How Fabulous Fablessness: Environmental Challenges of Economic Restructuring in the U.S. Semiconductor Industry

Jan Mazurek[1]

Introduction

In 1965, Intel Corp. founder Gordon Moore accurately predicted that the semiconductor industry's focus on continuous innovation would double the power of a computer chip every 18 to 24 months. Such advances have been powered in part by the industry's use of chemicals that rank among the most toxic in industrial production (LaDou 1986). From the onset, the U.S. semiconductor industry's focus on rapid innovation has confounded attempts to evaluate the environmental and human health effects of microchip manufacture. More recently, large-scale shifts in how and where U.S. firms produce or "fabricate" chips, has made tracking and evaluating the environmental impact of semiconductor manufacture even more complicated.

This paper examines three organizational and spatial manifestations of restructuring to show how economic and geographic changes complicate efforts to evaluate and manage the industry's environmental performance. The manifestations include "fabless" firms that focus only on design and subcontract fabrication to third parties; strategic partnerships; and "freestanding" production plants or "fabs" erected and operated by companies far from Silicon Valley research and design functions. The ability of microchip companies to build fabs anywhere and/or subcontract with third parties obviously makes environmental problems harder to identify, to understand, and to manage.

The following case study shows how the leading U.S. chemical registry, the Toxics Release Inventory (TRI), fails to account for the effects of globalization and economic restructuring in the U.S. semiconductor industry. The TRI is based on the increasingly outmoded assumption that one firm, under one factory roof in the United States still conducts production. Although TRI data show a decrease in toxics released and transferred offsite by the semiconductor industry since 1988, it is likely that organizational and geographic shifts have contributed to the declines.

Another problem with relocation is that, although U.S. environmental laws help to ensure that states follow uniform environmental standards, not all jurisdictions possess the same level of resources, industry-specific expertise, and even political will to administer and enforce federal laws. The case is even more pronounced at the international level. The uneven capacity among countries to administer environmental programs may help to heighten controversy associated with industry expansion. Although there is insufficient evidence to show that U.S. semiconductor companies build new fabs in regions where environmental regulations are weak, it appears to be the case that some localities most anxious to lure microchip fabs often possess the fewest public resources to protect human health and the environment.

Sources and Types of Restructuring

Restructuring may be understood as an effort among U.S. semiconductor firms to improve long-overlooked weaknesses in production methods (Angel 1994). As long as U.S. semiconductor firms faced few foreign competitors, there was little need to focus on product quality and manufacturing methods. U.S. firms instead largely pursued a strategy of continuous technological innovation. Increased international competition, coupled with the complexities and spiraling cost of constructing fabrication facilities (a new fab may cost up to $5 billion), have prompted some firms to pool the construction and operating cost of microchip fabs and others to abandon manufacturing entirely.

Table 1 illustrates three ways in which U.S. semiconductor firms have restructured. As mentioned, fabless companies are firms that design and sell chips but do not fabricate them. Others have entered into strategic alliances to pool the cost of fab construction. Freestanding firms such as Intel find it in their interest to maintain control over production. However, improvements in design and manufacturing allow freestanding firms to increasingly locate them outside of Silicon Valley in other parts of the United States and the globe. Whereas microchip design, fabrication, and assembly once took place under a single company roof, a chip engineered and sold by a Texas firm may now be crafted by a competitor in Phoenix, New York, or Taiwan, assembled in Singapore, and sold in Los Angeles.

Table 1 Three Production Types

Company

Headquarters Partner

Fab locations

United States Asia Europe Middle

East

Fabless Companies

SEEQ Technology

California American Microsystems Inc. (AMI)

Hualon Microelectronics

International Microelectronic Products

Ricoh

Rohm

Samsung Idaho

Korea

Taiwan Japan

Cyrix Corporation

Texas. IBM Microelectronics

SGS Thomson New York

New Jersey

Vermont

Arizona

Texas France Italy

Strategic Partners

Advanced Micro Devices

California Sony Microelectronics

Fujitsu Ltd. California

Texas Japan Germany

National Semiconductor

California Intel Corp.

National Semiconductor Sunrise Ltd.

Synaptics Inc.

Integrated Information Technology

Maine

Texas

Utah Scotland

Freestanding Fabs

Intel Corporation

California National Semiconductor

Advanced Micro Devices California

Arizona

New Mexico

Oregon

Puerto Rico Ireland Israel

Cypress Semiconductor

California California

Texas

Minnesota

Source: U.S. Securities and Exchange Commission (SEC). 1997. Edgar database 10K Reports for fiscal years 1995 and 1996. Washington, D.C.: Government Printing Office. Available at http://www.sec.gov/cgi-bin/srch-edgar? Note: Cyrix Corporation purchased by National Semiconductor in 1997.

