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Electronics Industry Environmental Roadmap

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Abstract: This 1996 Electronics Industry Environmental Roadmap continues ongoing efforts introduced in 1992 by MCC, working in concert with a diverse group of electronics and information technology manufacturers and their suppliers, and supported by the Advanced Research Projects Agency (ARPA) of the U.S. Department of Defense under a contract to Wright Labs. This year's Roadmap updates and expands upon the top priorities from the 1994 Electronics Industry Environmental Roadmap, produced by MCC with the participation and support of a wide range of companies and associations. One objective is to look at the priorities identified in the 1994 Roadmap and, through a review process, select the top priority issues that need attention in the near term. The discussion and recommendations in this document are intended to provide an agenda for a set of activities that can be launched in the near term, executed through a focused program of cross-industry collaboration, that provide a basis for the next generation of environmental management in the electronics industry. Ultimately, the results will manifest themselves at the bottom line—of the corporation, the industry, and the environment.

This document meets its expected scope and MCC's standards of technical quality.

Author: Steve Pedersen____________________ Date: __________

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Executive Summary

This *Roadmap* addresses a wide-ranging set of critical issues relating to strategic environmental management within the electronics and computer industry. The intent is to characterize the current state of environmental management, identify challenges and opportunities for improvement, and present specific needs or conclusions for taking significant steps forward.

The *Roadmap* addresses technical and non-technical issues, spanning the enterprise from senior-most management through product design, assembly, and distribution. This broad focus is necessary given the enterprise-wide nature of environmental management. Traditional industrial strategies of remediation and compliance-based management are giving way to waste reduction, pollution prevention, and beyond-compliance programs. As a consequence, an effective roadmap for environmental management in any industry requires that several priorities be recognized:

- The importance of integrating environmental goals into corporate culture and strategic plans must be recognized by top management, thereby implementing the necessary steps to ensure that environmental issues are given due consideration in all key functions.
- The importance of a broadened view of environmental management must be recognized, reaching from the research laboratory, where environmental considerations should be part of initial product concept and experimentation, through design, manufacturing, distribution, and end-of-life disposition.
- Environmental information must be generated, captured, recovered, and analyzed, then integrated into larger corporate decision-making processes.
- Environmental impacts of emerging technology must be understood, establishing environmentally focused goals for technology development.

Each of these priorities is addressed in detail in this document, along with a variety of supporting materials presented in attachments intended to further illustrate or clarify key findings.

Chapter 1: Introduction
The introduction sets forth an overall mission for the document, including recognition of complementary roadmapping efforts of other industry associations and organizations. The environmental roadmap draws upon these other documents to create a focused agenda for environmental management across the electronics and computer industry. This industry-wide, cross-disciplinary approach is consistent with MCC's mission to serve as a source of research and development that spans the full breadth of the information technology industry and places a priority on system development and integration.

Constructive involvement in environmental management has been a priority for MCC for several years, and the specific topics addressed in the *1996 Roadmap* emerge as a result of the earlier *1994 Electronics Industry Environmental Roadmap* and other supporting documents that have emerged from MCC's efforts.

Chapter 2: Strategic Business Opportunities

Responsibility for environmental management has traditionally been delegated to a specified group of environmental safety and health professionals. Although the existence of qualified professionals is an important part of advancing the state of environmental management, this approach is not sufficient to create the kind of organization-wide environmental awareness that beyond-compliance programs require. Therefore, environmental issues must be effectively incorporated into the corporation's strategic planning process, with particular consideration for financial implications of environmental decisions, ongoing environmental performance monitoring, and "Total Quality Management"-like commitment throughout the organization.

Industry organizations have prepared a variety of standards and principles to help guide effective corporate environmental management in the electronics industry and in other industries. These standards and guidelines provide an important benchmark for corporate environmental practices. In some cases, they also provide a set of baseline requirements for participation in certain industry activities or, potentially, access to markets. For example, the ISO 14001 Environmental Management Standard is currently going through an approval process, but it is reasonable to conclude that adherence to ISO 14001 may well become the kind of prerequisite for suppliers that adherence to ISO 9000 Quality Standards have become.

The quality movement, in fact, provides an important analog for raising the visibility of environmental management in the organization. Just as quality initiatives have become widespread and widely accepted, effective corporate programs to formalize, measure, monitor, and evaluate environmental initiatives will help increase the acceptance of industrial environmental management.

Furthermore, integration of environmental considerations into the cost-accounting systems of corporations will clearly demonstrate the "bottom line" impact that effective environmental management can have. A greater awareness of the financial implications of environmental decisions is also being driven by potential liabilities that manufacturers must recognize for their environmental actions.

The chapter also presents a variety of other corporate activities that can be used to raise environmental awareness including prototype facilities, model permitting processes, community outreach and communication, continuing education, and a variety of other approaches. These kinds of steps are essential if environmental management is to become a core corporate consideration, particularly given the general reluctance of many organizations to accept its fundamental importance. However, the development of new analytical tools and decision models will help support this increased priority. Furthermore, the establishment of viable measurement and evaluation programs will lend credibility to the effort. Once effectively implemented, the newly heightened corporate awareness of environmental issues can support more effective government/industry partnerships in pursuit of rational and cost-effective regulatory frameworks.

Chapter 3: Information And Knowledge Systems

A fundamental requirement of effective corporate environmental management is access to reliable data and the information systems necessary to store, retrieve, analyze, and manage it. There are currently significant weaknesses in environmental data available to corporate managers, particularly data relating to the environmental management within a particular corporation. Data are often specific to particular kinds of media, and can be limited in scope, unverified, inconsistent, and lacking context.

Emerging information systems, in particular the rapidly emerging Internet- and World Wide Web-based technologies, offer a mechanism for managing and sharing information widely both within and across the industry. The availability of data encompassing design; technology; regulatory, standards, and compliance; performance and risk; and other information is made substantially easier by the open, readily navigated environment of the World Wide Web. As corporate management increasingly emphasizes environmental considerations in decision-making processes, environmental measurement and monitoring systems will need to improve to establish more reliable data. The effective linkage with robust industry-wide data sources and benchmarking can provide a powerful tool for environmental management.

The effectiveness of data management will be substantially enhanced by a focused industry effort to develop improved analytic tools to take advantage of environmental data. Techniques such as data warehousing, data mining, and data fusion need to be employed and enhanced to specifically address the information needs of this industry.

Chapter 4: Design For Environment: Evolution And Tool Needs

The *Roadmap* focuses specific attention on the subject of design for the environment (DFE). DFE is a fundamental requirement for the electronics industry as it seeks to infuse environmental attributes in all aspects of design, manufacturing, and product life cycle management.

For the purposes of this roadmap, a limited survey was conducted evaluating the state of DFE tools available to industry and the key features that should be present in effective DFE tools. The survey found wide differences in the level and type of DFE activities undertaken, supporting a conclusion that DFE is in a very early stage of development within the industry. Most of the responding companies utilized DFE tools ranging from relatively simple information resources to more complex software-based products. The report includes a listing of DFE tools currently available, identifying their developer and providing a very brief assessment of their capabilities.

From a requirements standpoint, survey respondents indicated that key features required of DFE tools include built-in databases of environmental information, integration with CAE/CAD platforms or existing tool suites, support for technology trade-off studies (including real-time trade-off studies), applicability to multiple manufacturing areas, compatibility with standards, and the ability to generate ranked/priority results.

Chapter 5: Disposition

Planning for and managing end-of-life disposition of electronic products is becoming increasingly important. Regulatory requirements imposed upon OEMs and distributors, the increasing cost of traditional disposition alternatives, market demands, and other trends are increasing the priority attached to product end-of-life management. Product end-of-life management (PELM), in and of itself, represents a potential industry in its early stages of development. Recovery, remanufacturing, and recycling all have potential economic value to PELM service providers who overcome obstacles relating to recapturing end-of-life product and processing it appropriately for particular purposes.

The chapter describes model and pilot programs in the U.S. and abroad and presents a series of recommendations for improving the handling and processing of electronic products at the end of their life. Fundamentally, adoption of the recommendations would result in end-of-life products being managed as product rather than waste, seeking to find cost-effective alternatives to releasing end-of-life products to the waste stream if at all possible.

Chapter 6: Emerging Technologies

Constant innovation and continuing development of new electronic systems—whether characterized as evolutionary or revolutionary—is likely to continue well into the future. Roadmaps developed by other industry segments for semiconductors, printed wiring boards, displays, and other component areas all anticipate continued evolution of technology into systems that are smaller, faster, and cheaper. These evolving systems will result in changes in processes, materials, and chemicals for their manufacture. Each stage of the electronics production process has certain unique environmental issues associated with it, and changes in processes, materials, and chemicals will have implications for effective environmental management.

This chapter examines the electronics production process, exploring environmental implications at each stage, and assessing the likely evolution of electronics manufacturing as reflected in key industry roadmaps. As a result of this analysis, a series of "grand challenges" for technological advancement with significant environmental impacts are presented, including the pursuit of "dry" wafers, the packageless chip, zero emissions, fully additive substrates, and point-of-use generation of hazardous chemicals.

Appendices

The appendices present a variety of supporting material, including industry guidelines for environmental management, sources of data to support environmental decision-making, analysis of DFE processes and tools, examples of disposition programs from elsewhere in the world, statistical information about the industry, a discussion of contingent liabilities, and a variety of other data providing readers with background information that will be useful in planning their own environmental programs.

Conclusion

Previous reports in this series have emphasized the point that effective environmental management is good business. Reducing waste saves money—both in terms of lower production costs and avoided liabilities downstream. Market trends are showing preferences in many cases for products that demonstrate environmental sensitivity, and in some countries effective environmental practices will be necessary admission tickets to market participation.

At the heart of the issue is the simple fact that environmental management is becoming a fundamental competency for business success, as well as a requirement for effective corporate citizenship. This *Roadmap* provides a framework within which the electronics industry can pursue initiatives through alliances and collaborations *or* as individual companies. Regardless, constant improvement in our stewardship of the environment is a business essential.

1.0 Introduction

1.1 Overall Strategy

The electronics industry stands on the verge of a fundamental change in the way environmental policy is formed and implemented. This shift has several dimensions:

- From remediation to pollution prevention.
- From a regulatory structure based on command and control to one based on flexibility and collaboration.
- From environmental management as a secondary corporate function to environmental policy as an integrated corporate concern.

Accelerating and institutionalizing this shift requires a focused, industry-wide strategy, identifying common concerns, priorities, and objectives for collaborative action—a *roadmap for industry action.* The shift can be enhanced by developing community partnerships specific to each facility's circumstances to engender effective involvement, communication, and understanding between all stakeholders.

A discussion of environmental considerations in electronics manufacturing has many dimensions. A strong argument can be made that progress in electronics has been a significant force in enriching and enhancing the overall environmental movement throughout the world, and contributing to significant changes in day-to-day life that reduce environmental deterioration. For example:

- E-mail can now move messages and documents in a matter of seconds without significant environmental consequences, especially when compared with the alternative of mailing a letter, which must then be physically transported via truck or airplane from one location to another.
- Electronics has contributed substantially to the capability of manufacturers to run cleaner and more efficiently, react to environmental accidents, increase productivity, reduce energy, and minimize required resources.

At the same time, these advances have occurred thanks to an increase in the production of electronic products. Therefore, it is important to assure that the environmental practices surrounding the production and manufacturing of electronics are a priority for industry.

This *1996 Electronics Industry Environmental Roadmap* continues ongoing efforts introduced in 1992 by the Microelectronics and Computer Technology Corporation (MCC), working in concert with a diverse group of electronics and information technology manufacturers and their suppliers, and supported by the Advanced Research Projects Agency (ARPA) of the U.S. Department of Defense under a contract to Wright Labs. This year's *Roadmap* updates and expands upon the top priorities from the *1994 Electronics Industry Environmental Roadmap*, produced by MCC with the participation, support, and endorsement of a wide range of companies and associations. Both *Roadmaps* are intended to provide a framework for constructive action.

An important distinction in this year's edition of the *Roadmap* is the emphasis on strategic business opportunities, such as design for the environment practices and consumer electronics product disposition. The previous *Roadmap*, and MCC's report that preceded it entitled "Life Cycle Assessment of a Computer Workstation," focused much more heavily on environmental issues associated with particular technologies or component areas. Since MCC's environmental roadmapping efforts first began, technology roadmaps have been completed, or are under way, by several other key electronics associations:

- The Semiconductor Industry Association (SIA), in association with SEMATECH, has developed the National Technology Roadmap for Semiconductors.
- The Institute for Interconnecting and Packaging Electronic Circuits (IPC) has developed a National Technology Roadmap for Interconnects.
- The National Electronics Manufacturing Initiative (NEMI) has developed a broad roadmap for information hardware, encompassing a variety of specific technology segments including both technology issues and policy/infrastructure issues.
- The Optoelectronics Industry Development Association (OIDA) produced a roadmap for optoelectronic technology, including a section addressing displays.
- The U.S. Display Consortium (USDC) is in the process of developing a comprehensive roadmap for the flat panel display industry.
- NEMI, in association with a group of leading battery manufacturers, is currently launching an effort to produce a roadmap for energy sources and passive components.

These roadmaps generally address the current state of technology, including emerging technologies, the requirements for and impediments to technological advancement, and a variety of policy issues associated with maintaining competitiveness of individual corporations and the entire industry. Most of the roadmaps also address certain cross-cutting challenges, i.e., issues that are pervasive in their importance to technological evolution within the particular electronic segment, although none comprehensively deal with environmental issues. A detailed summary of the various roadmaps can be found in Appendix A.

This environmental roadmap has many similar characteristics, but to be effective it must operate at a different level. Given the body of knowledge represented by the other roadmaps, it would be misguided to attempt any significant additional technical analysis of these industry segments. The approach instead is to examine the technical and strategic business opportunities described in the roadmaps and identify those common or pervasive issues that seem to emerge. By doing so, the fundamental, cross-cutting requirements for effective industry action and environmental processes can be identified.

For example, the similarity of chemicals, materials, and processes across various industry segments make the pursuit of environmental excellence in the electronics industry an inherently multi-company, and in fact, multi-industry endeavor. Therefore, the development of a true roadmap for environmentally conscious electronic systems manufacturing can only be accomplished through a cross-cutting view—identifying overall industry trends, examining common solutions and the distinctions among the various segment roadmaps, and highlighting opportunities for effective coordination and linkages.

These kinds of cross-company/cross-industry challenges have led MCC to establish environmentally conscious manufacturing as a priority for its ongoing program of consortial research.

1.2 Why MCC?

As a research and development consortium, MCC is dedicated to providing a forum through which diverse interests can convene, share intelligence, map requirements, and pursue a highly leveraged program of industrially-focused research. Furthermore, as a venture operating under the auspices of the National Cooperative Research Act of 1984, companies who participate in consortia such as MCC can do so relatively free of concerns about frivolous anti-trust actions, to the extent their cooperation remains within the bounds of the Act. Therefore, it is consistent with MCC's mission—and, some would argue, a responsibility of an organization like MCC—to pursue critical issues that are inherently multi-company, multi-industry, or multidisciplinary, or better addressed in a leveraged, collaborative manner.

Since 1983, MCC has pursued an aggressive program of research and development in several areas of advanced electronics. MCC's work has placed it among the leaders in advanced integrated circuit packaging and interconnect, including issues associated with equipment, processes and materials. In carrying out this research effort, MCC has addressed a variety of challenges that affect the environmental impact of the resulting products, including lead alternatives, additive processes, and other cutting edge issues. The relevant projects have been carried out in a consortial manner—based on the collaboration of many of the nation's leading electronics companies. These activities have provided MCC with significant experience in many of the areas that are emerging as environmental priorities in evolving technologies.

1.3 Priorities from the 1994 Roadmap

The *1994 Roadmap* addressed key environmental issues for integrated circuit (IC) packaging, printed wiring boards (PWBs) and their assembly, and displays. The *1994 Roadmap* also addressed business and strategic planning issues, disposition and end-of-life management, and regulations and standards.

One objective of the *1996 Roadmap* is to look at the priorities identified in the *1994 Electronics Industry Environmental Roadmap* and, through a review process, select the top priority issues that warrant attention in the near term. A sub-group of the Advisory Committee met several times over a period of three months to identify the top priority issues listed below, and categorized them as *strategic, longer-term* or *tactical, near-term* goals. In addition to making the issues identified in the previous roadmap more specific, the sub-group suggests organizations that may be appropriate to address the identified priority need. Table 1-1 lists the needs and a sampling of tasks that resulted from the sub-group discussions, and categorized according to the type of need—strategic or tactical. They are listed in descending order of importance.

Many of these issues are addressed in greater detail in the remainder of this report. Specifically, the agenda for the *1996 Roadmap* has identified several issues that cut across these priorities, and addresses each in the following chapters:

- Strategic Business Opportunities,
- Information and Knowledge Systems,

- Design for the Environment,
- Disposition, and
- Emerging Technologies.

The discussion and recommendations in this document are intended to provide an agenda for a set of activities that can be launched in the near term, executed through a focused program of cross-industry collaboration, that provide a basis for the next generation of environmental management in the electronics industry. Ultimately, the results will manifest themselves at the bottom line—of the corporation, the industry, and the environment.

Strategic Priority Need	Task	Possible Organizations
Business Strategies		
• Characterize elements of environmental decision making	• Establish metrics to ensure environmental quality in design processes	• Industry/MCC/EIA
• Incorporate environmental principles into existing business infrastructure	• Conduct benchmarking of corporate integration of DFE practices	• Industry/University/ Consortium
	• Analyze existing environmental financial and accounting systems for performance/cost metrics	• MCC
• Assist small- to medium-size companies implement environmental management systems	• Develop guidelines to assist supply-chain company managers to incorporate environmental principles	• EIA/Industry
Decision Making Tools		
• Enhance voluntary implementation of design-for-environment (DFE)	• Devise decision-making and financial analytical tools to support the understanding of DFE benefits	• Decision Focus/MCC/ Industry
	• Analyze existing design tools applicable to DFE practices	• Pacific Northwest Laboratories (PNL)/MCC
	• Create software-based DFE tools	• PNL/MCC/Software vendors
Disposition		
• Create guides to incorporate DFE into product design and manufacturing	• Provide designers with design guides, using the APC's "A Design Guide for Information and Technology Equipment" as a model	• EIA/MCC
• Capture and disseminate information on disposition options	• Develop markets for disposition options	• Recycling industry
	• Develop information in a format that is Web accessible	• Product and information suppliers

Cross Industry Efforts	• Establish a forum to facilitate communication between the electronics and chemical industries in materials science and chemical risks	• A standing Electronics-Chemical industry forum at a university with a strong business and engineering program

Table 1-1 is continued on the next page

Tactical Priority Need	Task	Possible Organizations
Displays		
• CRTs: Identify disposition options, recycling technologies, and transportation and handling needs	• Conduct R&D into alternative uses for CRT glass	• EIA/CRT Working Group DOD-ARPA
	• Develop technique to ensure CRT integrity during collection and transportation	• CRT Industry and Municipal Solid Waste entities
• Flat Panel Displays (FPDs): Establish DFE practices for design and manufacturing	• Document opportunities for integrating environmental needs into FPD design and manufacturing	• U.S. Display Consortium (USDC)
	• Work with FPD suppliers to understand the EHS effects of the materials that are used	• USDC
Printed Wiring Boards		
• More efficient use, regeneration, and recycling of hazardous wet chemistry	• Research in-line purification and regeneration techniques	• IPC/ITRI and universities
	• Develop chemistries and processes for existing operations that enable recycling	• IPC/ITRI and universities
• Convert to additive processes	• Develop additive processes that are competitive with existing processes	• MCC

Table 1-1. Strategic and tactical priority needs, tasks, and the appropriate organizations to deal with them, as determined by sub-group discussions.

2.0 Strategic Business Opportunities

> Imagine an organization that knows what its customers' environmental concerns will be ten years from now and knows how to win their business.
>
> Imagine an organization where the president communicates the vital few environmental strategic priorities, and every person participates in defining how his or her work provides a measurable contribution.
>
> Imagine an organization where everybody knows the methods to follow to guarantee that the organization will meet its environmental objectives.
>
> Adapted from Bechtell's (1995) "Imagine" in *The Management Compass*

2.1 Scope and Objective

Corporations are beginning to incorporate explicit consideration of environmental issues into evaluation of ongoing programs and strategic planning for the future. In the traditional way of operating, an Environment, Health, & Safety (EHS) Department is responsible only for *ex post* legal compliance with EHS regulations and laws, not for factoring current and future environmental costs into operations analysis and planning. This traditional approach is rational in a world where EHS laws and regulations are changing relatively slowly and/or not expected to change substantially in the future, and where there is little public concern with a firm's legally-permitted environmental impacts. However, this limited use of EHS departments is not recommended today for several reasons:

- Valuable expertise will be missing from new process and product design decisions.
- Public opinions about a firm's environmental commitments and impacts can affect a firm's ability to obtain financing, to secure insurance, or to undertake other activities.
- EHS laws and regulations tend to change frequently.
- Accounting systems using out-of-date costing methods can obscure the magnitude of environmental costs [1, 2].

This chapter is written specifically for three audiences:

- Senior management interested in evaluating whether environmental needs and costs are adequately factored into corporate decision-making,
- Mid-level management interested in understanding which environmental needs and costs are likely to affect them, and
- Managers of Environment, Health, and Safety units who need to communicate the effects of strategic decisions on the environmental costs incurred by a firm.

2.2 Incorporating Environmental Issues into a Corporation's Strategic Decision-making Processes

The strategic planning process of a company requires managers to set company goals, to develop processes for achieving them, and to motivate employees to accomplish them. There are financial advantages to incorporating environmental issues into strategic planning:

- To better understand the sources of cost-drivers for current environmental costs,
- To better manage future environmental costs, and
- To anticipate issues that could impede product development, distribution, and sales.

Because they can have large impacts on corporations, environmental issues need to be incorporated into the strategic planning process. Incorporating environmental issues into the strategic planning process requires that firms do more than merely comply with existing laws and requirements. Managing environmental impacts needs to be part of a firm's goals, understanding how these impacts are generated needs to be considered in process and product design, and company environmental performance needs to be factored into employee compensation. Compliance is still important as a basic tactic, but compliance without the strategic evaluation of environmental impacts and costs often will lead to incomplete (and potentially expensive) strategies. As an example, Shell had permission from the British government for the deep-sea disposal of a North Sea drilling platform but failed to anticipate the strength of public opposition to their plans. "Compliance" had been achieved, but strategic planning had been limited. Unanticipated international pressures, including a consumer boycott of their products, contributed to Shell's decision to change their disposal plans even though international regulatory approval was not required.

Corporate environment management has often been regarded as a cost center associated with "extra" financial outlays, where the aim was mainly to achieve compliance at minimum cost. This view is shifting towards a more proactive approach where some companies are identifying new commercial areas of opportunity—even pursuing leadership on environmental issues as a means to achieve a competitive advantage. The idea of optimally combining economic goals and environmental responsibility is catching on with a number of business leaders. This is having a significant impact on how people in organizations think and on training and educational requirements.

Continuous environmental performance improvement relies heavily on harnessing the efforts of line managers, non-environmental staff, and individuals across all levels of the organization. Responsibilities that were previously carried out by environmental professionals and consultants are fast becoming the tasks of teams of individuals charged with "operationalizing" a company's environmental policy and achieving measurable environmental performance improvement. In this context all employees need to become environmentally aware [3].

A number of leading firms are modifying their corporate strategic planning and decision-making processes to include prospective consideration of environmental issues. As noted earlier, in many firms, "environmental issues" have been sequestered in the Environment, Health, and Safety department. In these firms, strategic plans were ordained without involving EHS and, after the fact, EHS would undertake whatever actions were necessary to achieve compliance. Increasingly, companies are adopting the perspective that "compliance" is only a legal license to operate and that moving "beyond compliance" is one strategy that firms can adopt to achieve a competitive advantage.[1] The EHS departments in these firms are evolving their focus from "pollution prevention" to "design for environment" and even to explicit consideration of their business activities in the context of sustainable development. Several companies have incorporated environmental performance measures into the presentations at corporate board meetings. For example, as described below, the vice president of B.F. Goodrich's EHS Management Systems has overseen the transition of his program from compliance orientation to one that is focused on a systems approach.

B.F. Goodrich's EHS Management Systems

Although often associated with the tire business they sold several years ago, B.F. Goodrich is in fact a world leader in aerospace and chemical manufacturing—two lines of business facing substantive environmental challenges. The chemical division has 5,000 employees and aerospace has 8,000 employees; the units each have about $1.2 billion in annual sales. Goodrich's experience with change is now being brought to bear on their EHS management system—changing it from a compliance-focused system to a strategically-oriented management system.

Goodrich has gained a significant competitive advantage from taking this approach. Internal efficiencies have increased due to higher product quality, fewer sick days for employees, and reduced costs of manufacturing. Access to new markets has improved; for example, an internal culture of environmental and safety awareness facilitates dialogue in developing countries. Goodrich shares experiences and information about successful environmental management practices with customers. As a result of these changes, the company experiences a high level of acceptance by public and private stakeholders.

Goodrich's vice president of EHS reports to a Board of Directors committee (with 4 outside directors) every six months, and this committee reports to the full Board. Overall environmental goals for Goodrich are ratified by the Board of Directors. Every business unit within aerospace and within chemical manufacturing is responsible for achieving its share of these overall goals.

Corporate environmental performance is tracked using historical, current, and prospective performance indicators. Historical performance indicators include:

- Number and amount of §313-listed chemicals used;
- Number and usage of chemicals included in EPA's 33/50 program;
- Emissions in excess of permitted levels;
- Number of environmental fines and penalties;
- Total waste, hazardous waste, and chemical wastes generated; and
- Worker's compensation costs.

[1] "Beyond compliance" does not necessarily mean discharging fewer wastes and emissions than legally permitted; rather, it means that firms have considered the long-term costs and benefits of the activities responsible for their current and future environmental impacts.

Goodrich is currently introducing new performance indicators based on product design. They want to add additional cost information to this list, but boundary uncertainties about which costs to consider need to be resolved. Currently, they do not measure the recycled content of inputs; although they *are* gradually implementing a Design for Environment program.

Additionally, the six "Codes of Practice" in the Chemical Manufacturer's Association Responsible Care® Program are measured and reported to CMA annually (as required of member organizations). Furthermore, Goodrich has extended the Responsible Care® practices to their aerospace businesses. In the chemical business, Responsible Care® is motivated by concerns about product stewardship; in the aerospace business, it is motivated by value-added concerns.

This highlights the fact that the business groups are both accountable and responsible for their environmental performance. General managers are required to fit environmental goals into their overall objectives and to ensure that adequate resources exist to meet these goals. The environmental professional is responsible for identifying requirements that make up the goals and for providing assistance to the businesses in achieving their responsibilities. Because of this, Goodrich does not need a large environmental staff; rather, their environmental professionals have broad expertise in planning and business processes, as well as environmental technology.

Goodrich's vice president hopes that all parties—industry, government, and environmental non-governmental organizations—analyze the possible future states of the world and consider what course of history, regulation, and voluntary actions will most smoothly get us to that point. "Using 20-20 hindsight hasn't worked all that well for us; hopefully, we can use 20-20 foresight to get us efficiently to our desired goals."

2.3 Standards Providing Guidance for Strategic Decision-making

Society and corporate boards have increasingly higher expectations for corporate environmental performance. These expectations are manifested in the following six initiatives: the CERES principles, the Responsible Care® Program, the International Chamber of Commerce (ICC) Business Charter's Environmental Management Principles, the British Standards Institution (BSI) Standard BS7750, the European Community Eco-Management and Audit Regulation (EMAR), and—especially—the ISO 14000 series of environmental management standards.

The CERES principles were one of the first international initiatives that addressed corporate environmental performance. The Coalition for Environmentally Responsible Economies (CERES) is a non-profit organization whose members include the National Audubon Society, National Wildlife Federation, Sierra Club, Social Investment Forum, Interfaith Center on Corporate Responsibility, U.S. PIRG, and the AFL-CIO Industrial Union Department. CERES developed the "CERES Principles" (listed in Appendix B) in March 1989 in response to the

Exxon *Valdez* incident. A business that endorses the CERES Principles is committing to becoming publicly accountable for, and to making continuous improvement in, the net environmental impact of all its activities. Approximately 60 businesses—including large corporations such as General Motors, Sun Company, Bethlehem Steel, and Polaroid—have made at least partial endorsement of these principles. Despite their recent creation, some observers suggest that the CERES principles now are mainly of "historical" interest because other standards and programs are currently receiving more attention from businesses, governments, and non-governmental organizations.

The Responsible Care® Program was organized by the Chemical Manufacturer's Association (CMA) in the United States.[2] The Responsible Care® Program is based on an earlier program developed by the Canadian Chemical Producers' Association (CCPA) for use by Canadian firms. The six codes of practice for the Responsible Care® Program are community awareness and emergency response, process safety, product safety, employee safety, distribution, and pollution prevention. The Canadian program has a similar set of codes: community awareness and emergency response, research and development, manufacturing, transportation, distribution, and hazardous waste management. These are essentially industry mandatory programs enforced by the chemical industry trade associations in the U.S. and Canada. Additionally, these Responsible Care® Programs apply to all of a company's operations worldwide. Member companies make an annual evaluation of their own progress towards implementing a complete environmental program [4].

The ICC's principal function is to represent business internationally at the United Nations; promote world trade and investment based on free and fair competition; harmonize trade practices and formulate terminology and guidelines for exporters and importers; and provide practical services to business. In carrying out these tasks, ICC has prepared and promoted the sixteen principles in its "Business Charter for Sustainable Development" (listed in Appendix C).

In 1993, Global Environmental Management Initiative (GEMI) released an Environmental Self-Assessment Program to help corporations assess the extent to which their operations are consistent with specific requirements for worldwide sustainable development. GEMI's members are 23 large, multinational firms (e.g., AT&T, Kodak, Union Carbide) with no explicit regulatory or other enforcement authority. Consequently, the Self-Assessment Program is adopted only voluntarily. Nonetheless, a number of companies have adopted the use of this program as an internal monitoring tool [4, 5].

Finally, three well-known environmental management-system standards exist or are close to adoption: BSI Standard BS7750, the European Union's (EU) Eco-Management and Audit Regulation 1836/93 (EMAR), and the ISO 14000 environmental management standards. All three allow for "certification" of a firm's compliance with the individual standards.

The British Standard BS7750, currently a voluntary standard, has been in effect since March 16, 1992. Facilities operating in Great Britain can be certified by external examiners to have environmental management systems that meet BS7750. Although other European countries have

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2 Cahill and Kane [1994] point out that adoption of the Responsible Care® codes of practice is now required of all CMA members.

considered similar standards, most of these have been set aside in favor of the ISO 14000 standards or the EU's EMAR.

The ISO 14001 standard is expected to be approved by the International Standards Organization in early 1996. Many observers believe that these standards will supplant the British, the European Union, and other environmental management standards in other countries and regions. ISO 14001 certification will require that firms have the basic elements of environmental management systems in place [6]. However, because ISO 14001 is not expected to establish "performance criteria" necessary for certification and because EMAR does, there is a real possibility that companies operating in the European Community will have to meet EMAR standards in areas that are not addressed by the ISO 14000 standard.

The European Union passed its Eco-Management and Audit Regulation 1836/93 in June 1993. This regulation established an Eco-Management and Audit Scheme (EMAS) that can be voluntarily adopted by industrial facilities as of April 1995. The scheme codified by EMAR requires an objective audit of participating firms' environmental management systems (even to the extent of determining compliance with a firm's environmental policies) and a public report on a firm's environmental performance. Further development of the EU program has been delayed until after adoption of the international ISO 14001 standard on environmental management systems. At the present, the EU is not scheduled to consider making EMAS mandatory until July 1998.

The implementation of these initiatives reflects a widespread and increasing public sophistication regarding corporate environmental management. In all likelihood, corporations will continue to experience pressure to incorporate environmental issues into their strategic decision-making process. Furthermore, the potential diversity of international environmental requirements rewards companies that can establish internationally-focused management systems. These environmental management system approaches will be more and more important in establishing a firm's public acceptance and competitive position.

2.4 Corporate Strategies for Elevating Environmental Program Management

2.4.1 A Parallel with Quality

Pushing environmental management to a higher level of strategic awareness and performance will, in most cases, require a cultural shift within the firm. Dambach and Allenby (1995) suggest several aids to promoting this "cultural" change [7]:

- Developing and disseminating strong rationales for incorporating environmental issues into strategic planning,
- Raising corporate awareness of the fundamental importance of environmental issues to strategic planning,
- Starting a training program with the objective of continuously improving the strategic planning process (as opposed to delaying implementation until a high level of accuracy is assured), and
- Basing the training program broadly throughout the organization (instead of primarily within a traditional EHS department).

Many of these same tactics are central to the increased role of quality management in the corporation. Total quality management programs, and the energy with which they have been accepted by U.S. industry, provide an effective model to be applied in the environmental arena. Total quality management efforts have been accompanied by well-accepted performance standards and guidelines, such as those specified in the Malcolm Baldrige National Quality Awards and the ISO 9000 quality standard. Local and state programs have emulated Baldrige, and a support industry has grown around process improvement, reengineering, and continuing education. One important step could be the incorporation of environmental performance as a Baldrige criterion.

Quality movement programs such as TEQM and those espoused by GEMI have led to an evolution in the culture of the professionals who are responsible for quality programs, emphasizing system-wide management processes, involvement of management at the highest levels, and measurable, reportable results. This same professional evolution is important for those responsible for environmental programs, many of whom have assumed a compliance-oriented, reactive approach to environmental management. As voluntary, prospective initiatives become more common, the opportunity for professional development must also increase. Environmental professionals must expand their expertise to include a broad range of management, financial, and marketing knowledge—and corporate management must learn to recognize environmental professionals as key contributors to strategic planning and cost-effective operations.

Another lesson from the quality movement is the necessity of involving the entire supply chain in the process. Supply and distribution relationships, raw material sources, service providers, and customers have a role to play in an integrated, life-cycle based environmental management process. Environmental programs are not the exclusive domain of environmental engineers.

2.4.2 Initial Steps

The same momentum that surrounds total quality management can be transferred into environmental excellence. There are many programs that industry can pursue to take the offensive. The following are just a sample of the initiatives that need to be assessed and considered by individual companies, consortia, or trade groups:

- Issues to be Considered when Establishing Performance Metrics:
  - Environmental performance is incorporated into a business' long-range planning.
  - Level and content of information shared with local community.
  - Annual benchmarks of environmental performance with competitors (nationally and internationally).
  - Annual benchmarks of environmental performance with suppliers (nationally and internationally).
  - Annual benchmarks of environmental performance with customers.
  - Compliance audit results are shared with the local community.

- Establishment of Performance Metrics: Metrics may include the following:
  - Total costs and benefits of environmental activities (including compliance with current environmental laws and regulations).
  - "Social costs" of current and future operations.
  - Number of business/government partnerships (i.e., a measure of the firm's relationship with regulatory agencies).
  - Environmental Management System certification (e.g., ISO 14001).
  - Establish minimum qualifications and standards for suppliers.
  - Establish mentoring relationships with suppliers and customers with respect to Environmental Management System.
  - For businesses with international operations, comparison of internally-imposed standards with local standards.
  - Issuance of an environmental report.
  - Issuance of an environmental report with third-party attestation.
  - Number of supplier audits as a percentage of total strategic suppliers.
  - Number of "green" products manufactured/marketed.

NORTEL Environmental Performance Index

Executives at NORTEL are held accountable for meeting environmental objectives and achieving results. In keeping with the maxim 'what gets measured gets managed,' the company is gathering large amounts of environmental data across a broad spectrum of programs and operational processes. A set of measurements is developed to gauge performance against the identified goals.

An environmental performance index (EPI) is one way to reduce this data into a manageable score. The index provides a single rating for the company. What prompted NORTEL to undertake the process of developing a company-specific EPI? Senior management and external stakeholders felt it was necessary to begin making business sense of all the environmental performance information that was being collected. NORTEL began environmental reporting in 1992, but little quantitative data was available. In 1994 NORTEL set out to establish specific targets and developed an internal EPI to measure progress.

NORTEL already has a reputation for excellence and leadership in product development and manufacturing—management decided it was now time to put these attributes to work on environmental issues. Further, standards and regulations are being proposed for Boards of Directors in Canada and the UK to report, on an annual basis, due diligence on other than financial aspects, such as social and environmental issues. NORTEL expects to increase shareholder value and achieve preferred investment status when they can show continual improvement toward meeting their goals for environmental improvement and resource management.

The EPI was designed on an Excel spreadsheet with all of the data linked. The normalizing factor for the data is cost of sales linked to the producer price index for Finished Electronic Goods. The benchmark year is 1993 and the following years are normalized and compared against the benchmark year (70% weighting) and the previous year (30%). Targets were set for a number of environmental media and a weighted score was developed for each of those media. The target year for achieving reductions is the year 2000. In order to achieve the reductions a total weighted score of 175 must be reached and maintained. This is compared against a neutral score of 100—scores below 100 indicate increased environmental impact and negative progress towards the target. No advantage is given to maintaining compliance as this is expected as a minimum performance standard. Any permit excursion or notice of violation gives the compliance parameter a negative score.

The EPI is used to provide both a score card and strategic direction to the company when dealing with environmental issues. It may have a future use in helping the company review performance across business groups to decide how to allocate resources or make decisions regarding product viability.

- Environmental Audits: The establishment of an environmental audit program—whether comprehensive or targeted at specific areas of concern—provides an opportunity for a business to demonstrate its commitment to environmental quality and continual improvement. Traditionally, environmental audits have focused on regulatory compliance. A more comprehensive audit should concentrate on a variety of areas or issues essential for effective corporate environmental programs. These areas might include:
  - Mechanisms for demonstrating senior management support,
  - Processes in place to assure that a systems approach is being taken,

- Incorporation of environmental concerns in product design,
- Environmental considerations in manufacturing processes and facilities,
- Compliance with existing mandates,
- Community awareness,
- Environmental considerations in marketing and distribution, and
- Strategies for addressing disposition or take-back.

Self-audits provide corporate management with an ongoing evaluation mechanism, and, to the extent management is willing to share some portion of the results, present a source for industry benchmarking. In order to provide appropriate incentives, regulators may want to assure businesses of a "safe harbor" for problems identified during self audits, allowing adequate time for any appropriate response.

- Improved Understanding of Environmental Costs: Analysis at many large businesses has revealed that many cost-accounting systems do not trace environmental costs to the production processes that generate these costs. This was acceptable historically because the costs were usually small and the expense of tracing was relatively large. However, the growing magnitude of these costs and the non-linear form of some environmental cost drivers can cause traditional allocation methods to produce suboptimal financing and investment decisions [1, 2].

  There is no single accepted definition of "environmental cost." Here, we use this term to describe costs that arise from satisfying corporate environmental objectives, including compliance with current and anticipated local, state, and federal environmental regulations. For example, the Occupational Health and Safety Act regulates employee exposure to hazardous chemicals and requires worker right-to-know training on handling them. The Superfund Amendments and Reauthorization Act (SARA) of 1986 and the Emergency Planning and Community Right-to-Know Act of 1986 also regulate the use and storage of hazardous substances. Federal legislation regulating the monitoring, handling, and treatment of hazardous wastes includes the Resource Conservation and Recovery Act (RCRA) of 1976, the Hazardous and Solid Waste Amendments of 1984, and the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) of 1980. The Clean Air Act, the Clean Water Act, and SARA are the basis for most federal regulation of air and water emissions. In addition to costs imposed by these regulations, businesses pay for insurance to protect against liabilities arising from hazardous materials use or pollution.

  Measuring and reporting the full life-cycle costs of products and their components will be an increasingly important component of strategic planning (see Figure 2-1). Strategic planning will need to incorporate information on both existing costs and likely future costs [7, 8]. Several recent reports indicate that many firms tend to underestimate the existing environmental costs associated with specific products and product lines [1, 2, 9]. A comprehensive, activity-based costing approach is commonly recommended for understanding existing environmental costs.

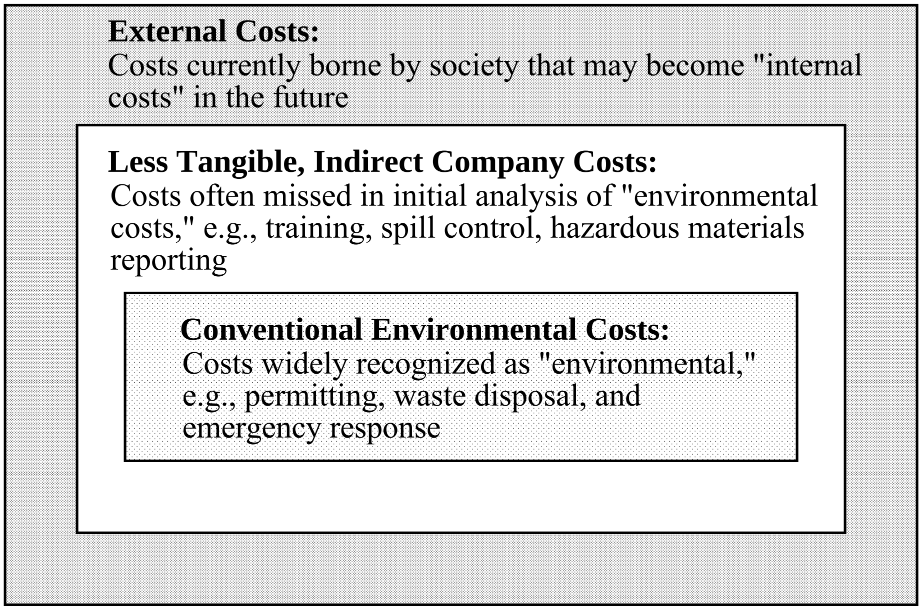

Figure 2-1. Total environmental costs (adapted from [10]). “Full cost” accounting considers “Less Tangible” costs plus “Conventional” costs. Strategic planning further considers which external costs may become internalized in the future.

Future costs are obviously more problematic to estimate. However several approaches to tracking changes in these costs have been proposed, including estimating future insurance costs, estimating the future economic impacts of current wastes and emissions, and estimating the expected mitigation costs associated with future expansion [8]. For strategic planning, firms need to predict and anticipate:

– Future laws and regulations (including changes in environmental taxes) arising from governmental bodies,
– The impacts of requirements from non-governmental organizations (e.g., the World Bank is currently incorporating estimates of current and future pollution into some of its analyses),
– The cost of responding to pressures from consumer groups and environmental organizations, and
– The cost of complying with “voluntary” standards that may affect international trade.

Table 2-1 lists a number of activities that generate environmental costs. The first column lists costs that traditionally are traced to specific processes. Compliance costs (in the second column) are those directly imposed by regulations—examples include pollution-control equipment costs, disposal fees, mandated safety supplies, and required worker training. Oversight costs (in the third column) arise indirectly from satisfying various compliance requirements, and include compliance-report generation, waste collection, and other related management activities. Careful analysis has shown that environmental costs make up a larger part of a firm’s total expenses than cursory consideration suggests [1]. A strategic “Design for Environment” program can eliminate many of these costs if they are properly anticipated in the engineering design process.

Environmental Cost Accounting at AT&T

AT&T has recently completed the first phase of a "green accounting" project (see EPA's [1995] "Green Accounting at AT&T"). The project was motivated by customer demands and management commitment to environmental protection. In the course of exploring environmental costs, AT&T has achieved the following key targets:

AT&T developed definitions and a common language to describe and discuss environmental costs, benefits, and issues. For example, AT&T defines environmental cost accounting as "identifying and measuring AT&T's costs of environmental materials and activities, and using this information for environmental management decisions." This and other definitions have been collected in AT&T's "Environmental Accounting Glossary."

Activity-based costing (ABC) is used to identify the true costs of products. Activity-based management (ABM) concepts are used to identify process cost drivers and meaningful performance measures.

AT&T developed a self-assessment tool that its manufacturing plants can use to establish baseline performance measures and goals for improvement. This tool includes an initial status survey, an activity matrix (listing possible cost categories for various "environmental" activities), and a suggested protocol for using the survey and the matrix.

In the first half of 1995, three AT&T sites completed reviews using the assessment tool. Feedback was positive overall, indicating that the assessment tool was useful in identifying and understanding the costs arising from environmental activities.

Traditionally Traced Costs	**Environmental Compliance Costs**	**Related Oversight Costs**
Depreciable Capital Costs	Receiving Area	Purchasing
Engineering	Spill response equipment	Product/vendor research
Procurement	Emergency response plan	Regulatory impact analysis
Equipment		Inventory control
Materials	Raw Materials Storage	
Utility connections	Storage facilities	Engineering
Site preparation	Secondary containment	Hazard analysis
Facilities	Right-to-know training	Sampling and testing
Installation	Reporting and record-keeping	
	Safety training	Production
Operating Expenses	Safety equipment	Employee training
Start-up	Container labels	Emergency planning
Training		Medical monitoring
Initial raw materials	Process Area	Re-work
Working capital	Safety equipment	Waste collection
Raw materials	Right-to-know training	Disposal management
Supplies	Waste collection equipment	Inspections and audits
Direct labor	Emission control equipment	
Utilities	Sampling and testing	Marketing
Maintenance	Reporting and record-keeping	Public relations
Salvage value		
	Solid and Hazardous Wastes	Management
	Sampling and testing	Regulatory research
	Containers	Legal fees
	Labels and labeling	Information systems
	Storage areas	Penalties and fines
	Transportation fees	Insurance
	Disposal fees	
		Finance
	Air and Water Emission Controls	Credit costs
	Permit preparation	Tied-up capital
	Permit fees	
	Capital costs	Accounting
	Operating expenses	Accounting system development
	Recovered materials	Accounting system maintenance
	Inspection and monitoring	
	Record-keeping and reporting	
	Sampling and testing	
	Emergency planning	
	Discharge fees	

Table 2-1. Typical activities to consider in economic analysis of environmental compliance costs. The costs of some activities (first column) traditionally have been traced to specific processes; environmental compliance and oversight costs have usually been allocated to overhead (from [2]).

- Prototype Facilities: Companies could collaborate in establishing prototype programs and facilities for managing significant environmental issues. For example, several pilot product disposition programs, such as the American Plastic Council's research program on plastic recycling are currently underway, most with some industrial involvement. Research programs, equipment development, process improvement, infrastructure development—all of these lend themselves to collaborative initiatives, and many are ideally suited for cross-industry cooperation or public/private partnerships.

- Model Permitting Processes: In some states, electronics and computer companies have worked with state regulators to develop model permitting processes that would accelerate permit approval. This occurs by specifying certain standards that are mutually acceptable to industry and regulators. To the extent an individual permit applicant meets the stated standards, permit approval would be expedited and substantial cost savings could accrue to the company. Proposals for the elements of these standard permits could be developed on a national basis and made available to regulators through professional channels in an effort to promote consistency among jurisdictions.

  Several models exist that could form the basis for innovative model permitting proposals. For example, the "Dutch Covenant System" encourages self-regulation within a framework developed and agreed upon jointly by industry and government. The framework includes performance-based, quantitative objectives, with emission targets for priority substances apportioned among industry sectors. Industry is then responsible for determining the best approach to meeting the standards, and documents its strategies and tactics in company environmental management plans. These plans are incorporated in company-specific licenses and permits, and updated regularly. A major benefit of the covenant approach is increased communication and understanding among parties involved in the regulatory process, which yields lower barriers to cooperation in the long run. Another approach is EPA's model-permitting program, which develops a spirit of partnership in the permitting process. An example of this approach is the Intel Corporation's P4 Project.

Intel Case: P4 Project

In late 1993, Intel Corporation, the U.S. EPA, and the Oregon Department of Environmental Quality entered into a partnership to evaluate opportunities to incorporate flexibility and pollution prevention into permits issued under Title V of the 1990 Clean Air Act Amendments. The Pollution Prevention in Permitting Pilot (P4) Project was undertaken to develop a facility-specific permit that incorporates pollution prevention as a model permit condition for achieving regulatory compliance. The project's goals are to develop an implementable permit, identify regulatory barriers affecting pollution reduction alternatives, document the process, and develop options and alternatives that can be useful to others.

The project demonstrated that pollution prevention performs equally well in the reduction of air emissions as do traditional, regulatory-specific, end-of-pipe controls. The project further showed the value of partnerships between industry and governments in promoting pollution prevention and prospective environmental management strategies that support a company's economic viability while maintaining a high standard of environmental protection. In determining the cost of pollution and, in turn, the benefit of pollution prevention, Intel examines and balances four factors: the cost of inputs that cause environmental damage, the cost of polluting behavior, the cost of public concern, and the cost of adopting pollution prevention alternatives.

The P4 Project was completed on September 26, 1995, becoming the nation's first air pollution permit under Title V that successfully integrates pollution prevention and operational flexibility. The key to this breakthrough was changing the focus from the minor process changes to the overall environmental results. Under the cooperative model, the site-wide air permit provides Intel the flexibility of adjusting its manufacturing processes on its own—as long as the changes meet specific pre-approved permit conditions—without going through an extensive approval process for each individual change. To get this flexibility, Intel agreed to use pollution prevention practices as the primary method to manage air emissions. In essence, the environmental agencies provide pre-approvals of minor changes in exchange for commitments to incorporate pollution prevention. As explained by Intel's executive vice president and chief operating officer, "this method maintains high standards of environmental protection, encourages efforts for pollution prevention, and creates an opportunity for common sense to be applied to environmental safeguards."

The permit meets all federal and state requirements identified under Title V of the CAAA and Oregon's State Implementation Plan. The permit is environmentally protective and fully enforceable under federal and state law. It contains emission limits for the entire plant site instead of limits for each individual vent or pipe. As long as Intel meets its site-wide emission limits, all minor process changes at the site are pre-approved.

- <u>Increased Program Visibility</u>: Some corporations have begun publishing environmental stewardship reports on an annual basis. A somewhat less comprehensive effort could incorporate an environmental section in an annual report. For private corporations, which may not publish an annual report, a statement to stakeholders about environmental objectives and activities could be prepared and distributed. Trade associations could also assemble these data from company reports and disseminate information to members.

  A U.S. firm's annual report typically includes some discussion of contingent environmental liabilities in the MD&A (Management's Discussion and Analysis) as required by the U.S. Securities and Exchange Commission and in the footnotes to the financial statements (as required by the U.S. Generally Accepted Accounting Principles). However, any discussion of environmental performance in the MD&A is not actually audited by the firm's independent auditor; the text is merely reviewed for consistency with the financial statement that actually has been audited. Because of this absence of explicit attestation and because the MD&A discussion is usually somewhat limited, a small number of firms have been experimenting with independent evaluation and/or certification of their voluntary reports of environmental performance.

For the past two years, NORTEL has inserted two pages on environmental performance into the corporate annual report. This is in addition to preparing a separate environmental report describing their programs and progress in depth, including the EPI score. The environmental report is audited by Deloitte and Touche as a third party reviewer. Cahill and Kane point out that "DuPont in its 1992 and 1993 Corporate Environmentalism Reports provided the executive summary, along with DuPont's response, from a third-party evaluation of the company's Corporate Environmental Audit Program…" ([4], p. 419). At the present time, there is no single "certification" that has industry or public acceptance.

Some firms have used information about environmental performance not only in internal planning, but also in external publications. In part, this is done to manage public and private (e.g., regulatory) perceptions of the firm. Because of concern about negative response to private and public information about a firm's environmental performance, some firms may be reluctant to publicly report this information (beyond what is required for compliance *per se*). However, a pure compliance-oriented reporting strategy may be insufficient if competitors are regularly making more extensive disclosures voluntarily. Consequently, many firms benchmark their environmental disclosures (both in the annual report and, if applicable, in separate environmental reports) against the disclosures of other firms. Environmental reports have been released by at least 70 firms from the United States, Canada, Europe, and Japan [4]; some companies even have Web sites that detail their environmental practices for anyone with access to a computer network service. These reports usually describe non-strategic measures such as Toxic Release Inventory (TRI) emissions and participation in voluntary regulatory programs (e.g., EPA's 33/50 program). In the future, disclosures with added strategic relevance might include such elements as the percentage of recycled materials included in products, the percentage of recycled components included in products, and product disassembly time.

- <u>Compensation:</u> If companies want managers to consider environmental issues, the companies need to incorporate appropriate incentives into management compensation. A number of firms surveyed by Deloitte & Touche (1995) include non-financial measures of division or company performance in the variable component of employee compensation—environmental performance could be one of the measures considered [11].

- <u>Community Outreach</u>: Some corporations periodically invite community leaders to plant sites as an educational activity to learn about ongoing environmental, health, and safety activities. These kinds of "community open houses" can go a long way in mitigating speculation about environmental conditions or hazards at an industrial site and can create informed advocates in the community. In addition, community advisory councils have also been used effectively to create community-based champions. These councils bring together a broad range of community interests in a setting that fosters communication and understanding. While some electronics manufacturers have established such councils, the chemical industry provides the best example of successful council operation. Monsanto, for example, operates fourteen domestic and four overseas councils, serving (in Monsanto's words) as the operating facilities' "ears into the community." These councils provide a forum for mutual education, emergency planning, and communication.

- Development of Educational Curriculum: Both facility and EHS managers can encourage and support the inclusion of environmental topics in the curricula of local educational institutions. This could be as simple as providing guest instructors for existing classes to share experiences and programs as examples of "real-world" environmental management. It could be as involved as working with the educational institution to develop new training programs.

- Internal Continuing Education Programs: Companies can create educational programs for employees on issues facing an entire industry or a specific operation. These should be technical in nature and address both policy and procedures. Professional certification or other incentives can increase the attractiveness of these programs.

  Training programs can be modified to facilitate improved consideration of environmental issues in corporate activities. For example, Motorola has developed a well-regarded training program, as described below, for their technical education system. Johannson (1994) reviews the development of an environmental-management systems training program that reversed the typical order of topics in many traditional training programs [12]. Specifically, legal, regulatory, and compliance issues are covered at the end (and not at the beginning) of the program. Programs that emphasize compliance run the risk of teaching managers to focus on current standards rather than to consider potential problems.

