How Green is Silicon Valley?
Ecological Sustainability and the High-tech Industry

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Sustainable development theory explores the tensions between ecological systems, economic growth, and technological advancement. Meanwhile public policy has focused on the compatibility of environmental and economic goals through sustainability discourse and indicators projects. High-tech is often perceived to be a clean industry and Silicon Valley has become an economic phenomenon that other regions attempt to mimic. Yet, industry-sponsored sustainable indicator reports have not fully explored the ecological costs of high-tech production processes. The intense chemical throughput of the manufacturing process and the high volume of toxic waste from the end products pose serious ecological and human health risks. The international scope of the industry and the frequent outsourcing of the production supply chain make regulating the high-tech industry a complex undertaking. Increased company responsibility for the impacts of their products is necessary for the industry to approach the ecological goals set by the sustainability and indicators reports of Silicon Valley.

Introduction

The de-industrialization of many areas of the United States has left cities and towns seeking new forms of economic development to attract investment and jobs from the new economy. At the same time, the environmental legacy of heavy industry has left them seeking environmentally sound forms of investment and development, leaving them vulnerable to a common misperception that high-tech manufacturing is an inherently clean industry.

A full look at the environmental impacts of the high-tech industry, however, reveals that the high-tech model of economic growth is not as ecologically sustainable as was originally assumed. Although it is not as visibly apparent as the pollution generated by traditional manufacturing, there are many long-term ecological and human health impacts of high-tech industrial development warranting careful monitoring and regulation. The manufacture of one 2-gram

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microchip, for example, requires the direct use of 72 grams of chemical inputs and the total mass of secondary material in manufacturing is 630 times that of the chip. The precision and complexity of chip manufacturing makes the materials intensity of the semiconductor industry orders of magnitude greater than older industries (Williams et al. 2002).

The Silicon Valley region of California serves as an interesting geographic focus for understanding the environmental impacts of the high-tech industry. Silicon Valley is not only the hub of the latest flurry of high-tech economic growth, but the location of a serious high-tech toxic legacy. Not coincidentally, it is also the birthplace of one of the high-tech industry's most diligent environmental watchdogs, the Silicon Valley Toxics Coalition (SVTC). Efforts by SVTC and other groups to develop environmental impact indicators for the high-tech economy let us explore the question "How green is Silicon Valley?".

This article begins with a brief discussion of various methodologies to measure ecological sustainability. The focus then turns to Silicon Valley and the evolution of sustainability indicator documents in Santa Clara County. A discussion of research on several overlooked environmental issues related to the high-tech industry in Silicon Valley follows. The paper closes with an effort to measure sustainability in the high-tech sector in order to contribute to a critical dialogue about the reality of sustainability initiatives and the effects of the new economy and the high-tech industry on these efforts.

Measuring Ecological Sustainability

It is useful for this paper to acknowledge that sustainability is first and foremost an ecological concept. There are important social dimensions to be explored within sustainable development theories, such as environmental justice, public health, and workplace safety, as well as economic factors, such as the effects of regulation on regional development and technological innovation. However, the term sustainability has grown out of resource management and environmental concerns and the main conceptual contribution of sustainable development is an acute awareness of natural limitations to the ecological systems within which modern society and future generations must function.

Yet, when focusing on the ecological elements of sustainability, developing an empirical measurement of change is difficult. This challenge is due to missing data, a lack of common measurement units, and difficulty in selecting ecological factors to measure. Theorists have developed various indices, ranging from the illustrative ecological footprint model, which measures environmental impacts in land acreage (Rees 1997) to the exhaustive Pilot Environmental Sustainability Index which collects 62 national-level measurements to calculate international sustainability rankings (Samuel-Johnson and Esty 2001). It is beyond the scope of this paper to evaluate these methodologies, but it is worth recognizing that the effort to calibrate local, regional, and national environmental impacts is ongoing.

Instead of relying on a single, empirical measure of local ecological sustainability, non-profits, government agencies, and academic researchers have come to use sets of sustainability indicators to measure change and guide policy. The attraction of indicators is the potential for using qualitative measurements with quantitative data, the ability to use data with unrelated units of measure, and the illustration of connections between different environmental issues. Indicators can quantify trends and simplify information about complex phenomena (Hammond et al. 2001). Indicator projects have been initiated throughout the U.S. as local, regional, and state organizations attempt to document progress towards sustainability and/or advocate for new policy directions.

Sustainability indicators are often crafted to be regionally specific. A great deal of effort has been placed on public participation in the selection of indicators. This has the advantage of engaging many stakeholders and setting local priorities or areas of concern. Unfortunately, this does not allow for simple cross-geographic comparisons. Indicator projects have been criticized for their lack of scientific grounding and their potential to be politicized (Brugmann 1997). Most indicators are based on secondary data sets, thus helping community groups and local governments develop appropriate measures of sustainability, but limiting the development of new data that may be necessary to capture the full scope of sustainability issues.

To assess the ecological sustainability of Silicon Valley, existing indicator documents became the original basis of this research. Through the use of past indicator projects, this article raises questions about the reliability of this methodology as a policy-setting tool. Additionally, one of the strongest conclusions to be made is that information required to accurately measure the impacts of the electronics industry is limited and significant efforts are needed to track the global impacts of this rapidly changing and de-centralized manufacturing industry.