Release and Transfer Trends

Although many of the environmental effects of chemicals used to fabricate microchips remain undocumented, a few notorious substances have been linked to spontaneous abortion among women who work in microchip fabrication facilities. Some health experts believe that chemicals used to manufacture microchips can cause more serious health problems, such as cancer. And as the legacy of Silicon Valley shows, the industry has generated large quantities of hazardous waste. In addition to housing the single highest density of high-tech electronic firms, Santa Clara County boasts 29 of the U.S. Environmental Protection Agency's Superfund sites — the largest collection of toxic contamination spots of any county in the United States.

Restructuring, including the attendant shift of chip fabrication out of Silicon Valley, complicates even further efforts to evaluate industry and corporate environmental performance. For example, in the firm's annual report for 1995, National Semiconductor as an example of environmental progress pointed to an 88 percent reduction in chemicals reported to the Toxic Release Inventory since 1988 (National Semiconductor 1995). The Semiconductor Industry Association (SIA) similarly cites TRI data since 1988 as an indication that toxics released and transferred offsite by the industry are declining (SIA 1997a). However, what National Semiconductor and SIA fail to discuss is whether the declines are due to superior environmental performance or to other factors. As the following case study makes clear, at least some of the declines are due to globalization and economic restructuring.

The chief reason that the TRI reports fail to account for the effects of globalization and restructuring is that organizational change in the industry has outpaced federal record-keeping methods. In a supplement on Silicon Valley, *The Economist* (1997, p. 19) observed: "It is hard to exaggerate how far ahead of the American government Silicon Valley has moved. Even the statistics are a quagmire."

Established in the 1930s, the nation's Standard Industrial Codes fail to reflect some of the most basic features of high-tech sectors. For example, software publishers in California are ineligible for research and development tax credits because the SIC fails to classify the companies as "manufacturers" (Hamilton 1996). The SIC is currently undergoing an overhaul to make it more accurately reflect the U.S. business landscape. Yet it remains unclear whether the revised codes will precisely reflect the new industrial configuration of chip making. Absent correct statistics, information to help chart economic alignments among designers, foundries and manufacturers is best obtained through trade press articles and reports filed annually by public companies with the Securities and Exchange Commission (SEC).

The weaknesses of the SIC system are incorporated into federal environmental tracking tools such as the TRI, which identifies sectors, industries, and individual facilities with two-digit and four-digit SIC codes. Congress created the TRI as part of Title III of the Superfund Reauthorization Amendments (SARA), in response to the deadly gas leak in Bhopal, India. Title III develops emergency response provisions in order to avert similar tragedies. The U.S. Environmental Protection Agency (EPA) developed the TRI to provide the public with continuing information on firms' emissions and transport activities.

The TRI is a useful tool for people who use the database to track chemical emissions at facilities that produce products designed and sold by one company. Interested individuals may use the database to track the 343 chemicals (expanded to roughly 650 in 1994) on which firms must report. For example, a Silicon Valley public interest coalition staged a protest at a Santa Clara IBM plant in 1989 after learning from the TRI that the facility was responsible for emitting the largest quantity of chlorofluorocarbons (CFCs) in the United States. The group demanded and received from IBM a pledge to reduce and eventually phase out the use of the ozone depleting solvents (U.S. EPA 1990, 323).

Although the database helps individuals to track and monitor progress at facilities owned and operated by a single firm, it is a less useful measure of industry progress in reducing TRI transfers offsite and emissions. For example, the TRI cannot be used to hold accountable a fabless company that merely designs and sells microchips but contracts their fabrication out to third parties. In addition, the TRI is not a useful tool with which to compare performance among firms that continue to own and operate microchip fabrication plants. Fab closure, strategic alliances and the increasing ability of chipmakers in recent years to build new fabs abroad further limit the TRI's usefulness as a measure of industry performance. Trade press articles and company shareholder reports help to plug some data holes, but notable gaps remain. The gaps are more glaring for product identity and output data — information necessary to evaluate environmental performance among different facilities and firms.

To gain further insight into the possible sources of the TRI declines the following discussion pairs economic information developed for six U.S. companies with the data reported by the companies to the TRI. The six companies appear in Table 2. They range in size from small (e.g., SEEQ Technology) to giants such as Intel as measured in terms of revenue. In fiscal year 1996, SEEQ's revenues were $31,338,000 (SEEQ 1997a, 2). In contrast, Intel's sales in 1996 came to $20.8 billion. The distinction is important because it generally is the case that smaller companies typically report that they are less able than Fortune 500 firms to devote resources to environmental, health, and safety issues (EHS). Combined, the six companies comprise between five and 12 percent of all releases and transfers reported to the TRI by semiconductor firms operating in the United States between 1988 and 1995, respectively.