Motorola's Environmental Training Program

Three years ago, Motorola's corporate EHS group received their CEO's approval and support for a company-wide initiative to train all associates on environmental awareness. This training program, based on company *and* personal (i.e., citizen-level) issues, is used to provide a common language/message to all employees. To date, over 100,000 Motorola employees have completed the program. Despite having only 14 employees in their corporate Environment, Health, & Safety group, Motorola has used this training program to leverage their worldwide influence. As a result of this training program, employees voluntarily began creating problem-solving teams that identified problem areas (both at work and in the broader community) where remedies were available.

After the training program was designed and operating, the Motorola EHS group created four follow-on "Design for Environment" courses. Five years ago, Motorola initiated a "Design for Manufacturability" program and these new courses are regarded as an integral (and continuing) part of Motorola's "Design for Quality" commitment. These "Design for Environment" courses target both product-oriented (e.g., recyclability) and process-oriented (e.g., chemical reduction) issues.

In addition to educating Motorola employees, Motorola has begun to share these training programs with their suppliers and customers. It is obviously critical to have suppliers working from a similar perspective if a corporation is going to implement a "Design for Environment" program. Customers have been enthusiastic about Motorola's initiative in these areas as well. The manager of Motorola's Environment and Safety Education group says that, for Motorola, "Compliance with regulations is obviously relevant in offering these program, but the fundamental course message is that DFE is good business."

Most recently, Motorola has partnered with a non-profit training organization, the Management Institute for Environment and Business, to develop a program for senior-level decision makers. Motorola's business leaders and environmental managers attend this two-day class on integrating environmental issues into business decisions. The class teaches environmental managers the skills and vocabulary they need to interact successfully with corporate decision makers. The senior-level business managers learn that the environmental managers can provide important information if the EHS people are sought out early in the strategic decision-making process.

- Technology Transfer: Companies, acting individually or in consortia, can develop models of best practices to be shared with other companies facing similar problems but without resources to develop solutions on their own. This approach is especially valuable for large corporations working with their second and third tier suppliers. Once developed, such guidelines can serve as a basis for industry consensus on operating philosophies and principles. The chemical industry, for example, has established a "Stewardship Initiative" which members of the Chemical Manufacturers Association must adopt in order to maintain their Association membership.

- Supplier Environmental Excellence Programs: Corporations are establishing supplier recognition awards for quality or performance. Similar awards could be established for environmental excellence by suppliers, establishing a standard of performance that a supplier is expected to meet if it is to remain a primary supplier of the corporation.

None of the initiatives discussed above is original or unique, and many companies have already embraced some of them. Creativity and communication can certainly help expand the list. But the true test will be in the breadth of acceptance within industry and the willingness of industry to make its commitment to the environment visible and continuous. If performance-oriented approaches are effectively implemented, industry can break the cycle of regulation-enforcement distrust that has inhibited the widespread acceptance of industry led initiatives. By responding to the growing opposition to ineffective, inefficient government regulation, while still recognizing and honoring the core environmental values of the community, industry can initiate a new era of partnership. Prospective industry initiatives, accompanied by government/industry cooperative programs and incentives, offer significant benefits to all involved.

2.5 Challenges to Incorporating Environmental Issues into Strategic Decision-making Processes

Despite the advantages discussed above, there may be organizational and/or psychological barriers to considering environmental issues as a critical component of a corporation's strategic planning process. These barriers may include the perception that environmental issues are primarily compliance problems or that there is a lack of familiarity with the broad spectrum of possible environmental impacts arising from business decisions.

Dambach and Allenby point out another obstacle—the lack of organizational acceptance of a broad EHS role ([7], p. 58):

> "Design for environment (DFE) is not, and in most firms never will be, a traditional Environment and Safety (E&S) function. This is partly a matter of tactics: financial personnel will put a lot more credence in a green accounting module that comes from the CFO's office than one coming from E&S. Similarly, engineering and technical managers are more likely to trust and use design tools coming from their R&D organizations and product development laboratories, rather than those coming from the E&S organization. In these cases, as in others, this is simply a recognition that the E&S group may be competent in environmental issues, but not in financial methodologies or CAD/CAM tools. The role of the E&S organization will be to provide technical support to the design community as it evaluates decisions, and E&S may be called on to initiate, facilitate, and drive the implementation of DFE."

The fact that EHS professionals have not traditionally participated in assessing and planning the financial aspects of environmental strategies has other implications, reflected in the lack of financial data about environmental costs and comprehensive environmental costing systems.

2.6 Summary of Current Industry Needs

There is a limited set of tools and decision models currently available for incorporating environmental issues into business decisions. Managers with strategic responsibility have often ignored environmental issues, and managers with environmental responsibilities have often not factored in strategic considerations. New analytical methods are being developed. For example, Townsend (1994) uses computer simulations to conduct sensitivity analysis on the probable outcomes of different decisions [13]. Grimsted *et al.* (1994) suggest a method for qualitatively ranking the environmental risks associated with different sets of hazardous emissions to air, water, and soil [14]. However, these methods will have to be tested and adapted for each firm's specific circumstances.

Alternative, non-financial measures of current and future performance include output quality, environmental performance, customer satisfaction, and employee training [11]. However, the various explicit measures of "environmental performance" that have been proposed (and used) are diverse, often vague, and lack widespread industry acceptance. Clearly, there is a need for environmental performance benchmarks that can be used for internal and external reports.

2.7 Conclusion

For many years, industry in the United States has advocated voluntary solutions to environmental concerns, while environmental interest groups and government regulators have chosen instead to pursue a policy of mandating the responsibilities, actions, and even the approaches of private business—sometimes even the specific technology to be used. These regulations have typically been born of legitimate concerns for threats to human health and sensitive ecological systems. Nonetheless, some regulations have been ill-conceived and politically motivated, thereby creating significant administrative inefficiencies, raising the cost of doing business, and threatening the international competitiveness of U.S. industry.

Some representatives in Congress are promoting a different philosophy of government regulation. The Administration and the U.S. House of Representatives support requiring cost-benefit analysis of new federal rules. At the same time, there have been federal, state, and local government initiatives to eliminate unfunded federal mandates and to reassert local control over a wide variety of matters ranging from transportation policy to education to the environment. These changes, if they succeed, will have a profound impact on industry's environmental strategy and management practices.

The potential for a decrease in regulatory action at the Federal level, and indications that similar philosophies may be guiding state and local policy-makers, gives industry an opportunity to demonstrate the viability and value of performance-oriented initiatives. However, industry must define the scope and nature of these voluntary efforts—seizing the initiative and forming a framework for individual company action and industry collaboration that will prevent pollution, improve process efficiency, and ultimately improve cost structures while at the same time maintaining product quality. Through these actions, industry also has the opportunity to "re-invent" itself in the eyes of many who have otherwise been adversaries. At the international level, competitive pressures in the global marketplace will require firms to develop universally-applied standards of care.

The time is at hand for industry to assertively communicate the message that performance-oriented efforts do work, and that industry is capable of sustaining effective environmental management. By taking the lead, industry can increase the probability that this regulatory revolution (or, perhaps more correctly, an anti-regulatory revolution) will be successful, and performance-focused programs will become a preferred strategy for environmental managers. Ongoing, visible programs decrease the potential strength of the argument that industry has insufficient interest and commitment to build and sustain these efforts. Table 2-2 lists the needs for strategic business opportunities identified during this roadmapping exercise.

Priority Need	Task
1. Knowledge of total environmental costs	1.a. Develop a research project to determine comprehensive environmental costs 1.b. Develop new accounting tools that will accurately assign environmental costs to specific processes 1.c. Test new analytical methods that are being developed 1.d. Develop business tools for estimating the costs of future environmental impacts in capital budgeting
2. Redesign evaluation/reward systems for senior managers to include environmental performance	2.a. Benchmark existing electronics industry environmental performance metrics 2.b. Research and prepare case studies showing link between positive environmental performance and senior manager accountability/responsibility 2.c. Investigate obstacles to achieving senior manager accountability/responsibility for environmental performance
3.a. Determine why environmental issues are targeted differently in business than issues such as quality 3.b. Determine how environmental issues can be smoothly integrated in business operations 3.c. Determine how environmental managers become an integral part of a business' strategic team	3.a. Develop an environmental/business curriculum 3.b. Integrate environmental issues into business operations 3.c. Provide necessary vocabulary and understanding of business drivers to tie environmental issues into strategic business planning

Table 2-2. Strategic business opportunities priority needs matrix.

3.0 Information and Knowledge Systems

3.1 Data Availability, Access, and Integration

Effectively using information technology to manage processes, support decision-making, and evaluate performance is a fundamental competitive differentiator. In the electronics industry—where cycle times are decreasing, complexity is growing, and margins are shrinking—the improved use of information systems for environmental management, from design to disposition, is increasingly vital for business success.

This chapter of the roadmap addresses one vital issue in the use of information systems for improved environmental management: access to and use of information to make sound environmental decisions.

It is important to note that information technology plays a variety of important roles in meeting environmental management challenges:

- Information technology plays a fundamental role in effective process integration. Increased automation, modeling, computer-aided manufacturing/computer-aided design (CAM/CAD) integration, *in situ* monitoring, process control, and feedback are all supported by advanced information systems technology.
- The National Electronics Manufacturing Initiative recommends that the factory should be integrated "from design to delivery," and information systems will be fundamental to accomplishing that objective. Rapid reconfiguration, agile systems, and flexible manufacturing depend on information systems, as do costing systems, communication, analysis, and a wide range of other steps fundamental to effective factory management. In addition, as factory processes evolve, information systems will play an increasingly important role in the management of environmental emissions at the factory level and in individual processes.
- Advanced information systems are key to effective computer-aided design and design for the environment (DFE). This is especially true if DFE tools are to be fully integrated into CAD systems. Design libraries, intelligent assistants, and automated trade-off analyses are just a few examples of information technology-supported processes.
- Information technology will also play a vital role in the cost-effective management of end-of-life products. Automated sorting and identification, logistics and management, and inventory tracking will be supported by constantly improving information systems.

A variety of tools and technologies are available or under development to support these various applications. The focus of this chapter, however, is cross-cutting. For any of these applications, a fundamental part of the "raw material" inventory is information—raw data, value-added analysis, directories, brokerages, benchmarks, and a wide range of other information—to guide and improve manufacturing processes. The data must be available, timely, and reliable.

3.2 Shortcomings in Information for Environmental Decision-Making

MCC's previous roadmapping activities have indicated a broad-based concern that there is a lack of reliable quantitative (or qualitative) data to support effective environmental decision-making—data about processes, components, costs, and materials, both technical and financial. The *1994 Roadmap* stated the issue succinctly: “Information and access to information is lacking: the knowledge necessary to make sound environmental/business decisions frequently does not exist or is not readily accessible…” ([15], p. 1) Whether a result of incomplete data, fragmented data sources, or inadequate data management, the lack of data hampers effective program development and implementation.

A paper included in the *Proceedings of the 1995 IEEE International Symposium on Electronics and the Environment* by White and Corbet detailed some of the difficulty with environmental data [16]:

- Quantitative environmental release and transfer data are often media-specific, limited in scope, subject to questionable verification, and may become outdated before becoming publicly available.
- Quantitative data frequently are inconsistent among data sources due to varying waste definitions and reporting methods.
- Few studies have addressed qualitative characteristics of firms that contribute to environmental performance.
- Almost no research links traditional quantitative data with qualitative information for measuring environmental performance in an integrated manner.

To this list should be added the proprietary nature of much of the industry data that might prove useful to effective environmental management or that might be suitable for environmental benchmarking, as well as shortcomings in data collection within companies, especially financial information. These shortcomings have several effects. Inefficiencies in decision-making, lack of industry-wide benchmarks, unnecessary repetition of errors or analyses, absence of well-established "best practices" standards, and difficulties in identifying alternative sources of systems, technologies, and solutions are just a few of the challenges that confront electronics manufacturers without an effective industry-wide information infrastructure in place.

3.3 Information Required for Environmental Decision-making

Table 3-1 defines several categories of information that, if made available to electronics manufacturers, could significantly contribute to improved efficiency and productivity.

The objective addressed in this chapter is the ultimate creation of an environmental information infrastructure that provides data to support decisions made at a variety of levels in the organization, from the individual designer through senior corporate management. These decisions will span a wide range of operational considerations: design trade-offs, optimization of materials, processes, chemicals, and design strategies; equipment purchasing, seeking the lowest cost provider of equipment that meets requirements; technology selection, evaluating from among a variety of alternative technologies for applications such as packaging, interconnect, and chip-attach; alternative manufacturing processes; life cycle impacts, seeking to minimize the environmental consequences of individual decisions across the entire life cycle of a product; investment strategies; and many more.

Transforming numbers and other data into knowledge for decisions can be viewed as a multi-stage process of information access, retrieval, and analysis (see Figure 3-1). The process begins with the assembly of raw data, most likely in the form of numbers but also in the form of anecdotes, listings, or directories. These data can be drawn from a number of sources and through a variety of approaches. Discrepancies occur, however, when individual corporations identify and assemble the data on their own, creating duplication, the likelihood of data inconsistency, and data gaps.

These data are organized in a variety of databases, where data is collected, stored, and indexed. This information needs to be made available for industry-wide access and analysis. The defining trend of information systems management throughout the 1980s and 1990s has been the support for accessing distributed databases, regardless of geographic location, database management system, or hardware platform. Although open systems architectures have not yet evolved to the point where users can truly expect a transparent, seamless access to data wherever it may reside, tools and technologies are such that most data can be made accessible even to the novice user.

Design Data and Tools	Information and data to design more environmentally conscious products, e.g., how to decide between two materials for a new product, life cycle data, risk data, external factors not commonly available to the designer.
Network Resources	Who is doing what in which area. Need to share information between colleagues, understand who is doing what, and understand "best practices." On-line forums, discussion groups, access to experts.
Technology Specifics	Data on technologies from diverse information sources (suppliers, OEMs, EPA, etc.) including MSDS data, materials property data, manufacturing and process data, recyclability, commodity prices.
Regulatory Standards and Compliance	Ready and easy access to relevant rules, regulations and legislation at international, federal, state, local levels. Ability to find the right document quickly and accurately. Resources to guide compliance, permitting, and certification.
Market and Cost Data	Data derived from various program activities of the U.S. Commerce Department focusing on the electronics industry. See Appendix D.
Performance and Risk	Searchable access to human health and toxicity databases, toxic release inventory (aggregates and site specific), other relevant "right to know" data.
Technology Sourcing	Supplier/vendor product data and sales brochures.
On-line Libraries	Technical articles, publications, journals—available and searchable on-line

Table 3-1. Categories of information important to electronics manufacturers for the purposes of improved efficiency and productivity.

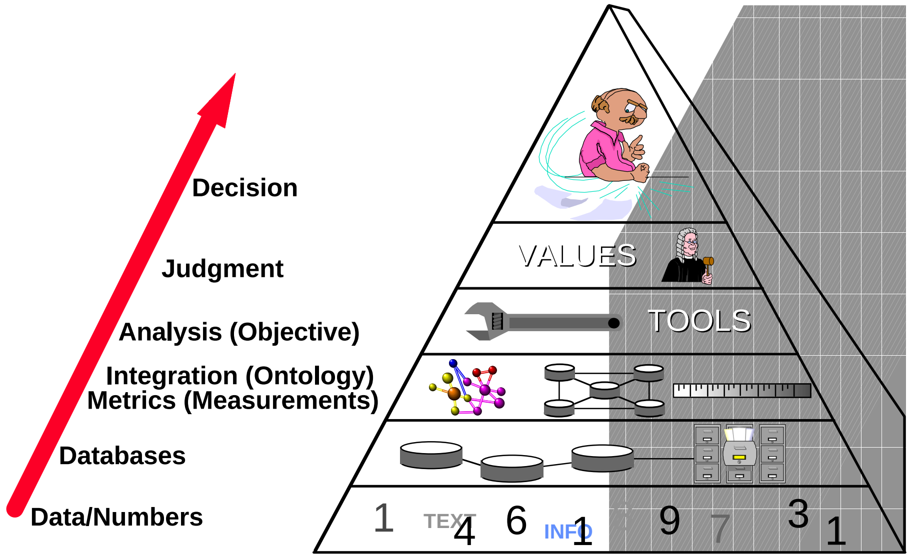

Figure 3-1. Process of transforming data into knowledge for decisions.

The most fundamental requirements for higher level decision support are the integration of the information in those databases into a meaningful structure—an industry-wide *ontology*[3] that provides a framework within which data can be accessed. The ontology provides a common foundation to which the specific data elements of individual databases can be mapped (even if the specific semantics of individual databases may not precisely match), queries can be executed to multiple databases, and common information identified and retrieved. An equally important step is the establishment of accepted metrics that can be applied to support decision-making.

Important industry-wide *metrics* provide quantitative means of measurement and comparisons for effective analyses. These metrics provide users with accepted guidelines for assessment and evaluation, whether in terms of cost, emissions, performance, or a wide range of other potential decision areas.

It is here, in the development of an industry-wide ontology and the establishment of industry-wide metrics, that the need for collaboration is most clearly evident. *These are inherently multi-company, and multi-industry, activities.* If multiple ontologies or widely varying metrics are created, they give rise to an environment in which fragmented networks of organizations may find themselves competing with one another for the dominance of their particular approach, forsaking the efficiencies and economies that a true industry-wide approach to the environmental information infrastructure can provide.

Once consensus industry ontology and metrics have been established, reliable analysis becomes possible. In this regard, the information infrastructure can provide access to tools (query, analysis, reporting, and data navigation tools) that support analysis and offer decision-makers a variety of reliable approaches to processing and evaluating information. These tools are provided by multiple vendors, with the information infrastructure either identifying how to obtain the tools or, in the ideal case, providing an electronic means for downloading, testing, and ultimately acquiring the tools that most effectively support the decisions in a particular company.

Many such tools are already available. Perhaps more importantly, new decision support tools will emerge when the capabilities of an integrated industry information infrastructure supported by a standard ontology and agreed-upon metrics becomes reality. Development of many of these tools provide opportunities for collaboration—whether by companies in the same market segment collaborating to accelerate the availability of tools or through the collaboration of original equipment manufacturers (OEMs) and their suppliers—as well as a rich opportunity for entrepreneurial activity as new companies grow to provide tools that will be offered across the network.

The significance of these envisioned tools lies in their ability to automate the intelligent analysis of the burgeoning stream of information as more and more becomes readily accessible. Such intelligent assistance will include transparent, yet dynamic, assembly and composition of content for its tailored presentation to each unique user. Users no longer will have time to wade through massive collections of potentially irrelevant data. Instead, they must have immediate access to only that information specifically required for their task at hand, presented in a coherent form

[3] An ontology is a set of concepts, relationships, and meta-information that describes and links data in a useful, functional fashion to other data.

best suited to their individual mode of content assimilation. Just as there is no "magic" user interface, neither is there a "magic" method of data presentation suitable to all users. The intelligent assistance tools must take into account the cognitive needs of each user.

Through the application of objective analysis, based upon reliable data drawn from a wide range of industry sources, environmental decision-makers can apply judgment in a more informed and rational way. Best practices, benchmarks, opportunities for competitive differentiation, opportunities for strategic alliances, and priorities for research and development are just a few of the decisions that become richer when supported by a broad base of information.

The ultimate objective is informed decision-making—with decisions being as timely as possible, based upon sound technical data, reflecting current information about regulatory considerations, and based on sound cost and performance data.

3.4 Building an Electronics Industry Environmental Information Infrastructure

If the infrastructure is put in place, will there be data available? Despite the shortcomings described earlier, there is a significant base of environmental data that is available. Many federal organizations, state and local agencies, numerous non-profits, and many private corporations are now actively engaged in producing or gathering environmental data.

A great deal of information is readily available on the World Wide Web (WWW or Web). Of all the changes that have occurred since the environmental roadmapping effort first began, none has been more pervasive than the emergence of the Internet as the basic element of the national information infrastructure. The Internet has evolved into a ubiquitous global network, or perhaps more correctly, an interoperable web of public and private networks. The capability of the Internet to serve as a linkage mechanism for information dissemination and retrieval is unarguable, particularly with the growing resources of the Web.

In the area of environmental information, the Web is filled with a wide range of options. Appendix E identifies notable sources of information on the Web and available through other sources. Universities, government agencies, environmental technology suppliers, and others have well-established sites on the Web offering a variety of technical, policy, advocacy-oriented, and other general information. The EPA, the U.S. Department of Commerce, the World Bank, the International Trade Commission, and many other agencies offer significant amounts of data over the Web, and the federal government has established electronic information dissemination as a priority. Consider a few examples of the data available via the Internet and the Web:

- U.S. EPA, Toxic Release Inventory (TRI): The Toxic Release Inventory (TRI) database has become a primary source of practical, usable information and data concerning individual manufacturing company performance with respect to pollution prevention and waste minimization activities in the U.S. The required reporting of toxic chemicals in general use in manufacturing by route of release/transfer for all but very small companies has resulted in a rich source of annual performance data since 1987. The data become available in May/ June of the second year following the reporting year (e.g., data for 1993 became available in May/June, 1995). Data are initially available on the TOXNET on-line database of the National Library of Medicine (NLM) and later are published on a CD-ROM.

- U.S. Dept. Commerce Current Industrial Reports (CIR): These reports, which are based on the Annual Survey of Manufacturers and the Census of Manufacturers, represent a more detailed examination of economic factors associated with production activities. The sub-sample of companies that are included in these surveys provide data projected to the industry (4-digit SIC) as a whole. Of particular importance is an annual report on pollution costs and expenditures. These cost data are stratified into several categories, including "Pollution Abatement Capital Expenditures" (PACE) and "Pollution Abatement Operating Costs" (PAOC). These categories are further stratified according to route (i.e., "air," "water," etc.).
- World Bank, Industrial Pollution Projection System (IPPS): The IPPS was developed by the World Bank to assist in estimating, quantitatively, sources of industrial pollution in developing countries. The IPPS was developed by merging U.S. data derived from the Longitudinal Research Database (LRD) of the U.S. Department of Commerce (establishment level economic data) with several databases (including the TRI database) maintained by the EPA associated with pollution emissions. The IPPS estimates pollution intensity associated with specific 4-digit SIC codes (U.S.) and 4-digit ISIC codes (internationally).

These are just a few of the federal resources available (or soon to be) on the Internet. Other examples include Enviroene and Envirofacts from EPA, the Council on Environmental Quality of the Executive Office of the President, the National Oceanic and Atmospheric Administration, the Department of Energy, and the network of federal laboratories, among others.

Numerous private organizations are also placing potentially important data in the Web. Several sites have been established that provide comprehensive indexes of WWW environmental data. One of the best is the Environmental Links Index (found at http://aazk.ind.net/environmental.html), which lists over two hundred sources of environmental information, including various EPA databases (chemical substance fact sheets, national materials exchange network, and a variety of other sources).

Another key source is GNET, the Global Network for Environmental Technology (currently under construction). This site is still being developed and expanded, and when complete will provide a central point for locating technologies available to support industrial environmental objectives. GNET also includes a news net and discussion forum.

Many organizations, both public and private, also maintain Web sites. Most of the major computer and electronics manufacturers have Web presences, as well as most consortia, trade and professional associations, and research institutes. Few of the corporate Web sites, however, provide details about environmental programs or use the Web as a means of disseminating information about environmental stewardship. This is particularly true of the corporate sites, with the exception of a few (e.g., NORTEL).

Of course, many resources are not yet available on the WWW. Several potentially useful sources of tools and information are available to the public, but are not yet integrated into the growing on-line community. For example:

- Global Environmental Management Initiative (GEMI): An organization of companies dedicated to fostering environmental excellence, worldwide, by promoting a worldwide business ethnic for environmental management and sustainable development. The growing number of companies (especially electronics industry companies) associated with this program and the consensus of member companies could be of considerable present and future value in attaining pollution prevention objectives. The success stories of member companies in resolving pollution problems would be of great use.
- EPA, Chemical Use Clusters Scoring Methodology: An EPA program for using algorithms to "score" the combined effects of groups of chemical substances used in various manufacturing processes. The purpose of the system is to emphasize the importance of pollution prevention—particularly the use of safer substitutes. The system operates by creating chemical "use clusters," sets of competing chemicals and technologies for a given use. When used in conjunction with other resources (e.g., known chemical use patterns, toxicity information, "Existing Chemical Data," and "New Chemicals Data" etc.), a predictive model to classify desirable vs. undesirable chemicals with respect to pollution prevention "intensity" can be derived.
- Tellus Institute, P2/Finance Computer Program: P2/Finance is an innovative approach to analyzing costs associated with pollution prevention, and is available for less than $100. The software consists of a series of Microsoft Excel spreadsheets for determining individual company costs associated with pollution prevention activities. This computer program appears to include all reasonable variables associated with the costs of pollution prevention for a company. It is possible that multi-company users could combine similar data for industry projections. Although the program itself is fairly rudimentary, it could be considerably enhanced for use in the U.S. electronics industry. The approach is very interesting and deserves in-depth evaluation.

At this point, however, there is no single consolidated source of environmental data about the electronics industry. The wide distribution and heterogeneity of the data, along with incompatible protocols, configurations, and platforms effectively impedes efficient access.

Effective data organization, access, retrieval, analysis, and management represents a prime opportunity for industrial collaboration. The emergence of new information technologies, including the increasingly ubiquitous global information network represented by the Internet and other emerging networks, provide a framework for integrating information both within and across enterprises. Furthermore, new information management tools supporting the navigation of diverse networks and the automatic, intelligent acquisition of data from those networks have the potential to enable a remarkable level of information access.

Accomplishing a well-integrated environmental data management system is not a simple task. The many tools and approaches to data management that are appearing on the scene provide some mechanisms to approach the challenge. But substantial research, development, integration, and testing will be necessary.

An effective information infrastructure should have several characteristics:

- Access should be transparent to the user and incorporate easy-to-use graphical user interfaces (or other simple interfaces).
- The system should incorporate a well-defined security protocol, blocking access by unauthorized users to company-proprietary data and carefully protecting the integrity of the data from unauthorized manipulation or change.
- The system should incorporate advanced user support tools, such as intelligent agents to facilitate search, data mining tools that actively seek data linkages and present value-added data in response to queries, and data consistency tools that support database maintenance and management.
- The system architecture should take advantage of information from multiple sources, such as databases, LAN application servers, data warehouses, and legacy applications.
- Expert systems, knowledge bases and representation, and content composition relevant to a user's cognitive profile (coherency suitable for an individual understanding) should be included.

There are several options for developing a comprehensive information management system for environmental programs. The options available to individual companies are changing as rapidly (or maybe even faster) as the underlying electronics technology that drives the need for environmental management programs.

The World Wide Web offers a logical starting point. Tools for establishing highly functioning Web sites are now widely available and well-accepted. As a first step, a Web site focused on environmental manufacturing for the electronics industry would provide a "meeting place" for the variety of interests who share common objectives. At its simplest, such a site or sites would provide an access point for a variety of relevant information, including:

- <u>Environmental Data:</u> The Web page could include links to a wide variety of sites where environmental data is maintained. The EPA's various databases present one set of logical links. However, corporate data on chemical or material use could also be made available for industry-wide benchmarking for comparative purposes. Some companies may view this information as being proprietary and, in those cases, information placed on an environmental Web page might be secured or compartmentalized in a way that would limit access to individuals or organizations with a legitimate right to know. This kind of data sharing also supports efforts to encourage consistency in reporting methods or even the use of common ontologies to support higher levels of data integration.
- <u>Regulatory or Policy Information:</u> Federal, state, and local regulatory agencies could easily post existing regulations, proposed regulations, or regulations in process to a central site for comment and review. The central posting, combined with the intelligent search agents currently available, could provide an important source of centralized information about the regulatory structures within which industry must operate. Furthermore, information about demonstration projects could be readily shared across the Web. For example, several states have worked on projects to improve permit flexibility,

emphasizing performance-based, multimedia permitting approaches. Details about these pilot projects could be made easily available to regulators in other states, or to industry advocates who are seeking to influence the structure of regulations. With the addition of powerful search agents, multi-jurisdictional analyses could be easily conducted to assess uniformity or lack thereof, and data about pilot projects or model programs made available.

- Source of Information/Data on Standards: Existing or emerging standards, whether formal or *ad hoc,* could be posted for review, comment, and dissemination.
- Component Specific or Media Specific Discussion Groups: As noted elsewhere in this roadmap, several efforts demand broad industry participation in order to accelerate the elimination of certain substances from the manufacturing process. For example, the focus on the elimination of lead from solder materials represents a priority across several segments of the electronics industry. An environmental interaction site could provide a ready, virtual discussion group of individuals who are involved in eliminating lead to share ideas, information, and breakthroughs. In this sense, the site fills the function of professional association or trade meetings but with more real-time input. The same kind of discussion groups could focus on environmental processes for specific components (i.e., printed wiring boards, displays, ICs, etc.) or other specific media, materials, or chemicals.
- Best Practices and Corporate Environmental Stewardship: The Web approach provides an ideal forum for presenting discussions of best practices in design for environment, manufacturing, end-of-life management, or a wide variety of other areas. Corporations with practices that have resulted in significant benefits could post descriptions and case studies to the net. Furthermore, trade associations or environmental advocacy organizations could also post studies to the net. Similarly, corporations that have adopted environmental stewardship programs or environmental reporting policies could post their stewardship reports to the net, providing a wide ranging view of industry's proactive environmental efforts. This kind of information could prove valuable to efforts aimed at improving regulatory practices and establishing community confidence in the environmental integrity of industrial operations.
- The Virtual Environmental Toolkit: Software for design, management, or other applications could be made available on the Web for evaluation, testing, or even purchase. Furthermore, industrial associations, consortia, or the government may wish to offer freeware across the net for use in certain high priority applications. Finally, such a "virtual toolkit" could provide the platform for creating a national testbed and framework laboratory, supporting the rapid deployment and harmonization of emerging tools.
- The Environmental Library: A meta-index of resources to support knowledge transfer, continuing education, technical research, and information sharing. The Library could also contain the capability to electronically disseminate standards information. The addition of advanced searching agents would greatly enhance the usefulness of the site.
- Professional Networking and Discussion: The Web can provide a forum for discussion and networking about key topics of concern. A discussion forum modeled after the popular news groups available on the Net could be fashioned to address specific topics, and provide a "virtual conference room" for peer-to-peer communication about technical and

policy matters. Furthermore, communications tools available to support web sites provide a mechanism for supporting professional networking and discussions. “Chat rooms,” bulletin boards, and discussion groups are all accepted Web functions, and the ability to establish multiple, specific networking opportunities, ranging from particular processes to broad consideration of emerging technologies, can be an especially important part of the site.

Furthermore, the development of middleware tools—directory services, security, financial services, authoring tools—make the Internet an even more valuable resource. Commerce is already being conducted across the Internet in a limited fashion, and new technologies promise to resolve issues of security and transactions management in the very near term.

Accomplishing a comprehensive Web effort would require a dedicated staff focused on the development, management, maintenance, and marketing of the site. Such a staff could be supported through existing industry associations, consortia, government programs or other means by which companies could share the cost of the resources required to maintain the program.

By and large, however, even highly interactive Web sites remain somewhat limited in their functionality. If, for example, partners working together on a process wish to undertake real-time transaction processing, utilizing some common data set, Web sites generally do not support this kind of activity. However, tools now becoming available on the market allows corporations to open gateways from Web sites to internal corporate databases. Utilizing these tools, along with increasingly reliable security and authentication tools, corporations could establish compartmentalized levels of access to corporate data. This would enable certain data to be made available industry-wide, other data to be restricted to strategic partners, and other data to be restricted for internal use for specified individuals.

It is, of course, also possible to establish these kinds of network systems on a private, proprietary basis. Strategic alliances, or virtual partnerships, pursuing particular products, establishing supply relationships, or working in the context of an industry consortium, can create a private network through direct dial-up or dedicated linkages. Once established, a variety of open tools exist on the marketplace to facilitate cross platform heterogeneous data access.

However, the objective of this discussion is to focus on the establishment of industry-wide information resources, and therefore, a preferred route would be a linkage with an open World Wide Web site.

One possible approach would be the creation of a multi-enterprise data warehouse through which corporations can share data about environmental processes and easily maintain, update, and retrieve data that might be useful to them, regardless of the platform on which any individual corporation maintains its data. A data warehouse revolves around a relational database management system (RDBMS) and contains data-management and data-access tools. Companies use data warehouses to store, integrate, and maintain business information that has been extracted from an operational database.

These kinds of data warehouses are supported by an increasing number of commercial tools that encourage or support cross-platform compatibility, either through the establishment of data migration systems, common user interfaces, or data mapping and mining technologies. Although data warehouses are generally operated and managed for the benefit of a single enterprise, there appears to be no technical reason why a multi-enterprise environmental data warehouse could not be established.

In this case, companies wishing to form the (possibly virtual) warehouse collaboratively develop the architecture, identify the infrastructure in place to operate the warehouse, identify and collaboratively assess tools available to support data transformation and integration, and undertake a comprehensive training and implementation program. Once operational, environmental specialists could access the environmental data warehouse to support decision making associated with environmental issues.

The data warehouse, or even the corporate databases of individual companies, can be integrated with a Web site through tools that are now emerging on the market. A common gateway interface (CGI) linked through an application program interface (API) to an internal database can generate scripts that manage transaction processing even through a Web-initiated connection. Other approaches to integrating Web-based information models and other information technology models are emerging regularly.

A number of advanced technologies are also emerging for data integration that can be integrated into the environmental information infrastructure:

- Data Mining: Data mining tools dispatch autonomous agents through targeted distributed databases and seek to identify common patterns or threads among the data. Data mining tools can identify patterns that previously may have been impossible to perceive given the fragmented nature of the data.
- Data Fusion: Data fusion is the art of blending, combining, filtering, comparing, selecting, and presenting the information into a usable medium. Imagine pulling information from disparate sources that include geopolitical data, chemical data, industry data and fusing it for more complex analyses.
- Data Consistency: Data consistency techniques search for anomalous data elements in an effort to improve the quality and reliability of data sets.
- Data Migration: Data migration techniques have been developed to automatically migrate data when an older database system is replaced by a newer one. These techniques are also adaptable to replicating data to optimize access times to data..

MCC has proposed a project, referred to as the Environmental Information Mall, that offers an evolution of the Web site attributes described above, combining many of these advanced data management tools. The establishment of an “environmental mall” for the electronics industry takes information dissemination a step further—enabling communication and commerce among those who provide tools and technologies to support industrial and environmental processes and the industrial end-users who require them.

For example, a software company providing design for environment tools could offer a beta version of their tool through the environmental mall. Users could experiment with the tool, either on a free basis or on a limited cost basis, providing important feedback to the software manufacturer. The software manufacturer could then offer a finished product through the environmental mall, and the user could execute the transaction of purchasing the equipment or software from the supplier in a fully electronic system. The advantage of this kind of process is providing the opportunity for vendors to present the full range of products and services available, and for industrial users to be able to search easily through the variety of tools and suppliers until they find the specific functionality they require.

The establishment of an environmental information mall is timely, because most of the needed technology components are now in place:

- The communication infrastructure has been fostered by the National Information Infrastructure Program and reflected in the increased use of the Internet and World Wide Web;
- Environmental data collected by many government agencies, commercial organizations, and consortia; and
- Environmental analysis and simulation tools are currently being developed by many commercial organizations.

3.5 Initial Steps to Building the Information Infrastructure

Regardless of the approach, some initial steps must be taken:

- Issuance of Invitation to Participate: The organizers of a collaborative effort could issue an industry-wide invitation to participate in establishing the environmental data system. This would involve a company making available its non-proprietary environmental databases or process data in a manner that is accessible through the architecture adopted.
- Development of a National Environmental Data Registry: The Environmental Protection Agency has called for development of a national environmental data registry, providing a central index and source list of data available to assist in environmental decision making. Resources currently available on the Web, as well as inventoried resources elsewhere provide a starting point for the national data registry.

  However, an aggressive effort must be launched to identify sources that are not immediately obvious or apparent. Databases maintained by OEMs, for example, can provide a rich source of information about processes, materials, performance, and challenges facing end-of-life management. Many OEMs will be reluctant to make this data widely available, due to the concern that some of the data may represent proprietary information about products and processes. Nevertheless, a focused effort to identify these sorts of data sources, and to work with corporate managers to "sanitize" the information in a way that does not compromise company-confidential material, is an important activity.
- Development of an Electronics Industry Environmental Ontology: The purpose of the ontology was discussed previously. As a consensus model of the data to be made available, and the structure of that data, the ontology serves as a central point against which other data sources can be mapped. This mapping allows automated query systems to execute searches across multiple databases and retrieve information concerning particular topics or of a similar nature. This facilitates navigation and access as well as provides a

common reference set to support communication among the various participants who are engaged in environmental decision making.

- Assessment of Commercially Available Information Management Tools: The project should then focus on identifying and assessing commercially available information management tools to support the objectives of the data warehouse or Web site. This would include capability of the tools to handle the volume of data that might reasonably be required, adaptability of the tools into integrated frameworks, compatibility of the tools with other technology computer-aided design tools that may be in use, and other key items. Tools to be considered should include browsing tools, data migration/consistency tools, graphical user interfaces (GUIs), data mining tools, agent-based tools, and others.

3.6 Conclusion

Ultimately, the issues associated with effective data for decision-making may well prove to be less those of developing data than locating data that already exist and establishing a coherent framework in which that data can be verified and made accessible to a wide variety of users with valid reasons for access. The information management tools available today, while not entirely satisfactory, could provide a significant starting point for building a new process.

Such a process would not stop at simply making data accessible for many users. There exists a requisite next step of automating the process of analyzing, composing, and presenting pertinent information to each user, tailored specifically to each user's individual needs. It is not enough to generate, find, retrieve, and make information available. This information must be further pre-processed and presented within a framework that will not only conduct an information search, but will also present the retrieved data to suit the contextual needs that motivated the search in the first place.

Once the electronics industry environmental information infrastructure has been established, the information can prove useful for the wide variety of other information technology-based applications that quality, efficiency, and productivity efforts demand. Data can be extracted to support design for environment and computer-aided design efforts; industry-wide benchmarks can provide data to support process control and monitoring; market data can assist manufacturers direct and manage end-of-life products by targeting companies that will accept, remanufacture, recycle, or dispose of used equipment. Table 3-2 lists the needs for information and knowledge systems identified during this roadmapping exercise.

Priority Need	Task
1. Develop a national environmental data registry to support environmental decision-making	1.a. Identify available sources of data, government, public and industrial 1.b. Establish standards for environmental data for registration 1.c. Encourage dissemination and adoption of registration standards
2. Develop an industry-wide environmental ontology and metrics	2.a. Establish standards for environmental data metrics 2.b Create relational models (ontologies) of environmental data in high priority/high interest data sets 2.c. Develop user friendly ontology tools to allow broad user input
3. Create/augment material and chemical databases to include environmental information	3.a. Develop the framework for a broad material and chemical database activity 3.b. Institute a collaborative process for database population and management
4. Develop decision support tools to augment intelligent access and analysis of information	4.a. Stimulate the development and implementation of software agents for access to the "right" information 4.b. Develop the methodologies to utilize emerging metrics of environmental information in business decision processes
5. Create a multi-enterprise environmental data warehouse	5.a. Collaboratively develop the architecture for data warehousing 5.b. Identify and assess the tools available to support data transformation and integration.
6. Create an "environmental mall" that offers an evolution to today's data access and retrieval options	6.a. Effectively link the emerging Web-based information sources 6.b. Incorporate intelligent software agents to aid in access to the right information 6.c. Couple distributed information with distributed software analysis tools and processing capability

Table 3-2. Information and knowledge systems priority needs matrix.

4.0 Design for Environment: Evolution and Tool Needs

The role of a roadmap is, in part, to examine trends and identify agents of change. One such trend in the electronics industry is the increasing consideration of environmental concerns across the business spectrum—from strategic decision-making to the technicalities of product design and manufacturing. In support of this trend is the move to develop and utilize a variety of tools to assist decision-making, including consideration of environmental impact.

The *1994 Electronics Industry Environmental Roadmap* (the *1994 Roadmap*)[4] addressed the trend toward design for environment (DFE), or the "…systematic consideration of design performance with respect to environmental, health, and safety objectives over the full product and process life cycle…" ([17], p. 3). In the time between the development of the *1994 Roadmap* and that of the follow-on document, the *1996 Electronics Industry Environmental Roadmap* (the *1996 Roadmap*), the basic principles of DFE have gained exposure in the electronics industry, as witnessed by DFE-related activities in companies, and interest generated in national laboratories, universities, and at technical conferences. Based on findings from the *1994 Roadmap* and the growing activity around this topic, a continued discussion of the approach to DFE and an examination of related agents of change in the electronics industry is warranted.

The goal of this chapter of the *1996 Roadmap* is to examine some fundamental elements of DFE and to present findings from a survey of the state of DFE practices in the electronics industry and the current and future need for support tools. Basic principles of DFE are discussed and the survey process is described. In addition, the results of the survey and follow-up interviews are summarized and closing comments provide a general statement about the challenges facing a broader implementation of DFE. A copy of the survey and compiled rankings of tool features can be found in Appendix F.

4.1 DFE Basics

Traditionally, electronics design has been based on a correct-by-verification approach, in which the environmental ramifications of a product (from the manufacturing process through disposition) are not considered until the product design is completed. DFE, by contrast, takes place early in a product's design phase to ensure that the environmental consequences of a product's life cycle are understood before manufacturing decisions are committed. DFE is actually a combination of several design-related topics, including disassembly, recovery, recyclability, regulatory compliance, disposition, health and safety impact, and hazardous material minimization.

DFE design topics can lead to a reduction in bottom-line costs and have a positive impact on the environmental impact of a product. In one example, AT&T's Western Electric Subsidiary has found that at least 80% of the wastes generated by its manufacturing processes are "locked in by the initial design." [7] DFE is part of a shift in mentality concerning trade-offs between

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4 The *Electronics Industry Environmental Roadmap* was sponsored by the Advanced Research Projects Agency (ARPA), the Environmental Protection Agency (EPA), and the U.S. Department of Energy (DoE). MCC (Microelectronics Computer and Technology Corporation) coordinated and produced the report, which was published in November 1994. For a copy of the report, contact the MCC Information Center at 512-338-3506.

environmental protection and economics. As described in *Green Gold*, industrial and governmental players see green processes and products as economic policy, not environmental policy [18].

The successful application of DFE to electronic systems requires the coordination of several design- and data-based activities, such as environmental impact metrics; data and data management; design optimization, including cost assessments; and others. Failure to address any of the aspects may limit the effectiveness and usefulness of DFE efforts. As discussed in the *1994 Roadmap*, three elements are key to integrating DFE into a product-development process: (1) eco-efficiency *metrics*, which are necessary for measuring environmental performance; (2) eco-efficient design *practices*, which are implemented during the design process; and (3) eco-efficiency *analysis methods*, which enable proposed designs to be assessed with respect to environmental metrics, costs, and quality tradeoffs. An extensive discussion of these elements is available in Joseph Fiksel's *Design for Environment: Creating Eco-Efficient Products and Processes* [17]. This report focuses on metrics, although practices and analysis methods are touched upon.

The concept of "eco-efficiency" was discussed by Stephan Schmidheiny with the Business Council for Sustainable Development (BCSD) [19] in the context of limits to growth being due to the ability of an ecosystem to absorb waste, rather than solely due to limited resources. This belief encourages a shift from compliance to pollution avoidance and to more efficient processes. Further defining the concept in terms of its direct applicability to industrial concerns, Fiksel states that eco-efficiency is "the ability of a managed entity to simultaneously meet cost, quality, and performance goals, reduce environmental impacts, and conserve valuable resources…" ([17], p. 499).

In order to attain an eco-efficient process, which is central to DFE, the entity must define the metrics by which to measure the efficiency. Such metrics include: energy (e.g., total energy consumed during the product's life cycle), emissions (e.g., toxic or hazardous materials used in production, hazardous waste generated during production or use), materials management (e.g., percentage of recycled materials used as input to product, purity of recyclable materials recovered), or economic (e.g., cost savings associated with design improvements, average life cycle cost incurred by the manufacturer).[5]

Practices adopted in industry to implement DFE, and the analysis methods employed to assess the impact—realized or estimated—of a new design, rely on the establishment of metrics. Some common DFE practices, such as material substitution, and design for X (where X is separability, disassembly, recyclability, disposability, re-usability, remanufacture, energy recovery, etc.), cannot be successfully carried out in the absence of a reliable means of measuring the impact of the decision. The analysis of the design, whether quantitative or qualitative, also rests on a foundation of metrics. After metrics have been established and practices implemented, analyses might be carried out based on product design, life-cycle assessment, chemical-use mapping, product cost, and time-to-market, among others.[6]

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5 For a more detailed discussion of metrics, refer to [15], pp. 20-21.

6 For a more detailed discussion of practices and analysis methods, refer to [15], pp. 22-24.

Because life cycle assessment (or analysis) is a commonly discussed element of the DFE process, it warrants attention in this report. Life cycle assessment (LCA) has traditionally referred to a family of methods for assessing materials, services, products, processes, and technologies over their entire life. LCA and environmental impact metrics will be of limited value unless the impact of decisions on other economic and performance parameters of the system can be quickly and accurately assessed by system designers (i.e., cost, electrical and thermal performance, reliability, size, etc.).

This relationship between the utility of LCA and other system performance elements is one reason there is currently a great deal of debate regarding its value. LCA is a complex process, but can be useful if properly bounded. It is important to have a sound understanding of the necessary metrics and a systematic method for collecting and analyzing data. Due to this complexity, alternatives to full LCAs are being developed. For example, the Canadian Standards Association created a life cycle *review* to assist companies, particularly medium and small enterprises, in attaining results from environmental analyses [20]. When pondering the decision to use an LCA to analyze environmental impact and eco-efficiency, there are a number of points to keep in mind, including:

- LCA is one of a number of environmental management/DFE tools and should be used in conjunction with other tools and techniques.
- The scope/system boundaries of the LCA is subjective and dependent upon a number of variables (e.g., target of the LCA).
- Currently, impact assessment techniques are immature.
- The potential subjectivity of assumptions and choices within the LCA framework may limit the models used for the LCA.
- The applicability of results is often limited to the original scope (e.g., cannot globally apply results of an LCA conducted in a small town or for one product).
- Relevant data is limited and collection techniques may not be adequate, thereby affecting the accuracy of results.
- The LCA process and results are complex and may not lend themselves to a simplified conclusion [21].

4.2 DFE Survey for the 1996 Roadmap

In many cases, the interest in, and difficulties of, applying DFE principles are at odds. For example, the interest in integrating DFE at various levels in the company may significantly exceed the knowledge of how to carry out that integration. Often the difficulties stem from a lack of established mechanisms for measuring the environmental impact of a product or process (metrics), communicating the impact, and incorporating the related changes into the product design or manufacturing process. Based on a priority need identified by the *1994 Roadmap* for the development of "tools to enhance voluntary implementation of DFE," ([15], p. 27) a goal of the *1996 Roadmap* is to begin laying the groundwork for such tools by understanding where the industry stands in its desire to implement DFE practices and the difficulties facing DFE implementation.

One of the first steps in developing the *1996 Roadmap* was to re-examine all priorities, including the need for "…follow-up tasks that provide best-practice tools and resources…" ([15], p. 25). The outcome of this exercise was the conclusion that the incorporation of DFE into product design and manufacturing is indeed important (refer to pages 4-5 of the *1994 Roadmap* for a list of priority needs). In order to move forward on this need, a task team was assembled[7] to examine the pervasiveness of DFE in the industry and to list desirable DFE tool characteristics. By means of a survey created by the task team and individual interviews of industry representatives, the *1996 Roadmap* is attempting to: 1) begin the process of defining the state of evolution of DFE in the electronics industry, 2) identify the type of tools that facilitate the application of DFE principles in design and manufacturing, and 3) recognize the potential mismatch between design tool needs and tool availability.

Survey participants were selected from a range of product domains in the electronics industry and represent varied design experience. The vast majority currently design, or have designed, at one or more of the following levels: semiconductor/integrated circuit, multichip module, printed wiring board, board assembly, sub-system, and system. It should be noted that the participants recommended by the task group (approximately 80% of the participants) were already somewhat familiar with the concepts, if not specific practices, of DFE.

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7 Task team members (in alphabetical order) were: Dave Allen (University of Texas at Austin, co-leader); Barry Dambach (AT&T); Joseph Fiksel (Decision Focus); Tom Fletcher (Honeywell Microswitch); Gary Halada (State University of New York Stoneybrook); Paul Iyer (Hughes Electronics); Gary Kirchner (Honeywell); David Ufford (Texas Instruments); and Colleen Wilson (MCC, co-leader).

4.3 Findings

As stated earlier, the value of a given type of tool will depend, at least partly, on the state of DFE integration in an organization. The survey was designed to focus on features of software tools, based on the belief that a number of companies had reached a level with DFE practices that called for rather sophisticated techniques. It was found that half of the 16 respondents currently use some type of DFE tool, ranging from relatively simple information resources to more complex, software-based products. The most common tools include: checklists, design standards, design guides, and databases on chemicals and materials. In some cases, the DFE process was facilitated by drawing upon groups in the company with specialized knowledge in materials and environmental science.

Interviews that followed the survey provided valuable insight into the current state of DFE evolution and revealed the need for relatively simple tools. The interviews also provided background on where the company stands with DFE: general acceptance of the concepts; the range of (typically non-software) tools used; and drivers to, success with, and obstacles facing the integration of DFE principles into the organization.

4.3.1 Surveys: Brief Summary of Tool-Feature Ranking

Tool features in this survey fall into six categories: Human Interface, Connectivity, Functionality, Scope, General Compatibility, and Environmental Results Generated. Participants were asked to compare the importance of features within a single category (not across the categories). Given the small sample size of this survey, no statistical analysis was attempted.[8] However, by simply ranking tool features as a High (three points), Medium (two points), or Low (one point) priority, it becomes clear that certain software-based tool features are perceived as critical to a successful DFE program (please refer to Appendix F for a full survey, with rankings). Those tool features receiving top ranking from each of the six categories are:

- Human Interface: Tool comes with databases of environmental information;
- Connectivity: Tool is fully integrated with computer-aided engineering/design (CAE/CAD) platforms or existing design tool suite;
- Functionality: Tool supports technology tradeoff studies (performance feedback of various technologies/materials; recommendations of alternatives/potential solutions/substitute technologies) in real time *and* tool provides environmental regulations, compliance, and environmental policies and procedures (both features tied for top ranking in this category);
- Scope: Tool is applicable to various areas of electronics manufacturing (packaging and interconnect, discrete components, PWBs, etc.)

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8 The following individuals participated in the survey, the interview, or both: Fred Earnst (Honeywell); Tom Fletcher (Honeywell); Tim Glahn (E-Systems); Marc Heyns (IMEC, Belgium); Tim Mann (IBM); Ed Johnson (Raychem); Bahiru Kassahun (AT&T); Cavan Kelsey (Eastman Kodak); Leo Klerks (Philips Semiconductors); Dennis Kodimer (Honeywell); Matthew Lukaszewski (Pitney Bowes); Markku Makkonen (Nokia, Finland); Herbert Reichl (IZM, Germany); Mike Sampson (Sampson Engineering); Paul Sheng (UC Berkeley); Joyce Smith (graduate student, Duke University); and an anonymous participant.

- General Compatibility: Tool is compatible with ISO 9000 *and* tool is compatible with concurrent engineering design and management approaches (both features tied for top ranking in this category);
- Environmental Results Generated: Tool provides relative environmental desirability ranking or ratings of materials/process selection *and* tool is able to evaluate recyclability (both features tied for top ranking in this category).

4.4 Observations of the Current State of DFE

Although respondents consistently cited customer requirements and current or anticipated legislation as the primary drivers to DFE, the respective companies differed in the level and type of DFE activities undertaken. Despite this varied state of development, some common issues in DFE development were identified. These challenges to the evolution of DFE will be grouped into those related to DFE metrics, DFE analysis methods, and general organizational (company) structures.

4.4.1 DFE Metrics

Even if complete material- and energy-use tracking is possible for an electronic product, DFE is not a simple exercise. Comparing different parts or the use of different materials invariably results in the comparison of environmental profiles (trade-offs). One material may be more energy efficient while another is more readily recycled. One manufacturing process may result in more air emissions than one that uses more water. Determining which environmental trade-off is more preferable involves value judgments, yet stating that it is impossible to select greener choices avoids the issue of DFE metrics and provides little value to a designer making choices.

A number of companies responding to the survey have developed metrics to characterize the environmental performance of products or processes. These metrics make the job of the designer more straightforward, but they are inherently dependent upon subjective values. An alternative approach is to identify a set of environmental stressors (e.g., electricity use, carbon dioxide emissions, copper and other material use, energy, and waste/emissions). The amount of each stressor associated with a part or a material can be tracked and individual companies are then free to assign their own weights to each stressor category to arrive at a composite green index.

The most pressing challenge facing the development of DFE activities in the design of electronic products is the development of standardized tracking systems that will allow DFE metrics to be consistently evaluated. There are a number of tools that can contribute to the solution of this problem, but none have gained enthusiastic support. For example, a variety of LCA databases and software tools are available that enable material and energy tracking from raw material acquisition to final product disposal. Unfortunately for the design of electronic products, the databases currently available tend to focus on commodity materials rather than the specialty materials that are frequently employed in the manufacture of electronic products.

4.4.2 DFE Analysis Methods

DFE activities occur at a variety of stages in product development, which calls for a range of analysis tools for the particular activities. For example, in the concept development stage, a number of companies use DFE checklists; in the simulation and physical design stages, several companies use overall environmental indices to guide material selection, part selection, and process design. In ongoing manufacturing activities, DFE checklists are often integrated into other concurrent engineering activities, and detailed waste and emission tracking is incorporated into process materials accounting practices.