Sustainability Indicators in Silicon Valley

Several organizations have undertaken significant efforts to measure the sustainability of Silicon Valley through indicator projects. The City Council of San Jose had a relatively early inaugural sustainability policy goal written into its 1994 general plan. That "Sustainable City Major Strategy" was followed up with the 1998 San Jose Sustainable City's Status Report, which listed a number of achievements of the municipal government and promised future research for the development of sustainability indicators (City of San Jose 1998).

Though the city has not followed up on this promise, the task of creating sustainability indicators has been taken up by the non-profit sector. The focus of these indicator projects has been on the entire Silicon Valley region, which crosses municipal and county boundaries. These include many indicators that are not directly related to the high-tech industry, but reflect the lifestyles of residents and land use within the region. In this section, three reports documenting the general sustainability of Silicon Valley are reviewed.

Three organizations have played key roles in developing independent sustainability indicators:

- **Working Partnership USA** is a non-profit started in 1995 to address the widening income gap in Silicon Valley. It conducts policy research and political organizing on behalf of labor organizations and community groups to "craft innovative solutions to the problems of the New Economy" (Benner 1998).
- **The Silicon Valley Manufacturers' Group** (SVMG) was created in 1978 by a collection of business leaders led by David Packard to work on policy issues "affecting the economic health and quality of life in Silicon Valley" (ABAG 1999).
- **Joint Venture: Silicon Valley Network** was established in 1993 as a non-profit organization supported by the area businesses to "promote environmentally sound business and community practices through collaboration and education" (SVEP 1999).

Working Partnership USA

In 1998, Working Partnership USA released a report entitled *Growing Together or Drifting Apart*, a critical look at the economic and social well being of Silicon Valley. The report highlights the widening income inequality in the region, the decline in public institutions, a reduced availability of affordable housing, and lower quality education and health services. Significantly, a chapter entitled

"Environmental Quality and Public Health Indicators of Sustainability" builds upon work by the Silicon Valley Toxics Coalition (SVTC). The report documents the materials intensity of the high-tech industry and lists 31 Superfund toxic clean-up sites in Santa Clara County. One of the key conclusions of the report is that, although "Silicon Valley's concentration of high-tech firms has positioned [the] community to be a global center of the new economy, it has also generated environmental and public health hazards not unlike those of the old economy" (Benner 1998).

Growing Together or Drifting Apart points out a broad sustainability link between environmental and labor concerns over hazardous materials use in the semiconductor industry. Although the light manufacturing nature of electronics production results in fewer workplace injuries, occupational illness cases are significantly higher than in other manufacturing industries. According to the Bureau of Labor Statistics, the percentage of work loss due to occupational illnesses in the electronics industry was a third greater than the manufacturing sector average and the semi-conductor field work loss rate was over twice the average (Ibid).

> "The rapidly increasing pace of technological change in semi-conductor manufacturing places workers in increasing danger. In the 1980's, a typical schedule of a new technology, from research and development to pilot lines to full manufacturing, was 6-8 years. Now these efforts are being compressed into a 2-3 year time frame. Any large semiconductor facility uses several thousand chemicals, and the opportunities for health professionals to evaluate new or unusual health hazards are being diminished by the quickening pace of technological change" (Ibid).

The Working Partnership report also discusses ecological concerns regarding energy use and transportation in Silicon Valley that are indirectly related to the high-tech industry. It notes a significant decline in renewable energy use by Pacific Gas and Electric, a dramatic increase in traffic congestion in Santa Clara County in 1996, and a shift towards driving alone over carpooling (Ibid.).

Silicon Valley Manufacturers' Group

Another important sustainability indicators project is the annual report, *Silicon Valley Projections*, begun in 1998, sponsored by the Silicon Valley Manufacturers' Group (SVMG), and published by the Association of Bay Area Governments (ABAG). In its second year, the report authors added a section on environmental issues to previous sections on transportation, housing, and education. The report focuses on anticipated population and job growth in the region to 2010 and highlights the serious ‘externalities’ associated with Silicon Valley’s phenomenal economic growth and calls for prompt action to protect the environment.

The 1999 Projections report (ABAG 1999) provided forecasts of growth in jobs and population without an equal increase in housing. This trend is closely linked to expectations of increased traffic congestion, energy use, and land consumption. The low-density development in Silicon Valley increases automobile dependency and limits the effectiveness of public transit.

The environmental section of the report continued with a focus on traffic congestion and its contribution to air pollution. Overall air quality has shown a significant improvement in the Bay Area, according to the report, which credits “cleaner fuels, better technology, and stricter standards” (Ibid.). However, national ozone standards were not met in 1995 and 1996. Additionally, congestion has contributed to elevated fine particulate matter in the air shown to contribute to respiratory illnesses such as asthma. State emission standards were exceeded on 21 days in 1998 due to the combined effect of traffic and hot weather. Santa Clara County has the highest ratio of cars per household in the region. Another ecological indicator discussed in the report is the threat to open space by development and automobile-facilitated sprawl. Over 110,000 acres of open space are considered at risk of imminent development (Ibid.).