Table 2. Firm size, by revenue, fiscal year 1996

Company	Revenues	Primary products
Intel	$20,870,000,000	Microprocessors
National Semiconductor	$ 2,623,100,000	System level products for fax machines, local and wide-area networking and telecommunications
Advanced Micro Devices	$ 1,953,019,000	Microprocessors
Cypress Semiconductor	$ 528,400,000	Memory chips and programmable logic devices
Cyrix	$ 183,825,000	Microprocessors
SEEQ Technology	$ 31,338,000	Local Area Network (LAN) chips

Source: U.S. Securities and Exchange Commission (SEC). 1997. Edgar database 10K Reports. Washington, D.C.: Government Printing Office. Available at http://www.sec.gov/cgi-bin/srch-edgar?

Table 3. TRI releases and transfers, 1988, 1995

Company	Reporting Year	
(pounds)	1988	1995
Intel	523,692	2,618,082
National Semiconductor	580,861	209,917
Advanced Micro Devices	442,246	308,670
Cypress Semiconductor	19,123	579
SEEQ Technology	2,950	N/A
Cyrix	0	0
Total	**1,568,872**	**3,137,248**

Source: U.S. EPA. 1997b. Toxics Release Inventory: Public data release. Office of Pollution, Prevention and Toxics. Washington, D.C.: Government Printing Office. Available at http://www.rtknet.org.
Notes: Computer search conducted for facilities that use 3674 as primary SIC code.
Search used medium level of emissions detail. Searches for "high" or "low" levels of detail produce slightly different totals.

Table 3 shows emissions and transfers off site of toxic chemicals for the six firms.[2] SEEQ filed TRI reports up to 1990. However, no TRI data are available for SEEQ in 1995 because the company by then had permanently closed its California fab. Likewise, Cyrix is a "fabless" chip company that relies entirely on third-party suppliers to manufacture its chips.

Overall, between 1988 and 1995, releases and transfers fell for three of the firms for which TRI data are available for both years. Only Intel's total TRI amounts increased between 1988 and 1995. Intel's increases are likely the result of significant expansion at the company's reporting facilities such as those in New Mexico. The increase also may be due to EPA's decision to nearly double the number of chemicals on which firms are required to report.

Table 4 TRI facilities reporting, 1988, 1995

Company	1988	1995
Cyrix	N/A	N/A
AMD	California (5)	
Texas (2)	California (1)	
Texas (1)		
Cypress	California (1)	
Texas (1)	Texas (1)	
Minnesota (1)		
Intel	Arizona (2)	
California (3)		
New Mexico (1)		
Oregon (2)	Arizona (1)	
New Mexico (1)		
Oregon (1)		
Puerto Rico (1)		
National Semiconductor	Arizona (1)	
Connecticut (1)		
Maine (1)		
Texas (1)		
Utah (1)	Maine (1)	
Texas (1)		
Utah (1)		
SEEQ Technology	California (1)	N/A
Total	23	11

Source(s): U.S. EPA. 1997b. Toxics Release Inventory: Public data release. Office of Pollution, Prevention and Toxics. Washington, D.C.: Government Printing Office. Available at: http://www.rtknet.org; U.S. Securities and Exchange Commission (SEC). 1997. Edgar database 10K Reports. Washington, D.C.: Government Printing Office. Available at http://www.sec.gov/cgi-bin/srch-edgar?

Note: A TRI "facility" does not necessarily denote a microchip fab.

To help account for TRI declines, Table 4 illustrates changes during the same period in the number and location of facilities operated by five of the six companies for which TRI data are available. Recall that Cyrix is a fabless producer that most recently contracted manufacturing out to IBM Microelectronics and SGS Thomson. The most obvious trend among the five firms is the shift of manufacturing facilities away from California to other parts of the United States. The number of AMD California facilities reporting to the TRI dropped from five to one over the period. Intel's dropped from three to one. SEEQ closed its California fab in 1992 and California-based Cypress opened fabs in Texas and Minnesota. The remaining AMD and Intel facilities in California primarily are used for research purposes rather than high volume production and thus are not likely to trigger TRI reporting thresholds.

With the exception of Cypress Semiconductor, which experienced no net change in the number of reporting facilities during the period, the number of facilities reporting to the TRI also declined. For all five firms, the number of facilities that filed TRI reports fell from 23 to 11 from 1988 to 1995. AMD's fell from seven to two and Intel's from seven to four. National's dropped from five to three.