In surveying the use of these DFE analysis methods, a common theme that emerged is the need for information on material and energy use—particularly the usage rates of environmentally hazardous materials. Although data needs are, to some degree, company dependent, there is value in gathering and assessing data that will benefit if not the entire electronics industry, certain sectors within the industry. One such example comes from within EPA's Environmental Technology Initiative program, which supports the "Design for the Environment Printed Wiring Board Project." This project has released a profile of the PWB industry, a profile of the processes involved in the manufacturing of printed wiring boards, and an industry survey on pollution prevention and control. The project is examining selected processes and potential alternatives and evaluating them based upon environmental impact, human health risk, performance, and cost.[9]

Discussions related to the survey revealed that few organizations have the capacity to track materials (type and volume) through their own manufacturing systems, and even fewer felt confident in their abilities to obtain information for the DFE process from their suppliers. While many respondents to the survey felt that customer demands are driving the development of DFE methods, means of communicating DFE achievements to customers were generally *ad hoc*. Thus, one major obstacle to the continued development of DFE is the standardization of material tracking and energy-use data. Standardized methods for tracking material and energy use will facilitate the development of generic DFE computer-aided design tools. Standardization will also facilitate communication between customers and suppliers and would lend a higher profile to DFE activities. Currently, few companies appear to have moved beyond the use of checklists and other semi-quantitative analyses. The lack of data needed to perform more quantitative DFE analyses is a major roadblock to further integration.

4.5 Closing Comments

The survey results and interviews show that many companies in the electronics industry are at the stage of defining metrics for DFE—determining what level eco-efficiency is desired within the particular company—rather than fully implementing the process and utilizing complex software tools. Given the state of incorporating DFE principles in various organizations, as revealed by this exercise, perhaps the most useful DFE tools are precisely those most commonly in use: checklists, conceptual guides, and relatively simple chemical and materials databases. Although some companies need or want to create particular guidelines for specific products, some more general documents are increasingly available. For example, the American Plastics Council has published a design guide that discusses such DFE- and recycling-related topics as material selection, use of recycled plastic, basic part-design concepts, fastening and joining, coatings and finishes, material identification and marking, and plastics processing, among others [22].

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9 *Printed Wiring Board Industry and Use Cluster Profile*, #EPA 744-R-95-005; *Printed Wiring Board Pollution Prevention and Control: Analysis of Survey Results*, #EPA 744-R-95-006; *Federal Environmental Regulations Affecting the Electronics Industry*, #EPA 744-B-95-001. #EPA 744-B-95-001 is not a direct result of the Printed Wiring Board Project, but an updated version of a previously published document.

However useful checklists and guidelines prove to be in the early stages of the DFE process, as the industry becomes more experienced at integrating this process into existing design and manufacturing systems, and as potential cost savings related to DFE become more evident, the need for software-based tools will likely increase. The integration of DFE principles at each design stage, from concept to manufacture, will encourage communication between equipment, chemical, and material suppliers and the manufacturer of the final product regarding the environmental impact of each choice. Particularly difficult, however, is the lack of a common language and standards for DFE (e.g., what is "recyclable" or "green"?) and the lack of data to support trade-off decisions. Appendix G provides an overview of selected projects in Europe that contribute to the data required for DFE practices.

The need for reliable data on environmental impact was often expressed during this roadmapping exercise, although it appears to be difficult for an organization to choose the optimal tool for data analysis and decision making. Ideally all of the various data and functions of a DFE tool should be treated in a concurrent, seamless, CAD design environment. This ideal tool would have the *intelligence* to allow the designer to make material, chemical, and physical design choices and to understand the trade-offs at each stage of the design process in a seamless and transparent manner.

A number of tools are already available for use in the DFE process. The bulk of them best fit into the category of life cycle analysis, although the list of tools is growing in such areas as design for recyclability and disassembly. Table 4-1 provides a sample list of current offerings.

Tool Name	**Developer/Vendor**	**Capabilities**
Boustead Database	Boustead Consultants	Life cycle analysis
Clean Process Advisory System (CPAS)	NCMS, Kellogg Co., CenCITT	Life cycle analysis
DFR-HUT	Helsinki University of Technology	Status unconfirmed
Design for Assembly (DFA), Design for Disassembly (DFD)	Boothroyd Dewhurst, Inc.	Disassembly/recyclability process assessment, process-flow assessment, and manufacturability assessment
DFD/DFR	IPA-FhG	Disassembly/recyclability for autos, household appliances, electromechanical parts
Diana	POGO International, Inc.	Disassembly/recyclability process assessment
EcoManager	PIRA, Franklin Associates	Life cycle inventory tool for products and processes
EcoPro	EMPA	Life cycle assessment on packaging materials
EcoSys	Sandia National Labs	Life cycle assessment
EcoTex	PNL (Pacific Northwest Laboratories)	Status unconfirmed
EDIP	Institute for Product Development, Technical University of Denmark	Life cycle inventory and assessment tool (available in 1Q96 in Danish only)
Envision	Dow Chemical	Process assessment tool for cost modeling of MCM-D fabrication
EPS	IVL (Sweden)	Life cycle analysis via environmental "load" calculations

GaBi	IKP	Life cycle inventory and assessment of chemical, metallurgical, and polymer processes
Green Manufacturing Shell	UC Berkeley/CGDM	Assessment of energy use and mass flows and environmental impact (i.e., toxicity, carcinogenesis, irritation, flammability and reactivity) for metal fabrication. Data linked to AutoCAD environment for design of chassis components.
IBIS	IBIS Associates	Life cycle and manufacturing cost simulation tool for electronic systems
IDEA	VTT (developed by IIASA in Austria)	Life cycle inventory and assessment of basic materials including biological production processes
IDEMAT	Technical University, Delft	Life cycle inventory and analysis (based on MET points)
Koning	Carnegie Mellon University	Material selection and substitution
LCAit	University of Chalmers	Life cycle inventory and assessment (mass balance)
LCM$	Decision Focus, Inc.	Life cycle cost management (avail. 1/96)
Life cycle Inventory Tool	EDIP (Environmental Design of Industrial Products)	Life cycle assessment
LiMS	Chem Systems	Life cycle assessment
LMS Eco-Inventory Tool	LMS Umweltsysteme	Life cycle inventory and assessment (raw material extraction, manufacturing, utility generation, transport, and waste disposal)
Tool Name	Developer/Vendor	Capabilities
LASeR (Life cycle Assembly, Service and Retirement)	Stanford University	Life cycle assessment
Manufacturing Advisor	Texas Instruments (developer), Mentor Graphics (vendor)	Manufacturability assessment
OEKO-Base Fur Windows	Migros-Genossenschaft-Bund	Life cycle inventory and assessment of packaging materials
Paradox	Delta	Database of components (construction drawings, material profiles, environmental specifications)
PEMS-PIRA Environmental Tool	PIRA International	Life cycle assessment
PIA Inventory Tool	TME	Life cycle inventory and assessment (handles no recycling)
PRICE	Martin-Marietta Price Systems	Life cycle inventory and modeling tool for electronic modules
Product LCI Spreadsheet	Proctor and Gamble European Technology Center	Life cycle assessment
Recreation	IPA (Fraunhofer Institute for Manufacturing Engineering and Automation)	Databases of materials, life cycle processes, safety standards, legal standards, and recycling/disposal options. Used, for example, to design for product retirement (DFPR) and to provide life cycle metrics.
Repaq Inventory Tool	Franklin Associates	Life cycle inventory (energy usage, solid waste, air and water emissions)
ReStar	Green Engineering Corporation	Disassembly/recyclability process assessment
SAGE	RTI	Database for alternative solvents used for cleaning and degreasing

SEER	Galorath Associates, Inc.	Process-flow, life cycle, and manufacturability assessments
SimaPro 3	Pre (Production Ecology Consultants)	Life cycle inventory and assessment
SWAMI	U.S. EPA	Process assessment tool that allows waste minimization assessments and mass balance calculations
TEAM and DEAMs	EcoBalance	Process-flow and life cycle assessment

Table 4-1. DFE-related tool listing.[10]

With or without the assistance of a software tool, DFE will inevitably cause some disruption during the initial phases of integration. Given that the responsibilities of designers tends to include product cost and time-to-market, the DFE process, without the support of all levels of management, will possibly place significant pressure on the designer. However, according to the survey and interviews, this potential pressure does cause opposition to DFE among designers. On the contrary, interviews revealed that few, if any, designers disagreed with the concept of DFE. Rather, there is opposition to the expectation that designers become environmental experts and to any expectation that the responsibility for potential increases in design cost and time to utilize the DFE tool and incorporate any related changes be placed on the design team alone.

The incorporation of DFE should enjoy corporate-wide education and acceptance, including the marketing and sales forces, whose close contact with the customer makes education and acceptance of DFE critical. The DFE process, which requires a team effort, involves not only the acquisition of reliable data, but also the capability for analyzing the data for decision-making. It has already been, and should continue to be, enabled by industry-wide activity. Table 4-2 lists the needs for DFE advancement identified during this roadmapping exercise. It is hoped that this table serves as a brief summary of the survey and interview findings as well as a working list for further developments in this process.

Priority Need	Task
1. Common DFE vocabulary/ontology	1a. Compile terms, classifications, vocabulary for consistent use and comparison
2. Comprehensive design data that includes “environmental” information	2a. Generate and compile critical “environmental” design data
3. Consistent, accepted metrics	3a. Establish consistent, standard metrics for effective measurement and comparisons of environmental parameters
4. Tracking systems for materials and energy usage and waste generation	4a. Develop models for cross-departmental tracking systems

10 Tool information sources include literature from tool developers/vendors and the *LCA Software Buyers’ Guide*, Atlantic Consulting, November 1994.

5. Models to support more comprehensive design decisions	5a. Develop models to incorporate risk, environmental performance, etc. into accepted design tools and decision processes
6. Tool development	6a. Incorporate accepted models into existing design platforms and tools for effective DFE
7. Broader understanding of DFE advantages	7a. Conduct workshops to train designers and managers on how to adopt DFE principles and practices 7b. Integrate DFE into university curricula 7c. Establish DFE presence at technical conferences

Table 4-2. Priority needs defined for an enhanced DFE process.

5.0 Disposition

5.1 Objective

This chapter addresses the challenge of creating a system that supports the economically viable and environmentally efficient disposition of electronic systems and products. Reaching this goal has both environmental and economic consequences. From an *environmental* standpoint, the consequences can be stated simply: reduced solid waste, reduced toxic materials released into the waste stream, and resource conservation. From an *economic* standpoint, the objective is to ensure that maximum value is extracted from electronic products, and that the disposition of material lacking any intrinsic value is managed in a cost-efficient manner. A secondary objective is the promotion of a viable product end-of-life management (PELM) industry.

Accomplishing this goal requires effective communication and coordinated action among a diverse group of interests, including:

- The electronics industry and its suppliers,
- Recycling and disposal companies,
- Solid waste system administrators,
- The financial community
- Regulators, and
- Consumers and the public.

This chapter of the *1996 Roadmap* is intended to facilitate that cooperation by fostering an understanding of basic issues in PELM, industry concerns, and potential impacts. It includes an overview of the current state of computer systems disposition and discusses obstacles to achieving a widespread disposition infrastructure. It is assumed that many of the issues discussed will also pertain to the wider range of electronic products as well. Examples of programs—some successful, some less so—are highlighted, and the chapter ends with recommendations and an action plan.

5.2 The Importance of Achieving the Goal is Increasing

Manufacturers and distributors of electronic products face many emerging issues that are increasing the priority of effective PELM:

1. <u>The volume of electronic products facing the prospect of disposition is very large and is increasing.</u> Over 12 million computers are disposed of annually, amounting to more than 300,000 tons per year. A 1991 Carnegie Mellon study predicted that 2 million tons of computers will be landfilled by the end of the decade, a prediction that was based on an assumption of just 200,000 tons per year [23]. The Carnegie Mellon study also estimated that two computers become obsolete for every three manufactured, and that by the year 2005 the ratio will likely be 1:1. Despite this volume of discarded product, some studies estimate that as much as 75% of old, used equipment is in storage—creating the potential for large volumes of waste if owners are forced to dispose of the products.

   These numbers also do not take into account the large quantities of electronic waste that enter landfills from products other than computers. Estimates range as high as 2 to 3 million tons per year of electronic scrap annually, and this number will likely increase as the volume of electronic products increases.

2. A major impetus for awareness comes from a court decision. Courts are influential in pressuring industry to adopt more aggressive PELM practices. For example, a decision in the case of The City of Chicago vs. Environmental Defense Fund, issued on May 2, 1994, caused a stir in the handling of ash by municipal solid waste (MSW) systems. The Supreme Court ruled that once products were incinerated, the ash from these exempt products was no longer eligible for the household waste exemption. This means that the ash must be tested using toxicity characteristic leaching procedures (TCLPs) prior to disposal. Immediate pressure was evident to remove all consumer electronic products from the waste stream in order to virtually eliminate the heavy metal residue from the incinerated MSW ash.

3. Several European countries have addressed PELM. Various countries, most notably Germany and the Netherlands, have proposed or adopted a variety of initiatives intended to create producers' responsibility for taking back obsolete electronic equipment. Most of these initiatives are still in the formulative stage, but the prospect of mandated take-back programs creates significant pressure on manufacturers actively doing business within the national boundaries of those countries considering such proposals.

4. Increasing landfill costs have also contributed to the pressure for electronic PELM alternatives. Rising property prices, a demand for new land in development, and increased operating and maintenance costs have all contributed to the increased cost of landfills. Furthermore, the increasing landfill costs have changed the economic equation affecting decisions about cost-effective disposition. What once may have been least costly to landfill may be better recycled or processed in some other way.

5. Consumer demand for "green" products is price sensitive, yet manufacturers are continuing to seek ways to translate environmental practices into a marketing advantage. Energy-saving systems are already well labeled and heavily promoted as a significant consumer feature. In some product segments the fact that a product is recycled may represent a desirable characteristic (e.g., paper products). If public interest increasingly stresses less electronic waste and better handling of end-of-life products, then environmental consciousness on the part of the manufacturer may well become a product marketing necessity.

   Furthermore, producer responsibility and design considerations may become subject to environmental and used parts disclosure requirements. A simple statement of power consumption could be augmented by a total recycled content statement. Refrigerator and air conditioner power efficiency ratings are an example of such information designed for marketing advantage.

6. Contingent liabilities create the potential for significant future costs. Generally acceptable accounting procedure (GAAP) liabilities that are uncertain in amount and/or

due date are called contingent liabilities. As a result of contingent liabilities, subject firms may have to reduce current-period profits by the non-discounted disposition costs for all past- and current-period sales. In subsequent periods, these firms will have to reduce profits by the anticipated disposition costs for all current-period sales; this will lower future profits. Although the exact amount (and even the timing) of the future obligation is uncertain, financial accounting rules often require current-period profits to be lowered by the expected amount of these future liabilities.

If proposals in Europe, Japan, and the U.S. become law, they may create substantial contingent liabilities for some electronics-industry firms. When faced with contingent liabilities, the firm can ignore the contingency (i.e., not make any public disclosure), report the existence of the contingency in a note attached to the financial statements (but not estimate its magnitude), or actually reduce current-period profits by the expected future payment (i.e., make an accrual that reduces net income and net worth). Which of these accounting treatments are used depends on the probability that the contingent liability will actually be paid, the estimability of the contingency, and the accounting standards and practices used in the country where the firm is issuing its financial-accounting report. For a more detailed discussion of country-specific financial accounting standards relating to the disclosure of contingent liabilities, refer to Appendix H.

5.3 Existing Practices and Infrastructure Fall Short of Meeting the Goal

There is a well-established solid waste management industry in the U.S. In recent years, however, that industry has gone through a radical transformation in the manner of processing certain materials (i.e., paper, aluminum, glass) as recycling programs became pervasive and successful. So far, these programs have extended only slightly into products with significant electronic content. Where such programs have been established, they are primarily directed at removing inefficient equipment from the power grid (e.g., refrigerators) or diverting certain hazardous materials from the municipal waste stream (e.g., mercury). Even in these cases, however, programs in the U.S. are pilots, at best.

Under current regulations, a dual infrastructure has emerged in the U.S., one that addresses commercial waste and another that addresses consumer waste. In this discussion of electronic product disposition and PELM, it is important to distinguish between consumer and commercial electronics. The infrastructure and approach for dealing with the two types of waste differ greatly, and are briefly discussed below:

- **Commercial:** A commercial electronic product is one that is purchased or leased by a company, academic institution, or government. The practice of recycling and reusing selected parts has been incorporated into commercial (non-consumer) electronic products remanufacturing and service to a limited extent for more than 20 years in the U.S. The basis for these approaches has been financial, such as parts-cost savings, as well as sound environmental practice. The process is fairly well understood for computers and large copiers or duplicators. It includes employee and contractor services used to demanufacture product frames, cooling subsystems, memory components, printed wiring boards, and a variety of other components. It is important to recognize that, in all cases, a company owns the collected items and intends to reuse them in one way or another. Thus, the producer has incentive to establish and maintain elaborate inventory and repair capability for significant quantities of similar commercial products. This collection and management of electronic equipment occurs independently of the municipal solid waste system.

- **Consumer**: A consumer electronic product is one that is privately owned and used primarily for non-business purposes. The conditions that generally justify a company's financial investment in reusable commercial parts do not exist in consumer electronics. Consumers typically buy a system, rather than lease or rent, unlike many companies. Therefore, there is little incentive for manufacturers and distributors to develop a process to recover and demanufacture used products. The consumer, though potentially interested in giving up a retired system for recycling, has little information or options available. Furthermore, most consumer waste is collected through municipal solid waste systems. Recognizing the difficulty of establishing comprehensive collection systems for consumer products, the EPA has established the Household Hazardous Waste Exemption, stating that small volumes of waste resulting from typical household use are not subject to hazardous waste rules, unless otherwise specified. This further decreases the incentive for consumers to seek alternatives for electronic PELM.

5.4 Obstacles to Improved Disposition

There are many obstacles to more effectively managing electronic products at the end of their life. These range from immature infrastructure and cultural impediments to inadequate technology and regulatory barriers to achieving effective PELM.

5.4.1 The Consumer/Commercial Collection and Processing Infrastructure

The infrastructure of third-party recycling companies providing collection and processing for electronic products has not matured to the point where the volume of product that might potentially be handled can be effectively managed. This is especially the case for consumer electronic products. The first difficulty occurs in guaranteeing an adequate volume of product entering the disposition pipeline to support the growth and increasing availability of PELM services. Economies of scale are achieved through high volumes of similar materials, yet collecting volumes of the same equipment is difficult, particularly when collected from consumers. Manufacturers with voluntary asset recovery sources have high volumes of the same item, leading to a separate infrastructure for their recovery. It is prudent to consider how to leverage the strengths of the consumer/municipal solid waste system and the commercial solid waste services in the future.

From the standpoint of consumer product, significant volumes of retired computer electronics products are stored in home closets or garages, in part due to a lack of an infrastructure to collect and transport them to a viable recovery facility. Many municipalities would prefer not to pick up large volumes of electronic equipment at curbside given their current inability to deal with them. Also, many consumers believe that used electronic equipment has residual economic value and are therefore reluctant to dispose of it without recouping some of this perceived value. Finally, the consumer may simply be unaware of disposition options.

The situation for commercial products is somewhat better. Several commercial electronic equipment manufacturers have created product recovery programs that allow purchasers to return used equipment when new equipment is being purchased. Some of these manufacturers have established internal programs to recycle and remanufacture these products, or recover value of the constituent parts and materials. There is also a significant number of commercial providers seeking to serve the electronics industry. However, even commercial owners of electronic equipment may be reluctant to give up their systems without recovering some of the perceived value. Furthermore, systems are often held in long-term storage as inventory that might potentially be needed or sold someday.

Once product flows into the pipeline, the disposition system is still hampered by the lack of an efficient, affordable, convenient transportation system to take products to a recovery site for further processing. In the absence of a well-established recycling network, a commercial electronic equipment manufacturer wishing to collect and recycle its retired electronic products will likely be faced with high costs of transporting product across the U.S. Recycling fees may be added to the purchase price of new products, potentially driving consumers across borders and state lines in search of products not subject to the added costs. In such cases, the marketing benefits of an environmentally conscious image may not outweigh a potential loss in sales.

Due in part to the difficulty of transporting the retired products from consumers to refurbishers and/or recyclers, long-term storage of obsolete or unused electronic equipment is another frequently used alternative to returning retired items to the disposition pipeline. A study by Tufts University noted that 75% of end-of-life electronic products are in storage [24]. For the remainder, 14% are landfilled and incinerated, 7% are sold, and 3% are refurbished or recycled.

Once product does begin to flow into the pipeline, the processing system must be prepared to handle the resulting volume. An example from Germany illustrates the problem. Germany’s Duales System Deutschland (DSD) made an aggressive effort to collect and recycle packaging waste. However, the system generated over 400,000 metric tons of plastic packaging waste in 1993—twice their capacity to recycle the product. The program finds itself in a significant supply and demand imbalance, and officials are taking steps to correct the situation.

5.4.2 Recycled Material Market Immaturity

A key force that could drive the development of new technology and improved collection systems would be the expansion of markets for products having recycled content or for the resale of recovered materials. In the history of other recyclable materials, one early impetus to the increased acceptance of recycled products was preferential purchasing policies that favored recycled goods. These kinds of purchasing preferences can significantly accelerate the market. Recent excitement about low-cost "Internet terminals" may also increase a secondary market for lower function equipment. With proper marketing, used equipment could be marketed into this product niche.

Markets for recycled products also need to be encouraged. The fact that a piece of equipment is refurbished, or contains recycled contents, should not result in a perception of inferior quality. One might look to the automatic teller machine (ATM) as a model for the disposition of all electronic products. Approximately 97% of all ATMs are refurbished, recycled, or reused in some way. The majority of ATM parts are reusable, such that a 15-year old machine retains approximately 20% of its original value. This is due, in large part, to the design of the product: the ATM, a commercial product, is designed with reusability and recyclability in mind. The example of the ATM embodies the major elements needed for an effective PELM system. There is high market acceptance of refurbished systems, and the ATM is designed to accommodate a closed-loop recycling system, which is frequently promoted as the most economical approach.

5.4.3 Lack of Data

A critical need in establishing an effective disposition system is a base of reliable information about electronic products entering the disposition system. Such information includes the value of constituent materials, risks associated with materials, liabilities associated with use, market demand for spare parts or supply, and a variety of other information requirements. There is a need for significant improvements in data and data access to support decision-making in PELM, especially with regard to risk and economics. This would include component and constituent material inventories for major categories of electronic products, cost data for product management and disposition, risk assessment data, and other categories of information essential to effective corporate and public policy decision-making. Related issues are discussed in the chapter on information and knowledge systems of this roadmap.

5.4.4 Regulatory Issues

The regulations that control the transportation and handling of raw materials headed to manufacturing can be very different than those that are applied to "waste," even though they may be the same material and in the same state as a raw material. As such, some materials that could be readily recycled are not, due to their classification as hazardous materials. Cathode ray tube (CRT) glass from the manufacture of monitors and televisions is a notable example. This glass often fails the TCLP (toxicity characteristic leaching procedure) and is therefore classified as hazardous waste under the Resource Conservation Recovery Act (RCRA) provisions defined by the EPA. CRT-funnel materials that are not recycled are RCRA class C materials and must be pretreated before land disposal can take place. The CRT industry believes the current approved treatment standard of micro-encapsulation is not optimum for glass materials. Copper-clad laminate, used to manufacture PWBs, is another example. PWB laminate material is considered a hazardous waste and has to be handled as such, even if it is destined for recycling. This is true even if there has been no change to the material, such as being scrapped without processing.

Among the more difficult issues is to define the "steward" or responsible party, for end-of-life products in a modern multi-national, multi-layer marketing arena. At present, these products are the responsibility of the owner, typically the consumer or a particular business entity. However, in the current discussions about "take-back" it is not obvious who should be taking back what, and under what conditions. In this context it is important to distinguish between *voluntary asset recovery*, which takes place today where there is economic incentive to do so, and *involuntary product stewardship*, whereby the responsibility is a mandated transaction under law. The definition of "steward" is an important concept since, ultimately, the steward will be held responsible for appropriate end-of-life management.[11] The range of possible stewards is broad. Candidates include distributors, value added resellers (VARs), original equipment manufacturers (OEMs), suppliers, exporters, holding companies, and end users. Furthermore, a product that is at one time owned by a commercial enterprise can easily become a consumer product if it is sold on the secondary market to a consumer.

5.4.5 Technology

Without sufficient market demand for refurbished products and recycled materials, it is difficult to establish widespread recycling networks and efficient logistics. However, without such logistics, the assurance of a successful business based on retired electronic product systems is diminished. An important factor in this equation is the availability of technology focusing on the end-of-life recycling processes, including disassembly, sorting, material identification, separation, and recycling.

There is a growing infrastructure for recovering and recycling end-of-life electronic products. However, most of the approaches focus on the recovery of metals and are less capable of dealing with the large quantities of glass and plastic that are associated with computers and other electronic products. Significant obstacles exist to cost-effective materials identification and separation, and significant development is needed of processes for post separation processing. A critical issue is the efficiency of the recovery process, i.e., recovering enough value to justify the cost of processing.

Displays offer a good example of the way in which technological limitations block a potential market. A draft report to the EPA states that more than 17 million computer displays were sold in 1994 [25] and cites an EIA estimate that 10 million television sets will be disposed of each year. Another report indicates that by the end of 1995, there will be a base of 300 million CRTs (televisions and monitors) in service [26]. The potential recoverable material in retired CRTs comes from leaded glass funnels, low carbon steel shadow masks, optical-quality glass face plates, conductive coatings, and luminescent materials. Recovering the value, however, depends on economically viable technology for glass separation and recovery, disassembly, materials identification, and a host of other difficult technical issues. Due to its low market value, high weight, and hazardous classification, CRT glass is not readily recovered.

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[11] See definitions given in Section 5.7.

One of the greatest challenges in electronics recycling is the recovery of plastics. Plastics represent a high intrinsic value, but a low recycling value due to the difficulty in separation and cleaning. One of the keys to the success of plastics in the marketplace has been the ability to tailor the material to specific needs and requirements. This has lead to the development of thousands of plastics, when one takes into account the different resins, fillers, additives, and coloring agents that distinguish a particular plastic product. Segregation of these plastics into marketable fractions is a tremendous challenge. Economically viable identification and separation techniques are needed to ensure the purity of recovered materials. These are just examples of some problems that must be overcome before the electronics recycling is an economically viable venture.

5.5 Opportunities in Product End-of-Life Management

The value of retired computer systems, like other end-of-life electronic products, is increasingly seen as manufacturing raw material replacement or commercial component recovery. In raw material replacement, manufacturers substitute waste-recovered materials for virgin raw material production. In component recovery, the system often retains some value if remanufactured or reconditioned, or made available for secondary markets. Even those components with no operating value may contain materials or sub-components that, if reclaimed and recycled, have value for a variety of users. Finally, those that contain nothing recoverable must be disposed of as waste in landfills or incinerated for energy recovery. The final category often challenges waste to energy operators because of the metals and other component materials contained in end-of-life electronic equipment.

5.5.1 Nature and Volume of Waste from Electronic Products

There is agreement developing that electronic products constitute approximately 1% of the MSW content by weight [27, 28]. For the typical desktop PC, the primary materials entering the waste stream include plastics (approximately 22% of the total volume), aluminum, lead, copper, iron, and silica. In terms of metals recovery, aluminum, iron, tin, nickel, copper, gold and silver represent the primary value opportunities. Plastics also represents a potentially valuable recyclable, but the recycling efficiency demonstrated by the recovery process is no better than 20%.[12]

Handy and Harman, a major provider of recycling services to electronic manufacturers, estimates that the intrinsic value of a typical desktop system (i.e., the market value of the constituent materials comprising the system) is about $51. Given the current efficiency of existing recycling processes, about $31 of value can be recovered from the systems. The principal recovery values are in aluminum, iron, copper, gold, and, despite the low recovery efficiency of existing systems, plastics. However, this leaves an additional $20 in value that could be obtained if recovery efficiencies were increased. The primary target for this effort should be the recovery of plastics.

In addition to the recovery value of components, there are potentially hazardous substances that need to be managed during storage and transportation, as well as during the ultimate disposition of electronic products, including cadmium, chloro-paraffins, chromium, copper, lead, mercury, and silver compounds. Many of these materials can be recovered and recycled, sold to reusers, or

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12 Statistics in this section are provided by Handy and Harman, and a specific breakdown, by material, of the components in a computer system is given in Appendix I, Composition of Typical Desktop Computer System.

returned to (relatively) virgin states. In some cases, where characteristics of the material cannot be restored to sufficient quality for use or no economically viable secondary market exists, they will have to be appropriately separated and disposed of.

5.5.2 PELM Business Opportunities

Currently, the primary business opportunities for handling retired computer systems fall into four categories:

- Direct reuse, in which typically older but usable equipment is tested and sold or donated to other entities that do not require the latest equipment. This is frequently handled by not-for-profit organizations with schools, developing countries, or charitable organizations as the recipients.
- Refurbishment/remanufacturing, in which the systems are collected from end-user sites and reconditioned to a state that would allow them to be resold as functioning systems through factory outlets or other channels.
- Reclamation and reselling of components, in which the electronic circuitry and components are recovered and incorporated into other products, where the processing power or functionality of the reclaim components would be sufficient. Marketing disclosure of used parts and Underwriter Laboratory (UL) requirements may exist.
- Salvage and recycling, in which materials are removed from the electronic system and recycled for their raw material value. Plastics, precious metals, glass, and a wide variety of other materials are candidates for reclamation and recycling.

Each of the alternatives has to be weighed against energy recovery and land disposal. While these disposition alternatives have environmental risks and consequences, including penalties imposed by regulations and restrictions, they may still be a preferable option for some individuals or businesses.

5.5.3 Model and Pilot Programs

Discussions are ongoing in the U.S., Europe, and Japan regarding the most effective mechanism for promoting electronic-product disposition. The approaches range from mandatory means to a system that relies on market forces to establish the infrastructure needed for effective disposition. These discussions have gained in momentum over the past few years, and, as a result, a number of programs are emerging in the U.S. and abroad that address some aspects of electronic-product disposition. The scope of these programs are wider than electronic equipment, as their primary goal is to reduce the volume of materials reaching landfills or reduce the toxic materials reaching waste-to-energy facilities. As such, they include white goods (e.g., refrigerators and washing machines) as well as a range of brown goods (e.g., televisions and video-cassette recorders). In 1995, at least four states—Minnesota, New Jersey, Rhode Island, and Texas—have stepped forward with PELM proposals.

Minnesota: After experiencing two consecutive decades of dramatic growth in the use of electronic appliances by every sector of society, Minnesota has issued a broad assessment of the effect of electronic appliances on solid waste systems and is evaluating potential problems when electronic appliances reach the MSW. In August 1995, the Minnesota Office of Environmental

Assistance (OEA) submitted a report to the Legislature on the management of waste electronic appliances, as required under the 1994 Minnesota Law, chapter 585.[13] In this report, OEA identified the following list of electronic products for priority attention, and further recommended that the state prohibit their disposal by business beginning on January 1, 1997, and by residences beginning January 1, 1998:

- All computers and peripherals,
- Televisions and video monitors,
- Copying machines,
- Stereos and stereo components,
- Telephones and facsimile machines, and
- Video cassette recorders.

In the report, OEA states that Hennepin County has operated a public electronic appliance reclamation program since 1992. The County collected more than 6,600 electronic appliances, ranging from computers to kitchen appliances to battery-powered products and toys. At a weight of over 150 tons, the cost was approximately $125,000. The OEA believes that these appliances should not be managed as MSW for the following reasons:

- They contain one or more components of concern, including CRTs, PWBs, batteries, mercury-bearing compounds, and PCB-bearing compounds;
- There is a high degree of market saturation, which will result in substantial discards in the future;
- They have high visibility to consumer due to complexity and size, making them good targets for public education about managing electronic appliances;
- They have a high purchase price, which may affect consumer perception that they are not disposable; and
- End-market capacity exists to recycle and reclaim the appliances.

OEA does not prescribe a PELM alternative for its 1% of total MSW, although representatives anticipate significant efforts by the private sector to meet the demand for alternative, preferred management options such as recycling and reclamation [27]. OEA believes that this approach will create incentives for businesses, retailers, and recyclers to offer management services and that it will allow the flexibility to determine whether to participate and how to cost-effectively provide services. Further, OEA believes that the municipal waste-collection programs are not adequately equipped or funded to manage end-of-life electronic products, although each jurisdiction is free to make its own determination. The OEA also believes that no one sector should bear the full costs of ensuring sound end-of-life management of electronic products.

It is important to emphasize, however, that OEA does not evaluate its beliefs based on environmental impact and differences between commercial and consumer products.

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[13] Minnesota Office of Environmental Assistance (OEA), Management of Waste Electronic Appliances, August 1995. This report also notes the higher electronic disposal rate (1.5%) in the Minneapolis-St. Paul metropolitan area than all of greater Minnesota, attributing this to higher household incomes and a higher population density.

Additionally, it does not recommend pilot projects to test the beliefs in the state or county, calculate the value of reclaimed materials, forecast future values based on content or prior experience, or analyze the overall environmental benefit. To date, the Minnesota Legislature has not taken any action on the report, although an initial draft of a future bill has been prepared.

New Jersey: The New Jersey Department of Environmental Protection (NJDEP) has proposed a demanufacturing system with the goal of reducing heavy metals (cadmium, lead, and mercury) in the solid-waste stream in order to improve the characteristics of MSW residual incinerator ash. In New Jersey, the proposed initial short-list of products includes: batteries, both rechargeable and mercury oxide; mercury-containing lamps; mercury switches, including thermostats; and consumer electronics and appliances including the thermoplastic housings. It is estimated that source-separation programs for these few categories of products can reduce the cadmium, lead, and mercury content of MSW by over 90%.

The Office of the NJDEP Commissioner started an initiative in April 1994 when it announced plans for establishing the collection of selected materials that could form the basis for reducing heavy metals in the waste stream. Programs for collection of rechargeable batteries, mercury-bearing switches, fluorescent bulbs, and CRTs were to be created. The state has chosen to encourage the counties to implement collection and consumer electronic demanufacturing programs involving consumer and/or MSW source separation, storage, and processing. Three counties have contacted the NJDEP to seek guidance for locally developed programs. One has asked for expressions of interest to manage an estimated 5,300 annual tons of electronic material. It had collected and managed over 115 tons of hazardous materials in six collection days in 1994. The same county estimates it generates 440 million kilowatt hours of electricity per year from its state-of-the-art waste-to-energy co-generation facility.

NJDEP has offered to give appropriate guidance on permitting and funding programs and to cooperate with the counties to achieve cost savings for the total cost of its MSW processing operation. The state is encouraging public-private partnerships, which lend expertise in specific material handling to the MSW systems. However, all responsibility for MSW management is vested in the MSW District, which is free under state guidance to establish creative programs to achieve its goals. The state has also created an analysis of the cost factors involved in total MSW processing as a part of the environmental justification. Similarly, the state has analyzed the MSW emissions and releases and other environmental effects of the proposed program components.

The demanufacturing system would operate as a public-private partnership, accepting electronic products from industrial, commercial, and residential sources. County authorities would collect electronic appliances from households and bring them to a demanufacturing facility for disassembly and processing into usable components. The proposed demanufacturing system (including collection) would be funded through the avoided costs of managing heavy metals in incinerator ash [28].

To facilitate the collection, storage, and transport of electronics, New Jersey proposes to ease regulatory restrictions. In cases where the manufacturer does not relinquish ownership of a product within the demanufacturing process, the NJDEP has determined that this equipment can be managed as a product, not a waste. The NJDEP will adopt the new Universal Waste Rule provision in other instances, which allows material to be collected, stored, and transported to an appropriate recycling facility without having to be managed as a hazardous waste.

Rhode Island: The Rhode Island Department of Environmental Management won a competitive grant from the EPA's Jobs through Recycling Program in September 1995 to create a self-sustaining disassembly, processing, and recycling center for appliances and electronic equipment in the State of Rhode Island. The project partners include: Government (U.S. Environmental Protection Agency-New England, Rhode Island Department of Environmental Management, and Rhode Island Economic Development Corporation); Industry (Citizens Bank); and Not-for-Profits (American Plastics Council, University of Rhode Island/Industrial and Manufacturing Engineering, Rhode Island Small Business Development Center at Bryant College, Northeast Recycling Council, Northeast Resource Recovery Association, and the Empire State Center for Recycling Enterprise Development). The project partners are working together to attract a facility operator and in conjunction provide consulting services to develop a viable business plan.

By coordinating efforts of key project partners with various expertise, this project will establish a long-term infrastructure for diverting a valuable resource from the solid waste stream while creating jobs. The project time period is anticipated to be approximately two years, at the end of which a Demanufacturing Facility would be fully operational in the State of Rhode Island by a private sector operator. The ultimate goal of the Demanufacturing facility is to process electronic equipment from both the commercial and consumer sectors of the solid waste stream.

Texas: The State of Texas has begun informal discussions with MCC, the University of Texas, and several leading recycling organizations to consider incentives for establishing an integrated recycling facility in the central Texas region. Several agencies have expressed their interest, including the Texas General Land Office, the Texas Natural Resource Conservation Commission, the Texas Department of Commerce, the Austin Chamber of Commerce, and the Texas Governors Office. The intent of such a pilot is to establish the economic viability of electronic products disposition by simultaneously optimizing reuse, refurbishment, recycling, and recovery. The facility would also serve as a collaborative development and demonstration site for improved recycling technologies and techniques.

5.5.4 Survey of Foreign PELM Programs

As the discussion evolves regarding disposition schemes for computer systems, it is valuable to review the approaches proposed or taken in various regions. Brief descriptions are given of plans in Austria, Switzerland, France, Germany, The Netherlands, and Japan.[14] The European programs represent industry's ideas in each country that are based on several years of discussions and experience on how to best manage the recycling of post-consumer goods given the constraints imposed by government. Whether voluntary or mandated, each model was spawned as a result of legislative activity or in an effort to preempt mandates. Although the undertaking in Japan is not a direct result of legislative pressure, the relationship between government and industry have led to a cooperative pilot project.

Austria: In response to a 1993 directive from the Environment Ministry, Austrian industry established a private collection and recycling system for refrigerators, freezers, and air

14 For a more detailed description of the programs in Europe, please refer to Appendix J.

conditioners. Although the product categories differ from the primary discussion in this chapter, it is valuable to note the decision to establish a dual infrastructure for these items. The program, thus far, includes 40 producers and importers of the final products (or approximately 95% of the industry) and creates a competitive partnership among retailers, transportation companies, and recyclers. In some cases, such as Vienna, the local authorities are also involved. Recycling costs have decreased by more than 40% in the two years of operation, due to increased competition and experience.

Switzerland: In Switzerland, where the government as yet has no plans to mandate the disposition of electronic products, a voluntary program called the Swiss Economic Association of Information, Communication, and Organization Technology (SWICO) was established in April 1994. SWICO membership is open to any company importing or producing office equipment or computers. Membership requires adherence to the convention, which calls for:

- Avoidance of wastes,
- Reduction of harmful substances during manufacturing processes,
- Waste utilization through reuse or value material recycling, and
- Environmentally sustainable residual material disposal.

The SWICO system utilizes three strategies to collect used equipment for recycling: 1) equipment distributors and dealers with the purchase of new equipment (any brand); 2) supplier-specified collection points, which may include on-site pickup; and 3) public drop-off sites located at Swiss railway stations. Following collection, used equipment is transported to recyclers that are licensed by SWICO. SWICO currently licenses 12 recyclers. While there is no limit to the number of recyclers in the SWICO system, recyclers must meet the licensing quality standards, which are based on processing capabilities, technology, and environmental performance. Recyclers are licensed for one year with an automatic extension if they continue to meet performance standards, which are monitored during SWICO's biannual on-site inspections.

The SWICO collection and recycling system is funded through pre-payment fees, charged at the point of sale, lease, or rental, with no additional cost to the customer at the point of disposal. The compulsory fee must be openly and separately displayed on all price lists and invoices, and no discounting is allowed. Participating companies manage the pre-payment fee revenue, with guidelines developed by SWICO on the kind of expenditures that companies can bill to their pre-payment accounts. External auditors, on behalf of the signatories, must guarantee to the public that guidelines are observed. Semi-annually, participating companies contribute 2% of the pre-payment fees to SWICO for system administration, and to cover the cost of recycling non-member equipment.

France, Germany, and the Netherlands: After several years of study and negotiation with their Ministries, the French, German, and Dutch electronic industry associations have proposed shared responsibility models for electronics disposition. Under these models, responsibility for the collection and processing of used electronic equipment would be shared by the chain of actors in the product life cycle, including product manufacturers, retail outlets, municipal authorities, and the waste management industry.

The proposals strongly argue for the continued role of municipalities as the principal entities for collecting electronic goods, rather than establishing an independent industry-financed infrastructure. These municipal-based systems are intended to preserve and augment the current collection infrastructure, which provides collection points close to households and is familiar to consumers, in order to ensure a high level of product returns. Under contract with municipalities, the waste disposal/recycling industry would be responsible for the environmentally-sound processing of equipment and for ensuring adequate capacities. Certification of recycling firms and reporting systems (e.g., of recycling rates) would provide increased assurance of environmentally-sound recycling. The expressed role of manufacturers in electronics disposition is two-fold:

- The design of new products to reduce waste generation, avoid harmful substances, and enhance recyclability at end of product life; and
- Information dissemination to customers and recycling firms to help ensure appropriate disposition.

In Germany and the Netherlands, industry proposes that consumers should pay for disposal at the end of product life, if needed, or municipalities should bear the cost through an increase in annual waste assessments to households. In Germany, industry proposes different financing mechanisms based on the size of the electronic equipment. For large electrical appliances and consumer electronics, municipalities could charge consumers a separate recycling fee, while no fee would be charged for small goods that fit in the trash bin (i.e., can be hidden in the trash). Industry proposes that municipalities assess each household an additional DM 15 (about U.S. $10) annually in their waste bills to cover the recycling costs for these small goods. Estimated recycling charges for several items are: washing machines, DM 20 (U.S. $13); refrigerators, DM 42 to 62 (U.S. $26 to $33); and televisions, DM 40 to 60 (U.S. $25 to $38).

Japan: Japan's approach, thus far, to product end-of-life management is primarily through government encouragement for more environmentally sound practices, rather than legislation. Although Japan's Ministry of International Trade and Industry (MITI) drafted the Recycling Law in April, 1991 (which went into effect in October of the same year), no mandate exists for manufacturers to collect and recycle end-of-life products. MITI has recommended that the Association for Home Electric Appliances (AHEA)[15] establish the *Property Disposal Operation Cooperative Center*, a recycling consortium to facilitate the transport of collected goods from the retailer to the recycling facility (municipal facility or private recycler).

This project will initially target televisions, refrigerators, washing machines, and air conditioners. The recycling consortium includes the Council and Centers. The Council consists of three subcouncils (central, regional, and local) that will facilitate negotiations between local governments, industrial associations, transporters, recyclers, and the Centers. Recycling companies with facilities and recycling technologies meeting established standards will receive a license to operate in the consortium.

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15 The AHEA is a MITI-sponsored non-profit organization chartered with public relations with consumers. The AHEA membership currently consists of approximately 32 manufacturers of home appliances and 14 industrial associations.

Disposition

The costs of collecting, transporting, and recycling used equipment is split between local authorities, AHEA members (equipment manufacturers and retailers), and consumers. Customers pay a fee when returning the product to purchase a new one, or when the product is delivered to the home and the used piece taken away by the retailer; the manufacturer pays a fee, based on product sales; and retailers pay transportation costs. However, some transportation may be handled by local governments and licensed recyclers, in which case the costs are shifted back to the retailers. The fees are negotiated by the Council.

5.5.5 Summary: Lessons from Program Examples

Several lessons emerge from the model programs:

- Most of the programs recognize "shared responsibility" in which manufacturers, sellers, government agencies, and consumers all share some piece of the responsibility for effective end-of-life management. A national recycling/demanufacturing effort must develop through the cooperation of businesses, consumers, municipalities, and governments.
- An important part of the system is to encourage manufacturers in their use of environmentally conscious design, producing systems that are well-suited to effective end-of-life management.
- There are costs of effective product end-of-life management that must be borne by someone. Generally, this will be the consumer (either through increased prices, special assessments, or increased taxes). The challenge is to establish a system that adequately spreads the cost pool so that the economic inconvenience for any single individual is not significant.
- The importance of economic viability of recycling and recovery as an incentive to the growth of a recycling industry and ultimately competition for recoverable electronic products must be emphasized.
- Bureaucracy must be minimized, while providing ample positive incentives for business and consumer participation.
- Energy efficiency and cost effectiveness must be emphasized to stimulate solutions that are environmentally responsible and viable.

Much like the collection and recycling of aluminum cans a few decades ago, electronic PELM disposition systems are now in an infancy period. Metals and plastic materials in computer systems offer a significant economic opportunity. Although metals have been reclaimed for a number of years, the economic recovery of plastics is still rare. Immature separation and recycling technologies create a barrier to tapping the equally high intrinsic value of plastics. Ultimately, the structure and success of any disposition system will depend on a variety of factors, such as logistics (including transportation infrastructure), supply of retired equipment, demand for refurbished product and recycled materials, recycling technologies, and regulations and legislation.

5.6 Recommendations for Achieving the Goal

In order to establish an electronics PELM infrastructure in the U.S, interested parties must find a way to pull the equipment into the pipeline efficiently, establish markets, develop technology for cost-effective and environmentally sound recycling, and support an infrastructure for spare parts databases, catalogues, and brokerage services that provide information on parts requirements, compositions, and sources of supply. Furthermore:

- Environmentally responsible design or "Design for Environment" (DFE) approaches must continue to encourage and simplify demanufacturing and recycling.

- Government, business, and consumers must all participate so that enough material is generated to be cost-effective.
- An increasing volume and variety of discarded equipment requires approaches that can grow and adapt to changing conditions.
- The results must be apparent and measurable. Measurements would include, for example, cost savings associated with reductions in hazardous waste volumes; energy conserved; volume of material diverted from landfills by the recycling of plastics, metal, and glass; and cost savings resulting from the use of recycled materials rather than new materials in production.

Cooperative efforts between industry and government might result in a focused legislative and public education program to stimulate markets and remove roadblocks to recycled products or materials, provide incentives to motivate companies to participate, and encourage and educate consumers. In such an effort, trade associations are critical. The goal is to influence opinion to remove barriers or create incentives, promote inter-jurisdictional (and international) conformity in definitions and regulations, and promote public acceptance of recycled-content products and materials. This effort would also address the importance of integrating environmental messages and supporting statements about recycled products into educational curricula.

Among private consumers, acceptability could be addressed through the provision of warranties comparable to new equipment, and increased use by the information technology industry of outlet stores (mirroring a national trend popular in many other product segments). In addition, secondary markets for refurbished equipment or recaptured components or materials need to be established. Perhaps an initial education-based step is a public campaign of consumer and corporate education that encourages the return of equipment.

One proposed infrastructure approach from the talan group, inc. (tgi) provides an incentive for the computer owner to make the system available for dispositioning. tgi proposes that home-computer owners be given a tax break for donating a computer system to a charitable foundation, the amount of the tax break will be dependent upon the particular type of computer. Via a network established for this program, the user would contact a commercial shipping company to receive a shipping package and arrange for a product pick-up. The shipping fee would be charged to the donor, and may be tax deductible. Once the foundation receives the system, the donor is provided with a receipt and the foundation moves forward with reclamation of components and recycling for resource materials.

Another potential collection infrastructure was discussed at the 1995 MCC Electronic Products Disposition workshop, where opportunities and challenges of attracting investment and entrepreneurs to opportunities with retired computers were put forth. One critical need identified was to more fully characterize the existing installed base and disposition channels. There is a need for a more in-depth understanding about the installed base of electronic products that might enter the disposition pipeline. There is also a need for a greater understanding of the channels available for managing retired computer systems. This effort could take the form of a joint effort between OEMs, suppliers of recovery/recycling services, and the government. Other industries would also be studied to identify applicable/replicable models. A general model was discussed at the workshop for the disposition of consumer electronic products (see Figure 5-1).

The left side of the model is essentially a manufacturer reverse-distribution system. The right-hand side illustrates curbside pickup by municipalities and/or a consortium. Both scenarios include generator drop-off options, especially for small products, such as calculators, portable radios, and digital alarm clocks. For larger items, such as 40-inch televisions and console stereo systems, curbside pickup is certainly the most reasonable procedure.

Below the horizontal line three different recycling options are represented that are currently operational for retired electronic products refurbishment, disassembly, and shred/post-shred separation. All three effectively achieve the intended objectives, but also create a waste fraction that must be characterized and properly managed. Technological development and test bed facilities would enable the reduction of this waste fraction and access to residual value in materials. In particular, developments need to occur around plastics separation and recycling and CRT recycling.

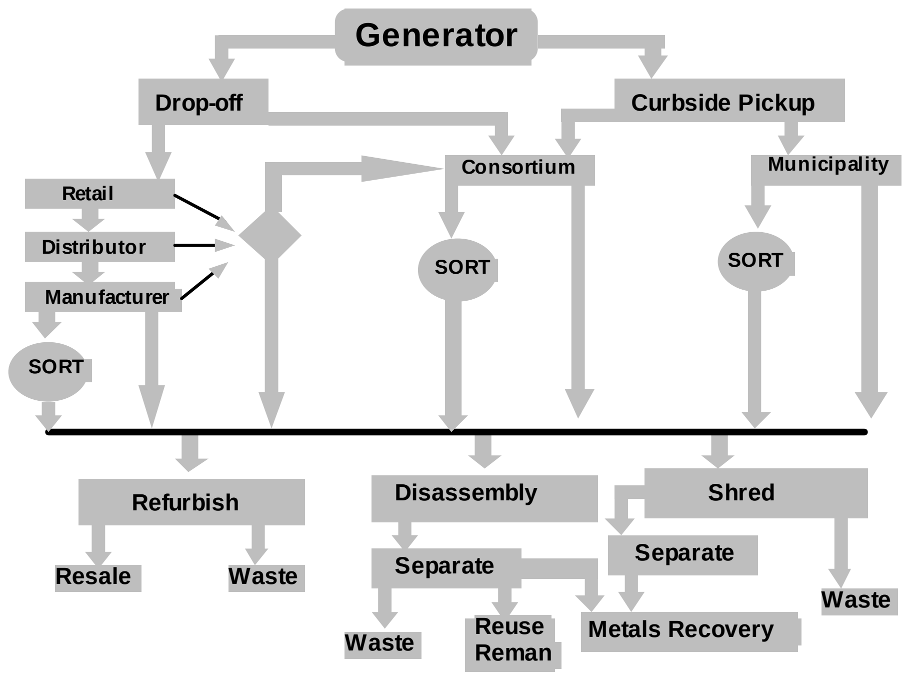

Figure 5-1. A potential disposition model for the U.S. consumer market.

The roadmap for accelerating the development of the disposition infrastructure serving the electronics industry calls for a number of significant initiatives, several aimed at technology demonstration and development and several at supporting processes, data, and regulations.

5.6.1 "Triage" Techniques: An Integrated Sorting and Assessment Center

Assuming that the collection infrastructure is generating a constant flow of product to the PELM pipeline, there is an immediate need for a system of "triage" to determine the condition, contents, and appropriate action for each unit received. One way to approach this challenge is to develop a pilot project for integrated sorting and processing. A prototype facility for managing retired electronics would be useful for testing and integrating existing technology, developing and evaluating new technologies, assessing collection and product management approaches, and supporting research in materials characterization and processing. This prototype facility could be consortially managed, providing a neutral test-bed for manufacturers, suppliers, and recyclers to collaborate and experiment. Such a facility would be ideally established through a public/private cooperative project, providing government cost sharing to increase the leverage of pooled industrial support.

5.6.2 Technology Development

Ultimately, the economic viability of effective product end-of-life management will depend upon the availability of techniques and technologies that can efficiently optimize the value recovered end-of-life products. This technology development should be undertaken in a way that leverages the resources of manufacturers and suppliers, preferably with some matching support from federal, state, or local government. This matching support will likely be critical until such time as the technology can accommodate larger volumes of product and feed stock and economies of scale allow unsubsidized operation.

Plastics: Plastics recycling represents a significant opportunity for retrieving material value that is unrealized due to immature technology. The state of resin identification technology renders plastics separation difficult, and sometimes impossible, for many plastic parts coming from durable-good streams, including computer and electronic equipment. To a large degree, for this reason less than 2% of the more than 2 billion pounds of plastics used each year to manufacture computer and electronic equipment is recovered at the end of the product's useful life [29]. This is particularly frustrating for the goal of recovering value, given that plastics are the most valuable material in a typical desktop computer system after metals (see table in Appendix I for specific values). The challenge in recycling plastics from computer systems includes:

- The plastics used in computer equipment are more specialized than those used in packaging. Whereas the majority of plastic packaging is categorized in six grades of plastic resin, more than a dozen families of plastic and hundreds of grades might be required to comprise a similar fraction of the durables market. This broad variety of materials increases the complexity of separation.
- Many parts contain a wide variety of reinforcements, fillers, and pigments. Changing filler content and foaming causes material density to vary, even within the same type of plastic.
- Computer parts often contain high levels of metal contamination, including wiring, brackets, structural pieces, and molded-in screw inserts.
- Paint and metallic coatings on some parts make identification, sorting, and melt reprocessing much more difficult.
- Larger and more variable-thickness wall sections increases the challenges associated with size reduction and particle-size and shape control.