Urban runoff is identified as the most significant source of water pollution, another key environmental topic. Though no data is given, the report lists household chemicals, lawn fertilizers, and cars as the main contributors. The report emphasizes the small impact of toxic industrial waste on regional water quality, yet metals and organic solvents are listed as issues of concern, as water treatment plants cannot remove them. The report credits Silicon Valley’s largest firms with making “great strides in reducing their toxic discharge” and points out the importance of San Jose’s partnership and incentives programs to further reduce the volume and toxicity of discharges. Groundwater is discussed briefly, with the carcinogen MTBE as the most significant source of contamination. There is no mention of the area’s Superfund sites or other groundwater contaminants.

The *Silicon Valley Projections* report focuses on the environmental effects of rapid population growth and automobile dependency. Land use patterns and traffic are identified as key concerns in planning for sustainability. Without data for all the indicators it is difficult to question some of the sustainability assumptions regarding the electronics industry. It appears that the report thoughtfully avoided the issues of toxic material use in the high-tech sector. This potential bias demonstrates a limitation of using selected indicators as the only source of sustainability assessment.

Joint Venture: Silicon Valley Network

In 1999, the Silicon Valley Environmental Partnership (SVEP) published the first *Environmental Index of Silicon Valley*. The SVEP was launched by Joint Venture and is an example of a multi-sector partnership involving Santa Clara County, SVTC, and industrial leaders such as Hewlett-Packard. In the introduction of the *Environmental Index*, SVEP's objective is stated:

> "SVEP promotes environmentally sound business and community practices through collaboration and education. Our vision for Silicon Valley is a sustainable community with a vibrant economy and a healthy environment. We focus on efforts that bridge the traditional 'tension' between the environment versus the economy, demonstrating that both goals can be achieved in a mutually supportive fashion to move our community toward sustainable development" (SVEP 1999).

The *Environmental Index* report provides the most comprehensive collection of environmental sustainability indicators of Silicon Valley to date. It tracks 21 indicators divided into six sections: resource use, population, air quality, water quality, species/habitat, and hazardous materials. Despite the optimistic vision presented above, the executive summary begins with five key findings:

- Two-thirds of the indicators in the report show a negative long-term trend or reversal of a positive trend.
- Environmental impacts per person are generally stable or improving, but are still large. Overall environmental impacts are increasing as the population grows and the economy expands.
- Transportation impacts are particularly extensive and serious.
- Habitat loss and non-native species imperil local species.
- Despite improvements, watershed health is in serious condition.

Table 1 lists trends in the report's indicators over the preceding 6 to 10 years. Many of the negative results were attributed to a rising population, development, and economic activity in Silicon Valley.

Table 1: Silicon Valley Environmental Index Trends, 1999.

	SV Environmental Index	
Topic	Measure	Total Change of Indicator
Resource Use	Energy Use	+20%
	Urban Land	+4%
	Density	+18%
	Water Use	+34%
	Waste	-17%
Population	People	31%
Air	Ozone days	-46%
	PM10 days	-73%
	commute alone	+9%
	VMT	+85%
	VMT / cap	+45%
	CO2	+19%
	Ozone Depletion	-77%
	Indoor Air	CA spend 87% of time in-
Water	Watershed Health	5 (scale 1-6, 6 worst)
	Drinking Water Compliance	over 99%
	MTBE cases	-38%
Species/Habitat	Endanger Species	33 threatened
	Tidal Marshes	-84%
	Clapper Rail Pop	+160%
	Burrowing Owl Pop.	-50%
Hazardous Materials	Toxic Chemical Release	-55%
	Toxic Recycling or Incineration	+50%
	Agriculture Toxic Pesticide Use	-51%
	Total Pesticide Use	+6%
	Hazardous Waste Generation	+15%

(Adapted from the SVEP 1999 Environmental Index. Shaded lines represents indicators showing improvement over the period of study.)

As a study sponsored by an industry organization, the *Environmental Index* deserves a critical review of its discussion of the high-tech economy. The report appears to shift the burden of responsibility for the negative trends in Silicon Valley away from industry and towards the general population and its consumption patterns. These issues of consumption and urban sprawl cannot be fully divorced from the industry that generates wealth, depends on work force growth, and establishes vast low-density job centers. The Index commits one page to increases in land consumption without any deeper look at how inefficient land use patterns have been established or reinforced. Although defined as an economic ‘cluster,’ high-tech firms have contributed to the region's low-density development and automobile dependency. These concerns are not discussed in the *Environmental Index*. It may be unrealistic to expect that such a report would attempt to make broad connections between industrial development, pro-growth economics, and environmental sustainability. However, this policy gap highlights a major fault of the centrist, accommodating sustainability movement that attempts to maintain high economic growth levels while pursuing ecological sustainability.

Additionally, there is a lack of discussion of the direct sustainability impacts of the high-tech industry that fuels growth in Silicon Valley. Of the 21 indicators, there are seven areas that are directly related to high-tech industrial processes: energy use, water use, solid waste, land consumption, air quality, toxic chemical use, and hazardous waste generation. However, there is little mention of computer manufacturing or any industry beyond agriculture. Historically, industrial operations are a centerpiece of environmental reporting, but in the SVEP report the impacts of the industrial sector are simply called "increased economic activity."