There are a number of possible explanations for the TRI declines. One is that the facility continued to operate but did not use any of the 650 chemicals in sufficient quantity to trigger a report. Another is that the facility was temporarily idled or converted to another use. Finally, facilities may simply have been closed. In the case of National Semiconductor, some of the TRI declines are clearly due to the closure of manufacturing facilities. According to annual reports and features in the trade press, National Semiconductor in 1988 announced plans to phase out its Santa Clara microchip production lines and shift production to Arlington, Texas. National also sold, then leased back its Texas fab and Santa Clara microchip development center in 1990. The firm's Danbury, Connecticut and Tucson facilities were idled by 1994. During the period, National also sold its Puyallup, Washington fab to Matshushita, a Japanese microchip manufacturer. Whereas National closed, sold, or idled some facilities in the United States, the company also expanded and constructed new microchip manufacturing facilities overseas. National, until 1998, operated three fabs in Scotland's "Silicon Glen."[3]

According to company reports, National has maintained a manufacturing presence in Scotland since the 1970s (National Semiconductor 1997). However, the company also significantly expanded production there during the reporting period. National reported that production at its Scotland facility increased 85 percent in 1994 (National Semiconductor 1996). Although the company obviously is not required to report to the TRI on emissions from its overseas facilities, National Semiconductor reports that emissions at the Greenock, Scotland fabs in 1994 declined more than 18 percent and water usage by 25 percent (ibid. 1996). National also operates manufacturing facilities in Malaysia. More recently, National Semiconductor also launched the company's first joint venture called National Semiconductor Shanghai Sunrise Ltd. in China (National Semiconductor 1997). Located in Shanghai, the joint venture includes manufacturing and testing facilities.

Advanced Micro Devices similarly shut down all manufacturing facilities in Silicon Valley, retaining only its advanced manufacturing facility. AMD also sold two of its Texas fabs to Sony Microelectronics. AMD currently operates a fab in Japan in conjunction with Fujitsu and is constructing another fab there, as well as in former East Germany.

Whereas National and AMD still operate fabs, SEEQ announced 1991 plans to phase out entirely production at its California facility and close the plant in 1992. SEEQ now obtains chips from a changing set of suppliers, known as "foundries." Foundry suppliers focus exclusively on manufacturing and not on design or sales. In 1996, SEEQ's manufacturing partners included American Microsystems Inc. (AMI) Semiconductor, Ricoh, Rohm, Samsung, and TSMC. According to its company reports, Ricoh lists manufacturing facilities in California and Georgia. Samsung operates microchip fabs in Korea and Portugal and recently announced plans to construct a new fab in Austin, Texas. Taiwan Semiconductor Manufacturing Corporation (TSMC) operates two fabs in Taiwan's version of Silicon Valley, the HsinChu region. TSMC has announced plans to add two additional facilities in Taiwan as well.

SEEQ's foundry partners in 1995, the most recent year for which EPA has released TRI reports, included AMI Semiconductor, Hualon Microelectronics, International Microelectronic Products (IMP), Ricoh, Rohm, and Samsung (SEEQ 1996). According to an electronic mail reply from a SEEQ representative, the company is too small to mount an active program to monitor the environmental performance of microchip suppliers. However, "SEEQ works under the assumption that local laws and ordinances in suppliers' respective jurisdictions govern day to day factory discharge and disposal (SEEQ 1997b)."

It is not possible to use the TRI to gauge emissions for SEEQ's overseas suppliers. However, releases and transfers in 1995 do appear on the database for SEEQ's U.S. supplier, AMI. That year, releases and transfers for AMI's Pocatello, Idaho facility came to 18,202 pounds. It nonetheless is impossible to determine what proportion of AMI's releases and transfers were due to production for SEEQ. It may be SEEQ's other foundry partners have facilities in the

United States as well but either failed to use TRI chemicals or used TRI chemicals in insufficient quantities to trigger reports. Another possibility is that TRI reports are listed under another SIC code. For example, SEEQ supplier Ricoh also makes photocopiers and other electronic equipment that appear under other parts of the SIC 36 designation and possibly also parts of SIC 35. In any case, it is impossible to use the TRI to identify what proportion of releases and transfers from SEEQ's third-party suppliers were due to production of SEEQ products. If revenues are a proxy for output, however, it is likely that environmental impacts from SEEQ are relatively small compared to companies such as Intel and National Semiconductor.

