Design for Energy Efficiency Adds Value to Semiconductor Company Shareholders

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Abstract

Conservation of resources and energy efficiency is an enterprise with many variables. The issues for implementing such a policy are not necessarily obvious or result in the most expensive option. A comprehensive monitoring of the relevant data requires great expertise. The problems are discussed in detail and various solutions illustrated with vivid examples. The excellent capital savings and real reduction in overheads should be highly attractive to cost conscious Fab management team members.

Introduction

Advanced resource efficiency, which includes Design for Energy Efficiency (DfEE), has measurably increased earnings per share in numerous industrial companies including semiconductor manufacturers. This article describes how energy efficiency investments can improve reliability and productivity, help to meet the strategic goals of the firm, and add to shareholder value.

Some examples and results you will find in this article include:

- An introduction to the fundamentals of energy efficient design from a systems integration perspective, and a source for detailed, objective technical information to support a systems analysis of fab design for energy efficiency
- STMicroelectronics, an integrated semiconductor manufacturer, expects its energy efficiency strategy to add some US $50 million per year to its bottom line, equivalent to finding a new customer to buy US $500 million of chips each year, and positioning it as a leader in addressing the growing environmental concerns of its customers
- Amkor/Anam's energy efficiency retrofit cut its electric bill US $2 million per year at this semiconductor back end packaging plant
- Western Digital's factory rebuild features energy efficiency design strategies which improved clean room cleanliness from class 100,000 to class 10 and cut total factory energy loads by 45 percent at less capital cost compared to conventional design
- First National Bank of Omaha's new data centre features an ultra-high-availability, lowest cost-of-ownership and environmentally green power supply which is keyed to marketing strategy addressing their customers' primary business concerns for reliability and cost effective service
- Improved exhaust systems, a critical point at which process tools and facilities intersect, can improve reliability in semiconductor process tools, reduce energy use, and reduce capital costs in new fab designs.

Energy efficiency opportunities in fabs and other electronics factories are numerous and valuable just in terms of energy cost savings. Management should regard design for energy efficiency as a strategy to capture both energy cost savings and the much higher value non-energy benefits, the synergies inherent in energy efficiency projects, as described below.

The non-energy benefits created by investments in energy efficiency can be worth much more than just the value of the energy savings. Well designed and implemented energy efficiency management plans improve both top and bottom line results. Some thirty non-energy benefits specific to fabs are identified and briefly described in Box 1.

A few key examples drawn from this list include:

- reduce capital cost and construction time in the next fab
- improve time-to-market from a new or rebuilt fab or new tool set and, hence, increase product profits from the device that is manufactured there
- improve reliability in both process and facilities
- improve yield, thereby decreasing waste and lost revenue
- improve throughput, production flexibility and set-up time
- reduce contamination risks inside the fab
- improve employee safety
- reduce regulatory exposure
- strengthen customer, investor, public and employee perceptions of the company as a quality and environmental leader.

Electricity is about 1 or 2 percent of semiconductor production costs. Energy efficiency opportunities are often passed over in favour of other investments that are perceived as being more central to the company's mission and

BOX 1 THE NON-ENERGY BENEFITS OF ENERGY EFFICIENCY INVESTMENTS

Each of the non-energy benefits listed below can be attributed to energy efficiency improvements in fabs.

Improve cost structure

- Reduce capital cost of the next fab
- Reduce operating costs (electricity, natural gas, water)
- Reduce maintenance cost
- Reduce air balancing cost
- Reduce effects of infrastructure instability (electric, gas or water supply disruptions)
- Reduce insurance and risk management costs

Improve critical time constants

- Improve time-to-market from a new or rebuilt fab or new tool set and increase profits from the device manufactured there.
- Extend equipment life in motor drive systems
- Extend maintenance interval for motors
- Improve process cycle time in furnaces
- Stretch infrastructure and provide time to add capacity

Improve manufacturing reliability

- “Stretch” capacity
- Reduce contamination risks inside the fab
- Improve maintainability
- Improve equipment life
- Improve power factor
- Improve facilities operation effectiveness
- Improve process engineer flexibility and precision
- Improve run-to-run process repeatability and yield
- Improve response to power supply disruptions

Improve environmental health and safety performance

- Reduce regulatory exposure
- Create environmental “auto-compliance”
- Reduce likelihood of environmental liabilities
- Improve safety and ergonomics
- Generate profits from sale of avoided greenhouse gas emissions

Improve reputation of company as a quality and environmental leader

- Strengthen customer, investor, public and employee relations
- Respond to customer interests in greening the supply chain
- Improve earnings for investors
- Create positive effects in employee morale, retention and recruitment
- Create positive effects in community and governmental relationships

contributing to profits. This is incorrect, both because energy, like any saved overhead, drops to the bottom line, contributing a far larger portion of profits than of revenues, and because energy investments can reduce fab construction time and cost and improve critical operating parameters. With industry margins thinning, the ratio of energy costs to profit deserves attention; a 10 percent profit margin and 2 percent energy cost means that saving half of fab electricity (an achievable goal) can increase profits by 10 percent, just counting the energy bill savings.