Separation: In spite of the volume and potential recoverable value of plastics used in computer systems, a jump start may be needed to build the capabilities and infrastructure needed to develop an economically viable industry. This is particularly true when attempting to recover value more broadly from electronic products other than computers. Given the advantages to both industry and government for establishing a disposition system, a cost-share project may be the linchpin to a successful and efficient plan. A potential project might target the development of innovative mixed-plastics separation technology and the integration of this new technology into state-of-the-art mechanical separation processes in a pilot facility. One goal of the project might be to develop a more sophisticated density, or another mechanical, separation technique to broaden the scope of materials that can be feasibly recovered from mixed rigid-plastics stream.

CRT Displays: In order to address the technical difficulties hindering the use of retired monitors as resource materials, a project might be launched to establish the infrastructure needed to obtain the CRT displays and overcome the technical challenges associated with recycling. The "Green Paper on the Environmental Issues and Needed Research in Color Displays," a draft paper prepared through the EIA, proposes the following projects to produce a viable recycling industry for CRTs [25]:

- Tube disassembly: alternative separation methods, such as hydrocutting, sawing, and laser assisted cracking.
- Downcycling: formulating glasses with other inexpensive materials to create useful glasses an/or useful forms for the secondary uses of the glass. Batch assay technologies and protocols would allow the use of variable compositions of glasses (avoids tank upsets).
- Phosphor and coating recovery: safe, inexpensive techniques to maintain the purity of the recovered glass stream; potential value in conductive-coating and phosphor-containing sludge resulting from the cleaning process.
- Sorting technologies: currently used UV and X-ray fluorescence technologies for identifying glass manufactured in 1994 and 1995, such as automated sorting via machine vision and fuzzy logic and segregation of mixed glasses by specific gravity.
- Risk assessment and proper treatment: refine the EPA risk assessment procedures to be able to compare eventual environmental outcomes of disposal practices with respect to heavy metal bearing glasses.
- Lead free solder glass frit: this material is used to join two major components of the CRT, the faceplate and the funnel. It is the highest lead content (80% to 85% lead oxide). Alternative materials would reduce the amount of lead available for leaching.

Printed Wiring Boards: Another valuable portion of most commercial electronic products is the printed wiring board. The PWB sector provides an important and encouraging example of actions to improve environmental performance and reduce manufacturing costs. Additionally, it is a target area for a number of disposition-related projects. One such project has been proposed to: 1) evaluate the feasibility of recycling PWBs and assemblies to lower product cost and decrease adverse environmental impacts from disposal, and 2) develop a national infrastructure for recycling the materials used in PWBs and assemblies. It is believed that the establishment of networks of recyclers on a national scale will allow manufacturers ready access to recycling markets for used boards and assemblies. The proposal also calls for a central data clearinghouse, which would provide a technology transfer mechanism for updated procedures and equipment. Marketing disclosure of used parts and UL requirements may exist.

Metals: The recycling process for recovering metal from electronic products builds upon the existing scrap metal industry. Unlike plastics, whose true raw materials are various forms of petroleum, metals are recovered back to elements. In most cases, therefore, the scrap metal from electronics is smelted and refined into numerous metals for sale. The key to optimizing metal recycling from electronic products is determining how much processing is warranted to remove components, plastic, glass, or paper from the metal stream before transferring it to a refiner or smelter. A series of technologies are in limited commercial use for removing ferrous materials (using a magnet), separating copper and nickel (using an air classifier), and separating aluminum (through an eddy current separator).

5.7 Definitions

Product end-of-life management (PELM) for electronic products is a relatively new undertaking. As is often the case with an emerging field, terms are sometimes used without clear understanding or agreement on their meaning. The following definitions are included as a reference guide to the terms used throughout this section.

- Asset (or Resource Materials) Recovery: The process of a seller voluntarily obtaining ownership of an item through a commercial transaction (e.g., sale, lease, rental, or trade-in) for any commercial purpose including parts recovery, remanufacturing, or recycling.
- Collection Infrastructure: Any mechanism, public or private, including reverse distribution and municipal solid waste collection, for recovering used electronic equipment.
- Demanufacturing: The process of disassembling products into usable components or material fractions.
- Disposition: The effective management of retired products according to current economics, market conditions, regulations, technology, and environmental factors. A broader term that envisions reuse, refurbishment, remanufacture, recycling, recovery, and other options.
- End-of-Life (EOL): The point at which a product is no longer useful to the holder for its original purpose. Synonymous with retired.
- Product End-of-Life Management (PELM): A system for managing retired products (i.e., a disposition system).
- Product Stewardship: One of the best definitions of product stewardship is provided by Hewlett-Packard, a leader in this area, as "…a philosophy and practice of designing products and their associated accessories and processes to prevent and/or minimize adverse health, safety, and ecological impacts throughout their life cycle, (i.e., design, manufacture distribution, use, take-back, disassembly, reuse, recycle and ultimate disposition of constituent parts and materials)…" [30].
- Product Take-Back: To some, product take-back refers to legislative mandates for the recovery and recycling of products, while to others, it refers to voluntary and involuntary efforts. Moreover, it should be noted that take-back legislation does not automatically require manufacturers to physically recover equipment themselves (i.e., bring it back to their facilities). Take-back legislation generally mandates that manufacturers ensure that recovery and recycling happens, either within the organization or through a third party.

- Recycling: The collection, reprocessing, marketing, and utilization of materials that were once considered waste. This involves closing material loops in order to diminish environmental impairment at both extremes of the linear economy, i.e., in an attempt to reduce resource depletion and waste.
- Remanufacturing or Refurbishment: The upgrading of a retired product or the use of parts from a retired system for use in a different product.
- Reuse: The search for the highest possible economic value in re-using goods, components, and materials-durability is a result of the capability to re-use goods and components. The requirements of reuse need to be taken into account in product design (modular system design commonalty principle); the incentive for this is, again, re-take [30].
- Reverse Distribution: The process of product recovery through the channels utilized to distribute new equipment. Reverse distribution can be used for asset recovery or involuntary product recovery.

Table 5-1 lists the needs for effective disposition identified during this roadmapping exercise.

Priority Need	Task
1. Understand positive and negative aspects of existing recycling technologies	1.a. Conduct assessment of existing recycling technologies in the U.S. and abroad
2. Encourage advances and improvements in recycling technologies for computer systems	2.a. Build a test-bed electronics recycling facility that pilots innovative techniques for problem materials 2.b. Analyze impacts from pilot facility's techniques in terms of environment and costs
3. Continued dialog between all interested parties	3.a. Promote dialog through multi-stakeholder activities such as CSI 3.b. Organize a national conference to involve stakeholders and raise awareness
4. Stimulate infrastructure for effective disposition.	4.a. Study market supply/demand issues 4.b. Analyze collection/distribution infrastructure to maximize benefit.
5. Improved education among business and consumers	5.a. Advertise and provide information to businesses and consumers
6. Consistently updated information of disposition activities outside of the U.S.	6.a. Continue to collect and publish information on disposition activities in Europe and Asia

Table 5-1. Disposition needs matrix.

6.0 Emerging Technologies

6.1 The Changing Nature of Electronic Components

The defining trend in electronics over the last several decades has been the unceasing emphasis on "smaller, faster, cheaper, and quicker." "Moore's Law," which states that integrated circuit performance doubles every 18 months has held remarkably true over the last several years, and trends seem to support its continued validity in the near future.

The challenge of effective environmental management in the electronics industry is complicated by this rapid pace of change. Many systems or processes now in common use have only been developed in the last few years (or even months) and new materials, devices, and applications are reported weekly. This constant change complicates thorough characterization of what truly represents "state-of-the-art" and challenges processes, suppliers, and materials to keep up with rapid evolution.

Consider a few metrics that reflect the trends in advanced electronic systems [31]:[16]

- As a result of concerted industry efforts, 0.35-µm line widths for ICs are becoming standard in the industry. The SIA roadmap anticipates an evolution to 0.18 µm by 2001 and to 0.07 µm by 2010.
- Shrinking line widths are accompanied by increasing chip size, driven by requirements for increased performance and functionality. DRAMs are expected to grow from 190 $µm^2$ to 1400 $µm^2$, microprocessors from 250 $µm^2$ to 620 $µm^2$, application-specific ICs (ASICs) from 450 $µm^2$ to 1400 $µm^2$.
- The result of this increased size and capability will be tremendous performance improvements from today's 64M DRAMs to 64G DRAMs by 2010.
- The number of transistors per chip for microprocessors will likely increase from today's four million to as many as ninety million by 2010. For ASICs, the number of transistors will increase from two million to forty million.
- Along with this growing complexity, the number of chip input/outputs will grow from 900 at the 0.35-µm level in 1995 to 4800 at the 0.07-µm level by the year 2010.
- Processing speeds for high-performance systems will likely increase from 150 MHz today to over 600 MHz by the year 2010.

Much of this improvement has occurred, and will continue to occur, within the context of technologies and materials already in use today (i.e., cell size reductions and architectural advances) ([31], p. 16). The SIA roadmap predicts that Moore's law will likely hold true through 2010, and that CMOS (complementary metal oxide semiconductor) technology will continue to be the dominant high-volume, high-performance technology throughout the foreseeable future ([31], p. 11). Beyond this, however, new processes, materials and approaches—for example,

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[16] The projections in this list are drawn primarily from *The National Technology Roadmap for Semiconductors,* published by the Semiconductor Industry Association, 4300 Stevens Creek Blvd., Suite 271, San Jose, California, 408-246-2830. Throughout this chapter, this document is referred to as the SIA Roadmap.

self-aligned processes, silicon-on-insulators (SOI), tantalum oxide (Ta_2O_5), 3-D cell structures, and chip scale packaging—will be necessary, and the vision of that future is less clear ([31], p. 16):

> "Beyond these trends, the direction of technology is largely uncharted with no consensus about which areas of innovation will be successful. In areas other than DRAM, it is even more difficult to find a consensus on the likely directions of technology."

This chapter begins with a brief characterization of current processes in key areas of electronic system development: IC fabrication, packaging, interconnect, and assembly, along with a specific discussion of issues related to displays. The chapter then presents an overview of significant issues in advanced electronics production drawn from a synthesis of several of the major segment-specific roadmaps: SIA, IPC, NEMI, and OIDA.[17] The production trends reflected in these roadmaps are considered specifically in light of their environmental implications. Finally, the chapter identifies a set of "Grand Challenges" for environmental excellence—several fundamental challenges that, if effectively met, could significantly improve the state-of-the-art in environmentally conscious electronic systems manufacturing.

6.2 Overview of Current Processes

Since current processes are likely to form the evolutionary foundation for technological advances through the immediate future, it is important to characterize the major processes of electronic systems production and consider the environmental issues inherent at each stage. In doing so, several contextual considerations relevant to the discussion in this chapter are important:

- The focus of this chapter is advanced electronics production, not final product packaging or use. Therefore, certain issues, such as technologies for energy conservation during use, are not discussed.
- It is fair to say that, in most cases, environmental considerations are not driving technology evolution. The real forces driving technology advancement are price, cost, performance, and market/user requirements. The exceptions to this occur when an externally imposed mandate forces attention on a specific challenge—for example, CFC elimination or alternatives to lead-based solders.

  However, to the extent that the trend is toward smaller devices, fewer processing steps, increased automation, etc., these evolving technologies will likely have a positive environmental impact at the unit production level—i.e., less materials, less chemicals, less waste related to each unit produced. The impact of this may be outweighed, somewhat, by the increasing demand for electronic devices in every conceivable product, and the resulting increase in total unit output. Generally speaking, the interest of environmental process improvement will be served by the continuing development of new technologies.

Furthermore, technology advances that have environmental implications at the upstream processing stage may well have significant benefits in the later stages of systems development and production. For example, material substitution in early production stages may decrease waste implications throughout the entire process.

6.2.1 IC Fabrication

The complex process of manufacturing semiconductor integrated circuits (ICs) often consists of over a hundred steps, during which many copies of an individual IC are formed on a single

[17] Appendix A presents a comprehensive matrix detailing the primary findings and conclusions of each of these roadmaps. We believe that this matrix also represents a template to which the findings from other roadmaps can be added as they become available, i.e., USDC.

wafer.[18] Generally, the process involves the creation of 10 to 20 patterned layers on and into the substrate, ultimately forming the complete IC. This layering process creates electrically active regions in and on the semiconductor wafer surface.

Wafer Production: The process starts with a thin silicon wafer[19]—currently in the range of 150 mm to 200 mm in diameter. The larger chips demanded by future performance requirements will be cut from larger wafers. Wafers are forecast to grow from today's sizes to wafer sizes of 400 mm by 2010.

To start, purified polycrystalline silicon, created from sand, is heated to a molten liquid. A small piece of solid silicon (seed) is placed on the molten liquid, and as the seed is slowly pulled from the melt the liquid cools to form a single crystal ingot. The surface tension between the seed and molten silicon causes a small amount of the liquid to rise with the seed and cool. The crystal ingot is then ground to a uniform diameter and a diamond saw blade cuts the ingot into thin wafers. The wafer is processed through a series of machines, where it is ground smooth and chemically polished to a mirror-like luster. The wafers are then ready to be sent to the wafer fabrication area where they are used as the starting material for manufacturing integrated circuits.

Wafer Fabrication: Silicon wafer processing is predominantly based on the Complementary-Metal-Oxide-Semiconductor (CMOS) process. CMOS technology is advantageous in that it can be easily powered by batteries for portable electronics, yet is extendible to high-performance applications as well. As the demand for electronics is increasing, it is expected that CMOS will remain the dominant technology.

The central activity of semiconductor manufacturing is the wafer fabrication area where the IC is formed in and on the wafer. The fabrication process, which takes place in a clean room area, involves a series of operations called oxidation, masking, developing, doping, dielectric deposition, metallization, etching, and passivation. Because of the number and complexity of steps in this process, more time and labor is invested here than in any other area of semiconductor manufacturing. Typically it takes from 10 to 30 days to complete the fabrication process. Following are the principle steps involved in semiconductor wafer fabrication.

- *Thermal Oxidation or Deposition:* Wafers are pre-cleaned using high purity chemicals required for high-yield products. The silicon wafers are heated and exposed to ultra-pure oxygen in diffusion furnaces under carefully controlled conditions forming a silicon dioxide film of uniform thickness on the surface of the wafer. The thermal oxide will form the important first layer on which circuitry in the IC will be based.
- *Masking:* Masking is used to protect one area of the wafer while working on another. This process is referred to as photolithography or photo-masking. A photoresist or light-sensitive layer is applied to the wafer, giving it characteristics similar to a piece of photographic paper. A photo aligner aligns the wafer to a mask and then projects an

[18] Much of the material that follows is taken from "How Semiconductors are Made," prepared by Harris Corporation and included in the Lexicon of Semiconductor Terms (available from Harris) as well as on the Harris Corporation Web site, found at http://rel.semi.harris.com/docs/lexicon/manufacture.html.

[19] For high-speed and high-performance devices (particularly in photonic or optical applications), gallium arsenide will be increasingly used as the starting material.

intense light through the mask and through a series of reducing lenses, exposing the photoresist with the mask pattern. Precise alignment of the wafer to the mask prior to exposure is critical. Most alignment tools are fully automatic.

- *Developing:* The wafer is then "developed" so that any exposed photoresist is removed, and the wafer is baked to harden the remaining photoresist pattern. It is then exposed to a chemical solution or plasma (gas discharge) so that areas not covered by the hardened photoresist are fully opened to expose underlying materials. At this point patterned photoresist is used to selectively cover areas on the wafer and allow removal of materials outside the photoresist areas (such as metallization or oxides) and to provide areas for selective deposition (such as doping).
- *Doping:* Atoms with either one less electron than silicon (such as boron) or one more (such as phosphorous) are introduced into the areas exposed by the developing process to alter the electrical character of the silicon. These areas are called P-type (boron) or N-type (phosphorous) to reflect their conducting characteristics.
- *Dielectric Deposition and Metallization:* Following oxidation and doping steps, contacts and interconnects are formed to create individual transistors and the interconnections between transistors (for implementing complex multi-transistor circuits). These contacts and interconnections are formed through repeated sequences of dielectric deposition, dielectric patterning, conductor deposition and conductor patterning.

Current semiconductor fabrication includes as many as five metal layers separated by dielectric layers to "wire up" the collection of transistors and implement the full IC circuitry. After the last metal layer is patterned, a final dielectric layer (passivation) is deposited to protect the circuit from damage and contamination. Openings are etched in this film to allow access to the top layer of metal by electrical probes and wire bonds. Figure 6-1 provides a generalized representation of the IC manufacturing sequence.

Environmental Impacts: Each of the major process steps used in IC manufacturing involves some combination of energy use, material consumption, and material waste. Table 6-1 illustrates some example environmental issues resulting from the more common process steps as outlined above.

Process	Environmental Issues/Impact
Silicon crystal ingot growth	Energy consumption
Silicon wafer preparation	Waste stream from chemo-mechanical polishing
Thermal oxide growth	Energy consumption
Resist application	Waste resist from spin-on-process (often 90% of total) and solvent vapors
Resist develop	Developer waste and dissolved resist
Resist strip	Waste stream from dissolved resist (gaseous or liquid waste) and wafer cleaning step
Conductor deposition including polysilicon and silicides	Gaseous waste

Planarization	Solid/liquid/gaseous waste depending on process
Dielectric deposition and etch	Gaseous waste
Cleaning (used between many steps)	Liquid and gaseous waste stream, especially sulfuric acid and water
General facilities	Energy consumption for lighting, air conditioning and air handling

Table 6-1. Environmental impact of some common semiconductor manufacturing processes.

Wafer size continues to increase from the present 150 to 200 mm and with larger wafers will come smaller feature sizes and finer line widths. This growing complexity leads to an increased requirement for photomasks, with SIA projecting that the minimum mask count will grow from eighteen today to twenty-four or more by the year 2010. Additional metallization layers will also be required to manage the increased complexity. As pointed out by the SIA roadmap [31]:

> "With each generation of logic products and microprocessors, the capability to fabricate more devices in silicon exceeds the ability to wire them. This results in a dramatic increase in the number of metal levels."

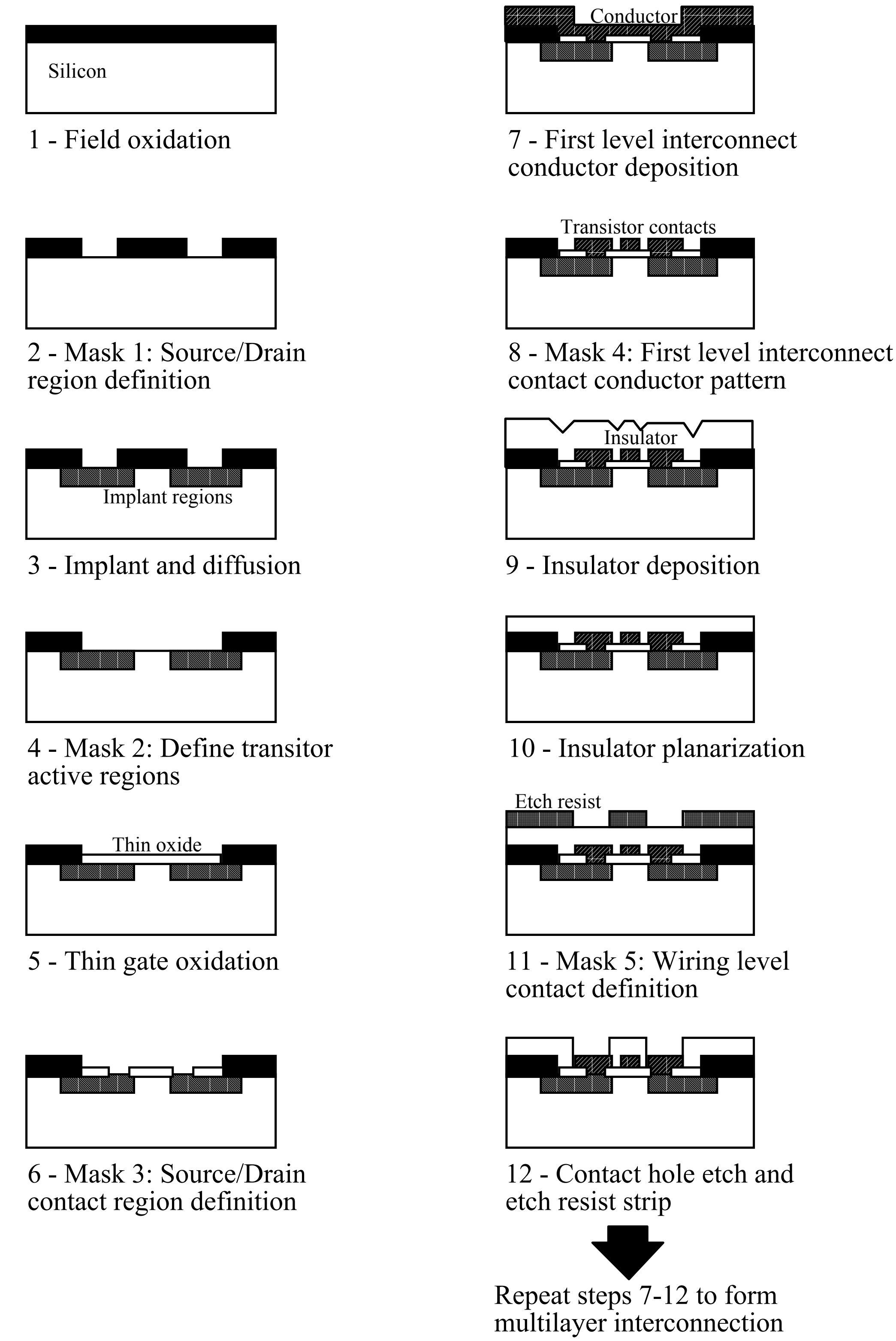

Figure 6-1. IC manufacturing process sequence and major process steps. Many of the detailed processes are unique to different manufacturers and have been omitted for generality. Multiple cleaning steps and their detailed implementation have also been left out of the diagram for simplicity.

Therefore, given larger wafers, the increased number of masks, greater number of metallization layers, and an overall growth projection for the IC manufacturing industry, environmental issues are unlikely to abate. Current environmental priorities include the identification of environmentally benign solvents, cleaners, and photoresists, and improved processes for recycling, recapture, regeneration, and reuse of process chemicals and solvents. Test wafers and wafer reworks are a significant contributor to environmental waste and should be reduced. Increased attention to dry and additive processes, for the environmental benefit as well as the apparent benefits in decreasing contaminants, is also a priority. Overall reduction in energy consumed per manufactured unit will also become a likely IC industry objective for economic and environmental purposes.

6.2.2 Packaging

When wafer processing is complete, the individual ICs ("die") are cut apart to be packaged and assembled. They may be passed along to be encapsulated in a protective coating or housing ("packaging") or be processed as "bare die" for direct attachment to a substrate. Packaging performs two important functions for ICs: electrical connection and protection of the semiconductor device.

Most semiconductor packages have the same basic parts and are assembled using the same general set of process steps. In most families of packaging technologies, a lead frame connects the chip to the printed wiring board. The lead frame is connected to the chip using a very thin wire welded to both the chip and the lead frame. There is also a material enclosing the chip, wire, and part of the lead frame, which must protect the chip from the external environment. During the process of assembly, the chip is attached to the lead frame, the wire is bonded to the chip and then to the lead frame, and the whole structure, except for a small part of the lead frame, is permanently encapsulated for protection.

There are a wide variety of packaging approaches, but generally speaking, the IC is encapsulated either in a hermetically sealed ceramic or metal package or in non-hermetically-sealed packages, usually made of plastic. Hermetically sealed packaging is particularly well-suited where high performance and high reliability are key drivers and non-hermetically sealed packaging where cost is a key driver. However, recent technological advancements have resulted in non-hermetically sealed packaging options with performance and reliability nearly equivalent to hermetics.

Increasingly powerful ICs will also require new technologies for packaging, interconnect, and assembly. The trends in electronic packaging are toward higher I/O counts, lower operating voltages, and faster switching speeds. Among the emerging technologies currently affecting packaging is a shift from peripheral interconnection to area array connections, from two-dimensional to three-dimensional packaging, and from single- to multi-chip packaging [32]. The driving force in the evolution of packaging technology is the need to minimize the package size in order to maximize the amount of active silicon attached to the circuit board or other substrate. As a consequence, packaging approaches such as chip-scale packaging and ball grid arrays (BGAs) are receiving substantial attention in the industry.

BGA packages eliminate the use of a lead frame, but introduce a small circuit board coupon to create fanout from the chip bond pads to the external package connections. The chip is bonded to the circuit board coupon and the chip/circuit board combination is then typically molded inside of a encapsulant similar to those used in more conventional plastic packages as described above. BGAs therefore will increase the use of circuit board materials and the associated environmental impact associated with their manufacture as described in the later discussion of printed wiring boards.

Environmental Impacts: In each of these cases, environmental issues that require attention concern the constituent materials of the encapsulant, the metals used for connection and attachment, the energy consumed in high-temperature processes (especially for hermetic processes), and the chemicals and solvents used in the packaging process. It is worth noting that, in terms of overall contribution to the waste stream, packaging plays a substantially smaller role than other stages of the electronics production process. Certain substances, however, such as butyl acetate, xylene, chlorine, various acids and sulfates, and a variety of other chemicals are used in the process. Important concerns also surround the use of the metals that form the "bumps" that provide a platform for connecting the device to circuit boards or other substrates. In these cases, lead-based solders are frequently used, and are currently the subject of a substantial research activity throughout the industry.

In many cases, emerging packaging technologies will have the effect of reducing the quantity of materials used in the packaging process by virtue of shrinking IC package sizes, and the increasing predominance of plastic packaging will reduce energy consumption associated with hermetic ceramic packaging. Despite the comparatively small influence of packaging, areas of potential environmental impact must be still be addressed. Table 6-2 illustrates some example environmental issues resulting from the more common packaging techniques.

Process	Environmental Issues/Impact
Ceramic (hermetic) package production	Energy consumption and waste stream from metallization plating
Plastic (molded) package production	Chemical and solid waste from encapsulating resin production
Laminate-based plastic packages (BGA)	PWB production issues (see next section)
Lead frame and finishing	Chemical waste from lead frame etching and plating/coating metals (e.g., lead, tin, gold, palladium, etc.)
Cleaning (used between many steps)	Chemical waste stream and wastewater
General facilities	Energy consumption for lighting, air conditioning, equipment

Table 6-2. Environmental impact of some common semiconductor packaging processes.

6.2.3 Interconnect

Printed Wiring Boards: Printed wiring boards (PWBs) represent the dominant interconnect technology on which chips will be attached and represents another key opportunity for making significant environmental advances. According to NEMI [33]:

> "The challenges of lowering costs and improving interconnect density while becoming more environmentally benign are best solved through the development of new materials and improved manufacturing processes. A method must be found to restore significant research and development capability to the industry."

There are several types of PWBs. They may be rigid, generally made of a glass-reinforced epoxy-resin laminate, or flexible, generally made of polyimide and polyester substrates. Printed wiring boards may be either single- or double-sided, or may have multiple layers. PWB production is a complex process requiring many individual steps to complete the board. Regardless of the type of PWB, common processes include drilling, image transfer, and electroplating [34].

- *Base Material:* The base material for most PWB fabrication processes is a copper-foil-clad resin/glass composite. A woven cloth (typically made of glass fiber) is impregnated with a plastic resin (usually an epoxy) and both surfaces of the impregnated cloth are then covered with a copper foil. The base material is purchased by the PWB manufacturer as a starting material for the overall circuit board process described below.

- *Innerlayer Fabrication:* The base material is received from a supplier and cleaned, after which photoresist films are applied to both surfaces. The photoresist films are imaged by shining light through a photomask, selectively exposing photoresist. Those areas of photoresist exposed to the light are developed out to leave copper foil not needed for conductor patterns exposed. A chemical etch is performed next to remove unwanted areas of copper, at which point circuit board traces remain on the innerlayer surfaces. Resist, used to mask the copper during etch, is next stripped chemically. If the patterned innerlayer is to be combined with other layers as described below, a final chemical treatment of the exposed/ patterned copper is performed to enhance adhesion to other layers in subsequent steps.

  Innerlayer fabrication is really the process of creating a double-sided circuit board with patterned conductors on both top and bottom of the base material. For certain applications, such a double-sided board represents a completed PWB, but in most cases, it is combined with other layers to form a complete PWB. Figure 6-2 illustrates the innerlayer manufacturing process, an important building block for circuit board manufacturing.

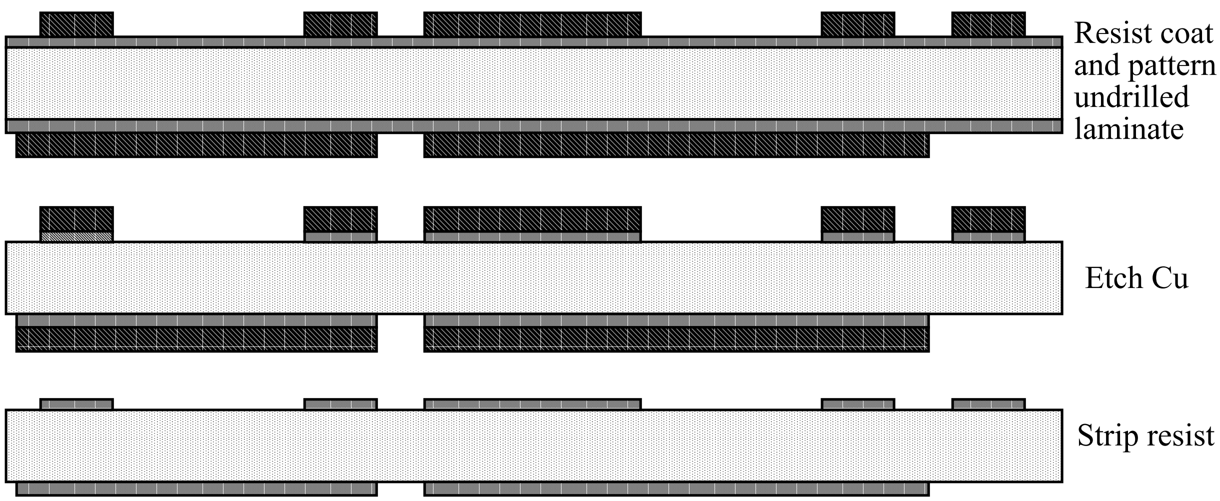

Figure 6-2. Multilayer PC board innerlayer fabrication.

- *Lamination:* Multiple innerlayers typically are combined together as part of forming a multilayer PCB. Lamination is the process by which these innerlayers are joined. During lamination, innerlayers are stacked together with a glue layer between them. The glue layers are often simply base material (impregnated glass cloth) without the copper foils on the surface. The innerlayers, the glue layer separators, and typically a copper foil layer on top and bottom are then placed under heat and pressure to create a single multilayer circuit card ready for further processing.

- *Drilling/Desmear:* To create connections between the multiple layers in the PWB, holes are drilled through the laminated stack. These holes will form the basis for conductive paths through the PWB. Prior to plating the holes a desmear process is necessary to remove epoxy residue adhered to the walls of the drilled holes. The desmear process ensures fully exposed copper of the internal layers and a glaze-free hole surface to promote adhesion of subsequent plating. This is usually accomplished using a wet chemical process.

- *Through-hole Plate:* To render the drilled and desmeared holes conductive, copper is plated onto the wall of the drilled holes. A variety of techniques are used at the hole plating step, each incorporating differing chemical processes.

- *Outerlayer Processing:* Outerlayer processing represents the final major process step to complete a multilayer circuit board. Through-hole plating adds metal not only to the hole walls themselves, but also to the outer layers of the laminated innerlayer cores. These exterior surfaces must ultimately be patterned to provide the necessary connections for circuit components later added to the PWB. Most PWB outerlayers are produced through a subtractive process, in which copper is selectively removed from the plated PWB to form a circuit [35]. Semi-additive or fully-additive processing, in which the manufacturer forms the copper image by selectively plating copper onto the substrate, are alternative outerlayer processes emerging in the manufacturing base. Improvement of additive metal deposition technology, according to the IPC, requires higher precision, consistency in resolution, and demands a focused program of research for new equipment, processes, and infrastructure [36].

Figures 6-3 through 6-4 summarizes the overall multilayering process including lamination, drilling, and outerlayer processing. Subtractive, semi-additive, and fully-additive techniques for outerlayer processing are detailed.

- *Final Surface Preparation:* Numerous surface finishes are possible once all copper circuitry has been patterned on the PWB. Depending on the component assembly processes to be used on the circuit board, gold, solder, or bare copper (with a anti-tarnish coating) are possible. In one common process termed hot-air solder leveling (HASL), the panel is dipped into molten solder, and then blasted with hot air to even out the solder coating on which customers will mount parts.

- *Environmental Impacts:* PWB manufacturing is a complicated process and includes several steps that use significant quantities of chemicals and metals. On average, the waste stream constitutes 92%—and the final product just 8%—of the total weight of the materials used in the PWB production process. Approximately 80% of the waste produced is hazardous [37], and most of the waste is aqueous, including a range of hazardous chemicals. Table 6-3 illustrates some example environmental issues resulting from the more common process steps as outlined above.

Process	**Environmental Issues/Impact**
Base material manufacturing	Chemical waste stream from copper foil manufacturing, resin production
Lamination	Energy consumption
Drilling	Solid waste products from drilling
Desmear	Chemical and/or gaseous waste from etchback of drilled PWB
Through hole/outerlayer plating	Chemical waste from electrolytic and electroless copper baths
Resist develop	Chemical waste from dissolved resist and spent developer
Resist strip	Chemical waste from dissolved resist and spent stripper

Etch	Chemical/solid waste from etched copper and sacrificial tin etch resist from outerlayer processing
Cleaning (used between many steps)	Liquid waste stream
General facilities	Energy consumption for lighting, air conditioning, equipment

Table 6-3. PWB process steps and related environmental implications.

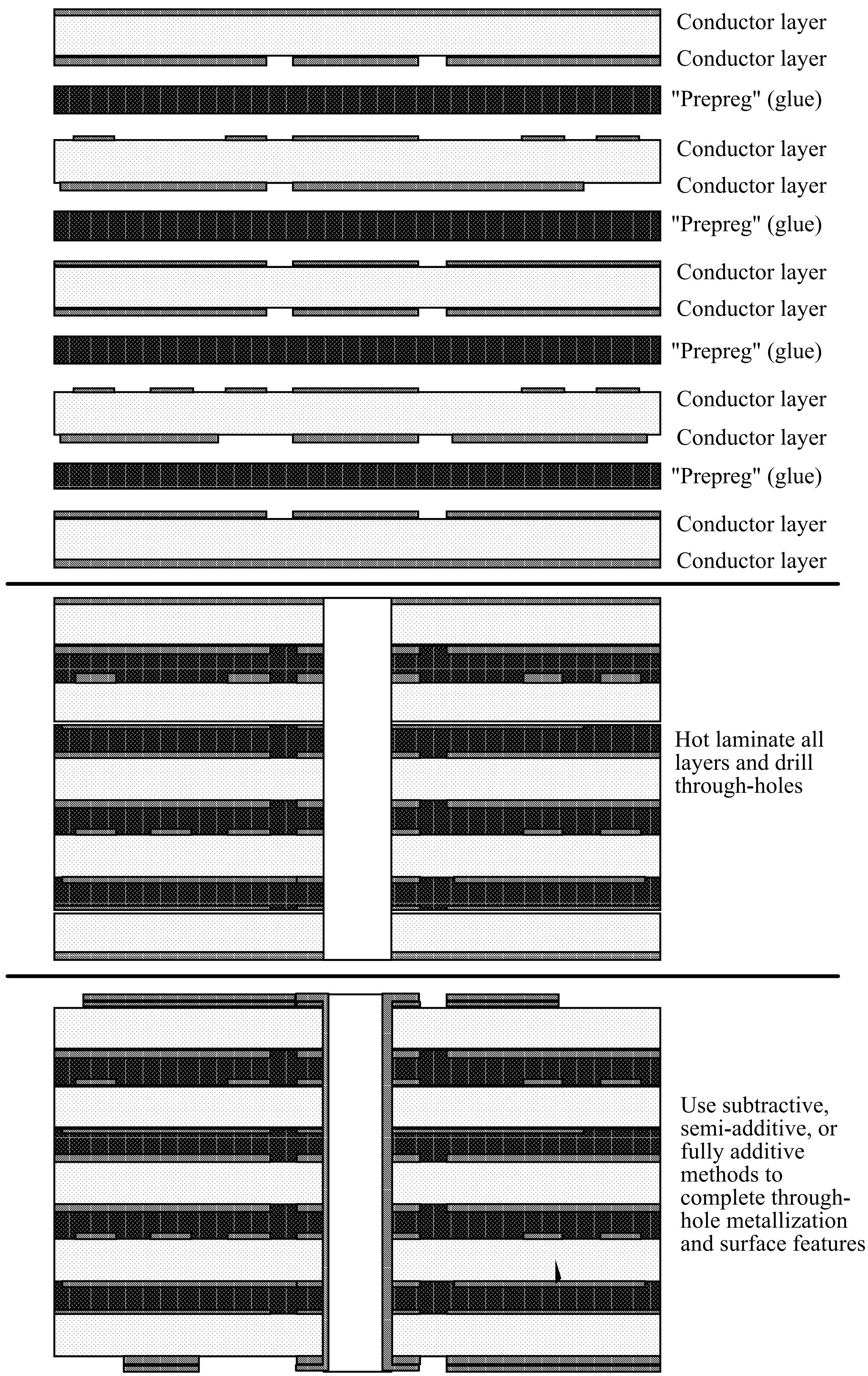

Figure 6-3. Example 10-layer PWB final manufacturing steps. Note that inner-layers could contain blind or buried vias.

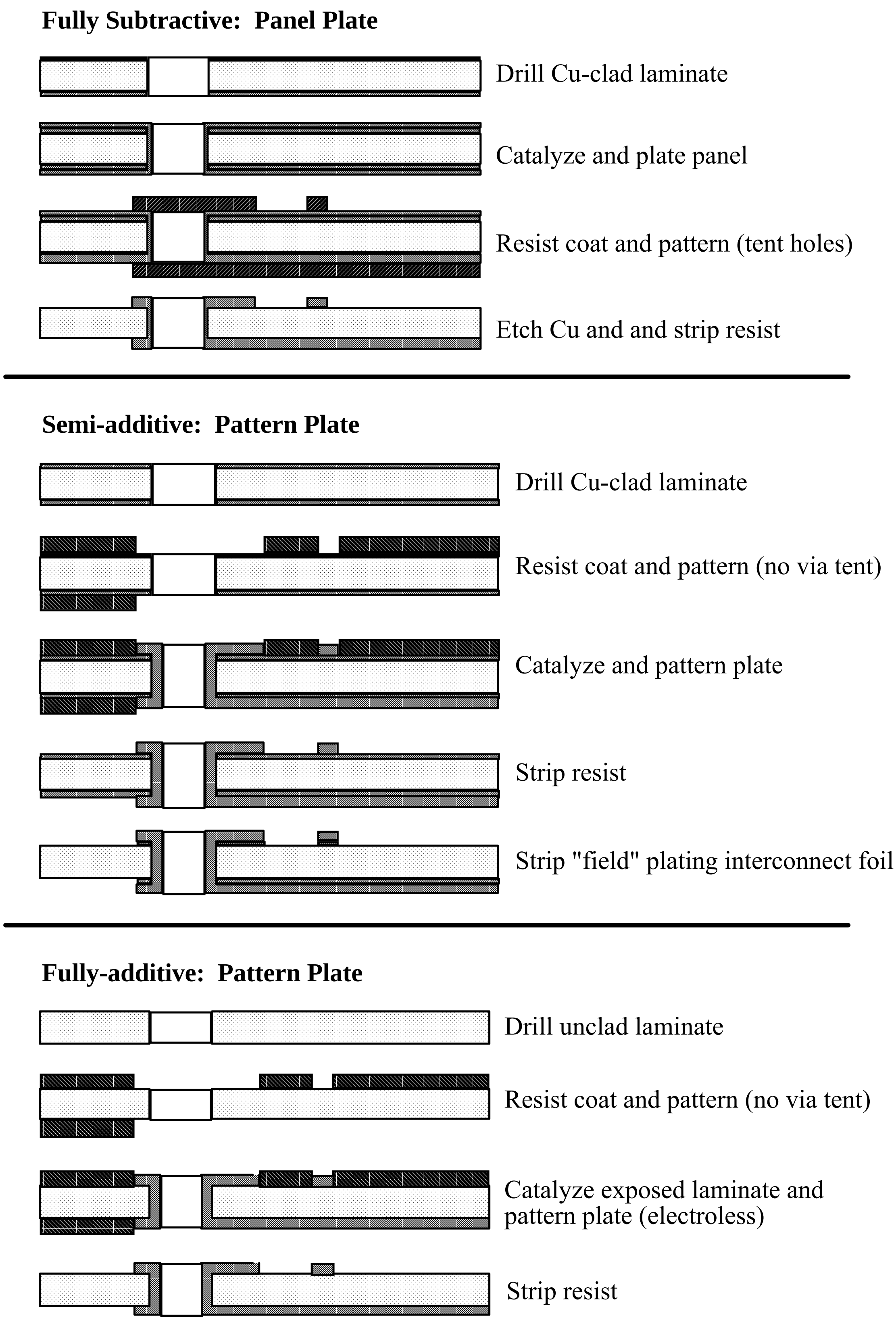

Figure 6-4. Outerlayer manufacturing options (internal layers are optional and not shown).

Multichip Modules: A significant trend affecting advanced electronics, packaging, and the PWB industry is the emergence of a new class of devices known as multichip modules (MCMs). MCMs are basically of three types [35]:

- Ceramic multichip modules (MCM-C), which use ceramic materials as a substrate;
- Deposited dielectric multichip modules (MCM-D), which use deposited organic and inorganic dielectric films and metal conductors, often using processes similar to IC technologies; and
- Laminate multichip modules (MCM-L), which use existing PWB materials, technologies, and facilities. MCM-L assemblies are essentially higher precision PWBs with a high packaging density.

The emergence of multichip modules brings with it environmental issues that are fairly well understood within the context of the emerging processes. For example, MCM-C, like other ceramic processes, introduces issues of high-temperature processing and energy usage. MCM-Ds and MCM-Ls share chemical and material issues with other IC or PWB technology processes.

6.2.4 Attachment

For many years, the attachment of advanced circuits used a through-hole approach in which small wires from the packaged IC were inserted through holes in the PWB and connected to its back side. The predominant attach technology today is surface mount in which devices are directly attached to the surface of the PWB. In this process, principal issues concern the materials used to complete the attachment, with a particular emphasis on the elimination of lead-based solders, and the processes for cleaning the circuit board after attachment to remove waste materials.

Demands for increased density and performance, however, require acceleration of advanced approaches. There is a fundamental transition underway from packaged ICs to unpackaged ICs that are directly attached to boards. It is especially reflected in the emergence of multichip modules of various types, as well as 3-D packages and new PCMCIA technologies. In the short run, these demands will be met by the accelerated adoption of ball grid array packaging approaches. In the longer run, direct chip attach approaches will become far more common and accepted.

NEMI explains that solder-based direct chip attach processes substrates will likely be used for systems requiring high reliability, while adhesive-based direct chip attach processes and thin PWBs or flex circuits will likely be used where cost is a dominant factor in system design [33]. The NEMI roadmap points out that:

> “One key implication is that bare die will begin to dominate over time. This will be driven by the movement to multi-chip modules and chip-on-board for a wide variety of systems.”

Therefore, finding new materials that enable direct chip attach and other advanced methods must be a high priority, since there is a strong consensus that the best environmental practices, as well as regulatory requirements, may demand the elimination of lead-based solders. Anisotropic adhesives and other types of conductive adhesives will be an important technology for achieving the new packaging and assembly processes anticipated in the roadmaps.

Environmental Impacts: Any assembly process will involve materials and chemicals with potential negative environmental impact. While assembly/attachment processes do not pose as large an environmental threat as IC and interconnect production, Table 6-4 illustrates potential impact areas for the major solder-based attachment processes.

Process	Environmental Issues/Impact
Through-hole Assembly	Solder flux vapors, solder dross, energy consumption for solder pool heating
Surface Mount Assembly	Waste solder from solder screening and screen cleaning, solder flux vapors, energy consumption for solder reflow ovens
Cleaning	Solvent/CFC/water waste stream for some solder flux removal processes but being eliminated
General facilities	Energy consumption for lighting, air conditioning, equipment

Table 6-4. Environmental issues associated with predominant electronic assembly technologies.

6.2.5 Displays

An additional set of issues concern displays. Flat panel displays will become increasingly predominant, especially as resolution and performance issues are resolved by new types of displays. However, cathode ray tubes are not likely to be displaced from their market leadership at any time in the near future, and therefore associated environmental issues must be addressed (for example, new yoke materials, new glass formulations, and improved disposition processes).

Key market targets for displays include today's high-volume, high-value market for laptop computers and other portable information devices and the market likely to emerge later this decade for larger TV/HDTV displays. Key areas for expanded research and development include large area photolithography, high-resolution printing techniques, packaging/integration of displays and drive electronics, low-cost drive electronics, inspection and repair techniques, and in-process measurement techniques. Clearly, there are environmental considerations throughout these research priorities.

Just as there is a requirement for increased research and development throughout the various families of displays, there is also a need for attention to environmental characterization. For example, a key issue relates to materials used in liquid crystal displays. A wide variety of different liquids can serve as the liquid crystal materials in flat panel displays—generally speaking, these liquid formulations are treated as highly confidential trade secrets. Therefore, little characterization of the environmental consequences of their use has been undertaken, nor does there appear to be substantial characterizations of much of the other material content in the displays [39]. Similarly, environmental characterization of other display technologies should also be completed in a systematic way. Most of the displays will contain mercury, radioactive isotopes, heavy metals, and a variety of other substances and materials that warrant consideration.

6.3 Key Trends as Reflected in Industry Roadmaps

Perhaps the most valuable source of insight into the direction of technology is provided by the variety of industry roadmaps that have been published in recent years. Appendix A provides a matrixed overview of four of the principal roadmaps guiding the development of electronics technology: the Semiconductor Industry Association (SIA), the National Electronics Manufacturing Initiative (NEMI), the Institute for Packaging and Interconnecting Electronic Circuits (IPC), and the Optoelectronics Industry Development Association (OIDA). The matrix in Appendix A represents an initial effort to conduct a cross-sectional analysis of the major roadmaps, and identify similarities, overlaps, and differences.

An examination of the principal technology roadmaps indicates that fundamental changes in underlying processes and materials in the major component areas are not expected over the next several years. This is to not say there will not be substantial evolution of technology or changing requirements for equipment or processes; but the more "exotic" kinds of materials and components will likely not become significant issues in industrial management until well into the 21st century.

To a large extent, the various roadmaps focus primarily on technological evolution rather than revolution, since evolution can be mapped but revolution can seldom be anticipated. In examining the various technology roadmaps, one overriding conclusion emerges: the evolution of technology will continue unabated, making electronic systems smaller, faster, less expensive, and more powerful.

This common conclusion has implications for business processes, including environmental management. Systems must be in place to comprehend, accommodate, and manage rapid technological evolution and to adapt effectively in those cases when revolution does present itself. This means that environmental consciousness must be a fundamental part of corporate strategy, and that analytic and tactical measures must exist for understanding the environmental impacts of technological development.

The roadmaps also offer insights into priorities for effective environmental management and policy making. Upon examination of the various segment roadmaps, several cross-cutting requirements emerge with significant impacts for environmental management and research:

- Improved Design Tools: All of the roadmaps address a pressing need for improved design tools. In general terms, a continuing concern is raised about the adequacy of current tools to accommodate the rapid advancement of technology, and the fragmented and often disparate nature of tools currently in place. When tools are discussed in the roadmaps, the primary emphasis is on IC or system-level design tools, supported by integrated data management systems and rich modeling and simulation tools.

  To the extent that Design for Environment (DFE) tools are discussed in the roadmaps, they are generally given brief attention. Nevertheless, environmentally-driven decisions have significant implications for cost and performance, and integration of DFE tools into the overall design tool hierarchy is critical. In the process of mounting a concerted, cross-industry effort to improve CAD technology, specific attention to DFE is essential.

Elsewhere in this roadmap is a detailed discussion of DFE tools currently available. In this regard, a structured assessment effort can provide valuable information. Through a collaborative effort, companies using DFE tools could join together to identify, test, and evaluate tools that are currently available or in development. This kind of characterization and evaluation project might also assess the compatibility of the tools with other modules of integrated, hierarchical design tools, and define a common framework, if required. These tools should address a variety of design for environment issues, including chemical and material evaluation, alternative/substitute analysis, waste-stream impact analysis, energy use implications, and design for recyclability. In advanced design for environment tools, automatic processes for minimizing harmful emissions, and incorporation of end-use support systems to optimize environmentally appropriate end use should also be included.

- Integrated Modeling and Simulation: Tools that permit effective modeling and simulation of processes and materials are also vital to the design process. Simulations and supporting data, however, should extend beyond performance data and include environmental characterization. Such simulations could enable informed trade-off analyses when considering material or chemical substitutions or alternative processes. Adoption and development of new or improved analytical tools should be a priority, including mass balance tools to allow for identification of risks and improvements in process, tool, and factory design; cost of ownership models that will drive toward low-cost process, tool, factory, DFE solutions; and risk assessment tools to provide for systematic data-driven ES&H decision-making. The infrastructure must be in place, however, to enable the tool user (e.g., an engineer) to implement changes based on results. The integration of environmental data into the model/ simulation would also facilitate cost, performance, and manufacturability evaluation.

- Information Systems Management and Process Integration: Each roadmap addresses the importance of leveraging information systems for productivity enhancement and effective factory/process integration. Again, the specific concerns relating to incorporation of environmental data in the MIS system are marginally addressed. However, application of information tools, such as network data access or real-time *(in situ)* environmental process monitoring systems, have the potential to decrease costs and increase process efficiency. The use of information networks can also facilitate supply chain management, integrating external suppliers and other organizations with source reduction, design, process management, and factory/process systems.

- Materials and Chemistries: Across the spectrum of electronic components, certain common challenges are faced in the areas of materials and chemicals used as raw materials, in processes, or remaining in end products. Key environmental safety and health issues include improved handling of hazardous materials, alternatives to hazardous materials, waste stream minimization or abatement, selective deposition processes, point-of-use chemical generation, water recycling, process material minimization, and chemical reprocessing.

The IPC roadmap identifies a specific agenda of material and chemical replacement, including brominated materials, solder replacements, ODS and VOC elimination in cleaning, and the development of aqueous solder masks. The IPC roadmap also emphasizes the importance of solvent recovery and closed loop techniques and additive processes and direct plating [36].

The SIA roadmap also calls for hazardous chemical use reductions, reducing use and waste-at-the-point-of-use through process efficiency, reuse, substitution, and additive technologies [31]. This includes total phase-outs of ozone-depleting substances and ethylene glycol ethers. Establishment of specific emission reduction goals is recommended, including efforts to use control technologies for emissions reductions until source reductions take effect. The roadmap also recommends efforts to reduce natural resources required to produce wafers and devices, with specific emphasis on water and energy.

Other challenges also remain, and are reflected in the recommendations of the individual roadmaps. For example:

– Alternatives should be found to lead-based solders, including lead-free solders and conductive adhesives.
– New coatings or chemical formulations, used to improve processes or to enhance performance, are beginning to emerge and require environmental characterization. In IC manufacturing, for example, increased aspect ratios in lithography may require chemically amplified resists to maintain the requirements of process latitude, etch resistance, implant blocking, and mechanical stability [31]. In the fabrication of substrates and displays, diamond coatings have received considerable attention due to the manufacturability and performance benefits they promise. Effective environmental characterization methods must be applied early in the development process in order to avoid problems in later stages of production.
– Emission abatement, processing optimization, and replacement chemicals for atmospherically long-lived process gases, such as perfluoro compounds.
– Alternative chemicals and safer delivery methods for silane, dopants, and hazardous solvents and degreasers.
– Evaluation of OEM/government specifications to ensure support for reduction or elimination of targeted chemicals.
– Recycling or end-of-life management for cupric chloride and ammoniacal etchants, the largest single waste stream for most PWB manufacturers [36].

- <u>Processes:</u> The SIA roadmap notes that "There will not be radical changes in the process technology used to manufacture semiconductors throughout this decade. Rather, there will be expansion and refinement of current processes." [31].

  Adapting to the rapid evolution of technology will require its own set of technology advancements to ensure that processes and materials are suited to the technologies that they must address. NEMI succinctly states the goal: "Cost-effectiveness implies high levels of automation (in an effort to reduce variation, not necessarily increase throughput) and processes that are environmentally friendly. These processes would use materials that do not impact the environment with zero discharge process characteristics as a goal." [33].

A variety of process improvements have been identified as part of a comprehensive industry agenda for improving manufacturing processes, materials, and integration of new technologies. The various roadmaps see as priorities several major process improvement opportunities, each having environmental implications:

– Need for advanced manufacturing and process equipment to keep up with rapid evolution of technology (infrastructure) is a continuing theme in the roadmaps, and new technologies, such as 300-mm wafers, flex laminates, and chip-in-glass, will drive the requirement for new equipment. The new equipment must incorporate much higher levels of precision and intelligence, and provide industry an excellent opportunity to "design-in" key features.
– Closed loop recapture and recycling of hazardous/valuable substances (point-of-use abatement and recycling) is one example of a process that should evolve to become a standard part of production processes.
– Increased use of *in situ* sensors and automation tools to control processes and collect process data is a universal recommendation. The obvious benefit to the environment is less product scrap and more efficient use of chemicals and materials. Generally, the roadmaps address this in terms of productivity improvements or process integrity, but improved process and sensors/monitors will yield valuable data for improving environmental management as well.
– Improvements are also recommended at the fabrication level including lower temperature curing materials or materials with shorter cure cycles to minimize energy consumption (among other recommendations aimed at improvement in energy consumption per square millimeter of silicon wafer processed), the elimination of oxide treatments in adhesion promotion; reclamation of etchants; and permanent inner layer etch resists in inner layer print. A variety of waste minimization recommendations are also made including alternatives to drilling, alternatives to tin lead etch resists, and the use of aqueous solder masks.