The use of gross data across all sectors of the region makes it difficult to discern any causes of negative environmental trends. For example, energy consumption is measured broadly to include fuels and electricity. The 20% increase in energy use is attributed to growth in population, vehicle-miles-traveled, and/or economic activity. The index also discusses a reversal of previous improvements in water consumption. The use of water increased 34% since 1991. It is reported that residential uses are responsible for half the county's water use while businesses and industry (not counting agriculture) use a third of the water supply, but no specific trends or sources of water consumption are revealed.

The *Environmental Index* includes a relatively lengthy section on watershed quality and groundwater. Overall watershed health is considered to be critical. Mercury contamination in fish is listed with a number of other problem areas. There is a section discussing motor fuel leaks into groundwater with particular concern over MTBE, but no discussion of semiconductor Superfund sites, a surprising omission, given the groundwater clean-up work being done by the electronic industry.

Hazardous materials is the only chapter of the *Environmental Index*, notably the last chapter, that directly discusses industrial activities. There are over 3,000 facilities in Santa Clara county that generate hazardous waste, only 141 of which are required to provide toxic release inventories (discussed below). From 1987 to 1997, there was a 55% reduction in hazardous material releases. However, since 1994 toxic releases bumped up 34% to almost 5 million pounds. "About one third of the increase since 1994 is attributed to expanded reporting requirements while the other two-thirds may be due to increased economic activity." Another 12.2 million pounds of toxic chemicals were recycled or incinerated in 1997 and 1.6 million pounds were disposed of off-site. This is up from a combined 9 million pounds reported in 1991. The last indictor discussed is hazardous waste generation, which increased 18% from 1989 to 1995 in the county.

The report emphasizes industry's role in reducing ozone-depleting compounds. Pounds of Ozone Depleting Potential (an aggregate figure for a mixture of chemicals) have diminished from 260,000 to 60,000 from 1994 to 1996. The signing of the Montreal Protocol is presented as a "Model Solution to a Global Threat" and the report shows an unusual interest in governmental regulation with the success of this international treaty. Improvements in regional air quality are measured by reductions in both ozone levels and particulate matter. Vehicles are the primary contributors to ground level ozone due to their release of nitrogen oxides and volatile organic compounds. Industry and agriculture are listed as contributors to fine particulate matter. Considering the increase in vehicle-miles-traveled in the region, improvements in ozone levels are attributed to stricter emission standards in the Bay Area.

As the reports above describe, economic development in Silicon Valley has fueled a high rate of population growth characterized by a consumptive living pattern dependent on automobile travel. Negative trends in emissions of vehicle exhaust, energy consumption, non-point source water pollution, and open space and habitat loss are not unique to Silicon Valley, although the San Jose area has the exaggerated sprawling pattern of many newer, western cities. The unique element of Silicon Valley is its tremendous growth in the high-tech industry and its role as the primary cluster of the new economy.

The two indicators projects sponsored by industry organizations clearly did not focus on the environmental pollution of the high-tech manufacturers in the Silicon Valley. Perhaps in volume the pollution released by the computer industry is dwarfed by other pollution sources. However, the toxicity of electronics and semiconductor industrial processes merits close attention. Sustainable development in a region cannot ignore the challenges of hazardous material use and production within one of the fastest growing sectors of the economy. For example, the Clean Technology Environmental

Management program stated that the computer industry was responsible for merely 3% of the toxic material releases nationwide (Krut and Karasin 1999). However, according to EPA Toxic Release Data, the electronics industry is responsible for between 16 to 20% of all toxic releases in Santa Clara County.

Although no intent can be confirmed from the text of the documents, the sustainability indicators reports funded by leading companies in the area actively reinforce the clean industry myth of computer manufacturing. The potential for 'green-washing' sustainability research is reason for skepticism of indicator-based measures of ecological sustainability. This problem is exacerbated when the indicator measurements are determined by a broad base of stakeholders that may resist including data that place responsibility on the economic growth sector of the region.

A Closer Look at Sustainability within the High-tech Industry

This section focuses on the environmental "externalities" of the electronics industry, particularly since 1995, when the region began its unprecedented boom in productivity and wealth generation. The success of Silicon Valley has drawn the interest of many other regions hoping to attract similar industrial development. It is the goal of this investigation to explore the sustainability impacts of what many consider an under-regulated electronics industry. Additionally, it points to some areas that deserve closer consideration in future environmental indicator reports of Silicon Valley.

Specifically, this section investigates the topic of hazardous materials used in the high-tech sector, focusing on three areas: toxic material releases in the air and water, workplace hazards of high-tech chemical handling, and the growing issue of post-consumer e-waste. There were three important sources for the research on this topic: the Silicon Valley Toxics Coalition, the Environmental Protection Agency's toxic release inventories, and the Bureau of Labor Statistics. These sources were used to follow up on already discussed indicators.

It must be stated at the start that there is an overall lack of quality information available on these topics. In order to develop more complete sustainability indicators for the high-tech industry, there is a need to increase the data availability and/or improve the precision of data collected on the topics discussed below.

