples:

An electric utility evaluated an epitaxial deposition furnace and reported that it could cost-effectively reduce the energy load of the furnace by 50 percent. These furnaces operate inside clean rooms, where cutting the cooling load creates more savings in the chilled water plant.

Vacuum systems, while not major electricity users, are reportedly based on outdated automotive vacuum pump technology. One company is now working to use scroll compressor technology to build vacuum pumps that use 80 percent less electricity to provide the same vacuum service.



An ion implant tool manufacturer has begun to market its tool as requiring two-thirds less energy and water than its competitor.

The next tool generation will be based on .18-micron feature sizes, and 300-millimeter diameter wafers. Tool and process designs for these new wafers are not yet committed, which provides an opportunity to work with the manufacturers and users to improve energy efficiency.

Based on discussions with tool manufacturers, users and energy-efficiency consultants, it appears likely that significant energy-efficiency improvements in tools and their supporting utility systems can be achieved. Sources estimated that improvements of 50 percent to 70 percent are probably achievable and economically justifiable.

Since most of the tool systems produce heat and some require large exhaust air streams, improvements to tool systems will also reduce HVAC energy usage and reduce the size of HVAC system required, ultimately cutting the plant's capital costs.

EFFICIENCY OPPORTUNITIES IN SILICON CRYSTAL GROWING FACILITIES

About half of all U.S. semiconductor-grade crystal and wafer production is located in the Pacific Northwest. The electric resistance-heated furnaces in these facilities produce, or "grow," single-crystal silicon ingots, from which wafers are made for the semiconductor and photovoltaic industries. For semiconductor-grade ingots and wafers, the furnaces typically are operated in a clean room environment, due to purity requirements. Photovoltaic-grade ingots do not require such purity, so photovoltaic industry crystal furnaces are operated in more conventional industrial facilities.

A typical crystal furnace has a nameplate rating of 125 to 250 kilowatts or greater, depending on the diameter of the ingot to be produced. The furnaces nominally operate at about two-thirds rated power. The power is on for an 18-hour-per-day duty cycle, which is necessary to melt the silicon and produce the ingot, followed by six hours off power, for maintenance and reloading. A large factory may employ several hundred of these furnaces. One crystal/wafer factory can typically serve between five and 10 chip manufacturing facilities.

To illustrate the energy use of these crystal growing facilities, 100 furnaces operating at 250 kilowatts each at 66 percent nominal power amounts to an electric load of 16.5 megawatts and consumes 104,000 megawatt-hours per year. Discussions with industry experts suggests that a whole-systems approach to efficiency improvements in these facilities could achieve impressive results, including significantly reduced energy use, increased productivity and reduced product prices.

Efficiency examples: Lessons from the photovoltaic industry

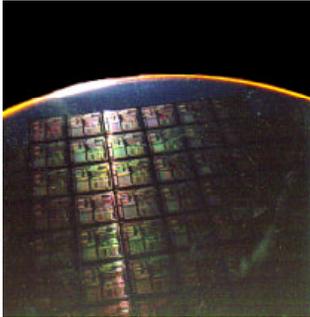
Siemens Solar Industries grows silicon ingots in its Vancouver, Washington, plant, from which it produces the largest volume of single-crystal photovoltaic cells in the world. Siemens recently tripled its Vancouver plant capacity, and plans to continue to triple capacity every few years. Crystal growing is a key limiting factor in photovoltaic capacity expansion.

Siemens Solar Industries has identified a number of technical improvements to its furnaces that could significantly reduce the energy used to produce wafers for photovoltaic cells. These improvements, Siemens maintains, could cut in half the time to produce the crystals, doubling the productivity of the furnace.

Specific furnace hot zone technical improvements identified by Siemens include: redesigning the thermal insulation components surrounding the crucible in which the silicon is melted; redesigning the argon gas management system; and installing a heat shield to permit more rapid cooling of the crystal as it is pulled from the crucible. Because furnaces used by Siemens are basically the same equipment used to produce crystals for the semiconductor industry, these technical improvements, if realized, should be transferable from one industry to the other.

Siemens executives report that eventual energy savings of 60 percent to 75 percent are achievable. Additional minor energy savings are reported to be possible from improvements to the power supplies that convert alternating-current to direct-current for use in the furnaces.

These cost reductions and productivity improvements, if adopted by the rest of the industry, would eventually result in lower product prices, and further expand silicon ingot production to meet growing world demands for photovoltaic power systems and computer chips. Importantly, if productivity increases as predicted, the capital required for industry capacity expansion, as well as the energy required to fuel that expansion, may be significantly reduced.