Other major recommendations include:

– Increasing role for lasers in curing, reflow management, direct write (eliminating masks) and via formation may decrease the need for certain chemical processes or more effectively manage waste through greater precision.
– Point-of-use generation in which chemical formulations are created in real time during the production process, is recommended in several places in the roadmaps in order to minimize storage of potentially hazardous substances.
– Continued improvement in on-site regeneration systems for plating baths, etchants, and other process chemistries.
– Reduction of cleaning and rinsing steps and eliminating parts handling.
– Additive plating, no smear laminates or drilling systems, and alternatives to electroless plating for PWBs.
– Improved use and recycling of water in processes.
– Water-based or solvent-free systems for PWB laminate production.

– Alternatives to solder plating as an etch-resist for PWB fabrication.
– Alternatives to solvent-based cleans and the use of concentrated acid/alkalis to minimize particles, corrosion and contact resistance.

• Standards: Standards are a fundamental priority in each of the industry roadmaps. The SIA roadmap notes "…the role of standards has changed from being simply a mechanism of the industrial revolution that allowed factories to achieve economies of scale through reduced customization. Far from simply restricting product choices in the name of economy, standards now often pave the way for technological advancement. In the last two decades this change has magnified the importance of standardization as a critical element in industrial economic and technological strategy…" [31]. Reflecting this broad importance of standards, each of the roadmaps emphasize the importance of standards in a variety of areas:
– Factory automation and integration: Standards are required to facilitate the automation and integration of factory processes, emphasizing flexibility and capability to rapidly reconfigure process lines and interoperability among the multiple control systems that govern operations, and modularity.
– Standards for effective information interchange, especially those that support true global interoperability of information networks.
– Standard test methods, standard reference materials, standard statistical methods, and standard data management systems for real-time monitoring and closed loop feedback control.
– Standard frameworks within which multiple design tools can operate efficiently as an integrated design system, including design for environment tools.
– Standard methodologies for risk assessment and benchmarking.

The pervasive importance of standards justifies a focused industry effort to specify an integrated agenda for standard's development and formal initiatives to accelerate the development, testing, dissemination, and adoption of each of the necessary standards area.

The term standards, however, is used somewhat loosely throughout the roadmap documents—sometimes referring to formal standards (those adopted by recognized standard-setting organizations) and sometimes referring to "standard practices" (processes or approaches that are so widely used they become *de facto* standards). For the purposes of the integrated agenda, both types of standards should be delineated, but it should be clearly noted where official action (i.e., voting by an official standards body) is required for the standard to have effect or impact. This differentiation will have significant implications for the process by which the standard is "marketed" and deployed.

• Benchmarking: The importance of a focused program of benchmarking is also indicated throughout the roadmaps. Benchmarking is a fundamental tenet of total quality management programs, and many individual companies have established benchmarking activities for certain processes. However, a coordinated industry-wide benchmarking program that looks at best practices in electronics manufacturing, including benchmarking environmental issues such as materials volumes consumed, waste production, emissions management, and other topics, could provide useful data that would establish industry expectation of best practices.

The IPC roadmap devotes a specific section to benchmarking, noting that "…association-led efforts to develop benchmarking programs for the industry is needed…" [36]. The IPC report specifically focuses on financial, employee management, product, and quality benchmarks. Again, environmental benchmarks would be an important addition to the list.

- Workforce Training and Education: Education and training is recognized as a pervasive requirement throughout the various roadmaps. IPC notes the importance of training in CAD/CAM and design for manufacturing—a list to which design for environment could easily be added. The importance of teaching factory-integration principles, education and specification and standards, training in new information technology tools (such as the Internet) and a focused effort to understand the impact of manufacturing design on environmental safety and health are also cited by the IPC [36].

  While the SIA roadmap does not address education and training in as much detail, several places throughout the roadmap note the importance of improved training, particularly the factory integration discussion [31].

  The NEMI roadmap addresses the issue most directly, including it as one of the key infrastructure policy issues. There, the Roadmap notes the importance of electronic technology training throughout the educational system including specialized grant programs and special partnerships. NEMI also notes the importance of manufacturing training at post-secondary education and IPC recognizes the importance of enhanced efforts to raise attendance in trade and engineering schools [33, 36].

  It is vital that a well-integrated element of the engineering curriculum be a consideration of the environmental implications of engineering design, product development, and manufacturing processes. Approaches for waste minimization and pollution prevention, recycling and recapture, and a variety of other design for environment and environmental management issues are critical to future educational programs.

6.4 Grand Challenges for Environmental Excellence

The system improvements described above will contribute significantly to improved environmental management in the electronics industry. However, certain challenges are ambitious enough that they should be established as "Grand Challenges" for collaborative industry research and development—a set of enduring issues that can provide a fertile base for focused research and development. By doing so, evolution can be accelerated and revolution can be facilitated.

The Electronics Manufacturing Technology Roadmaps published by NEMI call for the establishment of a clean electronics initiative, similar to the clean car initiative established to deal with emissions issues in the automobile industry. Such an action could make a significantly positive contribution by establishing a national focus on environmental processes in electronics manufacturing for government, industry, and academia. Once established, such an initiative should take ownership of the "Grand Challenges," mobilizing resources for a concerted public/private partnership. This chapter proposes seven such Grand Challenges:

6.4.1 "Dry" Wafers

The predominance of wet processing in wafer fabrication was referred to earlier in this chapter. Various industry efforts at SEMATECH, the Semiconductor Research Corporation, and elsewhere have started to address the substitution of dry processes in wafer fabrication.

For example, the use of laser direct-write as a patterning technology to replace masks holds a great deal of promise for the elimination of a substantial quantity of hazardous substances. Laser-direct write, however, will require a great deal of additional research and development before it reaches a point of acceptance in the industry. The dry wafer challenge could also address alternative technologies for contamination prevention and cleaning.

6.4.2 The Packageless Chip

Emerging packaging and interconnect technology is increasingly moving to the use of bare die and direct-chip attach, in which unpackaged chips are attached to substrates via advanced interconnect technologies such as array bonding and flip chip. Further improvements in chip performance have the potential of creating a "printed wiring board on a chip," in which case the highly integrated microprocessor may be directly attached onto a functioning physical component of a system, such as the glass for a display. The possibility for increased miniaturization by, essentially, making the display the mother board presents an intriguing possibility for future products.

In these cases, the materials used for bonding, materials used for underfill, and the processes used for minimizing (or eliminating) and removing excess materials will require great focus in research and development. A primary issue, from an environmental standpoint, will be the nature of the materials used—lead-free solders, anisotropic adhesives, and other of material combinations yet to be finalized. For example, a variety of lead-free solder alloys are currently being examined in laboratories, generally focusing on component materials such as indium, zinc, and tin. A collaborative effort at development and characterization of these materials and their application in environmentally conscious processes, could substantially benefit an industry seeking acceptable alternatives for increased system performance.

6.4.3 Zero Emissions Processes

Beginning with the development and implementation of robust mass balance tools, a focused effort to design, prototype, and implement closed loop processes in electronics manufacturing could yield significant benefits. Closed loop processes are already in use in some Japanese industry fabs, and more advanced U.S. fabs are beginning to experiment with closed loop modules within the manufacturing environment. These closed loops processes would depend heavily on improved *in situ* monitoring and feedback systems, providing reliable data on the application of materials, chemicals, and gases throughout the production process. Furthermore, a true zero emissions environment would incorporate effective recapture/recycling components in order to minimize, and eventually eliminate, emissions or additions to the waste stream.

6.4.4 Fully Additive Substrates for PWBs

One of the most important environmental accomplishment in PWB development would be the establishment of a fully additive printed wiring board process. The traditional PWB process has relied mainly on a subtractive print and etch process for forming copper conductors. Full build additive approaches for double- and single-sided boards have been in use for over twenty years. Processes that use full build to make multi-layer boards have more recently been developed. Since, in the additive process, most, or all, of the etching steps are eliminated, the use of additive processes would contribute significantly to reducing the waste stream.

6.4.5 Point-of-Use Generation

An important issue in any manufacturing environment where hazardous materials must be stored and maintained is the safety and stability of the storage environment. In situations where otherwise benign materials are combined through chemical or material formulations to become a hazardous material, point-of-use generation systems would only create the required materials or chemicals, at such time, and at the precise point, that they are to be applied in the production process. These point-of-use generation systems would, therefore, eliminate the storage of otherwise hazardous substances, and by doing so eliminate a significant concern in the fab environment.

6.4.6 Integrated Design for Environment

At the heart of electronics processing are well-integrated and well-established tools and technologies for design. In the course of new technology computer-aided design systems currently being developed, it is essential that any clean electronics initiative would promote, support, and facilitate the development of effective, robust, and easily-integrated design tools. Through the establishment of a collaborative industry assessment program, in which DFE requirements and tools could be identified and evaluated, subsequent activities could focus on the establishment of frameworks for tool integration and linkages with other elements of the design system. DFE is discussed in detail in Chapter 4 of this *Roadmap*.

6.4.7 Computer System End-Of-Life Management

A comprehensive "grand challenge" program would be the establishment of processes and technologies to support improved end-of-life management. This would include design issues relating to remanufacturing and recycling at end-of-life, materials identification technologies to support automated sorting upon disassembly, dematable connectors and other approaches to improve the ease of disassembly, and intelligent support systems to facilitate product tracking throughout multiple life cycles. Effectively implemented, these kinds of approaches could greatly increase the feasibility of successful end-of-life management/disposition systems and decrease potentially valuable product being sent to the waste stream. Disposition is discussed in Chapter 5 of this report.

6.5 Conclusion

The rapid advancement of electronics enables remarkable new capabilities in products and systems. Conversely, those new capabilities can be applied to improve the process by which electronic components are manufactured and produced. Particular emphasis should be placed on the elimination of widely used and hazardous materials development, adoption of environmentally benign processes, and aggressive support for innovation and dissemination of new technologies. Participation by companies across the full life cycle of electronic product production will make a significant contribution to improving the environmental performance throughout the industry. Table 6-5 lists the needs for emerging technologies identified during this roadmapping exercise.

Priority Need	Task
1. Clean manufacturing processes for electronic products	1.a. Establish a clean-electronic products manufacturing initiative similar to the clean-car initiative for emissions, e.g., zero emission processes and chemical point of use generation 1.b. As part of the initiative, develop a consensus work plan addressing materials, chemicals, processes and design/modeling/simulation tools 1.c. Develop mass balance tools that will focus design and prototype efforts on closed-loop manufacturing processes 1.d. Launch a collaborative effort to benchmark environmental technologies and practices 1.e. Develop an integrated curriculum addressing environmental management in electronics production
2. Accelerate research, development, and implementation of environmental implications in emerging technology trends	2.a. Advance technological applications for lead-free solders and anisotropic adhesives and other possible materials associated with packageless chip technology 2.b. Characterize and evaluate environmental implications of various display technologies 2.c. Evaluate implications of increasing wafer size and other key emerging trends
3. Additive processes for manufacturing printed wiring boards	3.a. More fully characterize commercially available laminate and prepreg materials 3.b. Generate data and documentation supporting feasibility and efficacy of additive processes

Table 6-5. Priority needs matrix for emerging technologies.

Appendix A. Other Industry Roadmaps

The following matrix is intended to represent major portions of the content of key industry roadmaps and provide a means for comparing issues across roadmaps. It is not intended to comprehensively present all aspects of the roadmap contents. Readers seeking further information about findings, conclusions, or context should consult the specific industry roadmaps.

Key Concept	
SIA/SEMATECH	• Identifies 0.35 µm and 0.25 µm line width as new generations for which the technical requirements are well understood, 0.18 µm and 0.13 µm as generations for which additional assessment and evaluation are needed, 0.10 µm and 0.07 µm as future generations for which significant technical obstacles still exist. • Objective is to provide a quality database and a framework for the industry to systematically assess research and development requirements
NEMI	• The challenges of lowering costs and improving interconnect density while becoming more environmentally benign are best solved through the development of new materials and improved manufacturing processes. A method must be found to restore significant research and development capability to the industry. • Emphasis on the supply chain and inter-relationship of components. • One U.S. substrate manufacturer reported that in 1991, 30% of its product costs was in waste disposal. • Cost-effectiveness implies high levels of automation (in an effort to reduce variation, not necessarily increase throughput) and processes that are environmentally friendly. These processes would use materials that do not impact the environment with zero discharge process characteristics as a goal.
IPC	<u>Revenue Center-of-Gravity</u> Those products within a particular market from which the company derives most of its income and profit. Revenue center of gravity should be in orbit with the industry capability identified as conventional technology. <u>OEM-driven Requirements</u> The telecommunications and computer industries are identified as leading edge markets; automotive and military products have the most severe environments which constitutes their primary needs; business/retail, industrial, and instrumentation are followers, taking those technologies that have become conventional and using them in the design of products they produced. Consumer is a leader in the cost-driven products.

OIDA	• Optoelectronics may be the most significant set of new technologies since semiconductors. It is the new frontier of the information age, making possible enormous advances in the collection, movement, and display of information. • Optoelectronics is the enabling technology for equipment with markets that will reach into the hundreds of billions of dollars in the next decade and for industries that will employ over a million people.

Overriding Issue	
SIA/SEMATECH	• Productivity Improvement • Complexity Management • Advanced Technology Development • Funding of research and development
NEMI	• Securing a sustainable world-class advantage for the U.S. electronics manufacturing industry motivates the national electronics manufacturing initiative. • The coordinated approach containing technology, policy and infrastructure options make NEMI an unusually comprehensive approach to complex problems. NEMI's goal is to promote collaborative development by industry, government, and academia of the underlying technology and infrastructure required to facilitate manufacture of new high-technology electronics products in the U.S.
IPC	• Electronic Interconnection is about to change due to: - Stiff and growing competition - Shift in responsibility for R&D from large OEMs to smaller printed board manufacturers and electronic assemblers - Exponential growth in demand for electronic product performance - Reduced design cycle window and life cycle environment.
OIDA	
Cross Cutting Technologies	
SIA/SEMATECH	• Contamination Free Manufacturing • Materials • Metrology • Modeling • Standards • Quality and Reliability
NEMI	• Manufacturing Information and Management Systems • Integrated Modeling and Simulation capabilities • Advanced electronics and manufacturing materials • Environmentally conscious manufacturing • Improved government business and regulatory procedures • Intellectual property rights • Workforce training and education • Cost and availability of capital

IPC	• Manufacturing Environment • Modeling and Simulation • Metrology • Test and Inspection • Exchange and Partnerships • Education and Training
OIDA	

Integrated Circuit Fabrication	
SIA/SEMATECH	• IC capability will grow rapidly over the next several decades, from today's 64M DRAMS to 64G DRAMS by 2010. • The number of transistors per chip for microprocessors will likely increase from today's 4M to as much as 90M by 2010. For ASIC, the number of transistors will increase from 2M to 40M • Processing speeds will likely increase from 150 MHz today to over 600 MHz by 2010 • Moore's law will likely hold true through 2010; • IC manufacturing costs will continue to increase • CMOS technology will continue to be the dominant high-volume high performance technology throughout the foreseeable future. • Chip size will continue to increase, as will the number of wiring levels. • Mask count will grow from 18 today to 24 in 2010 • Substrate diameter will grow from 200mm today to 400mm by 2010 • With each generation of logic products and microprocessors, the capability to fabricate more devices in silicon exceeds the ability to wire them. This results in a dramatic increase in the number of metal levels.
NEMI	• Even though IC feature sizes will continue to shrink, the demands for increased functionality will cause overall chip size to increase.
IPC	
OIDA	
Packaging	

SIA/SEMATECH	• The increasing aspect ratios of contacted, vias, and metal spaces necessitate conformal-coating solutions (e.g., CVD or chemical vapor deposition for barrier, adhesion, and plug formation. • Gap fill technology for metal spaces is required • Higher conductivity wiring (e.g., copper) and lower dielectric constant insulators will help reduce RC delays • In each process/tool, designed-in features should include minimized harmful emissions, particle avoidance, sensors, GEM communications, and control systems to meet the cost of ownership requirements • Look for alternatives to fluorine and halocarbons: used to dry etch multi-layer Al-based interconnects • Need techniques to remove oxides and metals from dilute waste streams. • New organic ILDs should be screened to see if these materials are EPA approved for sale in semiconductor operations • *Revolutionary breakthroughs might be superconductivity materials, optical interconnections, or use of biological materials (but not likely before the 2010 window.* (continued)
NEMI	• One key implication of current trends is that bare die will begin to dominate over time. This will be driven by the movement to multichip modules and chip-on-board for a wide variety of systems as movement to unpackaged devices will continue to the point that direct chip attach will be the dominant device-level packaging technology used. Solder-based direct-chip attach processes and multi-layered printed wiring boards and ceramic or silicon substrates will likely be used for systems requiring high reliability, while adhesive-based direct-chip attach processes and thin printed wiring boards or flex circuits will likely be used where cost is the dominant factor in system design. • Required core technology competencies in packaging include: integrated modeling and simulation; advanced manufacturing equipment; advanced materials; thermal management technologies; high-density, low-noise substrates; cost-effective high quality environmentally benign manufacturing technologies; and environmental protection technology. • Anticipation in packaging is 300 to 400 mm diameter wafer by 2001, approximately 0.2 μm thick. • Key technology options include direct-chip-attach, multi-chip modules and known good-dye, PCMCIA cards and ball grid array packaging. • The roadmap anticipates lead-use legislation, and recommends the establishment of a focused environmentally conscious manufacturing program.

IPC	
OIDA	
Interconnect and Assembly	
SIA/SEMATECH	
NEMI	• Solder-based direct chip attach processes and multi-layer PWBs and ceramic or silicon substrates will likely be used for systems requiring high reliability, while adhesive-based direct chip attach processes and thin PWBs or flex circuits will likely be used where cost is the dominant factor in system design. • A requirement will be new materials for low cost wafer bumping. • Lead-free solder systems will be implemented in the near term but will be replaced over time as Z-axis adhesive technology is developed • Plastic, “hermetic-like” packaging, will become increasingly important • Ceramic substrate, C4 processes for direct chip attach need to give way to organic substrates such as BT and others formulated with high temperature epoxy resins. Further, the cost and complexity of C4 requires alternative solder-based and adhesive-based processes. Technology requirements are driven mainly by end use. • High thermal conductivity, inorganic materials increasingly used. • Trend to less exotic materials, fewer layers, smaller substrates, less costly materials. • Attachment structure (solder bumps, conductive adhesives, palladium-coated lands) already on substrate. (continued)
NEMI	• Big requirement: DFM, DFE, DFA. • In a typical “best-in-class” high volume electronics assembly plant, board assembly processes will account more than 50% of the manufacturing and capital equipment, more than 65% of the defect opportunities, and more than 50% of all the parts in the product, and more than 50% of all the direct material in the product. • In the near term, most important is the transition from packaged ICs to package-less direct-chip attach and the associated assembly process. • Most important for low cost is to encourage a much higher level of technology and information sharing for board assembly processes. Other key priorities include the creation of a SEMATECH-like organization, centers of excellence, increased government sponsorship of programs, support for PCMCIA research, cooperative development of key technologies such as stereo-lithographic fabrication of plastic parts to reduce cycle time, DCA, CIM and BGAs.

IPC	<u>Conventional Interconnect Structures</u> • Conventional and threshold printed boards include all one-sided, two-sided, and multi-layer boards that are manufactured using FR-4, polyimide, cyanate ester, or other epoxy-based resins. • Needs in this area generally involve improvement of photo tools used to produce printed circuit boards, processes for fabricating finer and finer conductors on inner layers, processes enabling finer conductor widths (etch), improved mechanical hole-drilling as well as alternative hole formation techniques such as laser ablation, photo image and plasma techniques, (imaging outer layer?), improved copper plating processes, improvements in solder mask, more stringent final fabrication requirements, improved electrical evaluation and testing. • Highest priority in the short is smaller, less expensive holes. Subsequent priorities focus on electrical test capability, better laminate, recycling, waste reduction, and direct imaging. Evolution of equipment capabilities is also important. <u>Emerging Interconnect Structures</u> • Pressures toward miniaturization, portability, and, in general, the size and weight reduction of electronic products requires smaller assemblies and are driving toward increased use of direct placements of uncased, bare chips on the interconnecting structures. Such assembly technology is called direct chip-attach. • This approach is generally incorporated in multi-chip modules, of the type MCM-L, MCM-C, and MCM-D, or variations of these three types, as well as rigid-flex, memory modules (2D and 3D), single in-line memory modules and PCMCIA types. (continued)

IPC	• Substrate thickness in emerging modules will drop below 125 µm and approach 25 µm. New equipment will have to be developed to deal with these very thin materials. The cost of creating smaller vias and conductors will also have to be addressed. Methods of inexpensively creating large volumes of small vias such as plasma, laser ablation, chemical etching, or gang punching, will have to be developed. Imaging technology will need to address laser patterning and direct imaging systems to increase resist resolution. Also, additive technology with higher precision and consistency will be required. • Also, additive metal deposition technology, which requires higher precision, consistency and resolution will have to be used for manufacture of fine conductors and miniaturized vias. • The substrate dielectric materials for the modules, will have to include laser ablatable or photoimagible unsupported homogenous films, materials with lower dielectric constant, higher T_g, lower moisture absorption, and better dimensional stability. • Materials trends: review page B-31 and B-32 of the IPC map. <u>Conventional Assembly</u> • Surface mount continues at the expense of through hole with surface mount reaching 70-80%, 20-25% through-hole with <5% advanced assemble attachments including direct chip attach • The use of non-tin-lead coatings will increase. Coatings such as gold/nickel/copper, palladium copper, and metallic and/or organic preservatives will be adopted. • As the pitch of the peripheral package decreases, manufacturability decreases. • Change in chemistry requirements toward no-clean fluxes and paste and inert atmospheric soldering • As the process window narrows, process controls become more stringent • Assemblies are becoming harder to inspect and rework • PWBs will decrease in size and thickness, and increase in layer count and density • Environmental pressures on the assembly processes will continue to increase, impacting the use of lead-containing materials • Process control is becoming embedded in assembly process equipment • New technologies require new and tighter tolerances. • Possible solutions focus on solderability testing, alternatives to lead, development of fluxless systems, implementation of no-clean processes, improved solder joint reliability, improved mounting structures, assembly process optimization, fine pitch part placement, improved rework and repair, better process characterization

OIDA	

Precision Electromechanical Assembly	
SIA/SEMATECH	
NEMI	• The bottom line is straightforward: for a combination of reasons, U.S. companies have lost the know-how to apply precision electromechanical assembly in high volume electronics production environments. *Key elements:* • Focus on assembly application and system integration technologies, including end-effectors and data-driven software for various processes • Standards for interfacing diverse equipment modules, including mechanical, electrical, and communications standards. • Integration of 3-D simulation technology with real-time equipment control • Development of design rules and process modeling in 3-D simulation • Funding for advanced pilot assembly lines in test factories to demonstrate new concepts, and • Funding for training and technology deployment to disseminate and transfer results.
IPC	
OIDA	
Process and Factory Integration	

SIA/SEMATECH	• In selecting a new architecture, process designers should worry as much about the reproducibility of each manufacturing step as about devices and structures. This issue is addressed through suitable qualification procedures of the equipment. • The roadmap notes the importance of technology computer-aided-design (technology modeling) and states that CAD tools therefore need timely deployment on a hierarchical basis for optimum integrated technology design, including high speed and low power issues. • Predictive modeling and simulation of materials, processes and devices are critical to timely and economic technology development. • To design a high reliability process, better DFM and CAD techniques are needed. Wafer (device) level electrical tests, chip sort, KGD, and class yield analysis methods must be improved to meet feedback control standards for final product quality in the factory. Other challenges relate to the high integration density that creates power dissipation limitations and the interconnect bottlenecks on chips and at the I/O interface. • Roadmap notes that key requirements for improved process integration, device and structure design are improvements in on-chip and off-chip frequency, power density, and V_{dd} reduction. In the area of tools for design, the roadmap notes that tools for simulating performance and reliability require improvement, short-flow methodology should be developed, improved tools for KGD and BIST are needed, and improved strategies for yield analysis and defect allocation. (continued)

SIA/SEMATECH	• As CMOS technology is scaled to the 0.10 μm size/1.0 V supply regime, the trade-offs among performance, leakage, and reliability become increasingly constrictive. Two routes are suggested: evolutionary devices fabricated using a silicon technology or revolutionary devices, possibly using alternative devices and materials. • Traditional device and structure design procedures are incorporated in CAD. The full activity of process design includes design for manufacturability, reliability, performance (DFM, DFR, DFP, etc.). CAD is a means of linking data from various sources to enable the design of an optimum integrated process and device design." • With high performance 2.5-V devices, on-chip clock speeds of 300 MHz or higher should be feasible • Increasing the productivity of factories requires new factory designs for specific applications plus high adaptability to change as the pace of technology change accelerates. This results in the need to integrate disciplines that, to date, have been largely practiced in isolation. [NOTE: Illustration indicates that ES&H is one of these disciplines] • There is a need to integrate the fabrication facility and its associated suppliers throughout all steps of semiconductor device manufacturing from product development through product shipment. • Six areas covered in this Roadmap section are: Facilities infrastructure, Modeling and Simulation, Product and Material Handling, Manufacturing Information and Control Systems; Process and Equipment Control, and Human Resources (skills development) • Modularization and standardization of the equipment, building systems, and other factory components are vital to improve flexibility and reduce transition costs and time from generation to generation. • Key considerations in facilities' infrastructure: specialty gas systems, fluid delivery systems, factory environment, building systems, correlation (between direct process materials and process results), metrology. • Of paramount importance is developing a fundamental understanding of the relationships between the contaminants in chemicals, gases, and water and the surface concentrations of these contaminants on the wafer as a result of the process. Unless progress is made on modeling the transfer function for in situ contaminants to surface contaminants on silicon, factories will incur cost penalty for using ultrapure materials. • In the next 15 years, key changes in the semiconductor wafer factor architecture will include additional environmental emission controls at both the factory level and the local tool level.

NEMI	• Integrate the enterprise from design to delivery. • Improve software research for industry. • Improve computer-assisted decision support. • Development of intelligence sensors and actuators - in many cases it is impossible to capture, transmit, and act on needed information because the sensor-actuated technology does not exist or is not affordable. (continued)
NEMI	• Develop a MIMS capability that supports the use of so-called business rules that allows the user to tune the factory's behavior in response to current conditions with little or no reprogramming. • The roadmap also calls for centers of modeling excellence, development of appropriate standards to support MIMS technology, leveraging the factory integration roadmap, and building on national information infrastructure, and education and training for factory management • Three-dimensional imaging will become a critical technology to electronics assembly as current trends in miniaturization continue. Examples where 3-D imaging is currently being attempted include scanning solder-paced profiles for correct volume distribution and determining the coplanarity of surface mount device leads. • Thermal imaging offers opportunities in electronic process control. An example is control into solder reflow process. Thermal imaging would allow automatic sensing of thermal distributions and finer control of heating elements. • Among other options, the roadmap notes that environmental restoration and waste management activities within DoD and DoE have developed significant technical programs focused on sensors required to complete activities. ER and WM detectors/monitors use a chemically sensitive transduction mechanism that enables the sensor to select the chemical/gases of interest.

IPC	• "The coordination of all resources involved in operating a manufacturing business with the objective of insuring the most efficient use of, and maximum effectiveness of, all inputs to, from, and between the manufacturing processes." • Total quality management is a critical aspect of effective factory integration. • The roadmap stresses the importance of self-directed work teams, training and education. • Another critical element of factory integration is systematic benchmarking process. However, the roadmap notes the electronic interconnection industry does very little comprehensive benchmarking. • Another key element of factory integration is a strategic process for cycle time reduction (CTR). • Information systems (CIM/MIS) are also fundamental. • Costing systems which are used to estimate the real costs of a manufactured part could be better integrated with the manufacturing control systems that manage the series of processing steps that add value to a part. • EDI Systems which can provide enhanced communication with business partners by replacing traditional paper order processing are not commonly used in the interconnect industry. • Also stressed are manufacturing control systems, tooling systems, modeling and simulation systems, and process control systems. (continued)
IPC	• Improved factory automation is also essential to factory integration. • Automated material handling systems eliminate the need for manual intervention for the conveyance of product through the manufacturing process. Automated process control and monitoring systems utilize electronic sensors that monitor process variables and convert the level of measured variable into a proportional electrical output. Integration of the process control system with the manufacturing control/information system allows the automatic storage and retrieval of processed data and part-specific information. • The roadmap stresses the need for improved leadership/management, strategic planning, and better finance/accounting procedures, including activity-based costing.
OIDA	
Product and Material Handling	

SIA/SEMATECH	• The effects of specific molecular contaminants on semiconductor manufacturing processes are not well understood and the capability to measure and control molecular contamination is not well developed. • Improvements are required in the level of standardization and tool interfaces, wafer carrier orientation, ergonomic compliance, wafer-to-cassette precision, and high precision mechanical couplings between wafer carriers and process tools. • Priorities include developing accurate contamination measuring and modeling techniques, standardizing carriers and carrier interfaces, defining cost effective, contamination-free material movement mechanization approaches, and modularizing contamination control and material movement systems.
NEMI	
IPC	
OIDA	
Displays	
SIA/SEMATECH	
NEMI	
IPC	
OIDA	• Key market targets for displays include today's high volume, high value market for flat panel displays for laptop computers and other portable information devices and the market likely to emerge later this decade for larger TV/HDTV displays. Key areas for expanded R&D include large area photolithography, high resolution printing techniques, packaging/integration of displays and drive electronics, low cost drive electronics, inspection and repair techniques, and in-process measurement techniques. (continued)

OIDA	Specific technical priorities by display type: • CRT: multi-beam electron guns for higher resolution; alternative color selection technologies; higher efficiency phosphors, better deflection yokes, including new yoke materials and lightweight glass. • PMLCDs: lower viscosity liquid crystals; thinner cells; plastic substrates for lower cost and larger sizes; lower cost polarizers and color filters; and improved retardation films. • AMLCDs: low temperature polysilicon process for thin film transistors; simplified amorphous silicon TFT process with fewer mask steps; and scale-up of the manufacturing process to larger substrate sizes. • Electroluminescence: development of a blue phosphor with high luminous efficiency that does not require high temperature deposition and thus does not require expensive high temperature substrates; reduced IC costs; and higher density interconnect technology. • Plasma: new materials for barriers and phosphors that would provide an increase in the luminous efficiency by a factor of ten and would have longer lives; low cost IC drivers; longer-lived secondary electron emitters. • FEDs: cathode plates, either microtip or structureless thin film; efficient low voltage phosphors; spacers; vacuum assembly techniques. • Light emitting diodes: high efficiency blue and green emitters; development of alternatives to SiC blue such as ZnSe and GaN. • Holographic: high resolution, high speed liquid crystal light valves; high brightness, electroluminescent arrays; precision electronically steerable light sources, spatial light modulators based on LCDs; solid state red, green, and blue lasers. • Projection: high liquid crystal light valves; efficient solid state red, green, and blue lasers, high density, low cost integrated drivers.
Optical Technologies, Photonics, RF	
SIA/SEMATECH	

NEMI	• To reduce costs, power, and size, and to improve performance, it is necessary to realize higher levels of integration. This progression will require improved semiconductor processes as well as design techniques. • Global standards are needed to make the global wireless information highway available and connectable by all servers and users. • The advantage of open standards with universal adherents is worth the time and effort required to achieve them. • Materials used in RF communications electronics include silicon, silicon-germanium, and gallium arsenide. Much higher yield processes in these advanced materials is essential to achieving goals of low-cost manufacturing. • A key core competency needed is high frequency design tools. • Other issues include RF surface-mount printed circuit assembly and test technology, wireless interference community, and intelligent manufacturing systems. (continued)

NEMI	<u>Photonics</u> • Critical for communications applications; enabler for NII • Key environmental issue is the reliance on III/IV materials • Ceramic Packaging • Developments in components and subsystem assembly (i.e., lead-free solders) should be immediately applicable) • Significant need for equipment and test procedures • The major driver is cost reduction, including labor, materials, and capital equipment. Semiconductor process yield improvement, especially in high performance devices, is important. Other key issues are evolution of semiconductor devices to integrated functionality in order to reduce the number of parts and the associated precision assembly for fiber coupling; application of CAD at the semiconductor and package design level. • With respect to environmental concerns, photonics manufacturing differs from conventional electronics manufacturing primarily in the area of reliance of III-V semiconductor materials and devices. These materials systems are significantly more exotic and of more concern than silicon-based devices. Technology development in the materials growth and processing area will be of primary importance in minimizing the environmental manufacturing impact. Component and sub-system assembly are essentially equivalent to the analogous operations in electronics manufacturing, and developments there (e.g., substitutes for lead and solders) should be immediately applicable to photonics manufacturing. • The consistent trend in electronics technology is for increasing integration of systems and to a chips or even a single chip, with all the functionality and the value-added provided by the component chips. Recent examples include the cellular phone, which in the 1970s required over 120 chips and presently requires less than 50; the modem, which in the mid-1980s required over 20 chips and now requires only a single chip; and the personal computer which once required nearly 80 ICs and now requires less than 20 – all of which provide higher functionality at a lower cost because of this increasing integration.
IPC	

OIDA	• Key markets are long distance telecommunications, shorter distance communications, high performance data communications, and low cost data communications. • Key concerns include developing manufacturing technologies to allow high performance opto-electronic components to be made less expensively and developing the inherently low cost opto-electronics from consumer and industrial sectors into high performance technologies for a broad range of computer and communications sector applications. (continued)
OIDA	• Recommended efforts include automated passive assembly and precision alignment; opto-electronic package platforms that could accommodate both optical and high speed electronic requirements; CAD/simulation tools to speed system engineering or package devices; wafer processing equipment for both InP and GaAs-based technology; *in situ* monitoring and control; and flexible batch processing. Optical Storage • Encompasses a wide-range of products, media, and applications, ranging from compact discs to rewriteable magneto-optic drives used in work stations to optical disk libraries. • Key issues: Green, blue, and shorter wavelength lasers and low cost manufacturable substrate and media technologies plus complete optical recording systems that exploit both the lasers and the media. Hardcopy • Relates to the technology to support printing and copying image from electronic files onto paper, plastic, metal, film or other materials. • Key issue: need for a single color standard to support all color scanning, display, and hardcopy. • Need for high power, low cost UV lasers and special materials for solid imaging. Should include research on photopolymers, powder technology to produce full density plastic parts, an inert high temperature materials to be used in systems which directly deposit molten metals to form objects. • Roadmap also suggests work in improving inkjet technology and other generic technologies to support improved print technologies.
DFE/DFM/CAD/CAM, Rapid Prototyping, Simulation	

SIA/SEMATECH	• In a steady state basis, a linked set of CAD tools is needed to interpret a chip factory's technology performance and evolve its process design for improved yield. Design of new generations requires the added capability of predicting performance, reliability, and yield. These tools must cover a wide spectrum of technologies, be robust, be calibrated easily by the end user, and allow for routine technical support without the intervention of an expert user. • The roadmap includes a list of the sixteen top CAD priorities (Table 7), several of which potentially have some environmental implementation (i.e., defect-mediated dopant profile evolution, silicidation models). <u>Modeling And Simulation</u> • There will not be radical changes in the process technology used to manufacture semiconductors throughout this decade. Rather, there will be expansion and refinement of current processes. • Current modeling tools are isolated, sporadically used, seldom reused, and lack a common application plan or strategy. • Solving the problem requires fostering a unified modeling team effort that is cognizant of the full spectrum of modeling required to capture the manufacturing and business environment. A coherent modeling architecture, effective partnering with manufacturers, suppliers, universities, and national laboratories, and compatibility with industry standard systems. (continued)

SIA/SEMATECH	• Over the time span encompassed by the roadmap, the complexity of chips and systems will grow so dramatically that new approaches based on far more powerful and interoperable tools will be needed to handle the design and test processes. • Already, in many cases, system level integration is limited by existing CAD tools and their inability to let the designer work smoothly up and down the levels of abstraction from device details to product functionality. • Ideally, design will be done using an integrated tool suite that gives the designer the power to create products starting from customer specifications and working down to the details of wafer fabrication and factory economics. • The ideal solution for the design environment would be a formal database management system used by all tools. This solution will start with common access interfaces and formal approaches for mapping information between different representations and continue through research directed at more formal DBMS solutions. • Low power is an increasingly critical need for portable and mobile computing and communication devices. Good progress has been made in the past year, and, in the near term, standard logic synthesis methods can be adapted to create viable solutions. However, their quality relies heavily on accurate power estimators that are still lacking. • Report emphasizes the need for higher level synthesis with emphasis on improved optimization of constrained parameters. • Compute-intensive simulation for verifying system and chip functionality must be replaced by formal analysis and verification methodologies. • As performance demands increase further, IC level cell[?] libraries will need to be redesigned rapidly to support fine-grain speed-power tuning. (The report also notes that the trends to be considered are emerging product styles such as field programmable devices, mixed signal systems, and aggressive packaging strategies.) • The challenge in design is managing the exploding complexity. To provide the dramatic improvement necessary in the design process as the complexity of the chips and systems increases, two key paradigm shifts can be identified: (1) point tools giving way to self-consistent top down design, and (2) piecemeal solutions giving way to hierarchical modeling and analysis. • In the area of design, the second across-the-board critical issue is that of standards. Interoperability and related software tool and information standards must be improved and their acceptance by industry, both users and suppliers, as well as the universities and government organizations, needs to be accelerated. • Drivers for the improvements needed in the near term in design and test include the need for more accurate but predictive capabilities at the detail level and the continuous drive for performance, power reduction, and minimum silicon real estate for the extremely complex devices and systems. They must also be strongly coupled into the synthesis and test process. (continued)

SIA/SEMATECH	• Hand-in-hand with the need to master the complexity challenge comes the need to deal with the power dissipation problem. Techniques and tools are needed for improved power minimization, distribution and management, as well as maintaining signal integrity in the face of high clock rates, low supply voltages, and the need to accommodate mixed signal circuitry. • Also, as a direct result of the complexity explosion, the need for test minimization which maintaining product quality requires improvements in modeling defects and fault-for-test. • Need for shift from point-tools to top down design. • Need for benchmarks • Need for rapid acceptance of standards • From a testing standpoint, the roadmap concludes there is a need for a large scale shift from external vector testing to on-chip BIST, serial-scan testing, and DFT.
NEMI	• Key issues are design tool and prototyping tool interoperability, enterprise connectivity for knowledge assimilation and sharing, and electronic commerce. • Core competencies include modeling and simulation, technology integration (including materials, electronics, optics, computers and others); validation/verification; advanced computing. • Development of these technologies is proposed within a context of "factories of the future" along with focused programs and virtual prototyping and rapid physical prototyping. Key emphasis is also in interoperable prototyping tools and databases. • Key issues virtual prototyping, lot size one, special rapid prototyping techniques, enterprise connectivity, and concurrent culture.
IPC	
OIDA	
Manufacturing Information and Management Systems	
SIA/SEMATECH	• Refers to information technologies that describe and implement the overall structure and behavior of semiconductor factories. • The fundamental change is to drive the development and adoption of standards to realize manufacturing systems based on a common framework.

NEMI	• Stresses the importance of integrated manufacturing information and management systems • Advanced modeling and simulation will be an essential part of the MIMS • Emphasizes integration from design to delivery • There is a need for manufacturing metrics (continued)
NEMI	• Additionally, the manufacturing information system was thought of as the hardware/software infrastructure used to gather critical manufacturing data and transmit operating instruction to the diverse parts of the manufacturing system. Over time, the MIS role has expanded to include management-related functions at the shop floor level such as work-in-process (WIP) management and tracking, process control and quality management. Also discussed are manufacturing management systems (MMS), including materials and resource planning systems (MRP) and CIM technology. • The MIMS will include and integrate such functions as data acquisition from and communication with all parts of the manufacturing enterprise; scheduling and route building; intelligent capacity planning, including cost performance modeling and simulation; raw materials, WIP, and inventory management; process control and quality management; facility and equipment maintenance; and management of the design manufacturing interface. • Technology development includes new forms of interface, intelligent maintenance and scheduling systems, beta integration, and others.
IPC	• *Information Systems (CIM/MIS)* • Potential paradigm shifts highlighted by the roadmap include seamless data transfer, electronic verification, global parts libraries, and manufacturing assembly cost analyses. • The IPC's recommendation focuses on the development of a global parts library, including features such as mechanical, physical, environmental, thermal, electrical performance, special handling requirements for moisture/reflow/thermal-sensitive or high pin count parts. This library should be accessible via the worldwide web and routinely be updated by component package standard bodies to include new part descriptions.
OIDA	
ES&H	

SIA/SEMATECH	• Chemical, energy and water mass balance will support reducing chemicals and effluent, and sizing facility exhaust and waste handling systems. • Cost of ownership includes the purchase, use management, disposal and liability costs • Some progress beyond the 0.5mm technology level is being made in hazardous chemical use reduction, reduced emissions, and tool and factory mass balance. Very little progress has been made beyond the 0.5 mm technology level with regard to CoO, hazardous chemical risk assessment, and ergonomics. • Significant progress is being made in reducing the use of hazardous chemicals. Ozone-depleting substances and targeted glycol ethers are rapidly disappearing from semiconductor wafer manufacturing and assembly processes. (continued)
SIA/SEMATECH	• Alternative chemicals and safer delivery methods are being sought for silane, dopants, and hazardous solvents and degreasers used in equipment cleaning and product assembly processes. • Emission abatement technology, process optimization, and replacement chemicals are needed for atmospherically long-lived process gases, such as perfluoro compounds. • Advanced wafer cleaning methods that use either significantly less chemicals or none at all have been demonstrated, although much research is still needed. • Room for significant improvement in energy consumption per m^2 of silicon wafer processed. • Efficient use of water in processes and cost-effective recycling of ultrapure water in facilities are strategic needs that require more emphasis. • Calls for move to additive processes by 2010 • Key environmental safety and health requirements in materials involve processes include improved handling of hazardous materials, alternatives to hazardous materials, waste stream minimization or abatement, selective deposition processes, point-of-use chemical generation, water recycling, improved ergonomic design of equipment, process material minimization, and chemical reprocessing.

NEMI	• Establish a "Clean Electronics" initiative, similar to the Clean Car initiative. • Environmental Database: Define a dynamic, distributed information space where disparate data of use to the electronics industry, currently kept in myriad formats, can be located, organized with a common ontology, and easily and logically accessed • The EPA and state environmental agencies should work with industries and other stakeholders to develop an implementation plan to minimize compliance and enforcement costs while maximizing environmental performance through regulatory streamlining and elimination of redundancies, multi-media pilot projects, and expanded voluntary collaborations, such as the common sense initiatives. • Key environmental issues include: identifying environmental impact of bromine fire retardant additives and develop alternatives if necessary; design and implement improved solvent recovery enclosed loop techniques; develop water-based or solvent-free systems for laminate productions and cleaning processes to eliminate ozone-depleting substances and volatile organic compounds.
IPC	• Although the electronic interconnection industry has numerous environmental needs and goals, a few broad priorities rise to the top. First, industry needs better methods to more efficiently use, reuse, recycle, and regenerate the chemistries and materials currently available. Second, industry needs new choices of environmentally friendly materials and processes to replace older, more hazardous technologies. And third, industry needs greater flexibility in manufacturing to allow implementation of environmentally friendly alternative materials and processes. (continued)

IPC	• Several approaches may help meet these priority needs. First, developing on-site regeneration systems for plating baths, etchants, and other process chemistries or extending the life of these chemistries will help industry operate more efficiently. • Reducing cleaning and rinsing steps, eliminating parts handling, and improving process control tools will also improve operating efficiency. Also, better partnerships with suppliers in order to eliminate hazardous materials and develop more environmentally friendly alternative materials and processes. • Specific suggestions: additive plating, no smear laminates or drilling systems, and alternatives to electroless plating. • Key objectives should be broader use of design for environment tools including: - collecting environmental data relevant to DFE - performing data analysis and format appropriately for DFE - modification of design guidelines and specifications to incorporate relevant environmental data analysis - integrating DFE techniques and material properties into CAE systems - developing more appropriate activity-based accounting methods that take into account total life-cycle costs - incorporating environmental evaluation into the development of all products standards. • Some key data requirements: hazardous material usage, energy consumption, water usage, waste generation, and health hazards. • The industry needs to develop a task force to examine all existing specifications with the mandate to generate sufficient data to either support or eliminate the specification (example: UL temperature inflammability standards, narrow or nonexistent NEMA grade designators). • The reduction or elimination of some chemicals will require specification revisions from OEMs and identifying opportunities to reclaim and recycle by-products. • The roadmap identifies several specific areas where waste minimization or materials elimination can be pursued in printed board fabrication (page B-32). • Key approaches to environmental issues in the assembly phase include the development of on-site recycling methods for cleaners, identification of lead-free solders or solder alternatives (adhesives). • Cupric chloride and ammoniacal etchants constitute the largest single waste stream for most board manufacturers. These materials may be shipped off-site for metals reclamation, sold as raw materials for copper chemicals production, or recycled on-site, eliminating the shipment of a hazardous material. Page C-34, the roadmap identifies several materials that could be included in a successful recycling program.
OIDA	

Materials and Bulk Processes

SIA/SEMATECH	• Conversion from 200 mm to larger diameter wafers appears to be necessary in the late 1990s to achieve the required economies of scale. Larger diameter wafer fabrication, metrology, and process equipment costs must all be considered in selection of the next wafer diameter. • The cost of operations for the wafer cleaning performed in IC fabrication needs to be addressed inasmuch as a final clean is also done by the wafer supplier. A chemical nature of the wafer surface (i.e., hydrophobic vs. hydrophilic) is a critical issue for future technology notes as well as the implementation of wafer-edge polishing. • Metrology: Developing metrology equipment to ensure production-worthy counters capable of distinguishing 0.02 µm particles from haze and surface topological features is essential. Work to standardize terminology, test procedures, and reference materials for particles, metals, flatness, and micro-roughness must continue through international standards committees. • Silicon-on-insulator (SOI) obviates the concern over latch-up while offering the potential of low power applications, fewer process steps, faster device speed, and perhaps more importantly, the opportunity of fabricating a 0.18 µm IC utilizing a 0.25 µm in equipment tool set. Understanding the relative benefits of SOI technologies (i.e., bonded wafers, bond and etch-back SOI (BESOI), separation by implantation of oxygen (SIMOX)) is required in 1995 to determine whether SOI will become more than a niche technology. • Micron wafers are anticipated by the year 2001, and 400 µm wafers at the year 2007. Line widths by 2001 are anticipated to be 0.18 µm and by 2007, 0.10. • Achieving the long-term vision for surface preparation technology requires a managed transition from wafer cleaning to surface engineering technologies. Alternatives to solvent-based cleans and the use of concentrated acid/alkalis need to be developed to minimize particles, corrosion and contact resistance. • Minimizing surface roughness, particles, and metal contamination will dictate changing from the traditional RCA clean to dilute chemical mixtures and alternative chemistries. • The wet chemical cleaning technologies are favored because of many inherent properties of aqueous solutions, such as the high solubility of metals, zeta potential control, and the effective sonic energy transmission for megasonic particle removal. Wet chemical surface preparation methods are likely to find application for the foreseeable future. • The roadmap discusses near-term potential solutions for forming shallow junctions: low energy/high current ion beams in conjunction with heavy ion pre-amorphization and/or molecular species implants. Also notes selectively CVD deposited poly or epitaxial silica. Other future processes including plasma doping, gas immersion laser doping (GILD), and atomic layer epitaxy. The use of CVD or ALE source/drain heterostructures such as SiGe are for one means of achieving band gap engineered S/D regions required for device turn-off at the 0.13 µm and 0.10 µm technology notes. (continued)

SIA/SEMATECH	• The roadmap also discusses thermal/thin film processing contamination-free manufacturing and metrology. Regarding metrology, the report notes that processes need to be moved on-line (in-line, *in situ*) and notes the importance of data management systems that are an integral part of process control, defect detection, and data reduction methods.
NEMI	
IPC	
OIDA	
Standards	
SIA/SEMATECH	• New standards include software standards for CAD tools and operating platforms, as well as hardware standards in areas such as supply voltages, input/output level voltages, and other electrical parameters relating to the off-chip world. *These standards are of paramount importance in that they allow/restrict hand-offs between design phases. Smooth hand-offs avoid loss of design detail that can lead to failure or lack of an optimal solution.* • TO BE COMPLETED
NEMI	• TO BE COMPLETED
IPC	• Some of the more important include design standards, material definitions, product specifications, reliability requirements, test methods, and data standards. • A key consideration in standards development is the ability to rapidly respond to innovation at no increased cost. • Another key area is the need for comprehensive material property data. There are presently several databases for material property information. However, data at important temperatures such as T_g and T_x are lacking. Designers and model designers need these data. • End product acceptance methods must be eliminated and replaced by end process controls which maintain a high confidence level through the use of process control. For improved test accuracy, higher productivity, and increased reliability, the industry must move forward in automating the testing of critical product parameters. • Currently materials and reliability data are generated by directly affected parties. The result is the data are often incomplete, not shared, and not broadly accepted. As companies reduce research efforts, it becomes vital to promote increased use of other resources such as universities. • IPC also recommends development of a framework for electronic development and delivery of standards. • Consider using chart on page C-18.
OIDA	

Benchmarking	
SIA/SEMATECH	
NEMI	• Need for a focused program of foreign technology monitoring
IPC	
OIDA	

Other Issues	
SIA/SEMATECH	
NEMI	Business Issues • Business issues addressed in the roadmap include small business programs for electronics manufacturing applications; a permanent R&D tax credit; improved appreciation treatment of electronic equipment; improved government cost accounting procedures; legislation to discourage frivolous lawsuits; and ASBE stock option rules. Intellectual Property Issues • The report addresses the importance of improving treatment of government-funded technology development, as well as policies addressing licensing and sub-licensing, abatement of patent expenses, flexible intellectual property rights. Technology Transfer and Federally-Funded R&D • The roadmap calls for understanding of issues relating to international technology transfer; focused program of foreign technology monitoring and assessment; facilitated participation in global intelligent manufacturing initiatives; improved support for technology transfer organizations; elimination of nationality of ownership as an element in U.S. firms ability to participate in government R&D/technology programs. State and Regional Alliances Cost and Availability of Capital

IPC	Purchasing • Suppliers need to be evaluated based on their capability for supplying a certain product or technology range long-term rather than on simply short-term factors. Capability includes (in addition to unit price) one of the following: supplier technical/process/quality system capability and direction; environmental and safety factors; financial stability/performance; organizational culture; and quality and dependability. • In the future, the purchasing organization must be part of a multidisciplinary acquisition process team with the real-time knowledge of supplier technical capability, supplier capacity, supplier cost drivers, and customers capabilities/requirements. A value-based determination of supplier can be made by this team and as a result of this knowledge, procurement cycle time will be reduced by consideration of only critical drivers. • Suppliers must be involved up front in establishing requirements and designs. There must be an accurate information exchange between customers and suppliers. Effective information systems and enhanced efforts regarding information sharing and joint planning would described the future status of the electronic interconnect information exchange.
OIDA	

Education and Training	
SIA/SEMATECH	TO BE COMPLETED
NEMI	TO BE COMPLETED
IPC	TO BE COMPLETED
OIDA	TO BE COMPLETED

Appendix B. The Ten Ceres Principles

By adopting these Principles, we publicly affirm our belief that corporations have a responsibility for the environment, and must conduct all aspects of their business as responsible stewards of the environment by operating in a manner that protects the Earth. We believe that corporations must not compromise the ability of future generations to sustain themselves.

We will update our practices constantly in light of advances in technology and new understandings in health and environmental science. In collaboration with CERES, we will promote a dynamic process to ensure that the Principles are interpreted in a way that accommodates changing technologies and environmental realities. We intend to make consistent, measurable progress in implementing these Principles and to apply them to all aspects of our operations throughout the world.

Protection of the Biosphere. We will reduce and make continual progress toward eliminating the release of any substance that may cause environmental damage to the air, water, or the earth or its inhabitants. We will safeguard all habitats affected by our operations and will protect open spaces and wilderness, while preserving biodiversity.

Sustainable Use of Natural Resources. We will make sustainable use of renewable natural resources, such as water, soils and forests. We will conserve nonrenewable natural resources through efficient use and careful planning.

Reduction and Disposal of Wastes. We will reduce and where possible eliminate waste through source reduction and recycling. All waste will be handled and disposed of through safe and responsible methods.

Energy Conservation. We will conserve energy and improve the energy efficiency of our internal operations and of the goods and services we sell. We will make every effort to use environmentally safe and sustainable energy sources.

Risk Reduction. We will strive to minimize the environmental, health and safety risks to our employees and the communities in which we operate through safe technologies, facilities and operating procedures, and by being prepared for emergencies.

Safe Products and Services. We will reduce and where possible eliminate the use, manufacture, or sale of products and services that cause environmental damage or health or safety hazards. We will inform our customers of the environmental impacts of our products or services and try to correct unsafe use.

Environmental Restoration. We will promptly and responsibly correct conditions we have caused that endanger health, safety, or the environment. To the extent feasible, we will redress injuries we have caused to persons or damage we have caused to the environment and will restore the environment.

Informing the Public. We will inform in a timely manner everyone who may be affected by conditions caused by our company that might endanger health, safety, or the environment. We will regularly seek advice and counsel through dialogue with persons in communities near our facilities. We will not take any action against employees for reporting dangerous incidents or conditions to management or to appropriate authorities.

Management Commitment. We will implement these Principles and sustain a process that ensures that the Board of Directors and Chief Executive Officer are fully informed about pertinent environmental issues and are fully responsible for environmental policy. In selecting our Board of Directors, we will consider demonstrated environmental commitment as a factor.

Audits and Reports. We will conduct an annual self-evaluation of our progress in implementing these Principles. We will support the timely creation of generally accepted environmental audit procedures. We will annually complete the CERES Report, which will be made available to the public.

