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ENERGY, ELECTRONICS, AND ECOLOGY; TURNING A NEGATIVE INTO A POSITIVE

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ABSTRACT

Energy generation and consumption dominate public awareness of global ecological impact. Ecologically responsible design and application of electronic systems rehabilitate perceptions of technology from wasteful and insensitive to conservative, green, and ecologically sound. Even more important than changing perceptions, electronics hold the potential to alleviate energy scarcity with minimal ecological impact.

This paper presents examples drawn from electronics manufacturing, alternative energy production and distribution, LED lighting, and hybrid and electric vehicles illustrating opportunities to enhance the image (and marketability) of the electronics industry and ways to substantially improve the ecological impact of energy consumption and usage.

Key words: alternative energy, energy consumption, ecological impact.

INTRODUCTION

The public perceives the electronics industry as wasteful and insensitive to conservation. Figure 1 reproduces a commonly used photograph depicting “e-waste” or discarded electronic equipment in landfills. Short product cycles and rapid technology evolution reinforce this notion since most consumers replace electronic equipment every one or two years.

Electronics manufacturing realities often disappoint as well. For example, in 2002 Williams, et al, studied the ecological impact for the production of a 32MB DRAM[1]. This analysis shows that manufacture of a 2gm chip consumes 1.6kg of petroleum, 72gm of chemicals, 700gm gasses, and 32kg of water. Figure 2 shows a portion of the analysis. Additionally, the use of materials with well-known hazards, including Acetone, Arsenic, Benzene, Cadmium, Lead, Toluene, and Trichloroethylene increase environmental and health risk.

Finally, while acutely aware of the energy consumption by electronic equipment during use, the public may not fully appreciate the critical role of electronics in the efficient generation of energy, especially alternative energy such as solar, wind and fuel cells.

Figure 1. Landfill e-waste reflects public perceptions of a wasteful electronics industry.

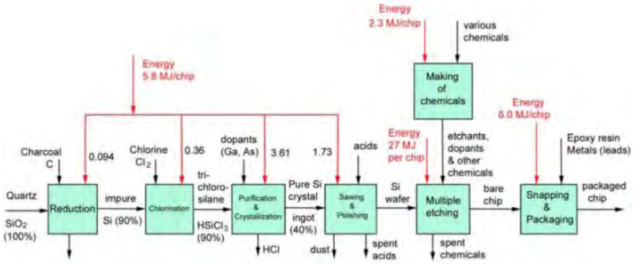


Figure 2. Ecological impact of memory chip production[1].

In the balance of this paper, we present a series of examples highlighting strategies to improve the ecological impact of energy production and consumption, and, in turn, to enhance the image and marketability of the electronics industry.

EXAMPLE 1: MANUFACTURING ENERGY AWARENESS

Manufacturing energy awareness refers to the notion of analyzing the energy consumption of a manufacturing process on a footing equal to the analysis of manufacturing cost, yield, and productivity (equipment utilization). When incorporated into product planning, manufacturing energy awareness provides answers to the following type of questions:

- How does energy consumption of various electronics technologies compare?
- Does the lowest cost process result in the lowest energy cost?
- Can product design impact manufacturing energy consumption?

Yielded cost modeling simulates production by means of a technical analysis of the manufacturing process[2-4] and provides detailed energy consumption data for existing and proposed processes and products. Using meticulous descriptions of the product geometry, process parameters, and the manufacturing environment, the yielded cost model generates capital equipment, material, labor and energy costs.

As a specific example, consider the fabrication of equivalent PWB and thick film hybrid substrates. Our analysis shows that the fabrication of a six layer fr-4 PWB costs 25% less than an equivalent thick film hybrid substrate built on alumina (one ground plane, one fine circuit layer, one resistor layer) and that material cost drives this difference. However, the hybrid process consumers slightly less energy than the PWB process due to the combination of plating bath and lamination press heating. See Figure 3.

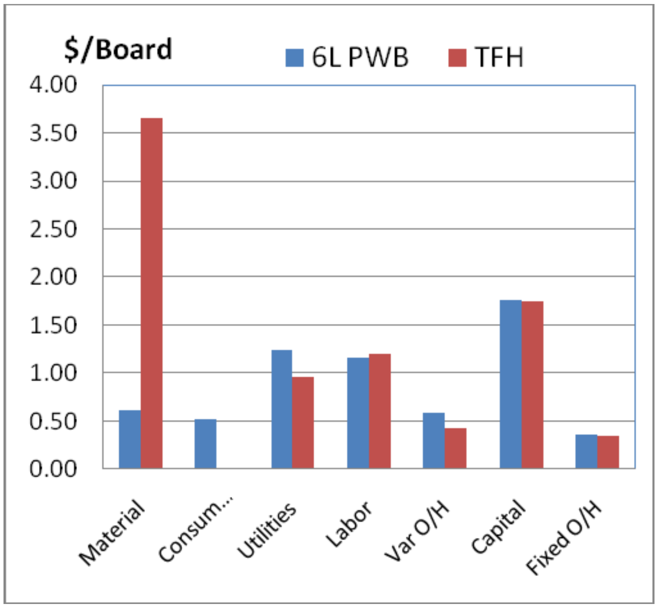


Figure 3. Analysis of manufacturing cost for equivalent PWB and thick film hybrid substrates shows lower total cost for PWB but unexpectedly lower energy (utilities) cost for thick film.