Similarly, no TRI reports exist for Cyrix because like SEEQ, the Texas-based microprocessor firm is a fabless company. Before the company was purchased by National Semiconductor in 1997, Cyrix primarily obtained supplies from IBM Microelectronics and SGS Thomson. IBM Microelectronics reported emissions and transfers to the TRI for its U.S. facilities in 1995, but it is impossible to determine how much of IBM's emissions are due to production for Cyrix. According to an electronic mail reply from IBM's Corporate Environmental Affairs department, it is not possible to segregate TRI release and transfer data for Cyrix's product because IBM manufacturers the product in the same buildings, using the same equipment as it does for the manufacture of IBM's own product. According to the company explains: "If IBM performed foundry work in a building on production lines dedicated solely to Cyrix production, segregating TRI data would be relatively simpler."

Presently, however, IBM representatives report that implementing a scheme to segregate releases and transfers from its own products and those of Cyrix would be costly because the amount of chips that the company manufactures for Cyrix's products represents a small portion of IBM's overall production from the facility. Since IBM's production for Cyrix forms a relatively small proportion of output and TRI releases and transfers, IBM believes that environmental health and safety resources are better invested "in producing real environmental benefits (IBM 1997)."

In terms of industry-wide trends, it is possible that a proportion of the TRI declines since 1988 result from firms shifting production to newer, more efficient fabrication facilities outside of California. In other words, emissions fell because one new fab can do the same work as two or three older facilities. However, in order to compare emissions among fabs, adjustments must be made for output, microchip type and chemical use — data that for the most part are impossible to obtain.

Tracking Global Emissions

Whereas some firms merely shifted production away from California into other parts of the United States, three of the six firms examined also constructed new or expanded existing microchip fabs abroad since 1988. Because firms with operations outside of the United States and its territories are not required to report to the TRI, such geographic shifts of both production and pollution may contribute to the appearance of improved environmental performance. For example, by 1995 Intel had expanded fab operations to Ireland and Israel. Similarly, National expanded production at its Scotland fabs. Finally, AMD in conjunction with Fujitsu constructed a new facility in Japan.

To help the public track emissions of its non-U.S. facilities engaged in computer and microchip manufacture, IBM Corporation in 1993 modified its internal reporting requirements. Although EPA does not require U.S. firms to report on emissions from overseas facilities, IBM voluntarily applied the TRI format to report on emissions from facilities abroad. The data — which do not distinguish between computer and microchip facilities — are available in the firm's 1996 annual environmental report for emissions from IBM facilities in the United States and abroad during 1995 (IBM 1996). That year, IBM's U.S. sites, which manufacture chips as well as products such as computers, used 27 chemicals in sufficient quantity to trigger reporting. Combined, the facilities released or transferred offsite as waste 12.43 million pounds. That same year, total SARA Section 313 and reportable quantities from IBM's non-U.S. sites, including chip fabs, was 23.4 million pounds (IBM 1996).

Between 1988 and 1995, several of the six firms studied here also sold or leased manufacturing facilities to foreign companies. For example, AMD sold two Texas fabs to Sony; National sold a Washington fab to Matshushita. National sold its Arlington, Texas facility to an unspecified company and then leased the site back.

It is possible to use the TRI to track changes in facility ownership that result from lease or sale because EPA supplies each reporting firm with a facility identification code that does not change when a plant is sold. For example, while emissions from National's Puyallup, Washington fab ceased in 1990, it is possible to use the facility identification code to determine that Matsushita now operates the facility. The TRI facility identification code also makes it possible to monitor emissions from the Texas fabs sold by AMD to Sony. While it is possible to use the TRI to continue to track emissions, the ownership transfers nonetheless contribute to the appearance that National and AMD's company-wide (as opposed to facility) TRI emissions and transfers declined.

Given the increased complexity of production relationships among chip firms, the TRI is an inaccurate measure of industry and company trends. As the six firms show, the development of the TRI coincides with the idling, closure, and geographic shift of fabs to other parts of the United States and abroad.

In addition to serving as a tracking device, interested citizens and regulatory agencies also use the TRI to promote industry's environmental performance. When a fabless company has foundry partners in the United States, it is possible to use TRI reports to examine emissions and transfers from foundries. However, few foundries make chips exclusively for one partner. Some, such as IBM, also produce chips for firms such as Cyrix, as well as for IBM machines. Since fabless companies seldom pinpoint where foundries produce chips and in what amount, it is impossible to use the TRI to track most emissions due to U.S. foundries. Foundry agreements and the location overseas of new U.S. fabs further complicate efforts to assess environmental performance because U.S. firms are not required to report on operations of overseas facilities. IBM's move to adopt the TRI format to report on its non-U.S. facilities is a notable and promising exception. National Semiconductor and Intel supply information on the environmental performance of their overseas facilities but not in a format identical to TRI. It also must be noted that while these three companies have elected to voluntarily report on some aspects of environmental performance of their foreign facilities, the data are impossible to independently verify. What is clear is that in the case of four of the sample firms examined here, declining TRI numbers may be due in part to the expansion both of U.S.-owned fabs overseas, as well as fabless partnerships with offshore foundries.