In this article you will learn why these DfEE investments have significantly more value than just energy cost savings, and why firms seeking to improve their environmental and financial performance have adopted resource efficiency as a significant strategy. (For more information, recent books and articles document scores of technical examples and the experience of companies significantly improving their energy efficiency performance by up to 50 percent or more, refs [1] to [5]).

Each fab is different, yet surprisingly similar in relative efficiency improvement terms and has large opportunities to improve energy efficiency. I have observed fabs ranging in age from 40 years old to brand-new. They include new mega-fabs with 30 megawatt loads and small, specialized facilities with less than 5 MW loads. Virtually every technical system and subsystem presents significant efficiency opportunities.

Energy efficiency benefits both existing and future facilities. A systems-oriented perspective, which involves design integration, technology and the company’s organization, is necessary to capture many of these benefits. Senior management can achieve these benefits by setting aggressive goals and resolving issues which limit the organization from achieving these goals.

SENIOR MANAGEMENT ATTENTION

It is tempting to see energy efficiency as mainly a technical problem to be solved by engineers, but I believe that is not the case. Based on my observations of the industry, I think the organizational change issues are at least as significant as the engineering knowledge and experience needed to achieve world class energy efficiency, and likely more so. If senior management wants to achieve company-wide, world-class performance in this area, then organizational constraints and issues will need to be identified and resolved.

The strategic value of energy efficiency benefits is large. Management should set aggressive requirements, goals and strategies to identify, quantify and capture this under-valued asset. Two semiconductor companies, STMicroelectronics and IBM, have goals of 5% and 4% per year energy efficiency improvement. These are ambitious and achievable goals that challenge the organization to continuously do better.

Strategies to achieve these goals will be more effective and valuable if they consider the allocation of benefits (and costs) on an integrated whole-systems basis throughout the whole organization. Benefits gained go well beyond the energy budget and the facilities and ESH departments.

Companies have achieved and continue to achieve dramatic results with well-structured corporate-wide energy management programs. Features include site experts, outside coaches, cross-functional teams, aligned incentives, capital budgets, measurement requirements, accountability and continuous improvement. Their energy efficiency investment strategies build a platform for future flexibility, capture low hanging fruit first and generate savings to finance later investments.

Empowered cross-functional teams should help to plan and evaluate energy and resource efficiency projects. The approach includes whole-system considerations in the project steps: plan, design, budget, implementation, measurement, evaluation, communication and feedback for continuous improvement. They should define technical energy efficiency performance metrics (kW/ton, cfm or gpm/kW) and assure the measurement systems are in place to track performance improvements.

Their charge includes seeking improvements and optimizing the timing and sequencing of key projects in both new construction plans and existing facilities. This is important so that large potential opportunities for improvement are not foreclosed by improper project sequencing, a value-losing effect that is all too common when care and attention are not well focused on these opportunities.

The team is responsible to account for budget savings, improved timing issues, operational improvements, better external relations and the numerous other benefits likely to occur in many aspects of the fab and the company's business. Depending on the specifics of the project, benefits (and costs) may be found in mechanical and electrical facilities, tool hookups and facility interfaces, process engineering, new fab development, marketing and customer relations, investor relations, regulatory compliance, ESH and outside contractors for bulk gas supply, ultra-pure water, engineering and maintenance services and electric, gas and water utility services.

A key to helping technical staffs evaluate energy efficiency investments is to provide them with guidance about the rate of return the company expects from these projects. Many engineers are accustomed to working with payback calculations rather than return on investment. Converting payback to ROI can be easily done with the formula which energy analyst Amory B. Lovins calls the "Rosetta Stone." Payback can be converted to after tax ROI by the equation:

$$\frac{1 - \text{marginal tax rate}}{\text{simple payback } (y) - 1}$$

So, if the company's marginal tax rate is 36 percent, then a two year payback equals a 64 percent ROI per year and an 18 month payback equals 128 percent ROI per year.

Chief financial officers should examine their methodology and data sets used for evaluating these investments. It will be worthwhile to collect broader data on the potential costs and benefits of energy efficiency projects, determine their economic value, and incorporate all significant terms into the financial analysis. A detailed net present value analysis by the company's financial group will be required to fully value the multiple, high-value benefits attributable to DfEE investments.

Accounting across functional boundaries will be required to capture the full value of some investments, since several departmental budgets, line items, and activities will typically be affected by resource efficiency strategies. Often costs and benefits will be buried in numerous parts of the organization's budget, and various levels in the organization will have different interests which are enhanced by energy efficiency strategies. Some, like speedier time-to-market, go to the core of competitive strategy. Staff members in affected segments of the organization may need additional training, guidance and requirements to assist the financial analyst to identify and collect relevant data.

Potential negative effects may be encountered and must also be considered. Concerns about risk and reliability (always at the top of the list), cost impacts, opportunity costs of diverting capital or staff time to energy projects and any other items should be carefully considered and addressed in the project planning and analysis.