The yielded cost model also reveals the impact of product design on energy consumption. For example, increasing PWB layer count (and wiring density) allows reduction in substrate size while maintaining constant wiring capability[5]. Table 1 reports the total manufacturing cost from the yielded cost model for two designs with roughly equivalent wiring capabilities.

Design	**Layers**	**Size**	**Cost**
A	6	100mm x 60mm	$6.24
B	8	75mm x 60mm	$5.75

Table 1. Analysis of manufacturing cost for two PWB designs having roughly equivalent wiring capability.

The different number of required panels drives the net manufacturing cost difference for the two designs. Being smaller, Design B requires fewer panels and therefore less material, capital equipment, labor and energy. See Figure 4. Thus, the more complex design (and process) consumes less energy and has a lower total cost.

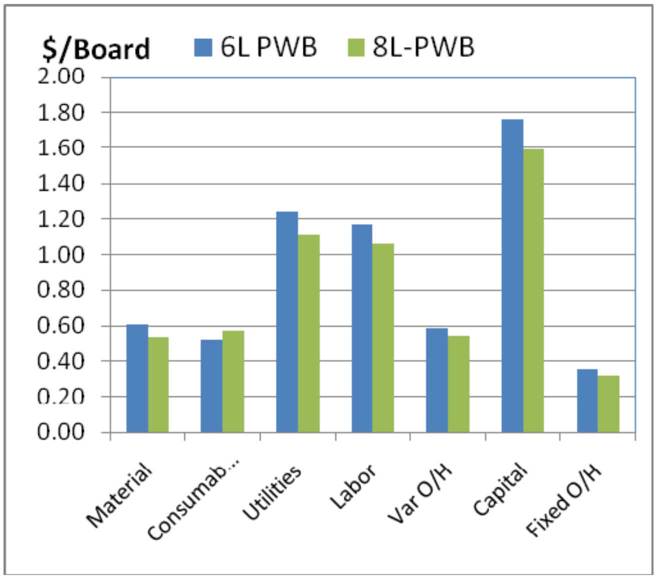


Figure 4. Analysis of manufacturing cost for two PWB substrate designs with equivalent wiring capability but different layer counts shows lower total cost and lower energy cost for the more complex design.

These examples demonstrate how yielded cost modeling can address the Manufacturing Energy Awareness questions listed above:

- How does energy consumption of various electronics technologies compare? Different manufacturing technologies have widely different energy requirements.
- Does the lowest cost process result in the lowest energy cost? Sometimes, but not always.
- Can product design impact manufacturing energy consumption? Yes!

EXAMPLE 2: IMPROVE SOLAR CELL EFFICIENCY AND/OR COST

Current solar cell research and development targets lower cost, higher efficiency, or both. Materials prove crucial to both cost and efficiency with low cost efforts emphasizing thinner cells, nano-materials, organic materials and roll-to-roll processing; and high efficiency efforts focusing on single and polycrystalline materials, increased absorption, reduced loss and multi-junction cells.

Figure 5 depicts the efficiency/cost trade-offs[6] while Figure 6 plots efficiencies achieved with various materials[7].

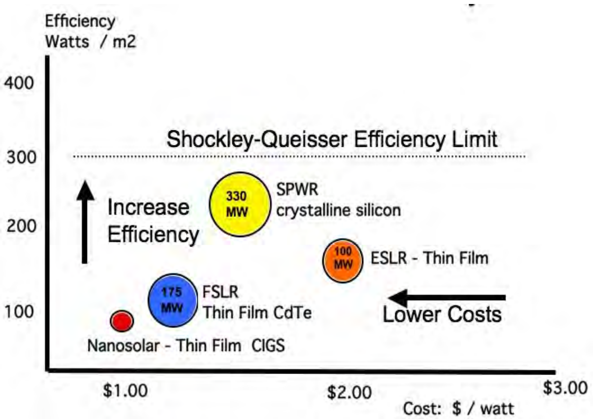


Figure 5. Efficiency/Cost trade-offs in photovoltaic devices[6].