Accountability Issues

As production relationships among chip companies become more complex, so do the associated environmental issues. One problem is that fablessness may reduce incentives for U.S. companies to promote better environmental results from their constantly shifting sets of foundry suppliers.

The rising prominence of suppliers is not confined to the semiconductor industry, but occurs everywhere from the automotive to the entertainment industries. To promote the environmental performance of suppliers, some firms, academicians, and environmental managers have endorsed the adoption of voluntary worldwide environmental standards. Among the most prominent is the 14000 initiative by the International Standards Organization (ISO), a private, non-profit organization that seeks to develop more uniform international business methods. The certification is predicated on the idea that attention to environmental concerns may become a source of advantage for suppliers and sellers.

To date, companies must obtain certification through third-party audits for one part of the series, ISO 14001. ISO 14001 describes in general features that a firm's environmental management system must contain. For example, companies should be committed to "continual improvement and prevention of pollution" (ISO 1995, 8) and develop procedures and plans to identify the environmental aspects of different corporate operations.

Whereas the European Union (E.U.) lobbied for performance standards, the United States and others successfully countered that standards on pollution levels could impose trade barriers (Milliman 1995, 8). ISO 14001 could become a way for customers in one country to compel suppliers in another to adopt more uniform environmental management systems. Indeed, some E.U. countries seek to give preference to suppliers that have obtained ISO certification (Milliman 1995, 10).

Supplier Selection

It is premature to evaluate the efficacy of ISO 14000 and 14001 because implementation is still largely underway. However, a growing number of studies have attempted to examine methods such as ISO to improve the environmental performance of suppliers in the electronics and computer industry (Bérubé 1992).

The studies identify what factors promote firms to employ environmental concerns when selecting suppliers, as well as during supplier partnerships (Bérubé 1992; Sarkis et al. 1995). In a survey of 50 of the largest U.S. computer companies, Bérubé, found that while firms' interest in integrating environmental concerns is growing, for most companies, environmental concerns still are the least important factor when selecting a supplier. Among the few proactive companies that do use environmental criteria to select suppliers, Bérubé found that large companies are much more likely than smaller to consider environmental issues when selecting suppliers.

Related to Bérubé's findings is a study that shows that strategic partnerships that are long-term, information-intensive, and forged from a small, rather than large, set of potential suppliers have a better chance of minimizing materials use and waste generation (Sarkis et al. 1995). Bérubé found that large firms are more likely to use environmental criteria when selecting suppliers.

In contrast, most fabless semiconductor companies such as SEEQ are relatively small, as measured in terms of staff size and sales. Recall that in 1996, the company employed around 74 people and had slightly over $31 million in revenues. In contrast, that same year Intel's revenues exceeded $20 billion and the work force worldwide was near 40,000. Another factor discouraging better supplier relationships is the extremely fluid nature of contracts — most of which are under five years. Recall that SEEQ, for example, does not maintain long-term, non-cancelable contracts with its microchip suppliers (SEEQ 1997b, 28). Consequently, suppliers could chose to prioritize manufacturing facilities for other uses or reduce or eliminate chip deliveries to SEEQ on extremely short notice.

Foundry partnerships also may discourage environmental concerns by providing few incentives for firms to enhance manufacturing methods. Producing microchips free of defects requires a high degree of technical skill, the latest equipment and close cooperation between microchip foundries and the circuit designer. However, short-term, variable partnerships and the often-great geographic distance between fabless firms and overseas foundries diminishes opportunities for designers and foundries to resolve production problems (Mazurek 1994). Though partnerships among producers require information exchange between product designers and manufacturers, technology licensing and cooperative technology development may provide greater opportunities to incorporate environment concerns into product and process design. However, Angel (1994, p. 135) found that most agreements by chip design houses are for fabrication, as distinct from technology licensing or cooperative technology development.

That fabless production may fail to fit the criteria for the promotion of environmental concerns is not surprising, given that the current emphasis of fabless companies is on design, rather than manufacturing. Though fablessness does reduce expenditures associated with fab construction, the diminished focus on manufacturing carries risks for fabless companies as well. For example, it is not uncommon for foundries to experience manufacturing problems that result in delivery delays, or for partnerships to dissolve in less than five years as a result of recurrent supply or product performance problems.

As Cyrix reports: “The company’s reliance on third-party manufacturers creates risks that the company will not be able to obtain capacity to meet its manufacturing requirements, will not be able to obtain products with acceptable yields, or will not have access to necessary process technologies (Cyrix 1996, 15).” The experience of SEEQ illustrates what happens when a foundry partnership ends in divorce: “In the second half of ‘95 our revenues were adversely affected by the unexpected phase-out of one of our foundry sources.” The company reacted by quickly establishing ties to two additional sources.