Some managers deny the existence of significant energy efficiency opportunities. They believe their plants to be already as efficient as is economically rational, and that even if some efficiency gains could be achieved their total value is not so large as to warrant shifting time and attention from core business activities. Resistance also occurs in managers who have historically been tasked and evaluated on meeting the strict reliability and performance goals needed to maintain the clean room manufacturing environment. The suggestion of inefficiency in their plants is felt by some as implied criticism and blame.

This denial and resistance is a normal human reaction, and I encourage facility managers and corporate directors to respond from these perspectives: (1) advanced energy efficiency engineering is a highly specialized competency which has not been systematically, widely, and deeply employed in the industry to this date, and (2) facility operations can now be converted from overhead into profit centres to provide a measurable boost to earnings per share. This adds value to the facility management team's work and contributes to profitability.

BOX 2

DESIGN FOR ENERGY EFFICIENCY

The term Design for Energy Efficiency (DfEE) is used in this article. This is different from Design for Environment (DfE), which is most often associated with environmental regulatory compliance, toxics reduction, air and water quality permitting, employee health and safety, pollution prevention, product design and stewardship, and environmental protection. These important subjects are usually in the province of the Environment, Safety and Health (ESH) organizational units.

Energy efficiency is often appended to the extensive ESH portfolio. This is due in part to the important environmental benefits of energy efficiency and also to the notion that energy efficiency is an "environmental" issue with possible regulatory implications. However, energy efficiency affects many parts of the organization, for many of the reasons described in this article, so it is useful to consider DfEE in a broader context.

DESIGN FOR ENERGY EFFICIENCY – FUNDAMENTALS

To achieve advanced energy efficiency results requires a design philosophy grounded on fundamental physical principles and is expressed through a comprehensive, sophisticated systems integration perspective that considers all of the building's mechanical and electrical systems, rigorously measures results, and feeds those results to the next design.

These fundamental design principles were described in a presentation by Amory B. Lovins at the Center for Environmentally Benign Semiconductor Manufacturing in August 1998. In "Negawatts for Fabs: Advanced Energy Productivity for Fun and Profit", ref. [6], he described these attributes as essential to achieving advanced energy efficiency results, often making large energy savings cost less than small or no savings:

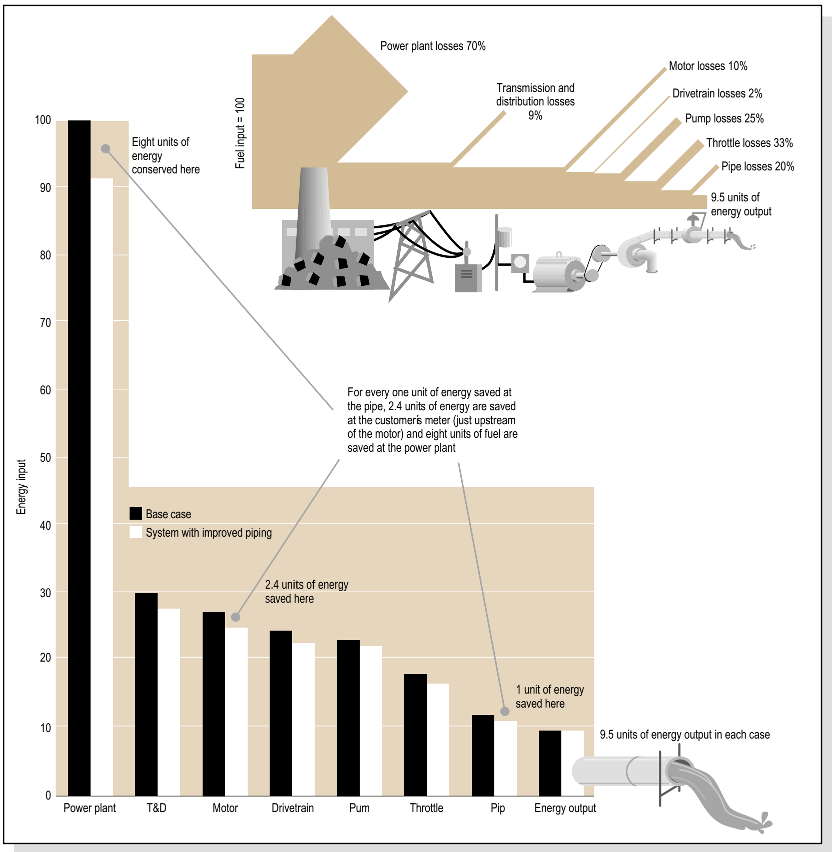

Figure 1
Saving one unit of flow or friction in pipes reduces the size and cost of pumps, motors, etc. by around twofold, and the fuel burned at the power station by about ten-fold
(Source: ESOURCE)

- use whole system design to make big energy savings cost less than small savings
- integrate design
- count savings from reduced infrastructure and other attributable benefits
- minimize friction first
- meticulously reduce pressure drop and static head
- use smooth, short, optimally designed pipes and ducts
- use few, short, sweet bends; install turning vanes
- use few low-pressure-drop valves/dampers
- use careful detailing to minimize turbulence
- minimize parasitic loads
- minimize flow, effectively upsizing existing pipes and ducts, then downsize pumps/fans
- design low-face-velocity (<200 feet per minute) filters and coils
- analogously for all power wiring: make it fatter
- start downstream at the end use to capture compounding savings further upstream, as illustrated in Figure 1.