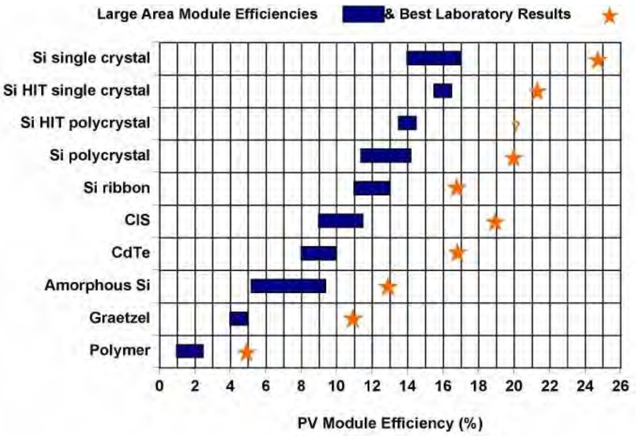


Figure 6. Solar cell efficiencies achieved with various materials[7].

Mitsubishi, for instance, targets residential and small-scale industrial solar cell applications with high efficiency, multi-crystalline Si and small-molecule organics coated on flexible substrates. Similarly, Sanyo targets residential and consumer product solar cell applications with micro-crystalline thin-film Si. Meanwhile, NanoSolar targets utility-scale power generation with nano-particle CIGS ink compatible with low cost, roll-to-roll processing.

EXAMPLE 3: REPLACE LIGHTING WITH LEDS

Today, specialty lighting, such as automotive, dominates the installation of LED bulbs, but soon LED bulbs will surely replace all lighting given the substantial efficiency advantage shown in Table 2 and the long life of LED bulbs.

For example, Ann Arbor, Michigan hopes to cut its $1.39 million street lighting budget in half (energy alone) with additional saving expected in maintenance. See Figure 7.

Table 2. Energy efficiency of light sources.

Technology	Energy Efficency (Lumens/Watt)
Incandescent	15
Halogen	24
Fluorescent	50-100
LED	150

Figure 7. LED street light pilot program in Ann Arbor, Michigan.

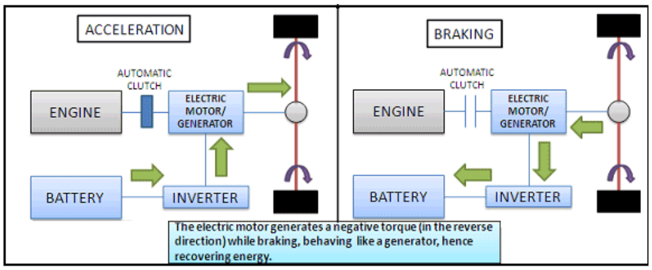
GE developed a Smart LED bulb (Figure 8) that consumes 9 watts and delivers the same light output as a 40-watt incandescent/halogen or a 10-watt CFL with the instant full brightness of an incandescent or halogen bulb. The Smart LED bulb lasts 25 times longer than a general service 40-watt incandescent or halogen bulb and more than 3 times longer than a standard 8,000-hour rated life CFL with no filament to break.

Figure 8. GE Smart LED Bulb.

EXAMPLE 4: REGENERATIVE BRAKING

Hybrid and electric vehicles use regenerative braking to recapture energy normally lost when slowing down or coasting. Conventional friction brakes convert the kinetic energy of the vehicle into heat, while regenerative brakes run the traction electric motor “in reverse” or as a generator to recharge batteries and/or super capacitors at roughly 31% electric generation efficiency. See Figures 9 and 10.

Figure 9. Regenerative brakes recapture energy normally lost when slowing down by using the traction motors as a generator.



The electric motor generates a negative torque (in the reverse direction) while braking, behaving like a generator, hence recovering energy.

Figure 10. Acceleration and braking configurations for hybrid vehicles.

Tesla Motors uses regenerative braking to enhance the driving experience in their high performance electric Roadster claiming that

> *"Driving with regen is fun! Having that instant positive and negative torque command right at your toes really make you feel in control."*

Figure 11. Tesla Motors' Electric Roadster.

Maxwell Technologies uses ultracapacitors (Figure 12) for bus and truck regenerative braking, citing fast charge and discharge and high energy storage. Most importantly, ultracapacitors are reliable through more than one million charge cycles.

Figure 12. Maxwell Technology ultracapacitor for truck and bus regenerative braking.

EXAMPLE 5: ALTERNATIVE ENERGY DISTRIBUTION

Distribution of electric energy generated from alternative or renewable sources such as solar cells and wind turbines to users embodies a number of difficulties. Solutions include efficient energy storage (for, say, night-time use of solar energy) and efficient distribution over long distances (using possibly superconductors).

Tying into the existing electric distribution network or grid requires special equipment and methods often referred to as the Smart Grid. Although no universal standard exists today, the Smart Grid will provide integrated communications for real-time information and control as well as sensing and measurement for remote monitoring, time-of-use pricing and demand-side management. See Figure 13.