It is possible that the current set of conditions that discourage environmental concerns among foundries will subside as third-party suppliers mature and gain the ability to invest in equipment and upgrades. Indeed, TSMC, one of the largest and most established foundries, currently is constructing two new microchip fabs in Taiwan that the company pledges will deliver state-of-the art environmental performance. The TSMC case suggests that as chip firms increasingly search for methods to differentiate products from the competition, ISO 14001 certification may serve as a way for chip manufacturers to distinguish themselves in highly competitive markets. Currently, TSMC prominently features its Taiwanese fabs as meeting ISO 14001 management standards. National Semiconductor similarly advertises the ISO 14001-certified status of its Scotland facility on the company’s web site (National 1996, TSMC 1997).

Bérubé finds that firms eventually may find it in their interest to incorporate environmental concerns if permitting or compliance problems lead to repeated product delays (Bérubé 1992, 1). However, such a scenario assumes that foundries are located in places with sufficient resources to scrutinize permits and conduct routine inspections. A recent analysis of 22 computer and electronics companies, including semiconductor firms based in five countries, found that even though all the companies are based in advanced capitalist countries, half of their manufacturing and assembly facilities are in developing countries (Plazola 1997).

By all accounts, the majority of developing countries simply lack comparable resources to inspect and, when necessary, bring enforcement actions against firms that violate standards. Taiwan, home of TSMC, is perhaps the most notorious example. The large island suffers from serious air and water pollution, as well as a growing number of contaminated industrial sites due to its rapid economic growth during the last two decades (Arrigo, Luen, and Lin 1996, 765-777). As environmental conditions in Taiwan have continued to deteriorate seriously, the government has recently passed a flurry of environmental laws and an enforcement agency patterned after those in the United States and Japan. Despite the proliferation of laws, Arrigo, Luen and Lin report that there is little effective enforcement against polluters due primarily to fears that more stringent environmental protection will retard economic growth.

In the context of Taiwan’s weak regulatory climate, efforts such as ISO 14001 could provide additional assurance that a company is meeting environmental goals. As the shortcomings of the TRI illustrate, the presence of voluntary international standards such as ISO 14000 may eventually help to make environmental management practices around the globe more uniform.

Summary

Changes in how and where U.S. semiconductor firms make chips outstrip the present ability of government institutions to track and monitor potential threats to humans and the environment. Mechanisms that could help to improve information about the industry, such as the TRI, are increasingly inadequate, due to complicated reconfigurations in how and where chips are produced.

Although new chip making regions such as Taiwan's HsinChu recently have enacted environmental laws with standards that are comparable to those on the books in the United States or Japan, these countries often lack both the resources and political will to conduct inspections and enforcement.

It is too early to assess how well voluntary initiatives such as ISO improve environmental performance among suppliers. However, U.S. semiconductor companies that rely on foreign foundries may find it in their interest to require their suppliers to adopt ISO or some similar voluntary standard if poor environmental performance is linked to low output and to production delays. **References**

Advanced Micro Devices (AMD). 1996. Manufacturing facilities overview. Available at http://www.amd.com/html/locations/mfg.html.

Angel, David P. 1994. *Restructuring for Innovation: The Remaking of the U.S. Semiconductor Industry.* New York: The Guilford Press.

Arrigo, Linda Gail, Tze Luen, and Yvonne Lin. 1996. Environmental conditions and environmental law in Taiwan. Available at: http://taiwanese.com/tw-env/about.htm.

Bérubé, Michael R. 1992. Integrating environment into business management: A study of supplier relationships in the computer industry. Cambridge, MA: MIT Technology, Business and Environment Research Group.

Business Week. 1997. Silicon Valley: How it really works. 18-25 August, 64-147.
Capria, Antonella, ed., 1996. *A World Survey of Environmental Laws.* Milano, Italy: Giuffre Editore. 765-777.

Chartered Semiconductor Manufacturing (CSMINC). 1997. Chartered Semiconductor Manufacturing named top fab by Semiconductor International magazine. Available at: http://www.csminc.com/pr18.htm.

Cyrix Corporation. 1996. 1995 Annual report. Available at http://www.cyrix.com/corpor/annual.

Dataquest. 1997. Top 10 Worldwide semiconductor market share estimates. 1996. San Jose, CA: Dataquest.

Economist. 1997. Silicon Valley survey. 29 March: 1-20.