Industrial pumping systems (of which fabs have many) designed to these principles can have dramatic effects. For example, a typical pumping loop in Interface Corporation's design for a new factory in Shanghai was first designed without these considerations and was conventionally "optimized" with trade-offs between the pipe diameter and the energy needed to overcome the pressure drop. The system was then redesigned, by Interface Engineer Jan Schilham, using a whole system approach to include consideration of the pipe size, layout, and the size of the motor, pump, variable frequency drive, and electrical service.

The original, conventionally optimized design required 95 horsepower and the improved design delivered the same service at 7 horsepower – a 92 percent saving. The new design cost less to build and worked more reliably. According to Lovins, this required "no new technologies-just two design changes: big pipes, small pumps (not the reverse) ; lay out pipes first, then the equipment (not the reverse). Optimize the whole system, not just each part in isolation (which pessimizes the system), and optimize for multiple benefits, not just one."

Lee Eng Lock, the Technical Director of Supersymmetry Services and a leading practitioner of whole-system energy-efficient design, summarizes a few of the results of his firm's design strategy in mechanical systems:

"Energy efficiency generally means downsized components, less stress and strain, lower rpm, less noise, less vibration, fewer valves straining hard to open or close, less water hammer, less inertia to overcome, less inrush to electricals to affect other loads, less electromagnetic and radio frequency interference in the wires and the air, smaller structures to hold it all up, higher frequencies to fight (easier to cancel high frequency noise and vibration than the low frequencies), lower heat loads, less congestion in the fabs due to huge stuff which crams together and causes sharp turns, inelegant layouts which promote more problems in safety, and less stuff to maintain."

According to Lee, whole-systems design perspective eliminates both equipment and the space it requires, reducing the capital cost throughout the mechanical, electrical and architectural budgets. Eliminating unneeded equipment, and reducing friction, pressure drops, turbulence, and flow, can in turn reduce parasitic cooling loads. In some fabs which Supersymmetry has measured, the parasitic cooling loads are approximately equal to the cooling loads imposed by the production tools. Parasitic loads are relatively easy to minimize, effectively reducing the required HVAC capacity and the electrical service necessary to power it.

Systems integration also means looking to the immediate site for opportunities to use flows of differing temperatures to meet needs elsewhere on or near the site. For example, Lee reports, "There is no energy efficiency design integration of the suppliers of gases with the fabs. Gas suppliers are next door to fabs and they have cooling towers busily throwing away heat while their customer (the fab) is busily making steam with large boilers." The bulk gas supplier's electric bill is often paid for by the fab customer. Integrating the energy design aspects helps the fab get its money's worth from this expenditure.

Connecting flows of different temperatures means using incoming and outgoing water or air for things like precooling make-up air or serving the process cooling needs. "In Oregon people heat up the process water entering the fabs with boilers, when in fact they should be using the cold incoming mountain water to cool the process in the fab, thereby preheat the water, and save on both ends. In many areas boilers can be displaced by use of ground water as heat source and heat sink."

Simpler systems are more reliable. They are also cheaper to build, even including due regard for needed redundancy and capacity expansion flexibility requirements. Construction is easier and faster, which if planned correctly can shorten the critical path to completion of a new plant.

Companies seeking an objective information source on energy efficiency technology and design can contact E-Source, Inc. E-Source publishes the “State of the Art” series, a technology encyclopedia which includes “Drive Power” and “Space Cooling and Air Handling” volumes, both of special interest to fabs, ref. [7].

MEASURE ENERGY EFFICIENCY PERFORMANCE

Accurate measurement of energy efficiency performance is the essential key to energy efficiency diagnosis and to achieving deep and lasting efficiency improvements. An effective measurement, data archive and data visualization system provides the critical analytical capability required for continuous improvement. It supports the company’s learning curve, as personnel and physical systems change over time, lest it become a forgetting curve.

Facility management control systems (FMCS) are typically not designed to measure the efficiency with which facility services are provided to each end-use task. FMCS usually lack critical sensors and, where a sensor is present, its accuracy and resolution are often inadequate for the efficiency measurement task.

The qualities of an effective energy efficiency performance measurement and data visualization system include the following:

- Accuracy and reliability are commensurate with the value of the information, which means high-quality, accurate, stable sensors for fab scale electric loads
- Reliability and stability over time are necessary (so data users will trust the system and make decisions based on its outputs)
- Visualization of high frequency data permits system performance analysis in real time
- Data archive captures and saves high frequency performance data on each energy-using system, starting at installation
- Baseline energy use is compared with improvements over time.