- IV -

WHAT'S HOLDING BACK EFFICIENCY IMPROVEMENTS?

There are a number of mutually reinforcing causes of energy *inefficiency* in the microelectronics industry. At the root of most of these problems is the intense competition in this industry to move from new concept to full market as quickly as possible. "Faster, better, cheaper" are this industry's priorities, not "more efficient." Ironically, this rapid innovation in products is in sharp contrast to the pace of change in facility designs and manufacturing processes. Manufacturers are reluctant to change facility designs if these changes could be perceived as reducing reliability or slowing the cycle time for bringing out new products.

New manufacturing facilities are designed and built to produce the next generation of technology. In a strong market, when the timing is correct, these facilities can be highly profitable. In a weak market, or if timing is bad, huge losses can result. As a result, construction project managers for new facilities are intensely schedule-driven.

Once a plant is operational, reliability

is critical. Because of the significant capital invested in a new facility, any time the plant is not turning out product results in significant costs and large revenue losses. Hence, engineering designs for new facilities are conservative, with a bias toward new facilities whose designs are consistent with existing plants.

These pressures generate barriers to increased energy efficiency:

Schedule: This industry faces incredible time pressures to get new products to market. Huge amounts of capital are spent on technologies and product lines that may be surpassed by the next generation in a few years. Thus, the primary objective in building any new tool or plant is to get the latest innovations out the door as fast as possible. Today, new, billion-dollar semiconductor manufacturing plants must be designed, constructed and operating in 12 to 18 months, to meet product time-to-market requirements. Facility and process engineering design time is squeezed, thus precluding major structural, mechanical or process efficiency improvements.

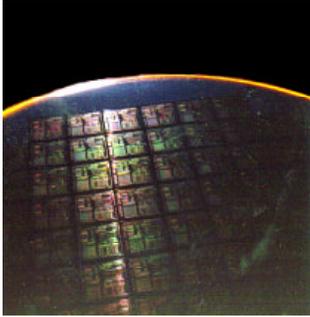
Risk: With such large sums of money at stake, many manufacturers perceive any change that is not absolutely critical to the end result as an unacceptable risk factor. This frequently results in specifications for new facilities that are based on previous designs, leaving little room for creative engineering for efficiency. Engineering conservatism says don't change what works, especially if it might delay production or adversely affect reliability.

Energy is perceived to be a small, unchangeable cost: Traditionally, energy costs in this industry are perceived to be a small percentage of total production cost (capital plus operating). Recent events with electricity market deregulation and a potential reduction in bulk electricity prices may reinforce the attitude that energy efficiency is not important.

Lack of Awareness: Owners may be unaware of energy and other resource efficiency opportunities and their potential benefits, including capital and operating cost savings, and improved reliability and productivity.

Fragmentation of the design process: Design engineering functions are fragmented (in part due to timing considerations) and fail to capture design synergies that could result in operating and capital cost savings. For example, capital cost savings in the electrical systems are not credited to more efficient mechanical systems because mechanical and electrical are two separate, independently managed design budgets.

Lack of feedback from operational plants: A fragmented design process that relies on replicating past, proven designs, does not use feedback from the current design to revise the next. It does not incorporate the principles of Total Quality Management: "design, build, measure, analyze, design." Often, facility managers have little control over the design or manufacturing processes, even though their experience in plant operations might offer substantial insights in new plant designs.



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STRATEGIES FOR COLLABORATIVE ACTION

The barriers that have slowed implementation of efficiency improvements in the microelectronics industry are substantial. They have their own momentum. To counteract them, the industry will need partners with solid arguments and proven technological alternatives. We suggest that a more integrated design process, emphasizing resource efficiency, could help this industry prosper in several key ways:

Save money: Capital and operating costs would be reduced.

Improve performance: Environmental controls and productivity would be improved, while providing continued assurance of reliability.

Reduce environmental impacts: Emissions at the facility, as well as at the utility power plant, would be reduced. This would reduce industry exposure to emerging international concerns regarding climate change.

Improve community relations: An additional result would be better community relations because of perceived environmental responsibility.

The strategies listed below are designed to test new technologies and provide defensible data to support the microelectronics industry in overcoming the barriers to efficiency. They will be most successful if supported by collaborative efforts of people within the microelectronics industry, as well as with others in the

energy and energy efficiency industries; with tool and other product manufacturers and vendors; and with local, state and federal government agencies.