Disclaimer

These Principles established an ethic with criteria by which investors and others can assess the environmental performance of companies. Companies that endorse these Principles pledge to go voluntarily beyond the requirements of the law. The terms may and might in Principles one and eight are not meant to encompass every imaginable consequence, no matter how remote. Rather, these Principles obligate endorsers to behave as prudent persons who are not governed by conflicting interests and who possess a strong commitment to environmental excellence and to human health and safety. These Principles are not intended to create new legal liabilities, expand existing rights or obligations, waive legal defenses, or otherwise affect the legal position of any endorsing company, and are not intended to be used against an endorser in any legal proceedings for any purpose.

Appendix C. The ICC Business Charter for Sustainable Development

1. *Corporate priority*. To recognize environmental management as among the highest corporate priorities and as a key determinant to sustainable development; to establish policies, programmes and practices for conducting operations in an environmentally sound manner.

2. *Integrated management*. To integrate these policies, programmes, and practices fully into each business as an essential element of management in all its functions.

3. *Process of improvement*. To continue to improve corporate policies, programmes, and environmental performance, taking into account technical development, scientific understanding, consumer needs and community expectations, with legal regulations as a starting point; and to apply the same environmental criteria internationally.

4. *Employee education*. To educate, train, and motivate employees to conduct their activities in an environmentally responsible manner.

5. *Prior assessment*. To assess environmental impacts before starting a new activity or project and before decommissioning a facility or leaving a site.

6. *Products and services*. To develop and provide products or services that have no undue environmental impact and are safe in their intended use, that are efficient in their consumption of energy and natural resources, and that can be recycled, re-used, or disposed of safely.

7. *Customer advice*. To advise, and where relevant educate, customers, distributors, and the public in the safe use, transportation, storage, and disposal of products provided; and to apply similar considerations to the provision of services.

8. *Facilities and operations*. To develop, design, and operate facilities and conduct activities taking into consideration the efficient use of energy and materials, the sustainable use of renewable resources, the minimization of adverse environmental impact and waste generation, and the safe and responsible disposal of residual wastes.

9. *Research*. To conduct or support research on the environmental impacts of raw materials, products, processes, emissions, and wastes associated with the enterprise and on the means of minimizing such adverse impacts.

10. *Precautionary approach*. To modify the manufacture, marketing, or use of products or services or the conduct of activities, consistent with scientific and technical understanding to prevent serious or irreversible environmental damage.

11. *Contractors and suppliers*. To promote the adoption of these principles by contractors acting on behalf of the enterprise, encourage, and, where appropriate, require improvements in their practices to make them consistent with those of the enterprise; and to encourage the wider adoption of these principles by suppliers.

12. *Emergency preparedness*. To develop and maintain, where significant hazards exist, emergency preparedness plans in conjunction with emergency services, relevant authorities and local community, recognizing potential transboundary impacts.

13. *Transfer of technology*. To contribute to the transfer of environmentally sound technology and management methods throughout the industrial and public sectors.

14. *Contributing to the common effort*. To contribute to the development of public policy and to business, governmental and intergovernmental programmes and educational initiative that will enhance environmental awareness and protection.

15. *Openness to concerns*. To foster openness and dialogue with employees and the public, anticipating and responding to their concerns about the potential hazards and impacts of operations, products, wastes, or services, including those of transboundary or global significance.

16. *Compliance and reporting*. To measure environmental performance; to conduct regular environmental audits and assessments of compliance with company requirements, legal requirements and these principles; and periodically to provide appropriate information to the Board of Directors, shareholders, employees, the authorities and the public.

from Robert Gray's (1993) *Accounting for the Environment*, Markus Weiner Publishers, Princeton.

Appendix D. Statistical Data Associated with Commerce for Major Selected Sectors of the U.S. Electronics Industry

This section contains a series of tables developed from data derived from various program activities of the U.S. Department of Commerce. These tables have been included with this roadmap document as an appendix to demonstrate the availability of the various types of data concerning the electronics industry that may be pertinent to the roadmap activity. The data contained in these tables are important for the following reasons:

- The data in the tables have been collected, compiled, and published by the federal government.
- The data have been statistically sampled from the major divisions of the U.S. electronics industry, so it is reflective of the industry as a whole and its stratified components.
- The various coding systems (e.g., SIC codes, ASM product codes, CIR item codes, etc.) used throughout the tables permit analytical comparisons with other data sources using the same or similar codes.
- The ongoing nature of the federal government programs from which these data have been derived ensures that a continuing source of knowledge will be available for purposes of periodic (e.g., annualized) comparisons, benchmarking, and analysis.

A brief explanation of each table is presented below, and the tables follow.

Table 1 contains summary demographic data for the major sectors of the U.S. electronics industry of primary interest in this roadmap document. These sectors are represented by two three-digit SIC codes:

- SIC 357: Computer and office equipment manufacturing
- SIC 367: Electronic components and accessories manufacturing

Table 1 presents the number of establishments, employment, and employee wage statistics for these two sectors of the electronics industry, stratified at the 4-digit SIC code level.

Table 2 cross-references the SIC codes for the primary sectors of interest with the product codes used in the Annual Survey/Census of Manufacturers (ASM) and the item codes used in the Current Industrial Reports (CIR). Both programs are sponsored by the U.S. Department of Commence. The codes demonstrate the possible cross-correlations that are possible among the various sources that use one or more of these coding systems.

Table 3 presents data associated with the costs of fuels and electricity used for heat and power by the listed sectors of the electronics industry. Such costs are directly associated with the costs of manufacturing and, indirectly, with both quantities of pollution and costs of pollution abatement and control.

Table 4 summarizes the value of electronics industry shipments as a function of the value added by manufacturing and the costs of materials (not shown are minor, other costs included in the value of industry shipments). These data include the value of all products shipped by the designated industry, regardless of type (e.g., including non-electronic products). The emphasis of Table 4 is on the industry SIC code.

Table 5 is similar to Table 4, except that the amounts reported are for the value of product shipments, regardless of industry. Unlike Table 4, the emphasis of Table 5 is on the product shipped, according to the SIC/Product code classification (listed in Table 5 as "SIC Code"). This table provides a five-year analysis of the data from 1987 through 1991 (see also Tables 6 and 7).

Tables 6 and 7 provide further stratification of the summary data presented in Table 5. The primary SIC/Product code classifications in Table 5 are stratified for SIC/Product code 357 in Table 6 and for SIC/Product code 367 in Table 7.

Tables 8 and 9 present detailed data for 1991 and 1992 for SIC/Product code 357 (Table 8) and SIC/Product code 367 (Table 9). Each table uses the ASM product codes summarized in Table 2. Both the quantity and value of product shipments are presented for each classification. Although data (especially quantity data) are not provided for all sub-divisions, the value of these data to the roadmap activity are readily apparent. They provide pertinent, annual, detailed benchmark data concerning the manufacturing experience of the various sectors of the electronics industry. It is doubtful that the whole of these statistical data are available elsewhere, especially as authoritative, national projections.

Table 10 summarizes pollution abatement capital expenditures (PACE) costs associated with air pollution for the selected sectors if the electronics industry for 1991. The costs are provided for total PACE, total air PACE, and for the various air PACE components. Although lacking in the detail provided for the SIC/Product codes data, these data nevertheless provide very useful indicators of industry experience with respect to abatement costs for air pollution.

Table 11 contains the pollution abatement gross annual costs (GAC) for the operation of pollution abatement methods and equipment, etc., for 1991 for the selected electronic industry sectors. Pollution abatement operating costs are provided for air, water, and solid (hazardous and non-hazardous) pollutants.

Table 12 is similar to Table 11 with respect to pollution abatement operating costs. However, the emphasis in Table 12 is on the kinds of costs associated with abatement activities, including equipment depreciation and costs associated with labor, materials/supplies, and other costs.

Table 1. Demographic and wage characteristics of major selected sectors of the U.S. electronics industry, 1991.

SIC CODE	No. of Establishments	Total Employment	Annual Wages (in thousands)	Annual Wages per Employee	Average Weekly Wage
3571	988	256,420	$12,576,940	$49,048	$943
3572	227	36,940	$1,382,103	$37,415	$720
3575	136	21,219	$961,054	$45,293	$876
3577	964	57,559	$2,295,810	$39,886	$767
3578	80	9,412	$344,810	$36,635	$705
3579	246	31,316	$1,259,685	$40,226	$774
3671	162	28,949	$991,201	$34,240	$658
3672	1,879	96,660	$2,570,774	$26,596	$511
3674	1,155	231,497	$9,389,690	$40,561	$780
3675	129	20,163	$476,211	$23,618	$454
3676	109	11,215	$251,581	$22,433	$431
3677	389	17,459	$351,341	$29,124	$387
3678	189	15,439	$411,677	$26,664	$513
3679	2,563	135,216	$3,846,822	$28,450	$547

SIC Codes:

3571 Electronic Computers
3572 Computer Storage Devices
3575 Computer Terminals
3577 Computer Peripheral Equipment
3578 Calculating and Accounting Equipment
3679 Office Machines, not elsewhere classified
3671 Electronic Tubes
3672 Printed Circuit Boards
3674 Semiconductors
3675 Electronic Capacitors
3676 Electronic Resistors
3677 Electronic Coils and Transformers
3678 Electronic Connectors
3679 Electronic Components, not elsewhere classified

Source: U.S. Bureau of Labor and Statistics, Employment and wages, Annual Averages, 1991.

Table 2. Correlation of Standard Industrial Classification (SIC) codes, Annual Survey of Manufacturers (ASM) product codes, and Current Industrial Report (CIR) item codes.

SIC Code	ASM Product Code	CIR (Form MA-36Q) Item Code
3671	3671400	5350; 5661 - 5678
3671	3671300	5710 - 5952
3674	3674100	6203 - 6285
3674	3674200	6302 - 6304
3674	3674300	6310 - 6324
3674	3679000	6328 - 6408
3675	3675000	6608 - 6782
3676	3676000	6805 - 6894
3677	3677000	6922 - 6956
3678	3678100	6996 - 7004
3678	3678200	7014 - 7024
3678	3678300	7034 - 7046
3678	3678400	7052 - 7060
3678	3678500	7070 - 7084
3679	3679100	7142 - 7182
3679	3679300	7510 - 8010
3679	3679500	8402 - 8592
3679	3679600	8727 - 8737
3672	3672000	8602 - 8638
3679	3679800	8752 - 8766
3671	3671500	6015
3679	3679900	9702 - 9770; 9804 - 9814

SIC Codes:
3571 Electronic Computers
3572 Computer Storage Devices
3575 Computer Terminals
3577 Computer Peripheral Equipment
3578 Calculating and Accounting Equipment
3679 Office Machines, not elsewhere classified
3671 Electronic Tubes
3672 Printed Circuit Boards
3674 Semiconductors
3675 Electronic Capacitors
3676 Electronic Resistors
3677 Electronic Coils and Transformers

3678 Electronic Connectors
3679 Electronic Components, not elsewhere classified

Source: U.S. Bureau of the Census, Current Industrial Report Series Reporting Manual, 1993 (MA36Q).

Table 3. Costs of fuels and electric energy for heat and power by major selected sectors of the U.S. electronics industry, 1991.

SIC Code	Cost of Fuel and Electric Energy (million $)	Electric Energy Quantity Purchased (million kWh)	Electric Energy Cost (million $)	Cost of Fuel Purchased (million $)
3571	$169.0	3,196.5	$155.0	$14.0
3572	66.1	1,086.2	60.5	5.6
3575	19.2	340.0	18.6	0.6
3577	50.6	862.7	44.1	6.5
3578	8.0	101.2	6.0	2.0
3579	25.1	304.0	20.6	4.5
3671	58.8	881.0	45.5	13.3
3672	126.8	1,653.8	103.8	23.0
3674	467.3	7,487.0	420.7	46.6
3675	33.1	552.4	28.7	4.4
3676	14.8	222.2	12.9	1.9
3677	10.5	125.0	8.6	1.9
3678	46.8	645.7	39.9	6.9
3679	186.6	2,5952.9	158.6	28.0

SIC Codes:

3571 Electronic Computers
3572 Computer Storage Devices
3575 Computer Terminals
3577 Computer Peripheral Equipment
3578 Calculating and Accounting Equipment
3679 Office Machines, not elsewhere classified
3671 Electronic Tubes
3672 Printed Circuit Boards
3674 Semiconductors
3675 Electronic Capacitors
3676 Electronic Resistors
3677 Electronic Coils and Transformers

3678 Electronic Connectors
3679 Electronic Components, not elsewhere classified

Source: U.S. Bureau of the Census, Annual Survey of Manufacturers, 1991.

Table 4. Costs of materials and value of shipments for major selected sectors of the U.S. electronics industry, 1991.

SIC Code	Value added by Manufacture (million $)	Cost of Materials (million $)	Value of Industry Shipments[1] (million $)
3571	$16,877.5	$19,078.4	$35,572.9
3572	3,600.2	3,674.2	7,188.6
3575	$865.0	1,429.5	2,326.5
3577	3,748.4	5,779.9	9,614.7
3578	617.5	482.4	1,086.6
3579	1,709.9	1,273.3	2,966.2
3671	1,131.0	1,454.6	2,568.3
3672	3,443.9	2,678.0	6,352.9
3674	20,151.9	9,197.7	29,668.1
3675	926.3	618.6	1,546.1
3676	510.4	277.7	797.1
3677	639.0	458.5	1,098.8
3678	2,334.7	1,321.3	3,751.2
3679	9,513.0	9,875.8	19,450.3

1 Value of *all products* shipped by the industry sector

SIC Codes:
3571 Electronic Computers
3572 Computer Storage Devices
3575 Computer Terminals
3577 Computer Peripheral Equipment
3578 Calculating and Accounting Equipment
3679 Office Machines, not elsewhere classified
3671 Electronic Tubes

3672 Printed Circuit Boards
3674 Semiconductors
3675 Electronic Capacitors
3676 Electronic Resistors
3677 Electronic Coils and Transformers
3678 Electronic Connectors
3679 Electronic Components, not elsewhere classified

Source: U.S. Bureau of the Census, Annual Survey of Manufacturers, 1991.

Table 5. Value of product shipments for major selected sectors of the U.S. electronics industry, 1987-1991.

	Value of Product Shipments (million $)[1]				
SIC Code	1991	1990	1989	1988	1987
3571	$28,158.0	$29,284.5	$30,397.7	$29,685.6	$26,624.2
3572	6,622.6	8,353.8	8,532.2	8,323.7	6,904.9
3575	2,326.6	2,571.9	2,559.7	2,565.5	2,729.7
3577	12,036.4	12,417.7	13,401.1	12,654.8	12,542.3
3578	1,165.8	1,391.3	1,366.4	1,061.5	1,208.5
3579	2,384.6	2,464.7	2,853.7	2,946.0	3,252.7
3671	2,658.6	2,649.7	2,638.2	2,464.6	2,329.3
3672	5,899.1	7,616.5	7,337.9	7,358.5	4,813.9
3674	27,437.5	23,977.7	23,488.3	20,332.1	17,928.8
3675	1,373.3	1,322.1	1,430.7	1,555.1	1,307.2
3676	791.0	831.9	850.3	866.0	860.2
3677	1,088.5	1,055.9	1,183.6	1,208.2	1,184.9
3678	3,451.3	3,578.4	3,789.0	3,911.6	3,731.4
3679	20,066.7	18,274.5	16,290.9	14,991.9	14,563.0

1 Value of shipments for product by *all industry sectors*

SIC Codes:
3571 Electronic Computers

3572 Computer Storage Devices
3575 Computer Terminals
3577 Computer Peripheral Equipment
3578 Calculating and Accounting Equipment
3679 Office Machines, not elsewhere classified
3671 Electronic Tubes
3672 Printed Circuit Boards
3674 Semiconductors
3675 Electronic Capacitors
3676 Electronic Resistors
3677 Electronic Coils and Transformers
3678 Electronic Connectors
3679 Electronic Components, not elsewhere classified

Source: U.S. Bureau of the Census, Annual Survey of Manufacturers, 1991.

Table 6. Value of product shipments for major selected sectors of the U.S. computer-related manufacturing industry, 1987-1991.

	Value of Product Shipments (million $)[1]				
SIC Code	1991	1990	1989	1988	1987
3571-	*$28,158.0*	*$29,284.5*	*$30,397.7*	*$29,685.6*	*$26,624.2*
35711	24,941.6	25,751.7	26,181.0	24,166.3	21,619.9
35712	2,445.2	2,671.3	3,571.3	4,774.8	4,288.8
35710	771.2	861.5	645.4	744.5	715.5
3572-	*6,622.6*	*8,353.8*	*8,532.2*	*8,323.7*	*6,904.9*
35721	5,599.8	7,403.9	7,858.5	8,323.7	6,311.8
35722	946.5	890.0	627.1	896.9	559.6
35720	76.3	59.9	46.6	39.1	33.6
3575-	*2,326.6*	*2,571.9*	*2,559.7*	*2,565.5*	*2,729.7*
35751	1,929.8	2,101.3	2,086.5	2,315.3	2,554.7
35752	338.6	412.2	331.6	212.2	139.0
35750	58.2	58.4	141.6	37.9	36.0
3677-	*12,036.4*	*12,417.7*	*13,401.1*	*12,654.8*	*12,542.3*
35771	7,448.1	8,089.9	8,139.9	7,646.4	7,955.3
35772	4,141.9	3,814.6	4,545.7	4,745.4	4,236.1
35770	446.4	513.3	715.5	263.0	351.0

1 Value of shipments for product by *all industry sectors*

SIC Codes:
3571- *Electronic computers*
35711 Computers (excluding word processors, peripherals, and parts)
35712 Parts for computers
35710 Electronic computers, unspecified
3572- *Computer storage devices*
35721 Computer storage equipment, auxiliary
35722 Parts for computer storage equipment, auxiliary
35720 Computer storage devices, unspecified
3575- *Computer terminals*
35751 Computer terminals
35752 Part for computer terminals
35750 Computer terminals, unspecified
3577- *Computer peripheral equipment, not elsewhere classified*
35771 Computer peripheral equipment, not elsewhere classified
35772 Parts for computer peripheral equipment, not elsewhere classified
35770 Computer peripheral equipment, not elsewhere classified, unspecified

Source: U.S. Bureau of the Census, Annual Survey of Manufacturers, 1991.

Table 7. Value of product shipments for major selected sectors of the U.S. electronic components manufacturing industry, 1987-1991.

	Value of Product Shipments (million $)[1]				
SIC Code	1991	1990	1989	1988	1987
3671-	*$2,658.6*	*$2,649.7*	*$2,638.2*	*$2,464.6*	*$2.329.3*
36713	1,017.0	1,071.5	1,128.9	1,175.8	1,114.9
36714	1,486.5	1,364.1	1,330.6	1,111.3	1,012.7
36715	124.4	155.8	148.9	154.9	180.1
36710	30.6	58.4	29.8	23.7	21.6
3672-	*5,899.1*	*7,616.5*	*7,337.9*	*7,358.5*	*4,813.9*
3674-	*27,437.5*	*23,977.7*	*23,488.3*	*20,332.1*	*17,928.8*
36741	19,894.2	16,371.8	16,682.5	14,857.1	13,300.1
36742	731.0	696.4	765.2	798.9	755.6
36743	630.9	643.0	686.8	793.6	692.4
36749	5,653.4	5,584.5	4,875.3	3,337.4	2,586.4
36740	528.0	682.1	478.5	545.1	594.2

3675-	*1,373.3*	*1,322.1*	*1,430.7*	*1,555.1*	*1,307.2*
3676-	*791.0*	*831.9*	*850.3*	*866.0*	*860.2*
3677-	*1,088.5*	*1,055.9*	*1,183.6*	*1,208.2*	*1,184.9*
3678-	*3,451.3*	*3,578.4*	*3,789.0*	*3,911.6*	*3,731.4*
36781	422.6	417.1	530.6	534.6	465.0
36782	479.7	529.6	524.2	634.0	579.3
36783	517.2	525.6	552.9	491.2	493.4
36784	831.1	898.6	960.2	1,192.8	1,024.9
36785	1,066.8	995.1	1,085.1	942.4	1,057.7
36780	134.0	212.4	135.8	116.7	111.2
3679-	*20,066.7*	*18,274.5*	*16,290.0*	*14,991.9*	*14,563.0*
36791	442.6	551.5	507.7	643.7	623.5
36793	1,434.5	1,364.2	1,262.3	1,233.6	1,188.6
36795	758.7	741.3	783.0	624.4	612.9
36796	533.3	614.2	595.8	663.0	745.9
36798	10,017.1	7,966.2	7,211.6	6,363,1	5,538.8
36799	5,363.7	5,337.6	4,588.5	3,693.3	4,261.7
36790	1,516.7	1,699.6	1,342.0	1,750.8	1,591.6

1 Value of shipments for product by *all industry sectors*

SIC Codes:

3671- Electron tubes, all types
36713 Transmittal, industrial and special purpose tubes, except x-ray
36714 Receiving type electron tubes, including cathode ray picture tubes
36715 Electron tube parts
36710 Electron tubes, unspecified

3672- Printed circuit boards

3674- Semiconductors and related devices
36741 Integrated microcircuits
36742 Transistors
36743 Diodes and rectifiers
36749 Semiconductor and related devices, not elsewhere classified
36740 Semiconductors and related devices, unspecified

3675- Electronic capacitors

3676-	*Electronic resistors*
3677-	*Electronic coils and transformers*
3678-	*Connectors for electronic circuitry*
36781	Coaxial (rf) connectors
36782	Cylindrical connectors
36783	Rack and panel (rectangular) connectors
36784	Printed circuit connectors
36785	Other connectors for electronic circuitry, not elsewhere classified
36780	Connectors for electronic circuitry, unspecified
3679-	*Electronic components, not elsewhere classified*
36791	Crystals, filters, piezoelectric, and other related devices
36793	Microwave components and devices
36795	Transducers, electrical/electronic input or output, not elsewhere classified
36796	Switches, mechanical, for electronic circuitry
36798	Printed circuit assemblies, loaded boards, and models
36799	Electronic components, not elsewhere classified
36790	Electronic components, unspecified

Source: U.S. Bureau of the Census, Annual Survey of Manufacturers, 1991.

Table 8. Quantity and value of shipments of semiconductors, printed circuit boards, and other electronic components: 1992 and 1991. Key to table is at the end of the table.

(Quantity in 1,000 units: value in thousands of dollars)

Product Code	Product Description	Company Count	Quantity (1992)	Value (1992)	Quantity (1991)	Value (1991)
3671	Electron tubes	(NA)	(X)	2,932,402	(X)	2,997,633
36713	Transmittal, industrial, and special purpose electron tubes (except X-ray)	39	(X)	948,316	(X)	1,072,549
	Power and special purpose tubes:					
36713 15	High vacuum tubes, including triodes, multi-grid external and internal anodes, diodes and other	6	174	79,735	255	88,726
36713 24	Gas and vapor tubes, including thyratrons, ignitrons, gas duplexers, spark gaps and other	9	2,584	37,341	3,845	35,182
36713 34	Klystrons, including amplifier, reflex and other	6	1,351	81,229	1,266	88,530
36713 47	Magnetrons, including pulsed, fixed, tunable, cross-field, continuous wave and other	7	37	60,699	23	72,722
	Traveling wave tubes (TWT):					
	Forward wave:					
	Continuous wave (CW):					
36713 55	Up to and including 10 watts CW power output rating	5	6	17,759	59	26,206
36713 61	Over 10 watts CW power output rating	6	230	69,610	261	86,599
	Pulsed power:					
36713 65	Up to and including 1 KW peak power output rating	4	506	23,175	468	22,741
36713 66	Over 1 KW peak power output rating	5	302	78,70	*375	95,938
36713 92	Backward wave	3	66	7,061	42	3,566
	Light sensing tubes:					
36713 70	Camera tubes, photo emissive and photo conductive	5	45	30,212	56	46,546
36713 73	Image intensifiers and converters AND	4				
36713 76	Photo multipliers and other	3	503	196,908	*479	194,212
36713 83	Light emitting devices includes storage tubes (all sizes), cathode ray tubes, color and monochrome (industrial and military), special display devices (includes alphanumeric readout tubes), figure indicating tubes, and other	18	3,302	147,666	5,067	156,761

Product Code	Product Description	Company Count	Quantity (1992)	Value (1992)	Quantity (1991)	Value (1991)
36713 96	Miscellaneous special-purpose tubes (reference cavities, radiation detection (Geiger, neutron counters, etc.), beam deflection, decade counters, orbital beam, vacuum gauges, vacuum capacitors, switches, relays, etc.)	10	(X)	118,212	(X)	154,820
36714 01	Receiving type electron tubes, all types (including rebuilt)	5	205	24,635	401	21,614
	Cathode ray picture tubes	(NA)	17,648	1,959,451	*16,749	*1,903,470
	Television tubes, including any defective tube that has been rebuilt:					
	Color having a video display diagonal of:					
36714 09	50 cm and under (20 inches and under)	6	9,319	717,578	*9153	*700,013
36714 12	Over 50 cm but not exceeding 63 cm (21 through 25 inches)	4	3,025	334,889	*2,678	*293,190
36714 14	Exceeding 63 cm (26 inches and over) AND	6				
36714 27	Other including rebuilt color and new and rebuilt black and white	3	5,304	906,984	*4,918	*910,267
36715 57	Electron tube parts, except glass blanks (bases, getters, cathodes, headers, guns, etc.)	19	(X)	129,542	(X)	*120,345
36720 --	Printed-circuit (wiring) boards	494	(X)	6,274,944	(X)	6,275,337
36720 12	Single-sided glass printed	227	(X)	193,411	(X)	*188,846
36720 14	Double-sided glass printed	329	(X)	1,016,100	(X)	1,055,427
36720 16	Multilayer glass printed	307	(X)	3,263,869	(X)	*3,284,711
36720 18	Paper/mat/composite printed	25	(X)	56,797	(X)	*49,768
36720 22	Flexible circuit printed	46	(X)	273,301	(X)	313,282
36720 24	Other rigid laminates	95	(X)	988,367	(X)	*918,560
36720 26	Receipts for contract work on printed circuit boards (etching, dip-soldering, imprinting, etc.)	69	(X)	483,099	(X)	464,743
3674	Semiconductors and related devices	(NA)	(X)	25,812,702	(X)	26,302,130
36741 --	Integrated microcircuit packages	168	(X)	18,455,646	(X)	19,150,958
36741 10	Hybrid integrated circuits, thick film composed of material deposited by silk screen process on a passive substrate combined with discrete active or passive components	60	(NA)	(NA)	(X)	808,084
36741 11	Hybrid integrated circuits, thin film composed of material deposited by vacuum deposition, sputtering or similar process on a passive substrate combined with discrete active or passive components	31	(NA)	(NA)	(X)	669,810

Product Code	Product Description	Company Count	Quantity (1992)	Value (1992)	Quantity (1991)	Value (1991)
36741 12	Hybrid integrated circuits, multi-chip circuits not incorporating film techniques. These are usually combinations of chips, active and/ or passive; discrete package devices may be used for some but not all circuits	25	(NA)	(NA)	(X)	88,164
	Monolithic integrated circuits:					
	Bipolar integrated circuits:					
	Logic/Microprocessors:					
36741 16	Transistor-transistor logic TTL, excluding microprocessors	15	(NA)	(NA)	3,667,700	1,403,721
36741 17	Current mode logic/emitter coupled logic (CML/ECL), excluding microprocessors	10	(NA)	(NA)	79,368	154,955
36741 22	Integrated injector logic (I2L), excluding microprocessors	2	(NA)	(NA)	(D)	(D)
36741 23	Linear bipolar, excluding microprocessors	26	(NA)	(NA)	2,247,117	1,690,743
36741 24	Microprocessors	8	(NA)	(NA)	10,683	107,008
36741 25	Other bipolar logic	13	(NA)	(NA)	70,732	216,729
	Memory:					
36741 27	Random access memories (RAM) AND	5	(NA)	(NA)		
36741 29	Read only memories (R0M)	3	(NA)	(NA)	32,260	56,665
36741 33	Other bipolar memories	6	(NA)	(NA)	23,521	148,769
36741 35	Other bipolar integrated circuits	18	(NA)	(NA)	746,121	576,120
	Metal oxide semiconductor (MOS) integrated circuits:					
	Logic/Microprocessors:					
36741 37	MOS linear ICs, exclude micro-processors and microcontrollers	20	(NA)	(NA)	302,081	727,075
36741 39	Microprocessors, 4-bit AND	4	(NA)	(NA)		
36741 40	Microprocessors, 8-bit	15	(NA)	(NA)	75,754	288,929
36741 41	Microprocessors, 16-bit	13	(NA)	(NA)	51,141	716,133
36741 42	Microprocessors, 32-bit	10	(NA)	(NA)	22,892	2,784,087
36741 43	Microcontrollers, 4-bit AND	4	(NA)	(NA)		
36741 44	Microcontrollers, 8-bit AND	11	(NA)	(NA)		
36741 45	Microcontrollers, 16-bit	6	(NA)	(NA)	209,823	695,428
36741 46	Microcontrollers, 32-bit	10	(NA)	(NA)	-	-
36741 47	Other MOS microprocessors	11	(NA)	(NA)	63,064	415,889
36741 48	Other MOS microcontrollers	10	(NA)	(NA)	82,494	387,823
	Memory:					
	MOS memories, dynamic random access, (DRAMs):					
36741 50	DRAMs, under 9,000 bits AND	1	(NA)	(NA)		
36741 51	DRAMs, 9,000 - 19,999 bits	4	(NA)	(NA)	1,519	9,444
36741 52	DRAMs, 20,000 - 39,999 bits	-	-	-	-	-
36741 53	DRAMs, 40,000 - 79,999 bits	5	(NA)	(NA)	2,440	11,237

Product Code	Product Description	Company Count	Quantity (1992)	Value (1992)	Quantity (1991)	Value (1991)
36741 54	DRAMs, 80,000 - 300,000 bits	9	(NA)	(NA)	65,823	350,695
36741 55	DRAMs, 300,000 bits-1,999,999 bits	8	(NA)	(NA)	140,924	915,881
36741 60	DRAMs, 2,000,000 bits and over	4	(NA)	(NA)	21,374	553,772
	MOS memories, static random access, (SRAMs):					
36741 56	SRAMs, < 9,000 bits	9	(NA)	(NA)	20,228	81,451
36741 57	SRAMs, 9,000 - 19,999 bits	9	(NA)	(NA)	14,658	74,640
36741 58	SRAMs, 20,000 - 80,000 bits	13	(NA)	(NA)	65,070	257,854
36741 59	SRAMs, > 80,000 bits	15	(NA)	(NA)	29,533	252,883
	MOS memories, read only (Mask):					
36741 61	MOS ROMs (Mask), <20,000 bits	4	(NA)	(NA)	387	2,110
36741 62	MOS ROMs (Mask), 20,000 - 39,999 bits AND	1	(NA)	(NA)		
36741 63	MOS ROMs (Mask), 40,000 - 79,999 bits	2	(NA)	(NA)	1,154	4,322
36741 64	MOS ROMs (Mask), 80,000 - 199,999 bits AND	1	(NA)	(NA)		
36741 65	MOS ROMs (Mask), 200,000 - 400,000 bits AND	2	(NA)	(NA)		
36741 66	MOS ROMs (Mask), >400,000 bits	0	-	-	5,234	1,115
	MOS memories, erasable programmable ROMs, (EPROMs):					
36741 67	MOS EPROMs, < 20,000 bits AND	4	(NA)	(NA)		
36741 68	MOS EPROMs, 20,000 - 39,999 bits	3	(NA)	(NA)	5,156	31,286
36741 69	MOS EPROMs, 40,000 - 79,999 bits	8	(NA)	(NA)	31,297	135,082
36741 70	MOS EPROMs, 80,000 - 199,999 bits	7	(NA)	(NA)	24,273	54,920
36741 71	MOS EPROMs, 200,000 - 400,000 bits	9	(NA)	(NA)	79,915	170,709
36741 72	MOS EPROMs, >400,000 bits	8	(NA)	(NA)	89,961	396,774
	MOS memories, electrically erasable programmable ROMs, (EEPROMs):					
36741 74	MOS EEPROMs, <20,000 bits	8	(NA)	(NA)	111,723	99,911
36741 75	MOS EEPROMs, 20,000 - 79,999 bits	6	(NA)	(NA)	5,549	39,470
36741 76	MOS EEPROMs, 80,000 - 200,000 bits AND	1	(NA)	(NA)		
36741 77	MOS EEPROMs, >200,000 bits	5	(NA)	(NA)	4,377	95,490
36741 79	Other MOS memories	4	(NA)	(NA)	(D)	(D)
36741 89	Other MOS integrated circuits	45	(NA)	(NA)	1,305,418	3,128,113
36741 99	Other monolithic integrated circuits	27	(NA)	(NA)	92,283	483,304
3674	Semiconductors and related devices	(NA)	(X)	25,812,702	(NA)	(NA)
36741	Integrated microcircuit packages (1992 basis):	181	7,348,370	18,455,646	(NA)	(NA)

Product Code	Product Description	Company Count	Quantity (1992)	Value (1992)	Quantity (1991)	Value (1991)
	Monolithic integrated circuits, digital, non-silicon (e.g., gallium arsenide):					
36741 19	Memory AND	3	(NA)	(NA)		
36741 28	Logic and other	9	136,223	403,197	(NA)	(NA)
	Monolithic integrated circuits, digital, silicon:					
	Bipolar transistors, memory:					
36741 07	Static read-write random access (SRAM)	7	6,847	31,782	(NA)	(NA)
36741 09	Other memory	11	9,908	248,350	(NA)	(NA)
	Other bipolar transistors, including logic:					
36741 13	Transistor-transistor logic (TTL)	12	1,660,591	952,500	(NA)	(NA)
36741 14	Emitter coupled logic (ECL)	9	85,131	210,645	(NA)	(NA)
36741 15	Other	18	179,058	623,285	(NA)	(NA)
	Metal oxide semiconductor (MOS) field effect transistors:					
	Volatile memory DRAMS (dynamic read-write random access):					
36741 81	Not over 80k	9	7,574	40,356	(NA)	(NA)
36741 82	Over 80k but not over 300k	8	30,310	201,583	(NA)	(NA)
36741 83	Over 300k but not over 3MB	12	142,114	1,121,722	(NA)	(NA)
36741 84	Over 3MB but not over 15MB AND	6	(NA)	(NA)		
36741 85	Over 15MB	2	20,648	224,133	(NA)	(NA)
	Volatile memory SRAMS (static read-write random access):					
36741 91	Not over 40K	14	32,947	173,143	(NA)	(NA)
36741 92	Over 40K but not over 80K	17	57,698	272,895	(NA)	(NA)
36741 93	Over 80K but not over 300K	18	51,725	360,548	(NA)	(NA)
36741 94	Over 300K, not over 3MB AND	3	(NA)	(NA)		
36741 95	Over 3MB	1	51,793	52,853	(NA)	(NA)
	Nonvolatile EEPROMs (electrically erasable programmable read-only memory):					
36741 96	Not over 80K	10	145,196	162,983	(NA)	(NA)
36741 97	Over 80K, not over 900K AND	7	(NA)	(NA)		
36741 98	Over 900K	5	22,538	197,479	(NA)	(NA)
	Nonvolatile EPROMs (erasable, except electrically, programmable read-only memory):					
36741 86	Not over 80K	10	38,662	192,026	(NA)	(NA)
36741 87	Over 80K but not over 900K	14	233,918	511,402	(NA)	(NA)
36741 88	Over 900K	9	138,321	144,430	(NA)	(NA)
36741 90	Other nonvolatile memory	23	466,067	626,926	(NA)	(NA)
	Other, including microprocessors, controllers, application specific integrated circuits (ASIC), and programmable logic arrays (PLA):					
36741 36	Microprocessors having an internal data bus of ≤ 8 bits	19	61,147	192,354	(NA)	(NA)
36741 38	Microprocessors having an internal data bus of 16 bits	14	283,349	854,421	(NA)	(NA)
36741 39	Microprocessors having an internal data bus of ≥32 bits	14	364,925	2,546,785	(NA)	(NA)
36741 18	Other (microcontrollers, ASICs, PLAs, etc.)	36	829,691	2,476,281	(NA)	(NA)

Product Code	Product Description	Company Count	Quantity (1992)	Value (1992)	Quantity (1991)	Value (1991)
	Other digital, silicon, including bipolar combined with MOS:					
36741 20	Complementary BiMOS (BiCMOS)	5	1,141	53,675	(NA)	(NA)
36741 21	Other complementary BiMOS (BiCMOS), including logic	6	326,166	177,429	(NA)	(NA)
36741 26	Other digital silicon ICs	14	85,833	210,639	(NA)	(NA)
	Nondigital silicon monolithic integrated circuits (e.g., linear, analog):					
36741 49	Radio frequency	5	27,241	42,293	(NA)	(NA)
36741 02	Other, analog	25	869,526	1,362,812	(NA)	(NA)
36741 03	Other, including mixed signal (analog/digital), logic AND	4	(NA)	(NA)		
36741 04	Other, including mixed signal (analog/digital), other	3	20,751	99,647	(NA)	(NA)
	Hybrid integrated circuits:					
36741 08	Radio frequency	17	2,138	261,426	(NA)	(NA)
36741 31	Other	45	77,468	647,977	(NA)	(NA)
36741 06	Other	46	881,725	2,777,669	(NA)	(NA)
36742 --	Transistors	37	(X)	733,729	(X)	*736,920
36742 63	Signal (< 1 watt dissipation)	24	(X)	283,183	(X)	*232,721
36742 64	Power (≥ 1 watt dissipation)	34	(X)	450,546	(X)	*504,199
36743 --	Diodes and rectifiers	45	8,830,779	660,940	5,567,425	653,478
36743 22	Signal diodes and assemblies thereof (maximum current 0.5 amps)	14	94,997	38,087	92,893	*37,989
36743 42	Semiconductor rectifiers/power diodes and assemblies thereof (current rating > 0.5 amps)	26	256,555	227,229	241,530	*262,697
36743 94	Zener diodes (voltage regulator and reference diodes) AND	16				
36743 12	Selenium rectifiers	3	1,414,667	159,736	1,088,492	144,818
36743 83	Microwave diodes (mixers, detectors, varactors, parametric, harmonic generators, etc.)	17	7,064,560	235,888	*4,144,510	*207,974
36749 --	Other semiconductor devices	162	(X)	5,962,387	(X)	5,760,774
	Light-sensitive and light-emitting devices:					
36749 12	Solar cells	7	(X)	36,339	(X)	36,905
	Light-emitting diodes (LED)					
36749 14	Discrete, infrared and laser	11	(X)	304,559	(X)	*284,527
36749 16	Alpha or numeric displays	10	(X)	75,383	(X)	*79,912
36749 22	Photodiodes, including infrared detectors	12	(X)	63,598	(X)	*60,585
36749 24	Optical coupled isolators, including sensors and emitters	8	(X)	76,837	(X)	74,097
36749 29	Other light sensitive and light-emitting devices, including photovoltaic devices and photoelectric-magnetic devices	15	(X)	174,843	(X)	168,517

Product Code	Product Description	Company Count	Quantity (1992)	Value (1992)	Quantity (1991)	Value (1991)
	Other semiconductor devices:					
36749 85	Thyristors (SCRs, triacs, PNPN diodes) AND	11	(X)	(X)		
36749 86	Hall effect devices	2	(X)	123,581	(X)	113,311
36749 87	All other semiconductor devices (tunnel diodes, thermoelectric semiconductor junctions, metal-oxide varistors, solid-state transducers, and special semiconductor devices n.e.c.)	31	(X)	858,219	(X)	*730,960
	Semiconductor parts:					
	Chips and wafers:					
36749 94	For integrated circuits (IC's)	54	(X)	2,912,176	(X)	2,675,542
36749 96	For discrete semiconductors	29	(X)	312,941	(X)	*331,553
36749 97	All other semiconductor parts (headers, packages, heat sinks, other accessories, etc.)	46	(X)	1,023,911	(X)	1,204,865
36750 --	Capacitors	84	(X)	1,250,592	(X)	*1,223,972
	Fixed:					
36291	Paper, plastic (film), metallized, and dual (film/paper) dielectric:	17	104,769	164,946	71,018	144,634
	A.C. types:					
36291 11	Less than 300 volts	13	10,049	15,702	6,210	11,917
36291 13	300 volts to 599 volts	17	83,082	122,252	53,415	106,351
36291 15	600 volts to 999 volts	11	7,049	12,975	5,844	9,955
36291 17	1,000 volts or over	10	4,589	14,017	5,549	16,411
	Capacitors having a reactive power handling capacity of 0.5 KVAR or less:					
	D.C. types/other:					
36750 19	Axial lead	29	42,183	47,735	59,211	*56,691
36750 21	Radial lead AND	14				
36751 24	Chips and other leaded devices	4	114,326	24,313	114,693	*28,184
	Tantalum electrolytic:					
36750 26	Metal case (incl. foil and wet)	6	47,273	57,665	49,484	73,255
36750 28	Dipped AND	2				
36750 31	Chips	4	1,026,598	180,715	736,262	152,104
36750 33	Other leaded (molded axial and molded radial)	3	103,271	24,957	188,308	47,422
	Aluminum electrolytic:					
36750 38	Less than 18mm through 35mm	4	51,510	46,782	50,997	53,625
36750 41	Small can style (over 35mm through 51mm)	5	1,539	7,639	2,599	14,420
36750 43	Other can style (over 51mm) AND	5				
36750 45	AC motor start	3	25,925	73,976	22,965	60,835
	Ceramic dielectric, single layer:					
36750 54	Axial and radial AND	7				
36750 51	Chips	2	367,880	17,862	552,010	21,901

Product Code	Product Description	Company Count	Quantity (1992)	Value (1992)	Quantity (1991)	Value (1991)
	Ceramic dielectric, multilayer:					
36750 53	Axial leads	4	137,267	10,300	141,708	12,002
36750 55	Radial leads	8	2,518,345	154,576	2,425,356	145,891
36750 57	Chips	13	13,226,559	349,598	10,964,093	313,071
	Other:					
36750 59	Mica dielectric	8	76,347	18,924	86,225	21,278
36750 61	All other fixed	20	101,602	55,212	156,496	72,349
	Variable:					
36750 63	Mica, ceramic or glass dielectric	5	21,357	29,370	18,955	26,793
36750 69	Other	7	2,464	10,440	*3,385	*12,901
36750 75	Parts of capacitors (including unfinished chips for further finishing and assembly)	7	(X)	140,528	(X)	111,250
36760 --	Resistors	91	(X)	696,448	(X)	*721,459
36760 11	Fixed carbon resistors, composition or film types	6	299,266	28,335	315,464	31,299
	Other fixed resistors (power capacity 20W or less):					
	Surface mounted, having two terminals:					
36760 24	Flat resistor chips	15	527,584	34,739	600,788	41,053
36760 25	Cylindrical leadless resistors (including metal film, metal oxide, and thick cermet film)	8	50,148	9,227	39,511	6,683
	Surface mounted, having more than two terminals (resistor networks):					
36760 28	Dual-in-line package	4	102,490	30,721	102,278	27,754
36760 32	Other (including flat packs)	6	42,391	17,075	47,268	18,998
	Resistors, having two leads:					
36760 34	Wirewound	21	192,128	76,255	203,681	79,935
36760 36	Other (including metal film, metal oxide, thick cermet film)	16	1,446,521	83,982	1,648,782	97,365
	Resistor networks, having more than two leads:					
36760 38	Single-in-line	12	221,296	62,258	*313,347	*56,133
36760 42	Dual-in-line	9	57,859	20,041	*74,318	*28,084
36760 44	Other	11	21,772	31,211	*15,367	*26,999
	Variable, non-wirewound:					
	Trimmers:					
36760 51	Single-turn, carbon, other film	9	115,089	38,788	108,247	40,897
36760 54	Multi-turn, carbon, other film AND	6				
36760 58	Surface mounted	4	76,871	55,133	60,972	45,223
	Potentiometers:					
36760 57	Precision type	11	17,505	49,504	*21,220	*57,432
36760 62	Panel type	4	7,684	9,545	*13,388	*15,155
	Variable, wirewound:					
36760 72	Variable wirewound, except potentiometers, including non-precision and trimmers	6	2,625	8,452	2,994	10,670
36760 57	Potentiometers, precision type	11	6,435	29,457	5,431	20,461
36760 62	Potentiometers panel type	5	3,670	10,658	3,919	18,009

Product Code	Product Description	Company Count	Quantity (1992)	Value (1992)	Quantity (1991)	Value (1991)
	Miscellaneous:					
36760 75	Varistors	6	113,798	15,948	94,383	13,624
36760 77	Thermistors, bead type, disc, rod	15	116,244	73,894	108,914	74,371
36760 79	Parts for resistors	12	(X)	11,225	(X)	*11,314
36770 --	Coils, transformers, reactors, and chokes for electronic applications	233	(X)	1,067,574	(X)	1,006,585
36770 32	Audio frequency (AF) transformers	91	23,303	92,001	20,344	84,385
36770 33	Low frequency (LF) chokes	87	5,623	40,196	4,265	*31,501
36770 41	Plate and filament transformers (including auto-transformers, except toroidal)	74	12,748	131,371	12,395	123,933
36770 61	Pulse transformers, computer, and other types	93	30,650	133,348	32,861	143,256
36770 12	Radio frequency (RF) chokes	43	79,736	32,733	*79,674	*31,656
36770 13	Radio frequency (RF) coils	48	101,794	57,830	*104,548	*60,721
36770 14	Intermediate frequency (IF) transformers	28	4,362	20,609	4,520	21,138
36770 71	Television transformers and reactors (horizontal output, vertical deflection, focus coils, deflection yokes, etc.)	16	3,620	41,700	1,581	20,931
36770 91	Toroidal windings (transformers and reactors), except complete magnetic amplifiers	106	16,875	96,210	22,080	106,290
36770 92	Other (balun coils, permeability tuning devices, etc.)	89	(X)	421,576	(X)	*382,774
3678	Electronic connectors	(NA)	(X)	3,183,337	(X)	3,265,396
36781 --	Coaxial (RF) connectors	39	392,804	420,840	381,086	384,398
36781 21	Miniature (BNC,PNC,MHB)	21	26,007	91,460	22,140	68,793
36781 22	Subminiature (SMA,SMB,SMC)	16	64,993	89,347	*51,993	*77,319
36781 24	Other standard and precision	29	301,804	240,033	306,953	238,286
36782 --	Cylindrical connectors	29	155,737	477,670	138,068	483,401
36782 25	Heavy duty and standard	21	33,835	196,184	34,507	205,075
36782 29	Miniature	14	20,703	114,871	30,035	155,028
36782 31	Subminiature	9	101,199	166,615	73,526	123,298
36783 --	Rack and panel (rectangular) connectors	27	747,952	358,519	1,291,435	484,883
36783 35	Integral shell, Mil-C-22857 (8434) and similar types	16	200,190	155,463	290,297	148,426
	Subminiature:					
36783 42	Ribbon (including planar cable type)	9	29,582	62,743	32,761	69,498
36783 44	D-Subminiature (including planar cable type)	11	516,680	118,386	967,014	246,500
36783 46	Microminiatures	8	1,500	21,927	1,363	*20,459
36784 --	Printed circuit connectors	48	5,266,568	929,103	3,949,330	843,840
36784 44	Card insertion types	29	1,389,622	348,925	*875,451	*224,210

Product Code	Product Description	Company Count	Quantity (1992)	Value (1992)	Quantity (1991)	Value (1991)
	Two-piece types:					
36784 48	Post, header and receptacle type	28	3,403,411	440,173	*2,909,721	*432,491
36784 49	Other two-piece types	17	473,535	140,005	*164,158	*187,139
36785 --	Other connectors including parts	81	(X)	997,205	(X)	1,068,874
36785 41	Hermetic sealed (except single-contact and coaxial types)	26	244,659	133,489	*304,517	*155,573
36785 51	Plate module types	6	7,388	27,809	7,104	30,067
36785 53	Fiber optic connectors	9	872	8,248	*855	*10,022
36785 59	Other planar cable (flat conductor or ribbon cable)(excluding rack and panel (rectangular) types)	17	723,209	229,518	*616,637	*249,153
36785 54	Miscellaneous special purpose	43	2,678,851	470,586	*2,623,114	*476,102
36785 56	Parts for connectors (connectors shipped but still requiring further manufacture)	23	(X)	127,555	(X)	147,957
3679	Electronic components and subassemblies n.e.c.	(NA)	(X)	22,309,151	(X)	20,383,831
36791 --	Filters (except microwave) and piezoelectric devices	108	(X)	442,443	(X)	451,476
	Filters (except microwave)	(NA)	48,122	205,284	40,656	192,991
36791 11	Mechanical, excluding optical lenses (germanium silicon, fused quartz, rock salt, and other)	4	114	17,207	*99	*16,293
	Radio frequency interference/electro magnetic interference (RFI/EMI) control filters:					
36791 13	Ceramic dielectric	11	22,522	83,239	13,551	68,268
36791 15	Combination or other dielectric	15	15,909	78,099	*19,423	*80,399
36791 21	Electronic wave filters (LC band and high pass)	28	9,577	26,739	*7,583	*28,031
	Piezoelectric devices	(NA)	(X)	237,159	(X)	258,485
	Oscillator crystals:					
36791 31	AT-cut	29	6,879	38,580	6,878	41,210
36791 33	Other	10	11,841	28,183	13,981	34,925
	Crystal oscillators:					
36791 35	Oven	5	46	10,149	*37	*9,380
36791 37	TCXO/VCXO	12	193	18,990	225	21,460
36791 39	Hybrid	14	2,269	26,519	3,140	38,134
36791 41	Other	9	2,376	30,487	2,036	27,425
	Crystal filters:					
36791 43	Monolithic (include filter crystals and/or monolithic filter units not assembled into filters)	9	764	9,346	*778	*9,730
36791 45	Packaged AT-cut (packaged incl. monolithic, tandem monolithic, and resonator filter assemblies)	14	2,827	16,894	4,790	21,603
36791 47	Other	11	487	23,909	358	17,840
	Crystal blanks:					
36791 51	AT-cut	8	3,468	5,824	5,703	*7,459
36791 55	Other	8	6,323	28,278	8,419	29,319

Product Code	Product Description	Company Count	Quantity (1992)	Value (1992)	Quantity (1991)	Value (1991)
36793 --	Microwave components and devices (except antenna), tubes, and semiconductors	137	(X)	1,144,244	(X)	1,178,455
36793 11	Ferrite (including yttrium garnets) microwave components (circulators, isolators, phase shifters, attenuators, equalizers, limiters, mixers, etc.)	42	(X)	223,029	(X)	*257,371
	Microwave devices, other than ferrite and solid state:					
36793 21	Attenuators (dummy loads, high and low-power terminations, etc.)	42	(X)	57,096	(X)	83,132
36793 23	Cavities (amplifier cavities, coaxial tuned cavities, etc.)	16	(X)	69,860	(X)	64,255
36793 25	Couplers (directional couplers, hybrid junctions, etc.)	33	(X)	55,573	(X)	56,386
36793 27	Reactive microwave components n.e.c.	42	(X)	119,688	(X)	146,519
36793 29	Switches, coaxial and waveguide	36	(X)	75,306	(X)	*104,397
36793 31	Rigid waveguide and fittings (bend and twists, couplings, flanges, other simple waveguide components n.e.c.)	29	(X)	70,787	(X)	59,075
36793 33	Flexible waveguides and fittings	19	(X)	29,920	(X)	38,004
36793 51	Other microwave components, except ferrite devices (coaxial to waveguide and other transitions, duplexers and diplexers, holders and mounts, linear and circular polarizers, magnetron test plumbing, rotary joints and sector scan joints, mixer arrays, shutters, tuners, windows, etc.)	49	(X)	184,848	(X)	*187,468
36793 71	Microwave subassemblies, including parametric amplifiers and other solid-state assemblies	34	(X)	258,137	(X)	181,848
36795 --	Transducers, electrical/electronic input or output n.e.c.	79	52,740	817,513	49,325	*799,509
36795 11	Electroacoustic (sonar, ultrasonic, vibration, etc.)	15	20,206	101,249	20,689	*100,702
	Electromechanical:					
36795 21	Accelerometers	15	212	106,375	224	*115,958
36795 23	Pressure	39	18,674	305,459	16,702	*294,823
36795 25	Strain gauges, other mechanical	21	467	88,587	442	88,521
36795 31	Thermoelectric (pyrometers, thermocouples, etc.)	8	1,992	74,578	1,640	*63,109
36795 98	Other (optical, chemical, magnetic, nuclear, etc.)	20	11,189	141,265	9,628	*136,396
36796 --	Switches, mechanical types for electronic circuitry	70	(X)	538,414	(X)	545,143

Product Code	Product Description	Company Count	Quantity (1992)	Value (1992)	Quantity (1991)	Value (1991)
36796 15	Slide (including rocker, miniature and subminiature)	15	(X)	58,648	(X)	*44,673
36796 19	Rotary selector (including lever and jog-lever, miniature and subminiature)	23	(X)	63,959	(X)	*67,924
36796 21	Keyboard	7	(X)	38,090	(X)	31,294
36796 25	Push-button	24	(X)	47,709	(X)	48,141
36796 29	Snap-action	10	(X)	21,945	(X)	*25,763
36796 31	Thumbwheel	7	(X)	17,579	(X)	14,027
36796 14	Membrane	7	(X)	26,741	(X)	17,644
36796 12	Toggle standard type AND	13	(X)	(X)		
36796 13	Toggle miniature and subminiature	4	(X)	58,093	(X)	54,358
36796 33	DIP	5	(X)	48,117	(X)	42,753
36796 39	Other	32	(X)	157,533	(X)	*198,566
36798 --	Printed circuit assembly (loaded boards, subassemblies, and modules, except filters and other items listed elsewhere)	336	(X)	14,224,827	(X)	12,590,366
36798 31	Under $1,000 (MLP)	19	(X)	597,860	(X)	282,721
36798 33	$1,000 - $5,000 (MLP)	15	(X)	404,933	(X)	270,661
36798 35	$5,000 - $15,000 (MLP)	11	(X)	71,381	(X)	88,066
36798 37	$15,000 - $50,000 (MLP) AND	6				
36798 39	$50,000 - $250,000 (MLP) AND	2				
36798 41	$250,000 to $1 million (MLP)	1	(X)	86,877	(X)	178,554
36798 43	Over $1,000,000 (MLP)	-	(X)	-	(X)	-
36798 15	Computer processors (system boards, array processors, etc.)	48	(X)	2,036,204	(X)	*2,632,111
36798 11	Memory boards	50	(X)	1,826,560	(X)	*1,598,173
36798 13	Peripheral controllers (graphic boards, drive controller, etc.)	44	(X)	1,463,407	(X)	*652,916
36798 17	Instrumentation boards (data acquisition, signal analysis, etc.)	35	(X)	2,125,802	(X)	*2,033,952
36798 19	Communication boards (LAN boards, D/A and A/D converters, etc.)	56	(X)	716,034	(X)	*615,115
36798 21	Other board level products for use within a computer system	23	(X)	844,532	(X)	771,998
36798 22	Other boards	87	(X)	2,210,779	(X)	*1,981,313
36798 29	Receipts for contract work by contract assemblers, board stuffers, and related job shops	69	(X)	1,355,021	(X)	1,051,588
36799 --	Electronic components and subassemblies n.e.c.	521	(X)	6,285,954	(X)	5,997,317

Product Code	Product Description	Company Count	Quantity (1992)	Value (1992)	Quantity (1991)	Value (1991)
	Antenna systems, except structural towers sold separately:					
36799 07	Home antenna	11	11,906	104,707	*11,020	*99,616
36799 08	Auto antenna	8	13,035	51,745	11,861	46,171
36799 09	Antenna accessories, sold separately (pedestals, drives, passive reflectors, rotators, radomes, etc.)	21	(X)	106,519	(X)	*87,166
36799 11	Delay lines (distributed constant, lumped constant, magneto-strictive, ultrasonic, etc.)	22	5,064	32,397	6,646	*36,570
36799 13	Oscillators, except instrumentation and crystal types	12	7,203	101,527	8,648	110,909
36799 20	Magnetic recording and reproducing heads including audio, video, digital and instrumentation	21	69,966	977,021	53,207	707,196
	Static power supply converters for electronic applications, sold separately:					
36799 21	Regulated	90	173,761	788,766	152,987	*847,793
36799 22	Other (unregulated, variable frequency, a.c., d.c., converters and inverters, vibrator, etc.)	61	(X)	797,963	(X)	*801,386
36799 31	Electronic cable harnesses and cable assemblies	197	(X)	1,161,299	(X)	*1,151,366
36799 33	Cryogenic cooling devices (cryostats, etc.) for infrared detectors, masers	4	(X)	47,095	(X)	58,306
36799 51	Liquid crystal displays (LCD) and other liquid devices	9	(X)	62,888	(X)	*63,551
36799 55	Magnetic cores	16	(X)	160,825	(X)	158,323
	Electronic parts n.e.c. and specialized electronic hardware:					
	Sockets for electronic component insertion:					
36799 66	Integrated circuit sockets	9	(X)	203,811	(X)	159,112
36799 62	Other including tube, relay, discrete semiconductors, a.c. and d.c. converters and inverters, etc.	17	(X)	57,572	(X)	*59,922
36799 98	All other electronic parts & specialized elec. hardware, n.e.c.	138	(X)	1,631,819	(X)	*1,609,930
	Electronic research, development, testing, and evaluation (receipts or billings, not reported as shipments of specific products):					
99980 42	Systems	20	(X)	137,402	(X)	194,808
99980 43	Equipment and subassemblies	39	(X)	438,975	(X)	111,219
99980 44	Component parts	52	(X)	117,153	(X)	126,269
99980 46	Basic scientific electronic research	22	(X)	206,244	(X)	196,400
99980 47	Design and engineering services	39	(X)	643,456	(X)	633,621
99980 48	Software	7	(X)	21,366	(X)	20,400
99980 49	Testing	-	(X)	-	(X)	-
99980 50	Supplies and accessories sold with components	6	(X)	2,388	(X)	8,988

Key to Table 8:

-	Represents zero
(D)	Data withheld to avoid disclosing figures for individual companies
(NA)	Not available
n.e.c.	Not elsewhere classified
*	Revised by 5% or more from previously published figures
(X)	Not applicable

Table 9. Quantity and value of shipments of computers and office and accounting machines: 1992 and 1991 (revised to the new product code changes created in 1992). Key at end of table.