A measurement system built on this protocol provides feedback and comparison capabilities that are useful and beneficial to many in the organization:

- Facility managers, to optimize plant operational efficiency over time
- Plant operators, to detect, diagnose and troubleshoot out-of-spec conditions
- Facility management group, to compare energy efficiency strategies from fab to fab
- Designers and specifiers, to improve the next plant design (the continuous improvement cycle — require, design, build, measure, analyse, improve, repeat —can only be completed with accurate data and feedback)
- Corporate finance, to evaluate the economic performance of energy efficiency investments.

Figures 2 and 3 illustrate the use of performance data from chilled water systems. The graphs are from Electric Eye™, a data visualization system proprietary to Supersymmetry Services and Electric Eye Pte.Ltd, ref. [8].

The data in these examples are presented at one minute intervals with a total system performance accuracy within +/- 5 percent, which is the accuracy required to test chiller efficiency by the Air Conditioning and Refrigeration Institute in their Standard 550-98.

Figure 2 illustrates patterns in chiller operation. It measures the kW per ton of refrigeration provided by the chiller. With these data, operators can see that their chiller is not performing to their purchase point specification. Problems with cycling and operating at low load conditions are also obvious from such data. These conditions, which are costly and degrade reliability, can only be seen with high-resolution, high-accuracy sensors and graphics.

Figure 3 documents the baseline performance versus improved performance of a complete chilled water system (chillers, pumps, and cooling towers). In this case the red (top) cloud of data points represents the system running before energy efficiency improvements were implemented. The blue (lower) cloud illustrates the post-improvement performance.

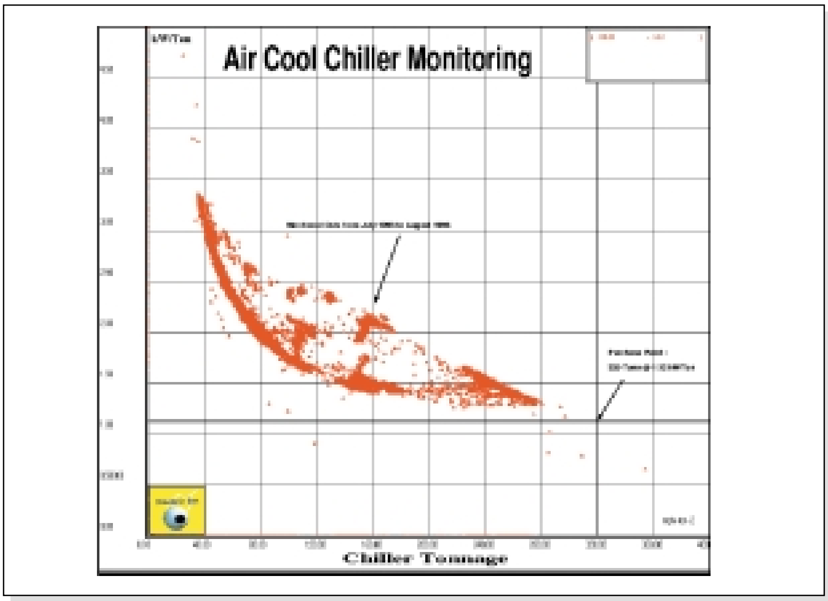

Figure 2
(Source: Supersymmetry Services)

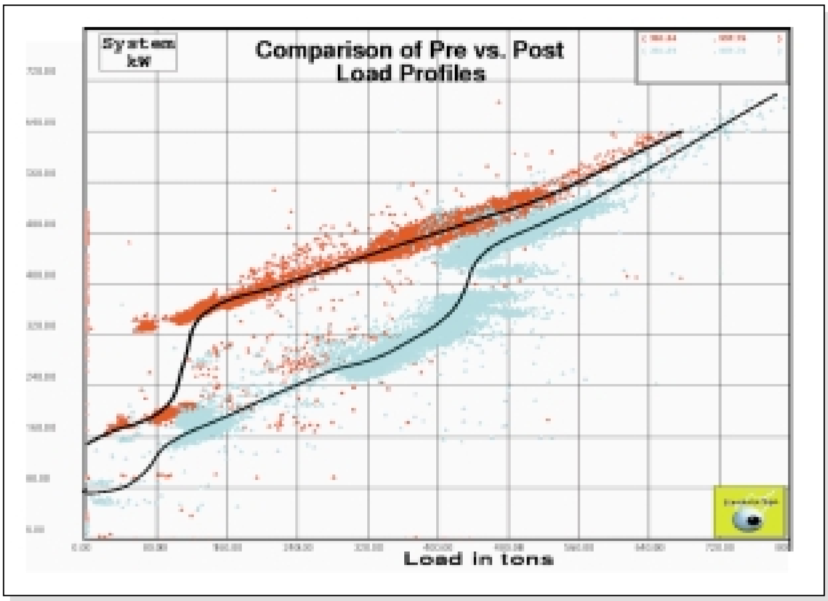

Figure 3
Comparison of Pre vs. Post Load Profiles
(Source: Supersymmetry Services)

Curves fitted through each data set define the means. The area between the curves represents actual energy savings.