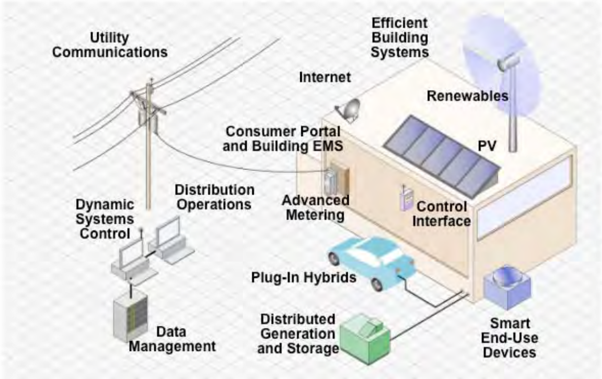


Figure 13. Elements of the Smart Grid for distribution of alternative energy.

In 2010 Honeywell acquired smart grid leader Akuracom which provides technology and services for Automated Demand Response (Auto-DR). Akuacom's open and interoperable Smart Grid messaging infrastructure automates the delivery of DR price and reliability signals to aggregators and to commercial and industrial facilities. Akuacom's Demand Response Automation Server, or DRAS, represents the core of the messaging infrastructure. By setting and communicating demand-based pricing, the utility provider provides incentives to consumers to reduce consumption peaks that may overload the grid as illustrated in Figure. 14.

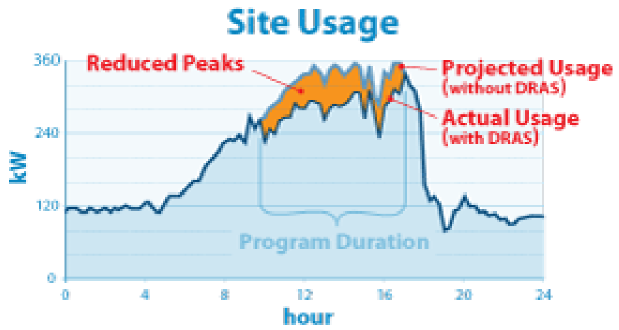


Figure 14. Demand-based pricing communication via DRAS avoids grid overload.

Smart Metering is a key element of the Smart Grid concept because it enables the consumer to automatically act on demand-based energy price changes. See Figure 15.

Figure 15. A Smart Meter.

For example, Enel SpA (Italy's largest and Europe's second largest power company) undertook the world's largest smart meter pilot which involved 27 million customers. Supplied by Echelon Corporation (USA), these fully electronic meters provide integrate bi-directional communications with advanced power measurement and management capabilities. System features include the ability to remotely turn power on or off to a customer, read usage information from a meter, detect a service outage, and detect the unauthorized use of electricity.

Inverters enable the link between the grid and local generation by providing DC to AC conversion. See Figure 16. Sales of excess energy to the utility company often drives alternative energy from break-even to profitability.

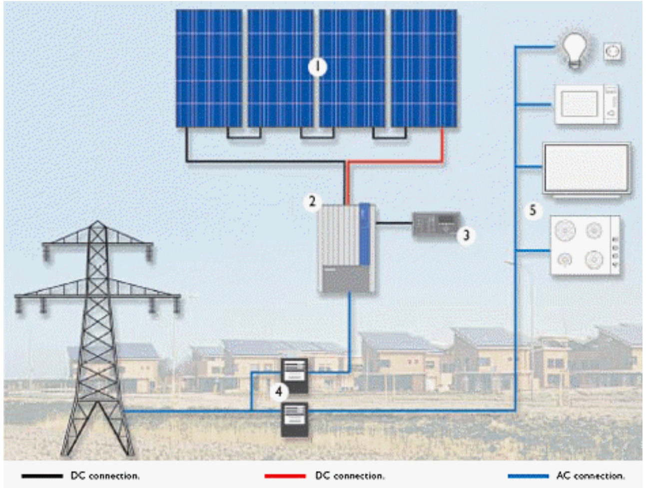


Figure 16. Inverts link local DC energy generation to the AC grid and enabler the sale of excess energy to the utility company.

CONCLUSIONS

The Green movement creates an opportunity for innovation and market penetration. While energy intensive, the ecological impact of semiconductor manufacturing may be offset by advanced features and efficient performance. In particular, innovative products reduce energy consumption through efficiency and recovery.

Moreover, disciplined product and manufacturing planning enables ecological sensitivity in terms of manufacturing, operations and recycling. Finally, electronics enable advanced alternative energy generation and distribution which holds the potential to relieve the scarcity of energy.

Electronics' tarnished ecological image can be rehabilitated which benefits business as well as our planet.

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