Develop Case Studies: Support the development of case studies, including measured, detailed energy performance data. This data will provide facility owners with objective information with which to evaluate the performance of their facilities and processes. The SEMATECH International Energy Project, which is designed to produce benchmark energy analyses, is one example of this type of activity. Such data could be produced at the level of individual factories and process tools. Key to this strategy will be development of protocols for measuring and visualizing energy performance, and distribution of the data – on the Internet, for example – so it can be readily studied and implemented elsewhere.

Create Ongoing Education Opportunities: Organize continuing professional education, including an information exchange network, where design professionals are provided opportunities to learn from industry innovators. The Northwest Power Planning Council and the Oregon Office of Energy have begun this process in the Northwest by sponsoring annual workshops with Lee Eng Lock of Supersymmetry Services. Other resources could include an Internet web site and a newsletter.

Improve Efficiency in Production Tools: Integrate design for energy efficiency with industry technical processes in a whole-system design review. We recommend that a charrette process (see charrette sidebar) be

used. This process, which has been used successfully in other industrial efficiency projects, can be used at any scale, from entire factory systems to individual process tool designs. The new tools to be deployed for the 300-millimeter wafer transition are a potential candidate for this process. Redesigning tools could then be independently evaluated to determine their cost of ownership.

Produce Efficient Design Guidelines:

Publish energy-efficiency oriented design guidelines. These could be developed collaboratively by parties with energy-efficiency expertise, organizations representing the microelectronics industry and other interested parties. Lawrence Berkeley National Laboratory and the California Institute for Energy Efficiency recently published a "Design Guide for Energy-Efficient Research Laboratories." This guide could serve as a useful platform on which to build a more comprehensive design guide for production clean rooms.

Assess Future Technology: Track advanced research and development activities that are focused on alternative production regimes for tool systems, including enhanced mini-environments and self-contained cluster tools. Facilitate the integration of energy-efficiency aspects into designs for prototype and conceptual models. The Semiconductor Research Corporation, its university-based research centers and the Electric Power Research Institute could be venues for these activities.

Provide Industry "Roadmap" Assistance: Provide objective information from an energy-efficiency and environmental perspective to inform the industry's "National Technology Roadmap for Semiconductors." This Roadmap is the industry source for planning technical research and development activities. It is revised every three years and would provide an effective context to articulate goals related to reducing industry energy use, while improving economic performance and reliability.

Support Research and Development Projects: Support potentially high-impact research and development projects designed to improve energy and resource efficiency in specific technical systems. Funding from organizations, such as the Northwest Energy Efficiency Alliance, participating industrial firms and industry associations, could be linked with appropriate technology transfer and commercialization commitments. Three examples illustrate this type of activity:

Silicon ingot furnaces: In the furnaces used to produce silicon ingots, Siemens estimates that research and development investments can improve energy efficiency by more than 50 percent, reduce use of expensive argon gas by 90 percent and potentially double furnace productivity. Reportedly, these technical improvements are applicable to the entire global base of crystal growing furnaces. If the research and development results are consistent with these expectations the energy and capital cost savings could be quite significant.

Lighting: Light guides are an advanced lighting distribution technology with potential application in this industry. This technology, which uses a remote light source and distributes light through plastic tubes, is a candidate to replace standard fluorescent lighting in clean rooms. This could save clean room operators the down-time expense and contamination problems inherent in relamping areas of the clean room where fluorescent lights have burned out.

Dry cleaning technologies: New microelectronics fabricating plants require on the order of a million gallons of water every day, a significant portion of which is used for cleaning. "Dry clean" technologies (cryogenic, laser or plasma) are being developed that promise better particle removal efficiencies, yet require

far less water and reduce wafer processing time. Care should be taken to design these new technologies to incorporate energy efficiency.

Low face velocity and particle contamination: HVAC designs using low face velocity have been shown to reduce filter bypass. However, more detailed, controlled, study of the impacts of low face velocity on particle contamination would help to quantify the non-energy benefits.

Putting it all together: a "green FAB" design charrette?

A "green FAB" design charrette could be effective in breaking through many of the technical and market barriers to improved energy efficiency in this industry.

The objective of a green fabricating plant design charrette would be to perform a detailed, systems-oriented analysis of existing and proposed designs, and to create proposals for design changes and improvements. Participants would form a technical team, spanning such disciplines as tool design; maintenance; manufacturing; facilities design; marketing; finance; environment, safety and health. The team should include the company's architect and consulting engineering firm, including mechanical, electrical and structural specialties, as well as specialists in resource-efficient design.