Toxic Material Releases

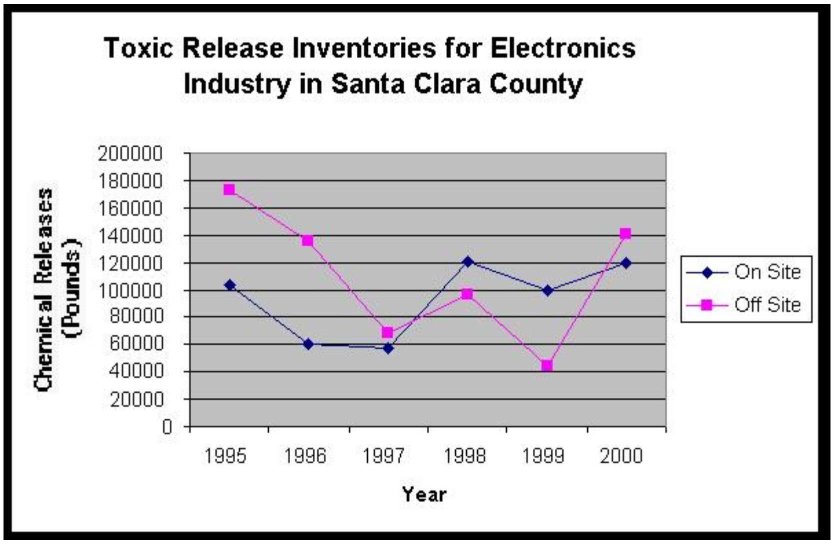
In 1986, the federal Emergency Planning and Community Right-to-Know Act (EPCRA) became a powerful new tool for advocates of corporate responsibility and environmental justice. Enacted two years after the Bhopal accident, the EPCRA is considered one of the most aggressive pieces of legislation for environmental protection in recent years (EPA 2001). It also represents a new direction in federal environmental programs with its focus on environmental hazards to people and communities, not just threats to natural habitats. This trend accelerated with the growth of the environmental justice movement in the 1990s. EPCRA requires that manufacturing facilities using a threshold level of listed chemicals report all releases of those chemicals into the environment. This data is reported in a publicly accessible Internet Web site called the Toxic Release Inventory (TRI) Program (http://www.epa.gov/tri/). This discussion of Silicon Valley uses Santa Clara County data from the TRI as a sustainability indicator and uses an expanded 1995 list of chemicals required to be reported. Thus, 1995 is used as a base year.

In Santa Clara County, there has been a measurable decline in total toxic chemical releases in all industries since 1995. The electronics industry has followed this trend in some types of toxic releases where others have remained stable. Most of the improvement from the electronic industry was in the category of off-site releases into the sewage system. Santa Clara County and the City of San Jose have focused efforts on reducing the quantity of heavy metals, such as nickel and copper, flowing into the sewage treatment system.

On-site releases are emitted directly into the air or nearby water bodies. On-site toxic releases directly into water bodies have declined dramatically - almost 60% from 1995 to 2000 - but they represent less than one percent of on-site toxic releases. Most on-site toxic releases are into the air and these figures have shown no consistent improvement since 1995. While Santa Clara County saw a 44% decrease in toxic air releases from all industries (1995 - 1999), the electronics industry showed a decline of only 3.3%. In 2000, reported air emissions jumped 17% over the 1995 base year (see Figure 1).

Looking a bit closer at the specific toxic air releases reveals that there has been a major improvement in what is termed fugitive air releases (i.e., those pollutants not passing through a controlled venting system) via leaks or chemical evaporation from spills. Fugitive releases decreased by 42% from 1995 to 1999. Meanwhile, toxic releases through stack emissions grew 15% from 70,000 to 80,000 pounds. Much of this growth presumably resulted from controlling and routing more air emissions through point source vent systems. In 1995, fugitive air releases were almost a third of all toxic releases, whereas, in 1999, fugitive releases were only 19% of the total (see Table 2). Once released, air pollution is impossible to direct or track, and is free to mix and react with other compounds in the air. Additionally, air toxins are a particularly challenging hazard for human health. Gases follow the most common toxicological routes of chemical exposure for humans, through the skin and the respiratory system.

Figure 1: Based on Toxic Release Inventories reported to EPA



Other analysis has found that TRI data severely undercount the use of certain toxic chemicals. However, no other industry wide data exists in the US. For example, the aggregate use of chemicals in the process of wafer manufacturing is estimated to be ten times higher than that attributed to TRI data when compared to data available from the Electronics Industry Association of Japan. This is attributed to the high thresholds of chemical use that must be reached before reporting is required (Williams et al. 2002).

Table 2: SV Toxic Releases to Air (in pounds)

Year	*Fugitive Air*	*Stack Air*	*Total Air*	*% Fugitive*
1995	33086	70254	103340	32.02%
1996	23582	37128	60710	38.84%
1997	22080	35780	57860	38.16%
1998	49912	71192	121104	41.21%
1999	19144	80744	99888	19.17%
Change 95-99	-42.14%	14.93%	-3.34%	-40.14%

(Based on Toxic Release Inventories reported to EPA.)

E-Waste

A report from the National Safety Council's Environmental Health Center provides some alarming findings regarding the future growth of waste from electronics. The "Electronic Recovery and Recycling Baseline Report" declared that only six percent of computers were being recycled relative to the volume of computers being sold on the market in 1998. They estimated that by 2004, more than 315 million computers would be obsolete in the US. Most of these will end up discarded in landfills, burned in municipal solid waste incinerators, or exported as hazardous waste for 'recycling' (SVTC 2001). Each of these disposal options has serious environmental and health consequences, due to the high toxicity of electronic equipment and the difficulty of sorting out various hazardous materials. Table 3 summarizes some of the key toxic chemicals found in computers today. The SVTC report "Just Say No to E-Waste" concludes that the life span of a computer is diminishing. The average life spans of computer towers and monitors were 4-7 years in 1997. Because of the rapid pace of technology, their life spans will decrease to 2 years before 2005.