This type of data analysis and presentation will be useful as financial officers seek to document, package and sell credits for reductions in energy related carbon dioxide emissions due to improvements in energy efficiency.

COST SAVINGS PLUS STRATEGIC IMPROVEMENTS: THREE MANUFACTURERS' RESULTS

STMicroelectronics has been implementing energy efficiency projects for most of the 1990s at their Ang Mo Kio fab (AMK) in Singapore. This fab is now one of the most energy efficient in the world. Table 1 illustrates the economic results and some statistics from about 30 energy efficiency projects at AMK. The investment and savings data are in thousands of US dollars.

STM's management is moving forward with technical studies and implementation planning throughout their system. STM's system wide goal is set to improve energy efficiency by 5 percent per year, ref. [9]. Their published intent is to reduce carbon dioxide (from energy use) per chip by more than 75 percent, thereby reducing global warming gas emissions, ref. [10]. To do this, STM plans to improve energy efficiency in each plant and move as rapidly as possible toward reduced carbon energy sources. In their Vision 2000 Initiative they state their goal: "To be 'best-in-class' in environmental protection."

Pasquale Pistorio, the STM CEO is fond of the phrase "Ecology is Free." Lee Eng Lock, the Technical Director of Supersymmetry Services and consultant to STM's AMK projects, likes the phrase "Efficiency is better than free: ask for more."

Amkor/Anam, a chip packaging facility in the Philippines, was also the subject of an energy efficiency retrofit. Fortune magazine reported their results as follows, ref. [11],:

"Ed Ornela, the company's corporate engineering director in the Philippines, calculates that the new air compressors cut the annual electric bill by $580,000; a new chiller and changes in chiller operation saved another $620,000; and other improvements lopped off $919,000."

In "Cool Companies" Joe Romm states that, "While chip output doubled from 1995 to 1997, the electricity bill declined. Adjusting for chip size, the power cost per chip fell 60 percent", ref. [12]. Amkor/Anam is one of the low cost producers in this competitive industry segment.

Western Digital's factory rehabilitation in Kuala Lumpur, Malaysia won the prestigious 1996 Energy Project of the Year award by the Association of Energy Engineers for the project's energy efficiency contractor, Supersymmetry Services. WD converted an 80,000 square foot factory, eliminating 15,000 square feet of class 100,000 and 10,000 clean room. The rebuilt facility contained a 12,000 square foot class 10 clean room and the size of the factory increased to 90,000 square feet. Improvements to the factory include:

- Recirculation air flows increased by about 15 times
- Filter efficiency increased by over 10,000 fold
- Chillers rebuilt to eliminate CFCs and improve efficiency, saving 75% of the cost of new chillers
- Lighting improved to 0.5 watts per square foot
- Improved vacuum pumps, compressed air, fans, fan motors, pumps, pump motors, cooling towers
- Cut recirculation air pressure drop to 1.5 inches water gauge
- Cut static pressure in chilled and condenser water pumping from 100 to 35 feet.

The power density of the building was reduced 45 percent from 16.9 to 9.4 watts per square foot. The capital cost to achieve these impressive results was slightly less than the competing bid to rebuild the plant using conventional, energy inefficient design practice. WD simultaneously achieved lower operating costs, lower capital costs, and greater reliability

The plant's chillers were converted to a non-CFC refrigerant and their efficiency was increased at the same time. This saved 75 percent of the cost of new chillers. However, WD considered speed of installation more important than cost savings. The refrigerant conversion was done much faster than new chillers could be ordered, delivered and installed. This shortened the critical path, and Western Digital made a reasoned choice to give up some potential energy efficiency improvements to meet the much more strategic interest in speeding time to market.

This facility is used for disk drive manufacturing, a highly competitive business with margins as thin as the DRAM business. Western Digital met all three competing interests: minimize both first cost and operating cost, and get product to market as quickly as possible.

The top line benefits are important. Vince Mastroprietto, the former managing director for this facility, said in 1997 that WD is marketing this plant as one of the world's low cost producers. The energy savings and reduced capital costs provide pricing flexibility which higher cost producers do not enjoy.

TABLE 1.
STM AMK ENERGY PROJECT SUMMARY (US $000)

	Investment	Savings/y	Payback/y
All Projects	$2,071	$2,190	0.95
Largest	$1,044	$790	1.32
Smallest	$0	$0.3	–

Source : STMicroelectronics

HIGH-AVAILABILITY GREEN POWER SUPPLY IMPROVES ELECTRIC SYSTEM RELIABILITY

A 1997 construction accident at Intel's Chandler, Arizona fab took out the two electric power distribution circuits to the plant. The fab's uninterruptible power supply (UPS) system failed to come on line, and Intel reportedly lost about a thousand wafers that were in process at the time.

Electric power supply reliability is always an issue for semiconductor fabs. Power supply to fabs in many parts of the world is unstable and requires the use of redundant generation capacity and UPS to condition the raw electricity and provide reliable power supply availability within the tight specification of the Computer Business Equipment Manufacturers Association (known as the CBEMA curve).