This team would analyze all energy-using systems of the plant, and determine where efficiencies can be realized. Examples where such a process could be effectively employed in the microelectronics industry include:

- A company with a fabricating plant that has been planned, but delayed due to market conditions;
- A company with a phased-construction plan for multiple fabs over a long time period;
- A company that wants to make environmental management a part of its corporate citizenship and market positioning;
- An engineering firm with an interest in improving the efficiency of its standard fabricating plant design
- Process tool manufacturers planning the next generation of tools, as in the 300-millimeter wafer transition

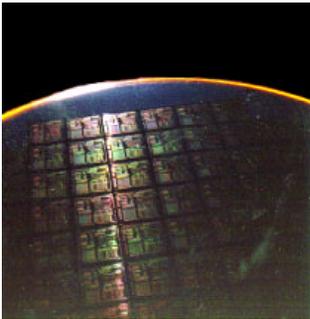
What is a design charrette?

Charrette is French for "cart." It refers to the practice used by French architecture students to cart their semester projects to the design review. Working in teams, these students were intensely involved in the creative process, constantly working with each other to refine their designs. This process was at its most intense as the teams were being transported on the "charrette" to present their design to their professors. Hence, the term charrette has come to mean a short, intensive, team-work-oriented design process.

■ Companies wanting to make improvements to mechanical and electrical systems in existing facilities.

For design charrettes to be successful, participants will need to provide the right mix of staff and consultants. They should allow time to innovate outside of production schedule time pressures. In addition, they should follow through, measure results and incorporate findings in the next plant or tool design.

As semiconductor manufacturers acquire experience with more efficient designs and processes, there is a high probability that the new approaches will become standard practice. Similarly, after an engineering firm has thought through the design issues, developed an energy-efficient plant design, and built and evaluated it for a customer, it is likely they will use this experience in their marketing and business positioning. In short, the design market will be transformed to a new level of resource efficiency.



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LET'S WORK
TOGETHER**

This report describes three key areas of the micro electronics industry where tremendous energy and other resource savings can be achieved: in fabricating facilities; in semiconductor production tools; and in the manufacturing process for silicon crystals. These savings translate to lower utility bills, of course, but also lower capital costs, increased productivity and improved environmental performance.

To bring these resource-efficient approaches to the attention of the microelectronics industry in the Pacific Northwest and elsewhere, the sponsors of this report want to help develop and carry out the strategies described earlier, including demonstration case studies that are carefully metered so efficiency results can be easily collected, analyzed and communicated. We view this as an opportunity to bring together the microelectronics industry, the electricity industry,

the energy-efficiency industry, local communities and federal and state government agencies in a partnership aimed at raising the state of the art in microelectronics manufacturing.

It is an opportunity to preserve and use wisely the very natural resources — the clean air and water, the low-cost electricity — that drew the microelectronics industry to the Pacific Northwest. This is an industry for which change is a constant, and these are changes on which this industry can thrive.

Key Industry Organizations

SIA: Semiconductor Industry Association is the trade association that represents the semiconductor manufacturers.

SRC: Semiconductor Research Corporation is an industry-funded consortium that supports university-based research centers that focus on advancing chip design and manufacturing methods.

SEMATECH: SEMATECH is a joint industry and government consortium whose mission has been to improve development of advanced, U.S.-based semiconductor manufacturing equipment. Its focus is mainly on the microelectronics chip fabrication process and necessary support facilities. The Environmental, Safety and Health Division at SEMATECH is the locus of interest in energy efficiency, and is working with the SEMATECH Facilities Council to advance their agendas.

SEMI: Semiconductor Equipment and Materials International is a global standards-setting organization, with technical committees, trade shows and technical conferences. Members are suppliers to the semiconductor manufacturers. (SEMI/SEMATECH members are U.S. tool and equipment suppliers, who work with SEMATECH through such venues as the Supplier Advisory Council.)

Sound Interesting? Care to join us?

For more information, call:

Jeff Harris, Northwest Power Planning Council,
1-800-222-3355, or 503-222-5161
or e-mail: jharris@nwppc.org.

Karl Vischer, Bonneville Power Administration,
1-503-230-3445,
or e-mail: kvischer@bpa.gov.

Chris Robertson, Chris Robertson and Associates,
1-503-287-5477
or e-mail: crobertson@igc.org



Produced by the
Northwest Power Planning Council
851 S.W. Sixth Avenue, Suite 1100
Portland, Oregon 97204



Oregon
Office of Energy