There is not a truly safe, sustainable means of disposing of many of these compounds. Incineration of 'electroscrap' results in concentrated hazardous waste and the dispersion of dangerous air emissions. Heavy metals such as cadmium and mercury are left in the fly ash and filters of municipal solid waste incinerators. Burning plastics, particularly PVC, results in dioxin releases into the air and incinerators are the largest point sources of dioxin air releases in North America. Despite improvements in liners and caps, landfills have yet to be made leak proof. Heavy metals and other chemicals leach out of landfills and contaminate groundwater and soil. Lead ions, mercury, PCB's, cadmium, and polybrominated biphenyls are all compounds that can be transported out of modern landfills and into the environment. Mercury can also vaporize into the air from waste disposal sites. Additionally, landfill fires pose a wide range of dangers as compounds of mixed chemicals are formed and released in the heat (Ibid.). Because of concerns about lead contamination, the states of California and Massachusetts have banned cathode-ray tube monitors and televisions from the solid waste stream (Schmidt 2002).

Recycling of computer waste may sound like a sustainable solution, but with the high toxic content of electronic equipment it poses many environmental and worker health threats. The extrusion of plastics during recycling releases halogenated chemicals such as dioxins and furans, particularly from brominated flame-retardants in plastic. Lead and cadmium may also be released during the recycling

Table 3: Based on SVTC E-Waste report (2001)

Material	% Weight Computer	Use in Electronics	Environmental Risks	Health Affects
Lead	6.2%	Tubes Of Monitors Solder	Bioaccumulation Toxic to plants, animals and microorganisms	Damage to blood, kidney, nervous and endocrine system Brain development
Cadmium	0.01%	Chip Resistors Infrared Detectors Semiconductors Plastic Stabilizer	Acute and chronic toxicity	Accumulation in kidneys
Mercury	0.002%	Thermostats Sensors Switches Batteries Wiring Boards	Settles into sediment Transforms to Methylated Me Travels through food chain	Brain damage
Hexavalent Chromium	0.006%	Metal Plating Steel Housing	Leaches from landfills	Toxic to cells DNA damage Severe allergic reactions Asthmatic bronchitis
Plastic / PVC	22.9%	Computer Housing Cabling	Produces dioxins	Carcinogenic
Polybrominated flame-retardants	variable	Plastic Housing	Endocrine disrupters Deposit in sediment Bio-accumulate in food chain	Affects hormone, digestive and lymph systems Digestive and liver cancers

process. The shredding of equipment can provide dangerous mixtures of metals, PCB's, and halogenated substances, which are released into the air or unintentionally dispersed into the recovery materials. Proper recycling of electronics is labor intensive so most e-waste slated for recycling is sent abroad. What happens to these materials is difficult to track. The Basel Convention on the Transboundary Movement of Hazardous Waste for Final Disposal was written in 1989 to end the shipping of waste from wealthy to poor parts of the world. The SVTC report *Just Say No to E-Waste* states:

> "The overwhelming majority of the world's hazardous waste is generated by industrialized market economies. Exporting this waste to less developed countries has been one way in which the industrialized world has avoided having to deal with the problems of expensive disposal and close public scrutiny at home" (SVTC 2001).

Electronic waste is classified as hazardous material by the Basel Convention Technical Working Group, but the U.S. government has not ratified the Basel convention. Even with the ban, materials are being exported by other industrial nations for recycling (Ibid.). The health effects of electronics recycling for workers have just recently become a topic of research, although stories and observations have preceded significant data collection. Charles Schmidt (2002) describes scenes from a visit to electronics recycling facilities in China where unprotected workers, many of them children, broke apart, melted, and acid-stripped computer components in order to extract valuable materials such as gold, steel, and copper. Other materials such as molten lead, glass, and plastics residues were left on the ground or burned off. E-waste has recently attracted the attention of the California Medical Association, which passed a new resolution titled "Toxicity of Computers and Electronic Waste" asking electronics manufacturers to take responsibility at the end of their products' life cycle (CMA 2003).

Worker Health and Safety

A third area of concern regarding toxins in the electronics industry is the threat to workers in fabrication plants and other electronics facilities. There is limited comprehensive information available regarding worker health issues outside data from the Bureau of Labor Statistics. The high-tech industry has, however, become a target of press reports and lawsuits highlighting worker illnesses. Many of the materials used in chip manufacturing are known or suspected carcinogens. Developing a direct link between long-term exposure to a chemical and chronic diseases is a challenging task for toxicologists. Still, chip manufacturers have recently negotiated out of court settlements of employee litigation cases and many more are pending. In January 2001, IBM settled (for an undisclosed amount) a 1996 suit by two former employees who charged chemical exposure resulted in their son's birth defects (Huffstutter 2001). Three hundred technical employees have brought another case against IBM and National Semiconductor (Lazarus 2000). National Semiconductor faces a similar class action lawsuit from workers in Scotland (Business Wire 1998).