Critical loads most often protected include computer centres and distributed computer controls on tools so recipes can be saved in the event of a power disturbance. These loads are highly sensitive to small variations in power supply. Process disruptions and large economic losses can occur when the power supply to a fab fails to meet the CBEMA specification.

The total electric demand per fab protected by UPS varies from almost zero to greater than 50 percent, depending on the reliability of the local electric distribution system. In some parts of Asia, the entire plant must sometimes be operated on redundant local backup power supplies, mainly diesel generators, which are themselves unreliable.

Sure Power Corporation, ref. [13], provides new and strong competition for the UPS and backup electrical generation industry. Its high-availability power supply system, now in use in the data centre industry, is being adapted to the fab business environment. Two semiconductor industry engineering firms are actively investigating integration of this technology into fab designs. At least three major semiconductor manufacturer are studying the technology for application in their factory systems.

Both data centres and fabs have 7x24 operating requirements and experience large economic losses and business disruption if power supply fails. Competition in customer service reliability is a major top line issue for data centres. A one hour outage can cost a data centre customer millions of dollars.

The new First National Bank of Omaha (FNBO) Technology Center, a major credit card transaction processor, contracted Sure Power to provide CBEMA curve power to its critical computer loads at no less than 6 nines availability, matching or exceeding their computer system's availability. Independent probabilistic risk analysis estimates the "independent failure-based unavailability" for this system to be 3×10^{-8}. This corresponds to CBEMA grade availability at greater than 7 nines.

The electric transmission and distribution grid in the US is becoming less stable as the electric power sector is deregulated, further increasing the importance of reliability investments. In the Western US in 1997 a transmission line went down on a calm sunny day, due to reduced right-of-way maintenance, and parts of 11 states found themselves without power for up to eight hours. The 1994 Texas Instruments Reliability Survey of 20 fabs found 166 events leading to loss of power with greater than 700 total hours of lost production. Weather events like lightning, wind and storms periodically knock out the power supply in many parts of the world. Climate change scientists predict more extreme and frequent weather events as weather patterns change.

Conventional UPS systems are normally some combination of equipment that may include switch gear, motor generator sets, lead-acid battery banks, and diesel generators. UPS systems require significant real-estate and equipment capital investment, maintenance, testing, and periodic replacement of major components. In some regions air quality permits and noise abatement are required. UPS systems consume energy, often 6 to 8 percent of the load protected by the UPS, which is lost as heat and must be removed by the HVAC system, further increasing the demand for power and the capital investment required for the HVAC system. Batteries also are potentially dangerous and present employee safety issues.

In contrast, the Sure Power System is comprised of fuel cells plus flywheel and motor generator equipment. ONSI Corporation, a subsidiary of United Technologies, supplies the fuel cells and Piller, a Lahmeyer company, supplies the rotary equipment. These are integrated into a highly robust, proprietary system designed to provide CBEMA grade power to the critical loads at a contracted level of availability.

The Sure Power system, at 6 to 7 nines availability, is cheaper on a net present value basis and is more reliable than a conventional UPS system at 4 nines availability. It operates continuously to meet the critical electric load, provides useful heat and surplus power for other loads in the facility, and operates independently of the grid when normal power supply is disrupted. The system is modular and scaleable to the size of fab electric loads.

The fuel cells convert hydrogen-rich fuel, processed on-site, to electricity, heat and water in an electro-chemical reaction. Suitable fuels include natural gas, CNG, LNG, or propane (or, in future, hydrogen when it becomes available as a fuel). The system's combined electric and thermal conversion efficiency exceeds 80 percent. Among the additional benefits are that the system:

- uses about 30 per cent less real estate than a conventional UPS
- can be sited outdoors
- requires no supplemental cooling
- runs in parallel with the electric grid or independently
- eliminates batteries
- avoids electric distribution system losses from the utility's power plant through the transmission and distribution system and through the battery charging, hence improving electrical system efficiency
- requires far less maintenance than a conventional UPS
- can be third-party-financed off balance sheet, freeing up fab capital to use for more productive purposes, and
- the facility's traditional electric utility can invest in and operate the system, creating a profitable opportunity for all parties.

Environmentally, the Sure Power System is virtually pollution free. It is exempt from air quality permits in Southern California, the most stringent air quality area of the US. It operates quietly, so local noise abatement is not required. Analysis by the Center for Energy and Climate Solutions shows the Sure Power System saves 1/3 to 1/2 of the carbon dioxide produced by a traditional electric utility plus UPS system. The actual savings depend on the local electricity grid and how much of the fuel cell's heat output can be used.

As with the other examples, a whole-systems perspective is required to capture the benefits of this technology. The classic wrong question which is often asked by those charged with buying electricity is, "How much is the cost per kW of this system?" The more correct questions to ask are: "What level of reliability is worth buying for which loads?" and "For those loads, what is the net present value of competing alternatives, when considering the whole-system economic effects?"

IMPROVED EXHAUST CONTROLS ENHANCE PROCESS AND FACILITY SERVICES

The exhaust system is a critical interface point between process tools and the facility HVAC system, ref. [14]. Lovins estimates that 1 cfm (1.7 m3/hr) is worth more than US $50 in present value energy costs.