(Quantity in number of units; value in thousands of dollars)

Product Code	Product Description	Company Count	Quantity (1992)	Value (1992)	Quantity (1991)	Value (1991)
3571 --	Electronic computers (automatic data processors)	185	(X)	27,189,967	(X)	26,274,061
	General purpose digital units by manufacturer's list price (MLP)	130	10,044,443	26,495,604	7,488,059	25,317,798
3571X 41	Under $1,000 (MLP)	28	4,635,809	1,830,968	3,311,064	1,989,420
3571X 43	$1,000 to $5,000 (MLP)	68	4,416,221	9,490,511	3,391,827	8,203,437
3571X 45	$5,000 to $15,000 (MLP)	54	794,361	5,726,648	529,007	3,681,539
3571X 47	$15,000 to $50,000 (MLP)	41	171,095	2,450,040	219,778	3,712,117
3571X 49	$50,000 to $250,000 (MLP)	41	21,961	2,108,106	29,233	2,796,740
3571X 51	$250,000 to $1 million (MLP)	23	3,225	1,162,957	4,694	1,058,111
3571X 53	Over $1,000,000 (MLP)	12	1,771	3,726,374	2,456	3,876,434
	General purpose digital units by type	130	10,044,443	26,495,604	7,488,059	25,317,798
35713 00	Large-scale processing equipment (64 megabytes in minimum main memory configuration)	27	78,776	5,536,418	(NA)	(NA)
35714 00	Medium-and small-scale processing equipment (up to 64 Mbytes in minimum main memory configuration), excluding personal computers or workstations	38	141,509	3,111,104	(NA)	(NA)
35715 00	Personal computers and workstations, excluding portables	77	8,468,727	16,023,874	(NA)	(NA)
35716 00	Portable computers (typically with attached display, e.g., laptops, notebooks, palmtops)	25	1,173,084	1,330,677	(NA)	(NA)
35717 00	Other general purpose digital processing units	19	182,347	493,531	(NA)	(NA)
35718 00	Other computers, typically specialized for an application, including array, database, and image processors, computer chassis, and other analog, hybrid or special purpose computers (excluding supercomputers, LAN servers, and engineering workstations)	70	(S)	694,363	(S)	956,263
36798 XX	Printed circuit assemblies (loaded boards, subassemblies and modules):					
	Loaded computer processor boards and board subassemblies by (MLP)[2,3]	336	(X)	14,224,827	(X)	12,590,386
36798 31	Under $1,000 (MLP)	19	(X)	597,860	(X)	282,721
36798 33	$1,000 to $5,000 (MLP)	15	(X)	404,933	(X)	270,661

Product Code	Product Description	Company Count	Quantity (1992)	Value (1992)	Quantity (1991)	Value (1991)
36798 35	$5,000 to $15,000 (MLP)	11	(X)	71,381	(X)	86,068
36798 37	$15,000 to $50,000 (MLP) AND	6				
36798 39	$50,000 to $250,000 (MLP) AND	2				
36798 41	$250,000 to $1 million (MLP)	1	(X)	86,877	(X)	178,554
36798 43	Over $1,000,000 (MLP)	-	-	-	-	-
36798 15	Computer processors (systems boards, array processors, etc.)	48	(X)	2,036,204	(X)	2,632,111
36798 11	Memory boards (including boards for adding memory to peripherals)	83	(X)	2,311,997	(X)	2,033,389
36798 13	Peripheral controller boards (e.g., graphics boards, I/O controllers)	71	(X)	1,463,407	(X)	652,916
36798 17	Instrumentation boards (e.g., D/A converters, frequency counters)	35	(X)	2,125,802	(X)	2,033,952
36798 19	Communication boards (e.g., FAX, modems, LAN adapters)	69	(X)	716,034	(X)	615,115
36798 21	Other board level products for use within a computer system	23	(X)	844,532	(X)	771,998
36798 22	Other boards	87	(X)	2,210,779	(X)	1,981,313
36798 29	Receipts for contract work by contract assemblers, board stuffers, and related job shops	69	(X)	1,355,021	(X)	1,051,588
35721 --	Computer storage devices and equipment	89	4,679,291	6,055,548	3,810,549	5,609,701
	Rigid magnetic disk drives:					
	Less than $5,000 (MLP) each:					
35721 35	Less than 2 1/2inch AND	4				
35721 37	2 1/2 inch up to but not including 3 1/2 inch	3	130,907	32,187	108,796	28,040
35721 39	3 1/2 inch up to but not including 5 1/4 inch	19	1,150,244	684,029	934,691	504,140
35721 41	5 1/4 inch and greater	24	709,809	1,135,704	789,256	1,235,544
35721 43	$5,000 MLP or more	10	62,610	1,197,978	68,731	1,315,095
35721 45	Disk subsystems and disk arrays for multi-user computer systems	20	83,046	642,827	15,601	343,613
35721 47	Flexible magnetic disk drives	9	457,260	65,621	263,852	53,335
	Optical disk drives, including CD-ROM and magneto-optical equipment:					
	CD-ROM:					
35721 51	"Juke-box" capable of handling multiple disks AND	7				
35721 53	Single-disks equipment	7	313,171	127,635	211,279	99,734
35721 55	WORM (write once, read many times)	7	6,518	40,924	8,826	37,023
35721 57	Rewritable	6	(D)	(D)	(D)	(D)
35721 59	Optical subsystems for multi-users computer systems	5	25,956	64,909	11,908	14,133

Product Code	Product Description	Company Count	Quantity (1992)	Value (1992)	Quantity (1991)	Value (1991)
	Auxiliary storage, not disc- or tape-based, for multi-user computer systems:					
35721 61	Encased or enclosed in a housing, enclosure or cabinet	5	(D)	(D)	(D)	(D)
35721 63	Other	-	-	-	-	-
35721 65	Other direct access storage equipment	12	103,960	215,530	108,431	267,928
	Serial access storage equipment (e.g., tape drives):					
35721 71	1/2 inch tape drives	12	142,414	577,005	169,213	606,941
35721 73	1/4 inch tape drives	15	713,219	303,907	497,042	226,480
35721 75	Helical scan tape drives AND	5				
35721 77	Cassette tape drives	4	197,988	283,530	138,873	223,480
35721 79	Other serial access storage equipment	13	525,510	617,206	471,322	603,754
35722 11	Computer storage parts and subassemblies	26	(X)	1,132,337	(X)	780,382
35751 --	Computer Terminals	72	3,868,871	1,697,555	3,281,810	1,729,507
35751 80	Remote batch terminals	8	38,562	74,236	30,031	67,103
35751 61	Teleprinters	11	121,036	230,143	209,005	346,593
	Display terminals, including graphics type, whether or not incorporating a printing mechanism:					
35751 63	X-terminals	17	302,809	382,838	353,810	330,744
	Other than X-terminals:					
35751 65	13 inch or less display	12	234,119	78,139	217,408	76,532
35751 67	More than 13 inch but less than 19 inch display	27	3,117,422	841,443	2,406,324	820,804
35751 69	19 inch or more display	14	54,923	90,756	65,232	87,731
35752 41	Computer terminal parts and subassemblies	21	(X)	209,289	(X)	416,988
35771 --	Computer Peripheral Equipment, n.e.c.	238	(X)	8,478,242	(X)	7,763,557
	Keying equipment:					
35771 33	Keyboards AND	20				
35771 35	Other keying equipment	5	22,481,305	636,004	15,618,678	576,145
35771 02	Mouse devices AND	9				
35771 04	Digitizers and light pen tablets	9	7,209,138	244,190	4,786,308	193,204
35771 06	Other manual input devices (joy-sticks, trackballs, touch screens, etc.)	6	574,705	32,310	337,215	23,638
35771 08	Computer output to microfilm (COM) equipment AND	3				
35771 12	Media copying and/or conversion equipment	4	13,858	86,661	19,051	93,359
	Optical scanning devices:					
35771 14	Bar code devices	27	761,072	471,677	862,650	496,906
35771 16	OCR equipment	18	328,960	189,791	267,532	182,477

Product Code	Product Description	Company Count	Quantity (1992)	Value (1992)	Quantity (1991)	Value (1991)
	Other than bar code or OCR devices:					
35771 18	Flat bed scanners	9	151,952	129,419	72,397	74,854
35771 22	Hand-held scanners	4	26,468	8,401	28,093	10,989
35771 24	Other	14	168,362	92,730	115,989	92,547
35771 26	Voice recognition equipment	9	15,139	23,458	9,944	26,820
35771 28	Magnetic strip and ink recognition equipment	9	36,541	97,744	12,537	84,742
35771 29	Other document entry equipment	1	(D)	(D)	(D)	(D)
	Computer printers:					
	Impact printers:					
35771 74	Line type (typically with a Centronics interface with output measured in line per minute	14	490,432	362,887	281,078	373,949
35771 72	Serial type (typically with a serial and/or parallel interface with output measured in characters per second)	27	637,030	944,359	829,112	806,308
	Nonimpact printers:					
	Laser:					
35771 41	Under $15,000 (MLP) AND	26				
35771 43	$15,000 (MLP) and over	9	1,833,182	2,419,309	1,326,192	2,163,193
35771 45	Other (inkjet, thermal, ion deposition, etc.)	20	1,426,500	741,980	520,272	504,509
35771 47	Peripheral sharing devices	9	383,674	227,072	318,344	293,725
35771 49	Font cartridges	3	4,162	617	(D)	(D)
	Plotters (including electrostatic):					
35771 51	Under $15,000 (MLP)	8	47,360	356,100	58,612	439,439
35771 53	$15,000 (MLP) and over	4	2,321	70,126	(D)	(D)
	Monitors (excluding terminals):					
35771 55	Flat panel displays	7	150,223	89,645	121,199	103,114
	Other than flat panel displays (e.g., CRT):					
35771 56	Less than 19 inch display	23	386,323	149,926	385,423	171,227
35771 58	19 inch or more display	12	239,709	162,314	210,771	103,245
35771 62	Monitor screen projection devices (e.g., LCD panels)	4	(D)	(D)	29,747	63,804
35771 63	All other input/output devices	63	(X)	521,697	(X)	564,567
35771 68	Accessories for computer peripherals (e.g., device supports, ergonomic aids, etc.)	38	(X)	321,540	(X)	305,876
35772 00	Parts and subassemblies for computer peripherals and input/output equipment	65	(X)	3,126,130	(X)	4,186,786
35784 --	Calculating and accounting machines	45	(X)	984,476	(X)	973,536
35784 54	Funds transfer devices AND	8	29,622	224,716		

Product Code	Product Description	Company Count	Quantity (1992)	Value (1992)	Quantity (1991)	Value (1991)
35784 55	Point-of-sale terminals	19	245,488	748,940	255,951	508,673
35784 16	Machines for sorting, wrapping, counting, changing or dispensing coins and/or currency	9	324,651	129,585	301,928	124,957
35784 59	Other coin or currency handling machines, including cash registers, calculators, accounting, bookkeeping and billing machines, and credit card imprinters	16	(X)	105,951	(X)	115,190
35789 00	Parts for calculating, coin or currency handling, and accounting machines	18	(X)	74,392	(X)	97,404
35792 00	Automatic typing and word processing machines (all types)	5	2,323,331	465,158	1,733,614	417,116
35793 00	Duplicating machines	5	(D)	(D)	(D)	(D)
35795 --	Mailing, letter handling, and addressing machines.	30	906,433	1,148,535	1,116,022	1,124,777
35795 34	Forms handling equipment, including bursters, decollators, and imprinters	9	491,334	53,481	604,651	53,856
35795 37	Mailing machines, including postage franking machines AND	12	482,496	816,606		
35795 43	Letter and envelope handling machines	14	401,883	994,677	18,930	174,093
35795 48	Other mailing, letter handling and addressing machines	11	13,216	100,377	9,945	80,222
35799 --	Other office machines, n.e.c	50	(X)	499,932	(X)	517,623
35799 31	Check handling machines	10	58,747	75,270	71,660	72,024
35799 32	Electric stapling machines, office type	3	177,773	8,502	176,764	13,850
35799 33	Time recording and time stamp machines	13	247,309	99,369	228,948	101,654
35799 41	Paper cutting machines and apparatus, office type AND	5				
35799 44	Paper shredders	2	521,701	31,220	476,082	30,088
35799 45	Perforating or stapling machines, nonelectric	6	5,382,514	45,344	5,231,155	47,615
35799 95	All other office machines, n.e.c., including pencil sharpeners, typewriters, dictating machines, binding machines, ticket counting machines and voting machines	25	(X)	240,227	(X)	252,392
3579A 00	Parts for office machines, not elsewhere classified (n.e.c.)	31	(X)	261,420	(X)	199,170
36950 --	Magnetic and optical recording media	57	(X)	3,999,538	(X)	3,894,393

Product Code	Product Description	Company Count	Quantity (1992)	Value (1992)	Quantity (1991)	Value (1991)
	Rigid disks:					
36950 12	Less than 2 1/2 inch AND	3				
36950 14	2 1/2 inch up to but not including 3 1/2 inch	6	(S)	41,414	(S)	63,808
36950 16	3 1/2 inch up to but not including 5 1/4 inch	9	(S)	531,605	(S)	511,593
36950 18	5 1/4 inch and greater	10	(S)	226,331	(S)	274,587
	Flexible disks:					
36950 22	3 1/2 inch up to but not including 5 1/4 inch	12	(S)	455,130	(S)	339,053
36950 24	5 1/4 inch and greater	15	(S)	195,745	(S)	222,297
36950 09	Optical disks AND	8				
36950 26	Bulk magnetic tape	3	(S)	222,337	(S)	186,797
	Packaged magnetic tape:					
36950 11	In reels for computer use	8	(S)	115,050	(S)	125,213
36950 13	In cassette and cartridge for computer use	19	(S)	641,374	(S)	560,694
36950 28	In forms suitable for audio use	10	(S)	270,180	(S)	282,975
36950 21	In video cassette, 8 mm and 1/2 inch	9	(S)	750,989	(S)	803,047
36950 23	In video cassette, 3/4 (19mm) and 2 inch (51 mm)	3	(S)	94,602	(S)	102,237
36950 34	Other package magnetic tape AND	3				
36950 39	Other magnetic recording media, including parts	18	(X)	454,781	(X)	422,092
	Nonmanufacturing revenue of manufacturing establishments:					
50650 00	Supplies and accessories for use with computers or business machines (resale)	46	(X)	885,578	(X)	687,527
99980 49	Research and development, testing and evaluation of systems and components	23	(X)	142,628	(X)	132,911
	Software sold with computer systems shipped by manufacturers:					
73721 00	Operating system software	23	(X)	150,838	(X)	143,207
73722 00	Utilities and device managers AND	9				
73723 00	Application software AND	26				
73724 00	Other software AND	8	(X)	188,083	(X)	57,968
73730 00	Systems integration revenues, including configuration, installation and site preparation, and custom programming	11	(X)	78,975	(X)	(D)
73700 00	Other nonmanufacturing revenues associated with computer systems	73	(X)	1,258,144	(X)	1,277,369

Key to Table 9:

-	Represents zero.
(D)	Data not shown to avoid disclosing figures for individual companies
(S)	Withheld because data did not meet publication standards.
(X)	Not applicable.
(NA)	Not available.
n.e.c.	Not elsewhere classified

Table 10. Air pollution abatement capital expenditures (PACE) for major selected sectors of the U.S. electronics industry, 1991. Key follows table.
(continued on next page)

(millions of dollars)

SIC Code	Industry	Total PACE	Total Air	Air Particulate	SOX	CO & NOX	VOC	Lead
	All industries	7390.1	3706.3	1087.3	489.9	234.0	946.7	16.9
36	Electronic and other electric equipment	233.7	90.7	30.1	2.2	2.7	29.6	10.0
361	Electric distribution equipment	9.1	3.6	1.3	-	-	1.9	-
362	Electrical industrial apparatus	5.6	1.6	0.3	-	(D)	1.0	(D)
363	Household appliances	7.6	(D)	0.7	-	-	(D)	-
364	Electric lighting and wiring equipment	33.6	24.9	18.9	2.0	1.1	1.2	0.4
365	Household audio and video equipment	10.0	(D)	2.0	-	-	(D)	-
366	Communications equipment	5.4	2.6	0.3	(D)	(D)	1.1	(D)
367	Electronic components and accessories	138.5	34.8	5.4	(D)	(D)	14.9	0.6
3671	Electron tubes	4.7	3.0	(D)	-	-	(D)	(D)
3672	Printed circuit boards	17.5	2.5	0.1	(D)	(D)	(D)	0.1
3674	Semiconductors and related devices	106.2	27.6	4.3	-	-	10.9	(D)
3675	Electronic capacitors	1.6	0.7	0.7	-	-	-	-
3678	Electronic connectors	2.0	0.3	-	-	-	(D)	-
3679	Electronic components, n.e.c.	6.4	0.6	(D)	-	-	0.3	(D)
369	Miscellaneous electrical equipment and supplies	23.7	13.0	1.2	-	-	2.5	8.8
357	Computer and office equipment	16.6	9.4	(D)	0.1	(D)	6.5	-
3571	Electronic computers	8.9	(D)	(D)	0.1	(D)	(D)	-
3572	Computer storage devices	(D)	1.5	-	-	-	(D)	-
3577	Computer peripheral equipment, n.e.c.	2.0	0.8	-	-	(D)	0.4	-
3579	Office machines, n.e.c.	(D)	(D)	-	-	-	(D)	-

Table 10. Air pollution abatement capital expenditures (PACE) for major selected sectors of the U.S. electronics industry, 1991.

(millions of dollars)

SIC Code	Industry	Hazardous Air Pollution	All Other	Air Tech.	Prod. Proc. Enhance.	SD Est. (%) PACE
	All industries	606.4	325.7	2553.5	1152.8	4.00
36	Electronic and other electric equipment	13.3	2.8	67.6	23.1	33.0
361	Electric distribution equipment	0.1	0.1	2.5	1.0	16.0
362	Electrical industrial apparatus	(D)	(D)	0.3	1.3	18.0
363	Household appliances	(D)	0.1	(D)	(D)	31.0
364	Electric lighting and wiring equipment	1.1	0.1	17.8	7.1	42.0
365	Household audio and video equipment	(D)	(D)	(D)	(D)	19.0
366	Communications equipment	0.3	0.7	1.3	1.3	4.0
367	Electronic components and accessories	10.9	1.4	30.3	4.5	54.0
3671	Electron tubes	(D)	0.3	(D)	(D)	19.0
3672	Printed circuit boards	0.6	0.6	(D)	(D)	34.0
3674	Semiconductors and related devices	10.1	(D)	26.1	1.5	70.0
3675	Electronic capacitors	-	-	0.7	-	83.0
3678	Electronic connectors	-	-	0.3	-	57.0
3679	Electronic components, n.e.c.	(D)	(D)	0.5	-	24.0
369	Miscellaneous electrical equipment and supplies	-	-	11.5	1.4	29.0
357	Computer and office equipment	(D)	(D)	6.8	2.5	11.0
3571	Electronic computers	-	0.6	(D)	(D)	12.0
3572	Computer storage devices	-	(D)	(D)	(D)	(X)
3577	Computer peripheral equipment, n.e.c.	-	(D)	(D)	(D)	62.0
3579	Office machines, n.e.c.	-	-	(D)	(D)	(X)

Key to Table 10:

- Million dollars, except %. Totals may not agree with detail because of independent rounding.
- The Pollution Abatement Costs and Expenditures survey includes all manufacturing establishments with 20 employees or more except Major Group 23, Apparel and Other Textile Products.

PACE	Pollution abatement capital expenditures
(D)	Withheld to avoid disclosing operations of individual companies
(X)	Not applicable
(NA)	Not applicable

Table 11. Pollution abatement gross annual costs (GAC) by media for major selected sectors of the U.S. electronics industry, 1991.

(millions of dollars)

				Oper. Costs by Form of Pollutants Abated		Solid or Contained		
SIC Code	Industry	Total GAC	Total Costs	Air Costs	Water Costs	Hazardous Waste Costs	Non-Hazardous Waste Costs	SD Est. (%) GAC
	All industries	17386.8	15763.8	5033.5	5127.4	2553.2	3049.6	2.0
36	Electronic and other electric equipment	833.0	756.7	100.0	266.4	196.7	193.6	12.0
361	Electric distribution equipment	26.1	23.6	2.4	6.8	7.8	6.6	11.0
362	Electrical industrial apparatus	43.2	35.5	5.8	8.1	9.7	11.9	14.0
363	Household appliances	41.1	35.1	7.6	11.0	6.6	9.9	15.0
364	Electric lighting and wiring equipment	76.7	69.5	8.6	12.8	34.7	13.3	32.0
365	Household audio and video equipment	94.5	93.2	2.0	2.0	2.2	87.1	35.0
366	Communications equipment	51.6	45.8	3.5	13.0	9.2	20.1	3.0
367	Electronic components and accessories	312.5	277.2	34.9	118.2	98.2	26.0	13.0
3671	Electron tubes	19.8	18.9	1.5	5.8	8.2	3.3	4.0
3672	Printed circuit boards	91.1	81.3	8.2	50.0	19.3	3.8	24.0
3674	Semiconductors and related devices	131.2	116.4	17.4	43.9	44.6	10.4	22.0
3675	Electronic capacitors	13.2	12.1	1.4	3.9	6.3	0.5	64.0
3676	Electronic resistors	3.4	3.1	0.1	0.0	2.4	0.6	83.0
3678	Electronic connectors	19.6	16.8	1.3	6.6	7.8	1.1	33.0
3679	Electronic components, n.e.c.	34.3	28.6	4.9	8.0	9.5	6.2	10.0
369	Miscellaneous electrical equipment and supplies	187.3	176.8	35.2	94.6	28.3	18.6	40.0
357	Computer and office equipment	80.9	71.3	6.8	17.1	33.1	14.3	16.0
3571	Electronic computers	25.3	21.00	3.00	6.5	3.3	8.2	13.0
3572	Computer storage devices	(D)	(D)	(D)	(D)	(D)	1.1	(X)
3575	Computer terminals	1.6	1.4	-	0.3	0.6	0.6	56.0
3577	Computer peripheral equipment, n.e.c.	32.2	30.4	0.8	4.9	22.3	2.4	35.0
3578	Calculating and accounting equipment	(D)	(D)	(D)	(D)	(D)	0.9	(X)
3579	Office machines, n.e.c.	5.7	5.2	1.00	1.9	1.3	1.1	37.0

Key to Table 11:

- Million dollars, except percents. Totals may not agree with detail because of independent rounding.
- The Pollution Abatement Costs and Expenditures survey includes all manufacturing establishments with 20 employees or more except Major Group 23, Apparel and Other Textile Products.

GAC	Gross annual costs (pollution abatement)
(D)	Withheld to avoid disclosing operations of individual companies
(X)	Not applicable
(NA)	Not applicable

Table 12. Pollution abatement gross annual operation costs (GAOC) by kind of costs for major selected sectors of the U.S. electronics industry, 1991.

(millions of dollars)

SIC Code	Industry	Operating Costs	Depreciation	Operating Costs by Kind of Cost: Labor Costs	Material/ Supply Costs	Other Costs	SD Est. ($) Op. Costs
	All industries	15763.8	2335.1	3089.2	4832.3	5507.2	2.0
36	Electronic and other electric equipment	756.7	85.6	163.5	155.2	352.4	12.0
361	Electric distribution equipment	23.6	2.4	6.0	3.0	12.2	11.0
362	Electrical industrial apparatus	35.5	2.6	5.5	6.8	20.6	14.0
363	Household appliances	35.1	4.9	9.1	5.7	15.4	15.0
364	Electric lighting and wiring equipment	69.5	4.4	18.2	8.9	38.1	32.0
365	Household audio and video equipment	93.2	1.1	2.2	1.3	88.6	35.0
366	Communications equipment	45.8	3.5	10.4	7.5	24.4	3.0
367	Electronic components and accessories	277.2	33.2	72.5	66.5	105.1	13.0
3671	Electron tubes	18.9	1.7	6.3	2.5	8.4	4.0
3672	Printed circuit boards	81.3	12.6	24.3	27.8	16.5	24.0
3674	Semiconductors and related devices	116.4	13.2	26.5	24.9	51.7	22.0
3675	Electronic capacitors	12.1	1.0	3.5	2.1	5.5	64.0
3676	Electronic resistors	3.1	0.0	1.5	0.5	1.1	83.0
3678	Electronic connectors	16.8	2.5	3.4	3.1	7.9	33.0
3679	Electronic components, n.e.c.	28.6	2.1	6.9	5.7	13.9	10.0
369	Miscellaneous electrical equipment and supplies	176.8	33.5	39.6	55.6	48.0	40.0
357	Computer and office equipment	71.3	5.8	15.1	6.7	43.7	16.0
3571	Electronic computers	21.0	2.2	6.7	1.8	10.3	13.0
3572	Computer storage devices	(D)	(D)	(D)	(D)	(D)	(X)
3575	Computer terminals	1.4	(D)	0.9	0.1	0.5	56.0
3577	Computer peripheral equipment, n.e.c.	30.4	1.0	2.9	2.3	24.3	35.0
3578	Calculating and accounting equipment	(D)	(D)	(D)	(D)	(D)	(X)
3579	Office machines, n.e.c.	5.2	0.3	1.0	1.4	2.6	37.0

Key to Table 12:

- Million dollars, except percents. Totals may not agree with detail because of independent rounding.
- The Pollution Abatement Costs and Expenditures survey includes all manufacturing establishments with 20 employees or more except Major Group 23, Apparel and Other Textile Products.

GAC Gross annual costs (pollution abatement)
(D) Withheld to avoid disclosing operations of individual companies
(X) Not applicable
(NA) Not applicable

Appendix E. Development of a "Meta Matrix" for Evaluation of Sources of Data and Information Related to Environmental Factors

The Meta Matrix is the name given to a procedure used to correlate and evaluate sources of information and data that may be of pertinent interest to the ongoing MCC Environmental Roadmap development effort. These sources have been identified from known federal and private activities or as identified by various individuals who were contacted to provide assistance. The Meta Matrix, by its nature, is not intended to provide more than a compilation and cursory evaluation of the identified resources. Some of these sources simply point to other sources, which, in turn, may point to still others. This is particularly true for those found on the Internet, which has been found to be a very valuable source of highly pertinent data and information. In some cases the data are directly accessible on the "Net" and can be downloaded into the user's computer. Many Internet sites identify or point to activities, publications, or ongoing programs that may be of considerable interest to the electronics industry with respect to source reduction/pollution prevention planning, performance, and evaluation. Other sources identified during the course of the Meta Matrix activity have included publications, reports, computer software, and individuals that may be of considerable interest to this Roadmap activity.

The Meta Matrix consists of a "meta evaluation" of each of the identified sources in a structured format consisting of the following elements:

- Item identification (1)
- Source (2)
- Content (3)
- Accessibility (4)
- Cost factors (5)
- Updating/modification/contemporary value (6)
- Pertinence and value to the *1996 Roadmap* (7)

This approach is, essentially, an attempt to evaluate a number of information sources in a concise manner. Obviously, this approach suffers from over-simplification and may tend to highlight less important sources at the expense of more truly valuable sources. However, for the purpose at hand, the approach makes available an awareness of sources of data and information that could prove to be of considerable value to both the MCC Roadmap effort as well as individual electronics industry companies.

A tabular presentation of the Meta Matrix has been developed in an attempt to quantify the significance and value of each of the identified sources. The numeric values assigned to a particular source for a given matrix element are completely arbitrary, although an attempt has been made to be consistent. During the course of the evaluation it became apparent that a "Future Value" column might serve to enhance several of the sources, which, on the surface, have little to offer at present.

The goal of the source identification and evaluation process was to find useful data, information, "tools," knowledgeable individuals, organizations, and programs that would prove practical to the electronics industry in better understanding the state-of-the-art with respect to:

- Quantities of pollutants emitted by chemical, product, route, industry sector, and process;
- Successful programs of source reduction, pollution prevention, or waste minimization;
- Computer programs that could provide model solution alternatives or planning for source reduction, pollution prevention, and waste minimization; and
- Government program resources available to the private sector to identify pollution prevention alternatives.

As an example of the manner in which the identified sources and their component data and information might be used by the industry for identifying pollution prevention goals and objectives, several of the sources (number 1 - IPPS and number 4 - CES Report) will be discussed briefly. These programs relied on available federal government data, including:

- TRI data (U.S. EPA)
- Aerometric Information Retrieval System (AIRS - U.S. EPA)
- National Pollutant Discharge Elimination System (NPDES - U.S. EPA)
- Human Health and Ecotoxicity Database (HEED - U.S. EPA)
- Toxicological Potency Indices (U.S. EPA)
- Longitudinal Research Database (LRD - U.S. Bur. of the Census)
- Pollution Abatement Cost and Expenditures Survey (PACE - U.S. Bur. of the Census)

Although the approaches used by the two groups differed slightly in terms of outcome and data sources, both activities had similar objectives—to use existing data resources to identify products and processes that were major sources of pollution and energy use in particular industries. Results were characterized in terms of "pollution intensity" for specific industries, or, when possible, pollution intensity identified with particular products manufactured within these industries.

In summary, the TRI database provided accurate estimates of toxic chemical releases for approximately 300 possible chemicals for individual establishments for a given year (e.g., 1987, 1990). The AIRS database provided establishment level data on EPA's priority pollutants (e.g., SO_2, NO_2, CO, VOCs), which are not part of the TRI database. The NPDES data provided pollution discharge estimates by establishment into waste water for several non-TRI substances, including BOD, total suspended solids (TSS), and pH. The HEED data were used to estimate toxicological potencies for individual chemicals. The LRD data (which are of limited public accessibility) were used to provide costs of materials and energy, capital expenditures, total value added to product categories, quantities of specific products produced, and the value of individual shipments, by establishment. The important common denominator among these various data sources was the individual establishment. Because these data could be tied to a particular establishment for a specific year, a series of algorithms could be constructed to relate pollution releases with component chemical toxicities with production intensity of specific products. A primary result of the projects was the ability to rank products according to plant-specific chemical releases generated during their manufacture. The algorithm was able to quantitatively estimate reduction in individual pollutant releases if other processes has been available for manufacture of high toxic intensive products. The Bureau of Census researchers (CEO's Report) emphasized in their report that "…the methodology can be applied to any industry, type of industrial waste, or pollution media."

The IPPS project has been developed into an ongoing project used by the World Bank to develop estimates of pollution intensities for various industries in developing nations based, primarily, on scale of specific industry activity and knowledge of processes used in production.

Both of these projects have used available data to develop usable estimates of pollution intensity associated with industries and/or products manufactured. The techniques appear to be directly applicable to developing pollution priority considerations for the U.S. electronics industry, component (4-digit SIC) industries, and/or individual products produced within these component industries.

The Meta Matrix consists of a "meta evaluation" of each of the identified sources in a structured format consisting of the following elements:

1 Item identification
2 Source
3 Content
4 Accessibility
5 Cost factors
6 Updating/modification/contemporary value
7 Pertinence and value to the *1996 Roadmap*

The matrix follows:

1

1 ITEM: **Industrial Pollution Projection System (IPPS)**

2 SOURCE: World Bank (Internet: http://www.worldbank.org/html/research/ipps/)

3 CONTENT: The IPPS was developed by the World Bank to assist in quantitatively estimating sources of industrial pollution in developing countries. The IPPS was developed by merging U.S. data derived from the Longitudinal Research Database (LRD) of the U.S. Department of Commerce (establishment-level economic data) with several databases (including the TRI database) maintained by the EPA associated with pollution emissions. The IPPS estimates pollution intensity associated with specific 4-digit SIC codes (U.S.) and 4-digit ISIC codes (internationally).

4 ACCESSIBILITY: Much of the World Bank data and the IPPS project are accessible in ZIP files and tables. It is the stated intention of the World Bank to make the IPPS available for use on the Internet site of the World Bank.

5 COST: Free access to all data/information

6 UPDATE: Unknown. The IPPS model, itself, is static. However the data used in the model changes constantly.

7 PERTINENCE: The IPPS may be of prime importance with respect to the MCC Environmental Roadmap. Together with a Bureau of the Census project [see Source 4] using the same approach (for the U.S. chemical industry) this linkage activity could assist the electronics industry in defining priority areas of environmental concern. Unfortunately, 4-digit SIC coded data for the U.S. electronics industry are not readily available from the IPPS published reports. However, discussions with the World Bank staff indicates that such data may be available. In any event, the IPPS approach and/or methodology could be applied to the electronics industry if the appropriate LRD data could be accessed. It is even possible that the model could be used successfully without the LRD data [which are closely held by the Center for Economic Studies (CES) of the U.S. Department of Commerce]. The approach would be to link the readily available U.S. EPA data sets with publicly available Commerce Department data at the 4-digit SIC level.

2

1 ITEM: **Common Sense Initiative (CSI)**

2 SOURCE: U.S. EPA, 401 M. St. SW, Washington, DC 20460

3 CONTENT: The Common Sense Initiative (CSI) was developed by the EPA to provide "…a unique opportunity to move beyond the adversarial relationships that have dominated recent environmental debates to identify 'cleaner, cheaper, smarter' solutions…" The aim is provide a forum, mediated by the EPA, to develop consensus solutions to environmental problems and regulations. Innovation has been stressed as a key perspective by the EPA. The U.S. computer and electronics industry has been selected as one of the initial six industry groups to be involved in the CSI by the EPA.

4 ACCESSIBILITY: It is assumed that all data and information of interest to the Environmental Roadmap would be available to the electronics industry, particularly since this is one of the industries involved in the CSI.

5 COST: Free access to all data/information

6 UPDATE: It is assumed that the CIS is a very dynamic program with new data constantly becoming available.

7 PERTINENCE: Although the CIS is not structured primarily as a data/information resource, it is assumed that because of the real-world approach to identifying and resolving environmental problems, a considerable quantity of data will be generated by the CIS. Certainly, the CIS could be a two-way street if the affected industries can provide effective data and information to substantiate industry positions on practical approaches to environmental regulation.

3

1 ITEM: **Envirofacts**

2 SOURCE: Internet (EPA) (http://www.epa.gov/enviro/html/ef_home.html)

3 CONTENT: This EPA-sponsored Internet site provides integrated, relational data from four major EPA databases: Resource Conservation and Recovery Information System (RCRIS); Toxic Release Inventory System (TRIS); Comprehensive Environmental Response, Compensation, and Liability Information System (CERCLIS); and Permit Compliance System (PCS).

4 ACCESSIBILITY: This is a publicly available report.

5 COST: Free access to all data/information.

6 UPDATE: Unknown.

7 PERTINENCE: The ability to perform on-line, relational searches of these databases makes this a priority environmental Internet site.

4

1 ITEM: **CES Report: "Toxic Waste, Product Choice, and Plant Characteristics: The U.S. Chemical Industries"**

2 SOURCE: Center for Economic Studies (CES), U.S. Bureau of the Census (301-457-1837)

3 CONTENT: This report is very similar to Source 1 (IPPS). Most of the same data resources were used by both groups. However, the CES report provides in-depth economic data at the 4-digit SIC code level and at the five-digit product code level. Although the focus of the report is the U.S. chemical industry, the techniques and data sources would be identical for the U.S. electronics industry. The CEA report focuses more on products/processes which are primary sources of pollution. The object is to identify possible research and development priorities by product class.

4 ACCESSIBILITY: This is a publicly available report.

5 COST: Free access to all data/information (except LRD).

6 UPDATE: This is a final report.

7 PERTINENCE: This report, dated December, 1993, is of considerable importance to the MCC Environmental Roadmap. Together with the IPPS (Source 1), the model developed in the report could be applied to individual 4-digit SIC codes of the U.S. electronics industry and, more importantly, to product classes within these 4-digit SICs. The confidentiality associated with use of the CEA's Longitudinal Research Database (LRD) presents a problem of data access. However, as discussed above (Source 1), this potential problem could possibly be overcome by using non-establishment-specific data sources.

5

1 ITEM: **Annual Survey of Manufacturers (ASM)/Census of Manufacturers (CM)**

2 SOURCE: U.S. Bureau of the Census, U.S. Department of Commerce, Washington, DC 20233

3 CONTENT: These reports are prepared on an annual basis for the U.S. manufacturing sector. The ASM is prepared every year except for years ending in a "2" or a "7." On these years the more detailed Census of Manufacturers (CM) is performed, which includes a greater number of smaller establishments. Survey instruments for these surveys are industry-specific: "MA35Q" for semiconductors, printed wiring board, and miscellaneous electronic components; and "MA35R" for computer manufacturing. The reports focus on economic factors associated with product production including numbers of establishments, employment, wages, costs of materials, value added, value of shipments, and capital expenditures. Also included are costs for fuel and electrical energy.

4 ACCESSIBILITY: This is a publicly available report.

5 COST: Free access to all data/information.

6 UPDATE: This is a final report.

7 PERTINENCE: These reports provide some of the most pertinent statistical data available for the MCC Environmental Roadmap with respect to electronic industry production activities. They form the basis for estimating the economic impact of the industry's manufacturing activities.

6

1 ITEM: **U.S. Industrial Outlook**

2 SOURCE: International Trade Administration, U.S. Department of Commerce, Washington, DC

3 CONTENT: This annual report draws on government source data, primarily from the Department of Commerce, to summarize the nation's past performance and make projections for the current year based on previous years' data and incomplete data collected for the current year. It is the most up-to-date, authoritative source for projecting expectations for all U.S. industry for the coming year (the report is published in January of the affected year). The report draws heavily on Department of Commerce surveys and also provides an international outlook with individual industry comparisons. Chapter 15 is dedicated to electronic components (SIC 367) and Chapter 26 concerns computer and related device manufacturing (SIC 357). The principal value of this annual publication is in the summary tabulations and annual projections.

4 ACCESSIBILITY: This is a publicly available report.

5 COST: Free access to all data/information.

6 UPDATE: This is a final report (annually).

7 PERTINENCE: These reports provide some of the most pertinent statistical data available for the MCC Environmental Roadmap with respect to electronic industry production activities as projected into the coming year. The reports also provide an international perspective for comparing statistics for the U.S. vs. world electronics industries.

7

1 ITEM: **Electronic Bulletin Board (EBB)**

2 SOURCE: U.S. Department of Commerce (202-482-1986)

3 CONTENT: The Electronic Bulletin Board (EBB) is sponsored by the Department of Commerce as an on-line resource for obtaining a considerable quantity of data and information developed by the Department for downloading onto the user's computer. Besides current trade statistics produced by the Department, a wide range of statistical data prepared by other government agencies are also available.

4 ACCESSIBILITY: On-line computer bulletin board and Internet.

5 COST: Both free access and subscription (detailed data access).

6 UPDATE: This is a final report (annually).

7 PERTINENCE: These reports provide some of the most pertinent statistical data available for the MCC Environmental Roadmap with respect to electronic industry production activities as projected into the coming year. The reports also provide an international perspective for comparing statistics for the U.S. vs. world electronics industries.

8

1 ITEM: **National Economic, Social and Environmental Data Bank (NESE)**

2 SOURCE: U.S. Department of Commerce (202-482-1986)

3 CONTENT: This CD-ROM is published quarterly by the Department of Commerce and contains information and data pertaining to the U.S. economy, social programs, and environmental programs. The knowledge contained on the CD-ROM is available elsewhere, but the CD-ROM provides a convenient access instrument, particularly if quarterly availability of data is sufficient.

4 ACCESSIBILITY: CD-ROM

5 COST: Single quarter - $95; 4 quarters - $360

6 UPDATE: Quarterly

7 PERTINENCE: The primary value of the CD-ROM for the MCC Environmental Roadmap is ease of access to timely data. Only the EBB would have more current data. The NESE CD-ROMs include most of the more pertinent Department of Commerce data of interest concerning the electronics industry. However, some of the data are summary only. One useful aspect of the CD-ROM is the extensive use of spreadsheets for downloading data (Lotus files).

9

1 ITEM: **The National Trade Data Bank (NTDB)**

2 SOURCE: U.S. Department of Commerce (202-482-1986)

3 CONTENT: This CD-ROM is published monthly by the Department of Commerce and contains information and data pertaining to export import statistics of the U.S. It is probably the most readily available source of such data and information from the federal government. Also, the CD-ROM contains numerous reports associated with international trade, for example, the U.S. semiconductor and computer industries.

4 ACCESSIBILITY: CD-ROM

5 COST: Single month - $35; 4 quarters - $360

6 UPDATE: Monthly

7 PERTINENCE: The primary value of the CD-ROM for the MCC Environmental Roadmap is ease of access to timely data concerning export/import statistics of the U.S. electronics industry. Although not directly pertinent, the statistical data may be of considerable value in estimating pollution prevention/”take back”/”end-of-life” considerations for exported electronic products. As with the NESE CD-ROM, extensive use is made of spreadsheets for downloading data (Lotus files). The industry-specific trade statistic reports are especially valuable for timely access and downloading.

10

1 ITEM: **Waste Wi$e**

2 SOURCE: U.S. EPA, 401 M. St. SW, Washington, DC 20460

3 CONTENT: This voluntary EPA program seeks to encourage companies to eliminate industrial waste through waste reduction and recycling. The program focuses on municipal solid waste reduction. The EPA provides registration and assistance. Participating companies are encouraged to provide EPA with "success stories."

4 ACCESSIBILITY: Direct, free access

5 COST: No cost for data access

6 UPDATE: Unknown

7 PERTINENCE: The primary value of this EPA program to the Roadmap activity is in obtaining anecdotal information of "success stories" of participating companies. The real value of this source may be in future years, if a considerable number of electronic industry companies participate.

11

1 ITEM: **Public Environmental Reporting Initiative (PERI)**

2 SOURCE: PERI

3 CONTENT: PERI is a set of guidelines developed by interested companies related to improving and reporting on environmental performance. The guidelines cover environmental policy, environmental resources, and environmental compliance.

4 ACCESSIBILITY: Direct, free access.

5 COST: No cost for data access.

6 UPDATE: Unknown.

7 PERTINENCE: PERI is less a source of data and information at this time as it is a framework for achieving environmental excellence by participating companies. The value of this program for the MCC Environmental Roadmap is in providing electronics industry companies with data and information that could be used in assessing company performance in accordance with the Guidelines. In future years, the PERI program could be a source of knowledge for the electronics industry as companies achieve voluntary Guideline compliance.

12

1 ITEM: **Toxic Release Inventory (TRI)**

2 SOURCE: U.S. EPA (Office of Pollution Prevention and Toxics: 202-260-1531)

3 CONTENT: The Toxic Release Inventory (TRI) database has become a primary source of practical, usable information and data concerning individual manufacturing company performance with respect to pollution prevention and waste minimization activities in the U.S. The required reporting of toxic chemicals in general use in manufacturing by route of

release/transfer for all but very small companies has resulted in a rich source of annual performance data since 1987. The data become available in May/June of the second year following the reporting year (e.g., data for 1993 became available in May-June, 1995). Data are initially available on the TOXNET on-line database of the National Library of Medicine (NLM) and later are published on a CD-ROM.

4 ACCESSIBILITY: TOXNET database; CD-ROM; EPA Internet.

5 COST: TOXNET (paid subscription): CD-ROM - $35/year.

6 UPDATE: Annual.

7 PERTINENCE: The TRI data are immediately recognized as a primary source of very valuable data concerning the pollution prevention and waste minimization activities of the U.S. electronics industry. No other source of information even comes close to matching the values of this EPA activity. Although the chemicals to be reported are limited to 300 to 600 (depending on the reporting year), the universal nature of compliance by the manufacturing sector according to a set format by individual establishment makes the TRI a required component in any industry program associated with pollution prevention. The anecdotal data collected since 1992 associated with pollution prevention "success stories" will become a highly valuable resource in future years.

13

1 ITEM: **Current Industrial Reports (CIR)**

2 SOURCE: U.S. Department of Commerce (202-482-1986)

3 CONTENT: These reports are based on the Annual Survey of Manufacturers and the Census of Manufacturers and represent more detailed examination of economic factors associated with production activities. The sub-sample of companies included in these surveys provide data that are projected to the industry (4-digit SIC) as a whole. Of particular importance is an annual report on pollution costs and expenditures. These cost data are stratified into several categories including "Pollution Abatement Capital Expenditures" (PACE) and "Pollution Abatement Operating Costs" (PAOC). These categories are further stratified according to route (i.e., "air," "water," etc.)

4 ACCESSIBILITY: This is a publicly available report.

5 COST: No cost for data access.

6 UPDATE: Annual.

7 PERTINENCE: The costs of purchasing and operating pollution control devices and equipment is documented by the program on an annual basis. The importance to the MCC Environmental Roadmap is in having benchmark cost data available for the U.S. electronics industry at the 4-digit level. Together with data from other resources, estimates possibly could be made on pollution abatement costs per unit product. Many other similar comparison possibilities may exist.

14

1 ITEM: **33/50 Program**

2 SOURCE: U.S. EPA, 401 M. St. SW, Washington, DC 20460

3 CONTENT: The 33/50 Program of the EPA is a voluntary program initiative that promotes reductions in releases and transfers of 17 high-priority toxic chemicals. Companies participating in the program aimed for 33% reduction in all of these chemicals by 1992, with a 50% total reduction by 1995. Reports of achieving the target objective by the deadline dates have been an integral feature of this program.

4 ACCESSIBILITY: Data are publicly available.

5 COST: No cost for data access.

6 UPDATE: On-going.

7 PERTINENCE: Although the chemicals associated with the program are limited, the importance of this EPA program to the MCC Environmental Roadmap lies in the nature of the program in achieving voluntary chemical release/transfer reductions within defined time intervals by any means desired. The Program has provided industry with the initiative to achieve the stated objectives on its own. The resulting “success stories” may provide a wealth of useful information concerning individual electronic industry company approaches in meeting the desired reductions.

15

1 ITEM: **Pollution Prevention Information Clearinghouse (PPIC)**

2 SOURCE: U.S. EPA (202-260-1023)

3 CONTENT: The Pollution Prevention Information Clearinghouse is primarily a distribution center for EPA documents associated with source reduction and pollution prevention.

4 ACCESSIBILITY: Data are publicly available.

5 COST: Documents are available free of cost.

6 UPDATE: On-going.

7 PERTINENCE: The importance of the Clearinghouse is that it is a source of available published EPA data. It is possible that the Clearinghouse may be the first source of certain EPA reports.

16

1 ITEM: **National Industrial Competitiveness through Energy, Environment, and Economics (NICE3)**

2 SOURCE: U.S. EPA and U.S. DOE, Washington, DC

3 CONTENT: This jointly funded EPA-DOE program provides grants to individual state/industry partnerships directed at improving industry energy efficiency, reducing energy costs, and promoting clean production.

4 ACCESSIBILITY: Data are publicly available.

5 COST: Data are publicly available free of cost.

6 UPDATE: On-going.

7 PERTINENCE: The value of this program to the MCC Environmental Roadmap is associated with the documented "success stories" that are applicable to the U.S. electronics industry. As with other programs geared to demonstrating innovative approaches to achieving source reduction and pollution prevention, the ultimate value of this program may be in the future, as more electronic industry companies participate.

17

1 ITEM: **P2/Finance Commuter Program**

2 SOURCE: Tellus Institute, Philadelphia, PA

3 CONTENT: P2/Finance is an innovative approach to analyzing costs associated with pollution prevention. The software consists of a series of Microsoft Excel spreadsheets for determining individual company costs associated with pollution prevention activities.

4 ACCESSIBILITY: Computer program available from Tellus Institute.

5 COST: Program casts less than $100.

6 UPDATE: Unknown.

7 PERTINENCE: This computer program appears to include all reasonable variables associated with the costs of pollution prevention for a company. It is possible that multi-company users could combine similar data for industry projections. Although the program itself is fairly rudimentary, it could be considerably enhanced for use in the U.S. electronics industry. The approach is very interesting and deserves in-depth evaluation.

18

1 ITEM: **Manufacturing Consumption of Energy**

2 SOURCE: U.S. Department of Energy, Washington, DC

3 CONTENT: This Department of Energy publication provides data concerning energy consumption for the U.S. manufacturing sector by 4-digit SIC code. Included are stratified data by type of energy resource, type of use, and quantities used.

4 ACCESSIBILITY: Publicly available data.

5 COST: Publication cost only.

6 UPDATE: Annual.

7 PERTINENCE: This program and documentation provides benchmark data for the U.S. electronics industry with respect to amounts of energy consumed including a number of pertinent variables. Together with other data (e.g., Department of Commerce) the data in this source can assist in estimating energy consumption by manufacturing process or unit product.

19

1 ITEM: **Existing Chemicals Program**

2 SOURCE: U.S. EPA, 401 M. St. SW, Washington, DC 20460

3 CONTENT: An EPA program for screening and testing chemicals associated with pollution prevention and risk reduction.

4 ACCESSIBILITY: Publicly available data.

5 COST: Data are publicly available free of cost.

6 UPDATE: Ongoing.

7 PERTINENCE: Could assist companies in selecting less toxic chemicals for use in manufacturing.

20

1 ITEM: **CIESIN (Consortium for International Earth Science Information Network)**

2 SOURCE: Internet (CIESIN) (Internet: http://www.ciesin.org/)

3 CONTENT: Consortium with considerable data/information concerning earth sciences. Fairly broad-based environmental focus. Includes active participation of several universities and federal governmental agencies (considerable funding from NASA and ATSDR). Objectives related to improving access to data/information for public policy decision making. Has special "Gateway" software tool for in-depth searching of data files maintained on-line.