A small collection of health studies have been conducted that attempt to make the link between chip manufacturing and illnesses, but only a few broad epidemiological studies have been undertaken. One frequently referenced study showed that 38% of pregnant women employed in 'clean rooms' had miscarriages (SVTC 2001b). Other reports listing the range of potential hazards have come out of the medical field. Authors often call for additional research and at the same time the application of the precautionary principle, a concept popular among sustainability theorists who advocate for the conservative application of new technologies when scientific uncertainty regarding health or environmental issues remains. There is also growing concern among health researchers over the shift of production facilities overseas into areas with less strict worker safety regulations and less resources for health monitoring.

Following up on the data provided in the *Working Together* report, the Bureau of Labor Statistics was consulted to see if the trend that they had reported through 1995 had continued. National labor statistics show that the illness and injury rate in the semi-conductor industry peaked in 1994 and 1995. Since then the illness and injury rate has declined rapidly to 45% of the 1994 rate (see Figure 2). This decline in workplace illness and injury likely reflects improved chemical handling facilities and worker protection. It does not, however, reflect improvements in rates of long-term illnesses such as cancer. A full epidemiological study of chronic exposure has not yet been conducted.

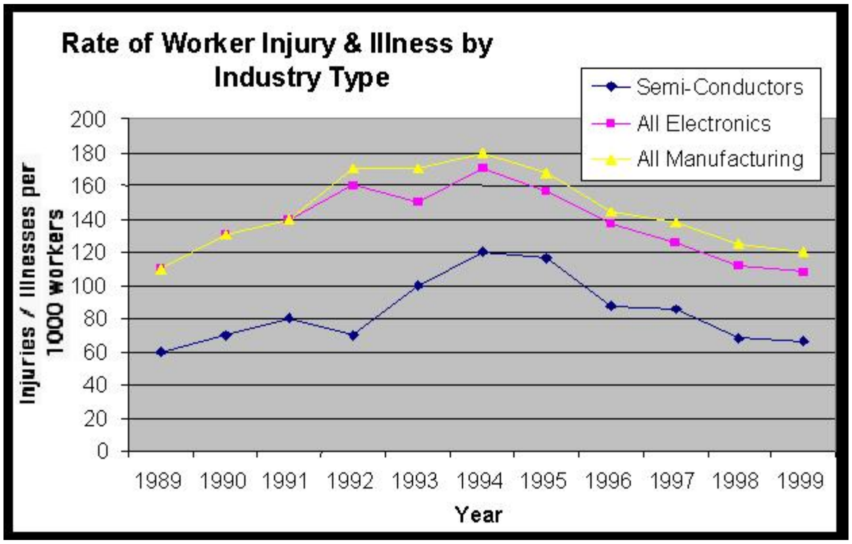
The individualized labor force of electronics manufacturers makes it more difficult to track information that might be demanded by a more unionized industry. Companies declare that they are protecting worker privacy by withholding data. Many sick manufacturing workers have stated their surprise to know that they had been handling dangerous chemicals. They describe a sense of trust they had felt towards their former employers (Lazarus 2000). The new economy fueled by the computer industry created a climate of optimism towards private companies and corporations. The issue of toxic exposure of workers asks that higher levels of corporate responsibility and/or regulation reinforce this faith in the industry.

The toxicity of the chemicals used and the seriousness of their threat to worker health are not well reflected in the data. Such determination can only be made on a chemical-by-chemical basis. Even this type of thorough analysis cannot easily measure the combined risk of the toxic chemicals used. The complexity of such analysis grows with changing technology, outsourcing of production processes, and the internationalization of computer fabrication. The invisibility of high-tech pollutants and their small ‘mass to toxicity’ ratio makes the light industrial activities in Silicon Valley appear relatively harmless. But the National Fire Protection Association placards outside fabrication facilities are a reminder that the computer manufacturing industry is also a chemical handling industry.

Conclusions

The rapid growth of the computer industry encouraged municipalities and states to start up their own high-tech centers in hopes of drawing sustainable economic development to their area. But the potential for future expansion of this industry in aspiring high-tech clusters, or in Silicon Valley itself, demands a careful look at the ecological sustainability of electronic manufacturing.

Figure 2: Based on Bureau of Labor Statistics data.



Silicon Valley has, unfortunately, followed a development pattern that suggests a ‘grow first, reflect later’ approach. This high-tech industrial cluster has had a wide range of well-documented ecological and social impacts beyond issues directly related to the manufacturing processes. Communities looking to build this type of industrial activity should first consider whether attracting economic growth or fostering community development is their end goal. Regions must recognize that rapid growth has multiple sustainability costs. Thoughtfully controlled development may result in a more livable urban landscape than that created by the auto-dominated, low-density campus model of Silicon Valley.

Though on close examination, high-tech industry in Silicon Valley shows some positive trends in the areas of toxic releases and workplace injury and illness, significant problems remain. Increasing quantities of electronic waste, for example, are a growing area of concern for environmental activists. The indicator improvements reported in this article do not necessarily mean that the issues of toxic chemical use or worker illness due to prolonged chemical exposure have been resolved. The lack of refined data makes improvements in broad indicator figures difficult to assess. Another complicating factor is that labor and land costs in California have encouraged many of Silicon Valley's largest manufacturers to take their fabrication operations into other areas of the U.S. and abroad. Thus, many of the externalities of Silicon Valley's economic growth have been exported, complicating the analysis of the sector's overall environmental impact.