Progressive Technologies, Inc. (PTI) exhaust control valve technology is a unique innovation in the field – simple, robust, passive, and fast-reacting, with one moving part powered by gravity and exhaust flow. It has significant implications for the semiconductor industry. Used now in some ten percent of process tools, I expect its use to increase as whole-systems energy efficiency engineering increases.

Facility engineering staff may dismiss this technology as an energy conservation measure if they use a non-systemic, narrowly focused energy payback analysis. The cost/benefit analysis considering energy savings alone is not compelling. But when considered using whole-systems, strategic perspectives, the PTI technology becomes more than just an energy saver or a process improvement device.

The primary business case for installing exhaust control valves from PTI is that they improve process stability and yield in atmospheric pressure tools. The technology stabilizes exhaust flow, permitting flow to be turned down typically 2 to 5 fold. It improves the process run-to-run repeatability, improves productivity (for example, by increasing the number of wafers which can be loaded into a furnace per run), and reduces wafer defects induced by the previously poorly controlled exhaust flow.

The technology confers both tactical and strategic benefits. An organization that fully uses this technology will see benefits in process and facilities engineering, environmental safety and health, new fab development engineering and specification, corporate finance, and the competitiveness of new product development. Valuable synergies happen when exhaust flow can be rigorously controlled and turned down. For example:

- Eliminates back flow through the tools, improving employee safety and fab reliability
- Reduces exhaust flow and therefore fan energy (which is a cube-law load – electricity use declines as the third power of flow reduction)
- Conserves or stretches exhaust system capacity
- Needs less make-up air to replace the now reduced exhaust flow, decreasing make-up air conditioning energy costs (the fans and pumps are also cube-law loads)
- Provides surplus capacity by similarly conserving or stretching make-up air and chilled water system capacities
- Eliminates exhaust air balancing costs for tools controlled with this technology
- Achieve energy cost savings estimated to be $3 to $4 per year for each cubic foot per minute exhaust reduction, depending on climate. This could be worth several hundred thousand US$ per year
- Reduce exhaust abatement costs.

Even more valuable strategic effects can occur in a new fab. If PTI's exhaust control valve technology is installed comprehensively in a new fab, then exhaust and chilled water capacity requirements are reduced substantially.

The capital cost savings in the HVAC system alone can be significant. A 100 cfm reduction in exhaust flow is equal to a 1 ton reduction in required chilled water system capacity in hot humid climates. Complete HVAC systems cost on the order of $3000 per ton of installed capacity. A substantial turn down in exhaust flow rates can be worth a nice sum, perhaps avoiding an entire large chiller and its associated piping, pumps, cooling towers and related equipment.

The time-to-market benefits to the firm are perhaps the most important. PTI expects up to six weeks can be taken off the time required to produce the first silicon wafers in a new fab, because exhaust air balancing is automatic and tool qualification time is reduced. How much could this be worth in a competitive race to the marketplace for the next generation device? In the recent book *Managing the Design Factory*, D.G. Reinertsen cites a McKinsey study: "...six months delay [for a new electronics product] can be worth 33 percent of life-cycle profits." ref. [15]. If the McKinsey study is right, and if PTI can achieve six weeks faster startup, then this technology increases profits by 8.25 percent.

This technology will be successfully adopted and provide its full revenue, profits, cost saving and reliability benefits if process, facility, ESH, and new fab development engineering staffs have a common understanding of the technology requirements and costs and benefits across the whole system. Only a system-wide, cross-functional analysis can reveal the full value of this technology.

CONCLUSION

Advanced resource efficiency and design for energy efficiency create powerful synergies worth far more than energy cost savings alone. This article focuses on whole-system design strategy to capture multiple non-energy benefits from single investments. In order to achieve world class performance in advanced energy and resource efficiency, management must create the resource-efficient-company vision, establish annual goals for continuous improvement, and align the organization towards the desired results.

The fab of the future can integrate these (and many other) technologies and whole-system design strategies to produce more competitive businesses and profitably meet the emergent, post-Kyoto environmental interests.

The resource efficiency agenda is one which the semiconductor industry is uniquely positioned to help lead. The semiconductor manufacturers can invite tool vendors, design firms, construction companies and other stakeholder groups to help co-create a vision of future fabs designed to achieve advanced resource efficiency. All will need to participate for the industry as a whole to be successful in this endeavour. If all participate, the industry will open opportunities for ecological renewal, even as the industry continues its growth curve to meet society's demand for increased electronics resource productivity.

Shareholders, customers, suppliers, the communities in which companies do business, and the people who make up the industry all stand to benefit from advanced resource efficiency.

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Mr. Robertson has been working on energy efficiency opportunities in the semiconductor industry since 1995, was a member of SEMATECH International Energy Project Technical Advisory Board, and is presently leading the Microelectronics Energy Efficiency Initiative for the Northwest Energy Efficiency Alliance (www.nwalliance.org). Consulting practice and network business alliances are focused in two areas:

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