___. Deep in the heart of Texas. 29 March: 14-15.

Economic Development Board of Singapore (EDB Singapore). 1996a. More semiconductor companies doing multi-activities. September. Available at http://www.sedb.com/what/index_search.html.
Search on "semiconductor."

Economic Development Board of Singapore (EDB Singapore). 1996b. Two new schemes to boost semiconductor industry. October. Available at http://www.sedb.com/what/index_search.html.
Search on "semiconductor."

Hamilton, Martha M. 1996. The economy gets a new taxonomy: Analysts welcome a SIC transit to '90s realities. *Washington Post.* 28 June.

IEEE International Symposium on Electronics and the Environment. May. Orlando, FL.

International Business Machines (IBM) Corporation. 1997. Electronic mail correspondence with Edan Dionne, Corporate Environmental Affairs, IBM Corporation. 14 October.

___. 1996. IBM and the Environment. Annual environmental report. Available at http://www.ibm.com/IBM/Environment/annual/01Ger.htm.

International Organization for Standardization (ISO). 1995. Environmental management systems - specification with guidance for use - draft International Standard ISO 14001. Geneva: International Organization for Standardization.

LaDou, Joseph. 1986. Health issues in the microelectronics industry. *Journal of Occupational Medicine.* 1:1-11.

Mazurek, Janice V. 1994. How fabulous fablessness: Environmental planning implications of economic restructuring in the Silicon Valley Semiconductor Industry. Master's thesis. University of California at Los Angeles.

Milliman, Kevin. 1995. ISO 14000 & U.S. manufacturing. Washington, D.C.: Center for Risk Management, Resources for the Future. 11 December.

Ministry of the Environment, Singapore. 1997. Available at http://www.gov.sg/etnet/inddevpl.htm.

National Semiconductor. 1997. List of worldwide manufacturing facilities. Available at http://www.national.com/company/index.html.

National Semiconductor. 1996. Greenock, Scotland. Available at http://www.national.com/environment/momentum/location05.html.

National Semiconductor. 1995. Annual report. Available at http://www.national.com/annual_report/Management's_Discussion.html.

Plazola, Carlos 1997. The globalization of high tech: Environmental injustices plague industry. San Jose: SVTC.

Sarkis, Joseph, Nicole M. Darnall Gerald I. Nehman, and John W. Priest. 1995. Paper presented at symposium, the role of supply chain management within the industrial ecosystem.

SEEQ Technology Incorporated. 1997a. 1996 Annual report. Fremont, CA: SEEQ Technology Incorporated.

___.1997b. Electronic mail correspondence with James Middleton, Director of Operations, 29 October.

___.1996. Corporate Fact Sheet. Fremont, CA: SEEQ Technology Incorporated. Available at: http://www.seeq.com.

___.1991. Annual report. Fremont, CA: SEEQ Technology Incorporated.

Semiconductor Industry Association. 1997a. Chip Stats. San Jose, CA: SIA. Available at http://www.semichips.org.

___. 1997b. Worker Safety & Environment. Available at http://www.semichips.org.

___.1994. The national technology roadmap for semiconductors. San Jose, CA: SIA.

Taiwan Semiconductor Manufacturing Company. Available at http://www.tsmc.com.tw/Image/iso14001e.html.

U.S. Department of Commerce (DOC). 1997. Current Industrial Reports. MA36 Series. Bureau of the Census. Washington, D.C.: Government Printing Office.

___.1994. County business patterns. Bureau of the Census. U.S. Summary Data. Washington, D.C.: Government Printing Office. Available at: http://www.census.gov/prod/www/abs/cbptotal.html.

U.S. Environmental Protection Agency (EPA). 1997. Toxics Release Inventory: Public data release. Office of Pollution, Prevention and Toxics. Washington, D.C.: Government Printing Office.

___.1990. *Toxics in the community: national and local perspectives*. The 1989 Toxics Release Inventory National Report. Office of Pollution Prevention and Toxics. Washington, D.C.: Government Printing Office.

U.S. Securities and Exchange Commission (SEC). 1997. Edgar database 10K Reports. Washington, D.C.: Government Printing Office. Available at http://www.sec.gov/cgi-bin/srch-edgar?

[1] Mazurek is the author of Making Microchips: Policy, Globalization and Economic Restructuring in the Semiconductor Industry (MIT Press 1999). She is an environmental policy consultant.

[2] Though SEEQ filed reports up to 1990, no TRI data are available for 1995, because SEEQ had permanently closed its California fab by then.

[3] In 1998, National announced plans to consolidate manufacturing from three fabs to one in Scotland and sought investors to purchase its remaining fab. The company's 1998 decision to seek investors for its remaining facility was reversed in 1999, however, National did proceed with its consolidation.