This illustrates the risk of over-reliance upon local environmental indicators as measures of sustainability. Issues of toxic exposure and contamination cannot be easily summed up and packaged in a few numbers. As the review of the reports above demonstrates, important ecological and environmental health issues can easily be obscured. Furthermore, indicator projects can direct attention away from the toughest issue of sustainability: Who carries the responsibility for controlling the externalities of growing economic productivity and consumption in a region?

Still, Silicon Valley's high-tech community does appear to have a growing environmental conscience. The sustainability indicators research suggests that things may be getting better within the high-tech industry while other environmental factors in Silicon Valley are declining. The efforts of industry non-profits to conduct reports on livability and sustainability in the region are a worthy gesture. But, as described above, these collaborative reports seem to avoid confronting the ecological issues for which the high-tech industry should take greatest responsibility. There are serious issues to be addressed within the industry regarding the relocation of toxic hazards overseas. As Silicon Valley toxic production and waste is sent abroad, the region's measurable environmental quality is improving while the global ecological footprint of the industry may be increasing.

Monitoring the sustainability of the high-tech industry has proven to be a complex task. It would be optimistic to believe that corporate responsibility is the means to guaranteeing a safe environment for neighboring communities and workers in high-tech areas. The reluctance of the industry to accept increased government regulation is an area of concern. Electronics manufacturers lobbied extensively against tighter TRI requirements in 2001 when the EPA decreased reporting thresholds for lead and lead compounds from 10,000 to 100 pounds. Additionally, U.S. manufacturers lobbied the US government to contest two new environmental regulations in Europe: a requirement to provide free take-back programs to insure manufacturers collect and recycle or dispose of the toxic waste generated by discarded products and a directive requiring electronic manufactures to eliminate the use of lead, mercury, cadmium, hexavalent chromium and brominated flame retardant in their products by the middle of 2006.

The political efforts of electronics manufacturers and their trade associations make their declarations of support for sustainability goals appear to be 'green-washing.' This fits into a pattern of transnational corporate behavior that Joshua Karliner argues is the co-option of sustainability:

> "On the one hand, under pressure from community organizing and/or government regulation, the transnationals are instituting a number of real changes in their technologies and practices that are leading to cleaner production in some locales. On the other hand, they have appropriated the language and images of ecology and sustainability in an effort to ward off the threat that the environmental movement might convince the world's governments to force them to make much more far-reaching changes. Self proclaimed corporate environmentalists have achieved this by absorbing the question of ecological sustainability into their overriding agenda of economic globalization" (Karliner 1997).

Silicon Valley's support for sustainability will be interesting to watch in light of the current economic downturn in the Silicon Valley computer industry. Reduced production may decrease certain toxic releases and temper the generation of waste. However, leaner economic growth could also lead to cutbacks in environmental management systems. Fortunately, some pioneering companies have realized economic benefits from toxic chemical reductions, resource conservation, and material recycling (Carter and Narasimhan 2000). They would help ensure greater progress toward sustainability by embracing open source philosophies towards their environmental management systems so that other companies, particularly small and medium size suppliers and manufacturers, can replicate their environmental progress.

As an industry that relies on the use of high levels of toxic chemicals within a rapidly changing production cycle, there is a growing need for strong public monitoring. It is vital that activists and legislatures increase pressure for thorough sustainability regulations rather than voluntary compliance programs. It is interesting to refer back to the environmental indicators of the Silicon Valley

Environmental Index. Of the ten indicators that showed positive trends, nine can be directly linked to state, national, or international governmental regulations and/or active local government programs. The ranking of countries in the World Economic Forum's Environmental Index also supports the importance of a strong public sector for environmental sustainability. They argue that the choice of economic growth is separate from that of sustainability goals. They are neither mutually exclusive policies nor mutually interdependent (Samuel-Johnson and Esty 2001). Economic development can occur within an environmental regulatory framework. Thus, industrial innovation and efficiency efforts should be applied to the development of less toxic manufacturing methods and products.

Depending upon 'corporate social responsibility' seems unlikely to provide thorough progress toward true sustainability, outside of a collection of progressive companies. Perhaps regulated international markets, growing consumer and worker demands, and innovative corporate leaders will accelerate sustainability practices within companies and strengthen the monitoring of manufacturing processes from the outside. A mixture of forces, from government regulations to market pressures, will hopefully encourage all members of the high-tech industry towards a more ecologically sustainable presence in Silicon Valley.

Taking a step back to reflect on the theories of sustainability, it is evident that the high-tech industry has a long way to go before meeting any but the shallowest definitions of sustainability. Although a soft technology approach may not seem suitable for this region, there are reasonable lessons to draw from the theories of appropriate technology. The responsible application of new technology is an idea being advanced by critics of biotechnology and genetics research, and should arguably be applied to semiconductor fabrication. The precautionary principle asks high-tech industry to consider the full range of impacts from the production process through the life cycle of its products on human and ecological health. True sustainable development requires a complete geographic scope that follows international trade routes of the supply chain and waste disposal processes. Electronic companies must take full responsibility for the products they design and produce in order to create an industry that approaches a sustainable use of resources.

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