4 ACCESSIBILITY: Unlimited (Internet).

5 COST: Free access to all data/information/sites.

6 UPDATE: Unknown.

7 PERTINENCE: Could be a very valuable resource for Roadmap. May involve future working relationship between CIESIN and MCC for data exchange.

21

1 ITEM: **Dataquest Data & Reports**

2 SOURCE: Dataquest, Inc., San Jose, CA (408-437-8000)

3 CONTENT: Dataquest is a private company that conducts comprehensive data and information surveillance of production and economic statistics of various industrial segments. The company has produced various reports for client companies concerning the semiconductor and computer industries. These reports and data are not available except through direct purchase.

4 ACCESSIBILITY: Limited (purchase only).

5 COST: Expensive to very expensive.

6 UPDATE: On-Call.

7 PERTINENCE: If cost was not a factor, the data and information that could be provided by this organization could be of considerable value. The company's knowledge of data/information resources, particularly for the U.S. electronics industry, is probably unmatched.

22

1 ITEM: **New Chemicals Program**

2 SOURCE: U.S. EPA (Office of Toxic Substances, 401 M. St. SW, Washington, DC 20466)

3 CONTENT: This program seeks to assess the toxicity of new chemicals under consideration for import in the U.S. or manufactured here. Of key concern is preventing pollution before it occurs. An inventory of chemicals is maintained in the TSCA inventory for companies desiring to import or manufacture a chemical not listed. The data concerning toxicity of all chemicals in the TSCA inventory is available for public access and review.

4 ACCESSIBILITY: Unlimited access.

5 COST: Free access to all data/information.

6 UPDATE: On-going.

7 PERTINENCE: The TSCA Inventory database can be of considerable value together with the EPA's Existing Chemical program to obtain knowledge concerning chemical toxicity for pollution prevention purposes.

23

1 ITEM: **Pollution Prevention Directory**

2 SOURCE: U.S. EPA, 401 M. St. SW, Washington, DC 20466

3 CONTENT: This directory contains listings of EPA voluntary, grant, and regulatory programs associated with pollution prevention. Also identified are individual state pollution prevention programs as well as other federal programs dealing with the subject, as well as listings of

clearinghouses, databases, periodicals, directories, hotlines, centers, and associations associated with pollution prevention.

4 ACCESSIBILITY: Publication.

5 COST: Free access.

6 UPDATE: Unknown - probably infrequent.

7 PERTINENCE: Good secondary information source. Contains identification of resources not identified elsewhere.

24

1 ITEM: **Global Environmental Management Initiative (GEMI)**

2 SOURCE: GEMI

3 CONTENT: Organization of companies dedicated to fostering worldwide environmental excellence by promoting a business ethnic for environmental management and sustainable development.

4 ACCESSIBILITY: Unlimited.

5 COST: Free access to all data/information.

6 UPDATE: Unknown.

7 PERTINENCE: The growing number of companies (especially electronics industry companies) associated with this program and the consensus of member companies could be of considerable present and future value in attaining pollution prevention objectives. The success stories of member companies in resolving pollution problems would be of great use.

25

1 ITEM: **Chemical Use Clusters Scoring Methodology**

2 SOURCE: U.S. EPA, 401 M. St. SW, Washington, DC 20466

3 CONTENT: EPA program for using algorithms to score the combined effects of groups of chemical substances used in various manufacturing processes. The purpose of the system is to emphasize the importance of pollution prevention and particularly the use of safer substitutes. The system operates by creating chemical use clusters—sets of competing chemicals and technologies for a given use.

4 ACCESSIBILITY: Unlimited use.

5 COST: Free access to all data/information.

6 UPDATE: Unknown.

7 PERTINENCE: Together with other resources (e.g., known chemical use patterns, toxicity information, existing chemical data, and new chemicals data), could be used a as a predictive

model to classify desirable vs. undesirable chemicals with respect to pollution prevention intensity.

26

1 ITEM: **Environmental RouteNet**

2 SOURCE: Internet (private) (Internet: http://www.csa.com/htbin/disphtml.cgi?un=none&ac=n)

3 CONTENT: Extensive source and links to many environmental sites on the Internet. Maintained by Cambridge Scientific Abstracts (CSA), which charges a fee for really detailed data access.

4 ACCESSIBILITY: Unlimited (Internet).

5 COST: Greater amount of free access to data. CSA databases are accessed on paid subscription basis and include: EIS digest of EIS databases, Pollution database, Risk database, and Toxicology database.

6 UPDATE: Unknown (assume frequent).

7 PERTINENCE: Several of subscription databases (e.g., pollution database) could be of considerable value (fee involved for access).

27

1 ITEM: **EnviroLink Network**

2 SOURCE: Internet (private) (Internet: http://envirolink.org/about.html)

3 CONTENT: Small- to medium-sized Internet site operated primarily by volunteers. Most links also are available from other more robust Internet sites, although not all. More of a public interest orientation.

4 ACCESSIBILITY: Unlimited (Internet).

5 COST: Free access to all data/information/sites.

6 UPDATE: Unknown (assume low key).

7 PERTINENCE: Low interest, although useful to check periodically.

28

1 ITEM: **EcoWeb**

2 SOURCE: Internet (University of Virginia)

3 CONTENT: Both data/information developed at the University of Virginia and links provided to other sites on the Internet

4 ACCESSIBILITY: Unlimited (Internet).

5 COST: Free access to all data/information/sites.

6 UPDATE: Unknown.

7 PERTINENCE: May have some pertinent data developed at the University of Virginia.

29

1 ITEM: **A Guide to Environmental Resources on the Internet**

2 SOURCE: Internet (private)

3 CONTENT: Directory of environmental sites on the Internet.

4 ACCESSIBILITY: Unlimited (Internet).

5 COST: Free access to all data/information/sites.

6 UPDATE: Unknown.

7 PERTINENCE: Several categories appear to be promising for further evaluation including “air pollution,” “greenhouse effects/ozone depletion,” “hazardous waste/pollutants,” and “recycling.”

30

1 ITEM: **CEDAR (Centrl. Eur. Environ. Data Req. Fac.)**

2 SOURCE: Internet (Internet: http://pan.cedar.univie.ac.at/)

3 CONTENT: Directory of environmental resources throughout world, with emphasis on European resources.

4 ACCESSIBILITY: Unlimited (Internet).

5 COST: Free access to all data/information/sites.

6 UPDATE: Unknown.

7 PERTINENCE: Many Internet sites not references elsewhere. Could be of considerable value.

31

1 ITEM: **University of Windsor and ECDM**

2 SOURCE: Internet (University of Windsor, Canada)
(Internet: http://ie.uwindsor.ca/ecdm_lab.html)

3 CONTENT: The Department of Industrial and Manufacturing Systems at the University of Windsor. Primary interest is ECDM (Environmentally Conscious Design and Manufacturing Infobase) which could contain pertinent data and/or knowledge on use/modeling of data.

4 ACCESSIBILITY: Unlimited (Internet).

5 COST: Free access to all data/information/sites.

6 UPDATE: Unknown.

7 PERTINENCE: Could be of considerable pertinence, at least indirectly, with respect to methodology and data modeling.

32

1 ITEM: **EPIC (Environmental Pollution Information Clearinghouse)**

2 SOURCE: Internet (U.S. Department of Energy) (Internet: http://146.138.5.107/)

3 CONTENT: Primary P2 data and information associated with Department of Energy activities and interests.

4 ACCESSIBILITY: Much of the data/information can be publicly accessed. Certain portions are password protected from direct access.

5 COST: Free access to most data/information.

6 UPDATE: Probably very frequent updating (including minutes of meetings).

7 PERTINENCE: Certain of the listed data/sites appear to be highly relevant.

33

1 ITEM: **SERDP (Strategic Environmental Research and Development Program)**

2 SOURCE: Internet (DOD-EPA-DOE Consortium)
(Internet: http://prop.wes.army.mil/serdp/home.html)

3 CONTENT: Site is under construction, but looks promising.

4 ACCESSIBILITY: Unlimited (Internet).

5 COST: Free access to all data/information/sites.

6 UPDATE: Unknown.

7 PERTINENCE: Difficult to determine value at present since site is under construction. Could be very useful. SERDP also funds the Enviroene program (see Source 53).

34

1 ITEM: **EMPF (Electronics Manufacturing Productivity Facility)**

2 SOURCE: Internet (U.S. Navy) (http://www.engr.iupui.edu/empf/)

3 CONTENT: Data and information of interest to U.S. Navy including technical reports and other publications dealing with electronics manufacturing productivity.

4 ACCESSIBILITY: Unlimited (Internet).

5 COST: Free access to all data/information/sites.

6 UPDATE: Unknown.

7 PERTINENCE: Because of emphasis on electronics manufacturing, could be of considerable importance.

35

1 ITEM: **SAGE (Solvent Alternatives Guide)**

2 SOURCE: Internet (EPA/RTI) (Internet: http://clean.rti.org/)

3 CONTENT: EPA software "tool" on the Internet for downloading. Assists companies in alternative solvent selection decisions.

4 ACCESSIBILITY: Unlimited (Internet)

5 COST: Free access to all data/information/software.

6 UPDATE: Unknown.

7 PERTINENCE: The SAGE program could be of considerable value as a "standalone" tool for end-user companies in making decisions involving solvent selection, or incorporated as part of a decision-making program with other consideration components. The SAGE software tool was not evaluated.

36

1 ITEM: **EPA Home Page**

2 SOURCE: Internet (EPA) (Internet: http://www.epa.gov/)

3 CONTENT: "Top Level" Internet home page for EPA. Includes EPA gopher, ftp access as well as WAIS indexes for on-line searching.

4 ACCESSIBILITY: Unlimited (Internet).

5 COST: Free access to all data/information/sites.

6 UPDATE: Assume frequent updating.

7 PERTINENCE: Important Internet site for continuing access to new EPA data/news, etc.

37

1 ITEM: **I3LA (Initiative for Information Infrastructure and Linkage Applications)**

2 SOURCE: USN sponsored Internet site
(Internet: ftp://taurus.cs.nps.navy.mil/pub/i3la/i3la.html)

3 CONTENT: I3LA contains both general and specific information with emphasis on information linkages.

4 ACCESSIBILITY: Unlimited (Internet).

5 COST: Free access to all data/information/sites.

6 UPDATE: Unknown.

7 PERTINENCE: Techniques used to link environmental data may be of importance to Roadmap. The pertinence of actual data is uncertain.

38

1 ITEM: **GILS (Government Information Locator Service)**

2 SOURCE: Internet (U.S. Government Agencies) (Internet: http://www.usgs.gov/gils/)

3 CONTENT: U.S. Government initiative (demonstration site apparently sponsored by USGS). Its purpose is to make publicly funded data/information available to the public(!) and other government agencies via the Internet.

4 ACCESSIBILITY: Unlimited (Internet). Could be some restricted access.

5 COST: Free access to all data/information/sites.

6 UPDATE: Unknown.

7 PERTINENCE: Could be of considerable value depending on government agency and type of data. The software access tools could also be of value. Only implemented in a few agencies at present.

39

1 ITEM: **USGS Home Page**

2 SOURCE: Internet (USGS, DOI) (Internet: http://www.usgs.gov/)

3 CONTENT: Data and information of importance to USGS, including environmental research and data products.

4 ACCESSIBILITY: Unlimited (Internet).

5 COST: Free access to all data/information/sites.

6 UPDATE: Unknown.

7 PERTINENCE: Certain areas may be of interest, especially environmental data manipulation and computer software tools. Actual value of data is uncertain.

40

1 ITEM: **Access EPA**

2 SOURCE: Internet (EPA)

3 CONTENT: Appears to be the Internet version of EPA's hard copy publication of same name. Includes a WAIS query tool. Home page is topically organized for easy access to EPA area.

4 ACCESSIBILITY: Unlimited (Internet).

5 COST: Free access to all data/information/sites.

6 UPDATE: Unknown (supposedly, at least annually).

7 PERTINENCE: Because of WAIS query capability, may be useful as an *ad hoc* source for data and information access.

41

1 ITEM: **National Toxicology Program (NTP)**

2 SOURCE: Internet (NIEHS/NTP/FDA) (http://ntp-server.nih.gov/))

3 CONTENT: Provides Internet access to the National Toxicology Program sponsored by the EPA, NIEHS, and FDA.

4 ACCESSIBILITY: Unlimited (Internet).

5 COST: Free access to all data/information/sites.

6 UPDATE: Unknown.

7 PERTINENCE: Considerable primary source of (official) evaluated toxicological data by U.S. government. Cited by regulatory agencies as evidence of recognized toxicity of chemical substances.

42

1 ITEM: **U.S. Department of Commerce Home Page**

2 SOURCE: Internet (Department of Commerce) (Internet: http://www.doc.gov/)

3 CONTENT: Contains data and information concerning the policies and activities of the Department of Commerce. Provides access to the NTDB (National Trade Data Bank) and NESE (National Economic, Social, and Environmental Data Bank). Sponsors the EBB (Economics Bulletin Board) and NOAA databases. Also access to Bureau of the Census demographic data by industry.

4 ACCESSIBILITY: Unlimited (Internet) [also CD-ROM & BBS].

5 COST: Free and subscription access to all data/information.

6 UPDATE: Frequent updating, based on quarterly reports.

7 PERTINENCE: Certain data/information are of considerable value to Roadmap, including EBB and NESE, which contain production costs and statistics by SIC and product codes and costs associated with pollution controls and energy consumption. The LRD data would be of great use if linked to the TRI data for the same establishments.

43

1 ITEM: **FedWorld**

2 SOURCE: Internet (U.S. Government) (Internet: http://www.fedworld.gov/)

5 COST: Free access to all data/information/sites.

6 UPDATE: Unknown.

7 PERTINENCE: May be of limited use in locating federal government Internet sites.

44

1 ITEM: **Environmental Sites on the Internet**

2 SOURCE: Internet (Royal Institute of Technology Library, Sweden)
(Internet: http://www.lib.kth.se/lg.html)

3 CONTENT: Comprehensive directory of Internet resources associated with the environment. Very broad in nature with many foreign sites.

4 ACCESSIBILITY: Unlimited (Internet).

5 COST: Free access to all data/information/sites.

6 UPDATE: Unknown.

7 PERTINENCE: Most of the useful Internet sites are duplicated in other Internet directories. Several foreign sites are not listed elsewhere—may contain useful data.

45

1 ITEM: **ISO Online**

2 SOURCE: Internet (ISO) (Internet: http://www.iso.ch/)

3 CONTENT: Information and meeting schedules related to ISO activities.

4 ACCESSIBILITY: Unlimited (Internet).

5 COST: Free access to all data/information/sites.

6 UPDATE: Assume frequent updating.

7 PERTINENCE: Probably not of direct value, but may be useful for inclusion on MCC's home page.

46

1 ITEM: **Environ/Net!**

2 SOURCE: Internet (private group) (http://www.w3.org/hypertext/DataSources/bySubject/)

3 CONTENT: Listing/access to companies and organizations dealing with the environment, includes index of "solutions" for environmental "problems."

4 ACCESSIBILITY: Unlimited (Internet).

5 COST: Free access to all data/information/sites.

6 UPDATE: Unknown.

7 PERTINENCE: Questionable value. Appears to be high on commercial content. However, the resources associated with real solutions to environmental problems should be assessed.

47

1 ITEM: **EINet Galaxy**

2 SOURCE: Internet (private company) (Internet: http://www.einet.net/)

3 CONTENT: General directory provided by commercial Internet provider company. Lists several categories of potential interest including "computer technology" and "environment."

4 ACCESSIBILITY: Unlimited (Internet).

5 COST: Free access to all data/information/sites.

6 UPDATE: Unknown.

7 PERTINENCE: Probably of limited use for the Roadmap. A one-time evaluation is in order to see if any data/information/sites are unique. Otherwise, only infrequent access would be of interest.

48

1 ITEM: **U.S. Bureau of the Census Home Page and DES (Data Extraction System)**

2 SOURCE: Internet (U.S. Bureau of the Census, Department of Commerce)
(Internet: http://www.census.gov/DES/welcome.html)

3 CONTENT: Access to activities, information and data of the U.S. Bureau of the Census. Includes WAIS search capability. DES provides a means for in-depth searching of census data and downloading.

4 ACCESSIBILITY: Unlimited (Internet).

5 COST: Free access to all data/information/sites.

6 UPDATE: Assume frequent updating.

7 PERTINENCE: Probably highly significant to MCC's Roadmap activity with respect to timely access to updated Census Bureau data and information, especially those census surveys that include production electronics industry data/pollution control costs/units manufactured, etc. Data may also be available via the Bureau of the Census EBB on-line. However, this Internet site may have data available earlier than the NESE and NTDB CD-ROMs.

49

1 ITEM: **ENN (Environmental News Network)**

2 SOURCE: Internet (private group) (Internet: http://www.enn.com/)

3 CONTENT: Fashioned after CNN. Contains directory of news and Internet sites related to the environment.

4 ACCESSIBILITY: Unlimited (Internet).

5 COST: Free access to all data/information/sites.

6 UPDATE: Unknown.

7 PERTINENCE: Of unknown value to MCC's Roadmap activity. Requires one-time evaluation to determine if unique data/information are available.

50

1 ITEM: **ATSDR and ATSDR Science Corner**

2 SOURCE: Internet (ATSDR) (Internet: http://atsdr1.atsdr.cdc.gov:8080/atsdrhome.html)

3 CONTENT: This agency's Internet site has been extensively developed in-house (Dr. Charles Xintaras) and is a valuable resource of data/information related to toxics in the environment and contains links to many other Internet sites.

4 ACCESSIBILITY: Unlimited (Internet).

5 COST: Free access to all data/information/sites.

6 UPDATE: Unknown.

7 PERTINENCE: Certain portions of this Internet site could be of considerable interest, including a directory of other pertinent sites.

51

1 ITEM: **WWW Virtual Library**

2 SOURCE: Internet (private group) (http://www.w3.org/hypertext/DataSources/bySubject/)

3 CONTENT: Large indexed general directory of Internet sites, including "environment" as a primary category. Also includes governmental agency areas.

4 ACCESSIBILITY: Unlimited (Internet).

5 COST: Free access to all data/information/sites.

6 UPDATE: Unknown.

7 PERTINENCE: Probably duplicates environmental resource listings in other general directories on the Internet. Should be given one-time evaluation for unique sites.

52

1 ITEM: **Enviroene**

2 SOURCE: SERDP (DOD-EPA-DOE sponsored program)
(Internet: http://wastenot.inel.gov/envirosense/)

3 CONTENT: Enviroene appears to be a major source of pollution prevention data and information in the making involving a federal agency network with distributed data management. Capabilities include a solvent umbrella that will allow users to search as many as sixteen component databases through a single command structure within the Internet environment. A major objective is to improve industry access to technical P2 information and assisting industry in implementing P2 alternatives.

4 ACCESSIBILITY: Unlimited (Internet).

5 COST: Free access to all data/information/sites.

6 UPDATE: Assume frequent updating.

7 PERTINENCE: Probably highly significant to MCC's Roadmap activity with respect to access to multi-agency data and information that is highly pertinent to pollution prevention activities. The available information concerning the development of this program is very impressive. Could be one of the most significant sources of practically usable data and information with respect to pollution prevention planning.

53

1 ITEM: **Industrial Pollution Prevention Project (IP3)**

2 SOURCE: U.S. EPA (Office of Water: 202-260-7811)

3 CONTENT: The EPA initiated the Industrial Pollution Prevention Project in 1991 to assist the agency in determining how pollution prevention can be incorporated into EPA's assessment of best available technology for specific industries. The program has involved sponsorship of research studies, demonstration project, and outreach activities.

4 ACCESSIBILITY: Unlimited access.

5 COST: Free access to all data/information/sites.

6 UPDATE: Limited updating; project-specific.

7 PERTINENCE: Many if the activities associated with the IP3 project appear to have strong interest for MCC's Roadmap activity. If the program continues into the future, there could be considerably more pertinent data and information available to the electronics industry.

54

1 ITEM: **SIA Trade Statistics Program**

2 SOURCE: Semiconductor Industry Association (SIA) (408-436-6600)

3 CONTENT: The Trade Statistics program of the SIA serves to provide participating SIA member companies with statistical data concerning sales of semiconductor devices throughout the world. Data are supplied by member companies to a third party that is responsible for compiling the data and publishing an annual report concerning the industry's annual production experience.

4 ACCESSIBILITY: Data available from the SIA.

5 COST: Annual report is sold by SIA.

6 UPDATE: Annually.

7 PERTINENCE: The SIA data, combined with value of shipments data derived from the Department of Commerce and TRI data from the EPA, could provide MCC's Roadmap activity with detailed knowledge concerning the status of semiconductor device production in the U.S. Such basic knowledge could assist in measuring the nature and scope of pollution emanating from the industry on a product-by-product basis.

55

1 ITEM: **UCLA Center for Clean Technology**

2 SOURCE: UCLA (310-206-3071)

3 CONTENT: The stated goal of the Center for Clean Technology is to create a science, technology, and human resource base for the design of clean, economically competitive technologies. The Center seeks to work with academia, industry, and government in identifying and resolving problems associated with remediation, pollution prevention, environmental transport, treatment, and disposal technologies.

4 ACCESSIBILITY: Unlimited (Internet); direct program contact at UCLA.

5 COST: Free access to all data/information.

6 UPDATE: Unknown; project specific.

7 PERTINENCE: Although the resources available to this Center are limited, it represents a source of academic excellence dedicated to research into pollution prevention. Such university centers can provide valuable resources for directed research into finding pollution control/prevention solutions.

Item #	Type	Source of Item	Access	Cost	Update	Pertinence	Future
1	P	IPPS (World Bank)	1	1	3	3+	3
2	P	Commonene Initiative (EPA)	1	1	2	2	3
3	I	Envirofacts	1	1	UNK	3	3
4	R	CES (U.S. Bureau of the Census) (Streitweiser Project)	1	1	3	3+	3
5	P, R	ASM/CM (U.S. Bureau of the Census)	1	1	2	3	3
6	R	Industrial Outlook Reports (U.S. Dept. of Commerce)	1	1	2	2	2
7	I	EBB (U.S. Dept. of Commerce)	1	2	1	3	3
8	R	NESE (U.S. Dept. of Commerce)	1	2	2	3	3
9	R	NTDB (U.S. Dept. of Commerce)	1	2	2	2	2
10	P	Wastewi$e (U.S. EPA)	1	1	3	2	2
11	P	PERI	1	1	3	2	2
12	P, I	TRI Database (U.S. EPA)	1	2	2	3+	3
13	R	CIR (U.S. Dept. of Commerce)	1	1	2	3	3
14	P	33/50 Program (U.S. EPA)	1	1	2	2	3
15	R	Pollution Prevention Clearinghouse	1	1	2	2	2
16	P	NICE3	1	1	2	2	3
17	C	P2 Finance (Tellus Institute)	1	2	3	3+	3
18	R	Manufacturing Consumption of Energy (U.S. Dept. of Energy)	1	1	1	2	3
19	P	Existing Chemicals Program (U.S. EPA)	1	1	2	3	3
20	P, I	CIESIN	1	1	1	3+	3
21	P	Dataquest	1	3	1	2	2
22	P	New Chemicals Program (U.S. EPA)	1	1	1	2	3
23	R	Pollution Prevention Directory	1	1	2	3	3
24	P	GEMI	1	1	2	2	3
25	C	Chemical Use Clusters Scoring System (U.S. EPA)	1	1	3	3	3
26	P, I	Environmental Routenet	1	1, 2	2	3	3
27	I	Envirolink Network	1	1	UNK	2	3
28	I	Ecoweb	1	1	UNK	2	2
29	I	A Guide to Environmental Resources on the Internet	1	1	UNK	2	2
30	P, I	CEDAR	1	1	UNK	2	3
31	P, I	U. Windsor and ECDM	1	1	UNK	2	3

(continued on next page)

Item #	Type	Source of Item	Access	Cost	Update	Pertinence	Future
32	I	EPIC	1	1	1	3	3
33	P, I	SERDP	1	1	UNK	2	3
34	P, I	EMPF	1	1	3	1	2
35	C, I	Solvent Alternatives Guide (SAGE)	1	1	3	3	3
36	P, I	EPA Home Page	1	1	1	2	3
37	P, I	I3LA	1	1	UNK	1	2
38	I	Government Information Locator Services (GILS)	1	1	1	2	3
39	P, I	USGS Home Page	1	1	1	2	3
40	R, I	Access EPA	1	1	2	2	2
41	I	National Toxicology Program	1	1	2	3	3
42	P, I	U.S. Dept. of Commerce Home Page	1	1	1	2	3
43	I	Fedworld	1	1	1	2	2
44	I	Environmental Sites on the Internet	1	1	1	2	2
45	P, I	ISO Online	1	1	UNK	1	2
46	I	Environ/NETI	1	1	UNK	1	2
47	I	EINET Galaxy	1	1	UNK	1	2
48	P, I	U.S. Bureau of the Census Home Page and DES	1	1	1	3	3
49	I	ENN (Environmental News Network)	1	1	1	1	2
50	P, I	ATSDR and ATSDR Science Corner	1	1	1	2	2
51	I	WWW Virtual Library	1	1	1	2	2
52	I	Enviroene	1	1	1	3+	3
53	P	Industrial Pollution Prevention Project (P3)	1	1	3	3	3
54	P	SIA Trade Statistics Program	2	3	2	3	3
55	P, I	UCLA Center for Clean Technology	1	1	2	3	3

Type:	I = Internet/On-line	R = Report/Publication	C = Computer Program	P = Program
Access:	1 = Readily Available	2 = Moderately Difficult	3 = Very Difficult	
Access Cost:	1 = Little/No Cost	2 = Moderately Expensive	3 = Very Expensive	
Update Frequency:	1 = Day/Month	2 = Quarter/Annual	3 = Infrequent/None	
Roadmap Pertinence:	1 = Low Value	2 = Moderately Valuable	3 = Highly Valuable	
Future Value:	1 = Low Value	2 = Moderately Valuable	3 = Highly Valuable	

Appendix F. Survey of Tool Characteristics and Usage for Design-for-Environment

The following survey is intended to gather feedback on design-tool features and capabilities that would allow a designer/engineer to integrate environmental data into product/process design and manufacturing. As environmental elements become more integral to business strategies, easy access to data such as characteristics and toxicity of materials, emissions, and recyclability of a product will significantly reduce the time and effort needed to incorporate this type of information into design decisions. *Tools that allow this integration are said to assist in "design-for-environment" (DFE) and, in this survey, are referred to as "DFE Tools."*

I. General

1. At what level of system design do you operate?

   ___Semiconductor/IC
   ___Single-Chip Package
   ___Multichip Module
   ___Printed Wiring Board
   ___Board Assembly
   ___Sub-System
   ___System (box level)
   ___Other (please specify):____

2. In your opinion, is customer perception of environmentally sensitive products important to the marketability of your product? YES NO

3. Do you currently use DFE tools in your design process? (Tools include software, checklists, guidelines, or other sources of design guidance) YES NO

4. If yes, which tools?

____
____

5. If yes, how is/are the DFE tools usage integrated with product/process design at your company?

____
____
____
____

6. If you are currently using a DFE tool for one or more design activities, please provide as much information on the tool as possible (for example, if software based, is the tool commercially available or developed in-house, what are the main functions, what platform does it run on?).

[Definitions for the design activities follow the matrix.]

Design Activities	Tool Description
Concept Development (estimation)	
Simulation	
Synthesis	
Physical Design	
Verification	
Prototype	
Manufacturing	

Concept Development: Design activities necessary to create the basic specification for a system (tradeoff analysis and partitioning). User supplied constraints ∅ executable specifications.

Simulation: Detailed analysis on a limited number of design structures (thermal, electrical, mechanical, factory).

Synthesis: Creating new design representations or providing refinement to existing design representations. Executable specifications ∅ netlists, component sets, test plans.

Physical Design: Floor planning, placement, and routing. Specification, component set description, netlists ∅ manufacturable artwork.

Verification: Analyzing the results of physical design to verify that they meet the design constraints.

Prototype: Construction of a working sample to verify that it meets the design constraints.

Manufacturing: Production of the part.

II. Tool-Characteristics Ranking

Within each of the following categories (Human Interface, Connectivity, Functionality, Scope, General Compatibility, and Environmental Results Generated), please rank the characteristics according to their relative importance to the DFE (design-for-environment) process.

Human Interface
(Please rank the importance of the features below as Low, Med, or High)

_2_ Allows user to enter data, update information, etc.

_1_ Tool comes with databases of environmental information

_5_ Able to present information in the form of visual charts and graphs

_6_ Offers graphical point and click interface

_3_ Has flexible report-generation capability

_5_ Provides on-line help

_4_ Is user maintainable (versus requiring a system administrator)

Other: ____

Connectivity
(Please rank the importance of the features below as Low, Med, or High)

_1_ Fully integrated with CAE/CAD platforms or existing design tool suite

_2_ Compatible with multiple platforms (please underline the most useful platform(s): PC, Mac, Mainframe, other:

_7_ Linked to World Wide Web

_4_ Capable of ready access to information from other non-environmental databases and design tools (inventory, factory components/parts, materials lists, process data, purchasing data; etc.)

_6_ Interfaces with project documentation software

_8_ Interfaces with project scheduling methods/software

_3_ Linked to existing material use and inventory databases at your facility

_5_ Is able to integrate seamlessly into time-to-market product design

Other: ____

Functionality
(Please rank the importance of the features below as Low, Med, or High)

_5_ Provides cost/benefit and economic impact analysis for lifetime of the product

_3_ Provides benchmarking capabilities for comparison

_1_ Supports technology tradeoff studies (performance feedback of various technologies, materials; recommendations of alternatives/potential solutions/substitute technologies) in real time

_7_ Captures design history of materials, processes, etc.

_6_ Able to trace requirements through a functional or structural hierarchy

__2__ Provides "flags" or other cautionary notes embedded within the design software triggered by potentially undesirable environmental characteristics of the process/material/product

__2__ Able to integrate DFE concerns into the overall (larger) trade-off analysis (consider environmental impact/factors as related to performance, costs, material availability, learning curve associated with new processes/technologies, etc.)

__4__ Provides access to "intelligent" on-line DFE guidelines

__1__ Provides environmental regulations/compliance data/environmental policies and procedures

Other: ____

Scope

(Please rank the importance of the features below as Low, Med, or High)

__2__ Applicable to mechanical designs

__2__ Applicable to electromechanical designs

__3__ Applicable to simple electronic designs

__4__ Applicable to complex electronic designs

__6__ Applicable to software designs, materials

__3__ Applicable to parts

__1__ Applicable to processes

__5__ Applicable to system engineering

__1__ Applicable to various areas of electronics manufacturing (packaging, discrete components, printed wiring boards, interconnects, etc.)

Other: ____

General Compatibility

(Please rank the importance of the features below as Low, Med, or High)

__3__ Is compatible with Total Quality Management (TQM) and Just-in-Time maintenance approaches

__1__ Is compatible with ISO 9000

__2__ Is compatible with ISO 14000/TC207

__4__ Applicable to supplier line management

__1__ Is compatible with concurrent engineering design and management approaches

Other: ____

Environmental Results Generated

(Please rank the importance of the features below as Low, Med, or High)

__9__ Includes a quantitative "green" rating with little or no accompanying environmental impact data

_5_ Quantifies and reports impact to air, water, and land as well as discharge, emissions, etc.

_8_ Provides a full-scale LCA on the product (including stages of raw material extraction, manufacturing, maintenance, and disposition/disposal options)

_7_ Provides an LCA on manufacturing stage(s) only

_2_ Provides relative environmental desirability ranking or ratings of technology tradeoff decisions

_1_ Provides relative environmental desirability ranking or ratings of materials/process selection

_4_ Provides direct cause and effect linkage between product design features and potential/adverse environmental effects

_1_ Able to evaluate recyclability

_6_ Able to evaluate durability

_4_ Able to evaluate reparability

_3_ Able to evaluate reduced-packaging (shipping) opportunities

Other: ____

III. DFE Tools--General Scope

Please fill in the following matrix, using the sample responses as a guide.

Sample Matrix Responses:

Design Activities	How many people involved?	Design Methodology	Use CAD tools?	DFE tool Useful?
Concept Development (estimation)	6-7	Group meetings	No	Yes
Simulation	1	Individual designers with tools	Yes	Yes

Design/Manufacturing Activities	How many people involved?	Design Methodology	Use CAD tools?	DFE tool Useful?
Concept Development (estimation)				
Simulation				
Synthesis				
Physical Design				
Verification				
Prototype				
Manufacturing				

IV. Additional Comments

Please use the space below for additional comments on DFE tool characteristics, tool usage, tools you are aware of (but don't necessarily use), thoughts and ideas that came to you as you read through the survey, etc.

Appendix G. Building Blocks for Environmental Tradeoff Assessments to Support DFE—A Sample of European Projects

Increasing pressure for more environmentally conscious processes and products comes in a variety of forms: legislation, eco-labeling, environmental auditing, and customer requirements, for example.[20] Each of these drivers will likely require that materials and processes be assessed. These assessments may either ensure that the best known options are being exercised, or point to some needed changes in materials and/or manufacturing processes.

The search for alternative materials or processes is usually complicated. It is often simpler to determine what *not* to use than it is to weigh alternatives, each of which might be legally and technically viable, but which may have undesirable environmental consequences. As discussed in Chapter 4, many companies are at the stage of discovering how to measure the tradeoffs for design for the environment (DFE)—determining what metrics to use in their assessments. A critical element for the decisions that results from such analyses is qualitative data, which is often not readily available. In some cases, companies may be facing tasks for which there is little support or infrastructure.

This appendix will present examples of activities in Europe that are providing support for the infrastructure necessary for environmental assessments. The goal of this section is not to present the findings, or evaluate the quality, of the studies. Rather, it is to briefly describe four efforts—three in Scandinavia and one Belgium—that provide the electronics industry with the type of information necessary for eventual DFE-based practices.

Danish Environmental Protection Agency

The Danish Environmental Protection Agency (DEPA) financed a joint research project to investigate environmentally problematic substances and materials in electronic equipment. As part of the “Cleaner Technology and Products” national program, the DEPA and the Danish Electronics Industry Association cooperated to provide quantitative data that would enable component selections based on environmental impact. The DEPA hopes that the resulting inventory data will better enable optimal disposition decisions for electronic equipment and that the tool will simplify the environmental impact assessments of materials used in electronic components.[21] An important issue that came out of the study was the need for improved communication and data transfer between materials and component suppliers and the electronic product manufacturer.

The project had four technical phases: preliminary investigation, component analyses, environmental specifications, and product materials flow analyses. Researchers concentrated on passive

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20 In Europe, a variety of drivers already exist: EC Directive on Environmental Impact Assessment, (EIA, Official Journal 1985 L 175, pg. 40), Draft Directive on Integrated Pollution Prevention and Control (OJ 1993 C 311/6); EC Ecolabelling Scheme (OJ 1992 L 99/1); EC Eco-Management and Audit Regulation (OJ 1993 L 168/1); EC Directive on Packaging and Packaging Waste (OJ 1994 365/10); and the German Law on Recycling and Waste (Kr-/AbfG; BGB1, 1994 I/2705) to be implemented in 1996.

21 The study findings are available in four different reports, some in Danish and some in English. For information on the reports, contact the Ministry of Environment and Energy, Danish Environmental Protection Agency, Tel: 45 32 66 01 00. Reference the *Miljoprojekt nr. 289, 1995.*

(e.g., arresters, capacitors coils, resistors), active (e.g., CODEC circuits, diodes, IC modules, ICs, smart cards), electromechanical, and a few other key electronic components. In addition to component evaluation, three products were analyzed: a hearing aid, a mobile telephone, and a frequency converter. Analytical tools were developed for the quantitative analysis of various components and the three products. The data collected is captured in the DELTA (Danish Electronics, Light & Acoustics)[22] database, Paradox. This tool is considered the first step towards the development/creation of a software-based tool for component selection and disposition options (reuse, recycle, incinerate).

Swedish Electronics LCA Project

An industry-government cooperative project, *Life Cycle Assessment (LCA) for Electronics* (1994 - 1995), was carried out to demonstrate the utility and efficiency of the LCA as a tool for investigating environmentally conscious opportunities in electronics production. Project participants were IVF, ABB Industrial Systems AB, Telefonaktiebolaget LM Ericsson AB, and Rifa AB. The participation of IVF (Swedish Institute of Production Engineering Research) was financed by AFR, the Swedish Waste Research Council.[23]

The project included two case studies: (1) an LCA of two capacitors—both functioning to suppress electromagnetic interference (EMI)—using the EPS method (the Environmental Priority Strategy, and (2) an LCA on 63/70 tin/lead solder and on a conductive adhesive material with silver filler material used to attach quad-flat packs on a printed wiring board (PWB). The LCA comparisons were based on the functions of the two materials as attach materials, not the volume used, and incorporated data from raw-material extraction to disposal (in Sweden). In both cases, two disposition options were examined: landfilling and recycling the PWB (i.e., recovering 80% of the solder and conductive adhesive).

The LCA of the tin/lead solder includes the following stages: tin and lead extraction, solder mixing, casting, atomization, paste mixing, additives to paste mixing, screen printing, use, and disposition. The LCA of the conductive adhesive (not commercially available at the time of report publication) covered: silver extraction, powder production, mill rolling, pre-blend, additives to the pre-blend, mixing, epoxy addition, screen printing, use, and disposition. The conductive adhesive studied had an 80%-weight silver content and thermoset epoxy as the basic resin.

The report also provides an appendix that details volumes, price, and environmental loads related to base- and previous-metals production at the Ronnskar smelter and the Laisvall, Aitik, and Garpenberg mines in Sweden.

The Nordic Council of Ministers[24]

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22 DELTA, which is affiliated with the Danish Academy of Technical Sciences (ATV), is a joint effort of the ElektronikCentralen, Light & Optics, and the Danish Acoustical Institute.

23 For information on obtaining a copy of the project report, contact IVF at Tel 46 31 706 60 00/Fax: 46 31 27 61 30.

24 The Nordic Council of Ministers is composed of representatives from Denmark, Finland, Iceland, Norway, and Sweden. The Danish delegation also includes representatives from the Faroe Islands and Greenland. The Council has 87 members, whom are elected and also members of parliament.

The Nordic cooperation group for cleaner technology of the Nordic Council of Ministers commissioned a project to examine: (1) the environmental impact of incinerating and landfilling waste from electric and electronic equipment (WEEE), and (2) the hazardous materials and substances in electric and electronic equipment.[25] Although the entire work was sponsored by the Nordic Council, the discussion of incineration and landfilling is based primarily on information gathered from Sweden and Denmark, due to the lack of information available from the other Nordic countries during this three-month project.[26]

The study compares the hazards associated with incinerating and landfilling WEEE, in particular cathode ray tubes (CRTs), flame retardant plastic, and printed wiring boards (PWBs). A sound understanding of the comparative environmental impact is crucial to improving product designs for future disposal. The report proposes ways in which incineration and landfilling might change to lessen the impact, and discusses CRT closed-loop recycling and flame retardant plastic in low-grade recycling as disposition options. In order to improve the outcome of such an exercise, more quantitative data regarding emissions from WEEE in landfills is needed. This highlights, once again, the lack of information on product materials and substances. Reliable information is critical for better estimates of the impact from WEEE incineration and landfilling, and to DFE in general.

A second portion of study funded by the Nordic Council of Ministers resulted in a ranked list of problematic materials in WEEE (products manufactured before 1993). In descending order, the problems were: mercury and PCBs; halogenated flame retardants; a lack of information about flat panel display content materials; cadmium in nickel-cadmium batteries; and lead oxide in CRTs.

The report[27] provides consolidated data on electronic systems. The data includes materials and substances for: printed board assemblies, including ICs, other semiconducting materials, diodes, capacitors, resistors, inductors, relays, PWBs, indicators and switches, fuses and circuit breakers, electron tubes, PBA connectors, and PBA front; displays (CRTs and FPDs); and other components (e.g., batteries, cables and wires, sensors, and connectors). The report also estimates the volume of hazardous substances in WEEE, looking at cadmium, PCBs, mercury, lead, beryllium, indium, arsenic, and gallium.

IMEC

Although the *1996 Electronics Industry Environmental Roadmap* is not chartered to study environmental activities in the semiconductor industry, a program at IMEC (Leuven, Belgium)[28]

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25 The Council report defines electric and electronic equipment as that which "...uses electricity or through which electricity flows and/or which contains an electronic circuit, i.e. with active and passive components."

26 For a copy of the report, *Environmental Consequences of Incineration and Landfilling of Waste from Electronic Equipment*, contact the Nordic Council of Ministers, Fax: 45 33 96 02 02. Reference *TemaNord 1995:555*.

27 "Waste from Electrical and Electronic Products—A Survey of the Contents of Materials and Hazardous Substances in Electric and Electronic Products," may be obtained from the Nordic Council of Ministers, Fax: 45 33 96 02 02. Reference TemaNord 1995:554.

28 IMEC was founded in January 1984 by the Government of Flanders and is the largest independent microelectronics research center in Europe. It has an annual research budget of $U.S. 60 million and 650 employees. It is closely linked to universities, research institutes, and industry and participates in a number of European R&D

in Environmental, Safety, and Health Issues in IC Production provides a good example of efforts in data-gathering and process improvements that are technology-, cost-, and environment-oriented. IMEC is serving an important need for future IC processing and demonstrates successful interaction within a highly competitive industry.

The IMEC program on ultra-clean processing technology is aimed at reducing resources and waste in IC fabrication, examining: resource reduction, re-use, waste treatment, and alternative chemicals and materials. The goal of the program is to move from ultra-clean requirements to "just-clean-enough."[29] Some of the major goals are to:

- Study the possibilities of reducing the use of the source material, such as the reagents chemicals, gases, and deionized (DI)-water;
- Reduce the use of volatile organic compounds if possible, capturing waste and re-using it; and
- Optimize the design of DI-rinse tanks (stating that currently only approximately 10% of the rinse water is effectively used) and the control of DI-water contamination to enable the re-use of the rinse water.

One outcome of this effort is the "IMEC-Clean," an RCA clean that reduces the steps from three to two, and replaces sulfuric acid-hydrogen peroxide solution with an ionized DI-water. IMEC has worked with a range of U.S. and European companies (e.g., Intel, TI, Motorola, Philips, Ashland, BOC, Wacker, and ASM), to enable such improvements in semiconductor processes.

The Institute's experience in microelectronics packaging and interconnect, and its work with designers to determine their system needs, is enabling the development of new design methods and tools. This experience could potentially be tapped for electronic materials and process studies that provide additional support to DFE practices for products beyond semiconductors.

Closing Comments

The volume of electronics-related environmental impact data is not keeping pace with the growing desire to consider environmental implications in design and manufacturing. This is not surprising given that the data needed to support environmentally conscious decisions requires significant resources to conduct environmental impact assessments and/or life cycle assessments and compile lists of constituent materials in electronic products.

Although various groups in the U.S. and Europe question the efficiency and outright utility of full-scale life cycle assessments, the need will continue to grow for data to support design and process decisions that consider environmental issues along with traditional factors (design-for-environment, or DFE). This appendix briefly outlined four efforts, completed or ongoing, in Europe to create building blocks of DFE infrastructure. Clearly, more projects must be

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programs. IMEC has a broad range of expertise from software to hardware, and is a center of excellence for microelectronics, developing and characterizing process steps such as optical lithography and full processes such as 0.35-micrometer CMOS devices. At the microsystem level, IMEC's work includes packaging and interconnect technologies and techniques and material characterization.

29 Information based on IMEC presentation to MCC in June 1995 as part of the Open-Microprocessor Initiative mission to the U.S.

undertaken to assess environmental impact, or load, of the wide variety of materials used in the electronics industry. These four European efforts may provide a stepping stone, if not models, for continued data gathering and impact assessments.

Appendix H. Contingent Liabilities Related to Mandatory Disposition

Mandatory electronics products disposition programs will create financial liabilities for firms. Firms may be required to reduce current-period profits by the non-discounted disposition costs for all past- and current-period sales. In subsequent periods, firms will have to reduce profits by the anticipated disposition costs for all current-period sales; this will lower future profits. Although the exact amount (and even the timing) of the future obligation is uncertain, financial accounting rules often require current-period profits to be lowered by the expected amount of these future liabilities. Liabilities that are uncertain in amount and/or due date are called contingent liabilities.

If the recent initiatives in Europe, Japan, and the U.S. become law, they may create substantial contingent liabilities for some electronics-industry firms. When faced with contingent liabilities, the firm can ignore the contingency (i.e., not make any public disclosure), report the existence of the contingency in a note attached to the financial statements (but not estimate the magnitude of the contingency), or actually reduce current-period profits by the expected future payment (i.e., make an accrual that reduces net income and net worth). Which of these accounting treatments are used depends on the probability that the contingent liability will actually be paid, the estimability of the contingency, and the accounting standards and practices used in the country where the firm is issuing its financial-accounting report.

The following sections provide: 1) a review of the country-specific financial accounting standards relating to disclosure of contingent liabilities for Germany, Japan, Sweden, Switzerland, The Netherlands, and the U.S.; 2) a review of the International Accounting Standards relating to disclosure of contingent liabilities; and 3) an analysis of whether the product end-of-life activities discussed in preceding sections are likely to require recognition of new contingent liabilities on the financial accounting statements of affected electronics-industry firms.

Germany

German accounting standards derive from several sources, including the German Commercial Code, pronouncements of the German Institute of Certified Public Accountants, and the German Stock Corporation Law and Limited Liabilities Companies Law [41]. All contingent losses that are likely to occur must be accrued on an estimated basis. A contingent liability that has not been accrued must be disclosed on the face of the balance sheet or in the notes. The Commercial Code [paragraph 251] requires that the disclosure differentiate between contingent liabilities relating to: the issuance and transfer of notes receivable; guarantees; warranties; and security granted for third party liabilities ([41], p. G-13).

Japan

Japanese accounting standards and practices are derived from a number of Japanese laws, pronouncements, and historical practices [41]. Contingent losses [guhatsu saimu] must be accrued if both of the following conditions are met: 1) information available prior to the issuance of the financial statements indicates it is probable that an asset had been impaired or a liability has been incurred at the date of the balance sheet, and 2) the amount of loss can be reasonably estimated.

If no accrual is made because one or both of the above conditions are not met, the contingency must be disclosed when there is at least a reasonable possibility that an unrecorded loss may have been incurred. In this case, a contingency should be disclosure in a footnote to the financial statements. This footnote should include the details of the contingency.

The Netherlands

The Council for Annual Reporting (Raad voor de jaarverslaggeving, CAR) is currently preparing a draft of The Netherlands' accounting principles ([41], p. N-1). Contingent losses should be provided for in the financial statements to cover the risk of the liability becoming unconditional. If it is probable that a contingent gain will be realized, the existence of the contingent gain should be disclosed in the notes, together with information about its nature and the uncertain factors that may affect the future outcome. Where no provision can be shown in the balance sheet for a contingent loss, because it is not possible to make a reasonable estimate of the amount of the obligation, disclosure should be made in the notes of the nature of the contingent liability, the uncertain factors affecting future outcomes and the fact that a reasonable estimate is not possible ([41], p. N-18).

Sweden

Sweden's generally accepted accounting principles are derived from a variety of sources, including the Swedish Accounting Act (Bokfaringslagen 1974), the Swedish Companies Act (Aktiebolagslagen 1975), and accounting standards adopted by the Swedish Financial Accounting Standards Board (Redovisningsrcdet) ([41], p. S-87). Contingent losses with a high probability of occurrence should be included explicitly in the firm's liabilities. Contingent liabilities must be disclosed as memorandum items at the end of the balance sheet [41].

Switzerland

The Swiss Company Law (Obligationenrecht in German, also called the Code of Obligations, Code des Obligations in French) is the basis for Switzerland's generally accepted accounting principles. Additionally, the Accounting and Reporting Recommendations of the Foundation for Accounting and Reporting Recommendations, an independent Swiss organization, are increasingly recognized, even though they presently are not mandatory ([41], p. S-111). Contingent losses that can be estimated at the balance sheet date and are likely to occur should be provided for. Company law specifically requires provisions to be made for any foreseeable losses in connection with the performance of contracts for delivery or acceptance of goods or services and similar contracts not yet performed. If a provision has been made for a contingent loss, no further disclosure is normally made in the financial statements. Disclosure must be made of a loss contingency that cannot reasonably be quantified. The disclosure might be made in the auditors report in a statement following the auditors approval of the financial statements ([41], p. S-120).

United States

The Statement of Financial Accounting Standards No. 5 (Financial Accounting Standards Board, 1975) provides general principles for treating contingent losses. Although this Statement was not written specifically for environmental contingencies, it is one of the primary sources of generally acceptable accounting procedures (GAAP) guidance on disclosing contingent Superfund liabilities [42]. Emerging Issues Task Force (EITF) Issue No. 90-8 considered whether environmental cleanup costs should be capitalized or expensed once they were disclosed.

Statement 5 requires an accrued provision for losses if the amount of the loss can be reasonably estimated and if the likelihood of a loss is probable. Footnote disclosure of the contingent loss is appropriate if the likelihood of the loss is at least reasonably possible. Finally, no disclosure of contingent losses is required when the likelihood of such a loss is remote.

Because many environmental liabilities, especially those associated with CERCLA site cleanup costs, are difficult to estimate with any degree of certainty, often those costs are not disclosed under GAAP [42, 43]. In addition, the Securities and Exchange Commission can issue pronouncements that supplement (and may even take precedence over) GAAP. The Securities and Exchange Commission can require these accounting changes only from publicly-traded firms.

These additional accounting requirements (e.g., disclosures in the Management's Discussion and Analysis section) are reviewed by the firm's independent auditors for inconsistencies with the financial statements, but are not covered by auditor's letter of opinion. Currently, the SEC requires the following additional disclosure regarding contingent liabilities: contingencies must be estimated and disclosed even when it is expected that the loss will not be material, but when there is at least a reasonable possibility that a loss exceeding amounts already recognized may have been incurred and the amount of that additional loss would be material to a decision to buy or sell the registrant's securities [44]. Slightly stricter guidelines regarding disclosure of contingent environmental liabilities are currently being considered by the American Institute of Certified Public Accountants [45].

International Accounting Standards Relating to Disclosure of Contingent Liabilities

International Accounting Standards are issued by the International Accounting Standards Committee, but are not mandatory in a specific country until they have been adopted by that country. Under International Accounting Standards, contingent losses should be accrued if it is probable that future events will confirm that, after taking into account any related probable recovery, an asset has been impaired or a liability incurred at the balance sheet date, and a reasonable estimate of the amount of the resulting loss can be made ([41], p. IAS-15). If these conditions for accrual are not met, contingent losses should be disclosed unless the possibility of loss is remote.

Appendix H

Appendix I. Composition of Typical Desktop Computer System

A breakdown of the composition of a typical desktop computer system (~70 lbs.) from Handy & Harman reveals that the plastics content is the highest value and the least recovered [one Troy Ounce (T.O.) = 1.097 Ounces].

Name	Content (%)	Value ($/T.O.)	Intrinsic Value	Recycl. Effic.	Value of Recycled	Value of Non-recycled	Use/Location
Plastics	22.9907	0.05	$11.73	20%	$2.35	$9.39	includes organics, oxides other than silica
Lead	6.2988	0.03	$1.93	5%	$0.10	$1.83	metal joining, radiation shield/CRT, PWB
Aluminum	14.1723	0.06	$9.11	80%	$7.29	$1.82	structural, conductivity/housing, CRT, PWB, connectors
Germanium	0.0016	93.00	$1.49	0%	$0.00	$1.49	semiconductor/PWB
Gallium	0.0013	90.00	$1.15	0%	$0.00	$1.16	semiconductor/PWB
Iron	20.4712	0.02	$4.18	80%	$3.34	$0.84	structural, magnetivity/(steel) housing, CRT, PWB
Tin	1.0078	0.20	$2.06	70%	$1.44	$0.62	metal joining/PWB, CRT
Copper	6.9287	0.09	$6.01	90%	$5.41	$0.60	conductivity/CRT, PWB, connectors
Barium	0.0315	1.35	$0.43	0%	$0.00	$0.43	getter in vacuum tube/CRT
Nickel	0.8503	0.25	$2.17	80%	$1.74	$0.43	structural, magnetivity/(steel) housing, CRT, PWB
Zinc	2.2046	0.04	$0.81	60%	$0.49	$0.32	battery, phosphor emitter/PWB, CRT
Tantalum	0.0157	1.71	$0.27	0%	$0.00	$0.27	capacitors/PWB, power supply
Indium	0.0016	30.00	$0.48	60%	$0.29	$0.19	transistor, rectifiers/PWB
Vanadium	0.0002	100.00	$0.16	0%	$0.00	$0.16	red phosphor emitter/CRT
Terbium	0.0000	933.00	$0.15	0%	$0.00	$0.15	green phosphor activator, dopant/CRT, PWB
Beryllium	0.0157	0.40	$0.06	0%	$0.00	$0.06	thermal conductivity/PWB, connectors
Gold	0.0016	390.00	$6.27	99%	$6.21	$0.06	connectivity, conductivity/PWB, connectors
Europium	0.0002	35.00	$0.06	0%	$0.00	$0.06	phosphor activator/CRT
Titanium	0.0157	0.30	$0.05	0%	$0.00	$0.05	pigment, alloying agent/(aluminum) housing
Ruthenium	0.0016	15.00	$0.24	80%	$0.19	$0.05	resistive circuit/PWB
Cobalt	0.0157	1.75	$0.28	85%	$0.24	$0.04	structural, magnetivity/(steel) housing, CRT, PWB
Palladium	0.0003	173.00	$0.56	95%	$0.53	$0.03	connectivity, conductivity/PWB, connectors
Manganese	0.0315	0.07	$0.02	0%	$0.00	$0.02	structural, magnetivity/(steel) housing, CRT, PWB
Silver	0.0189	5.33	$1.03	98%	$1.01	$0.02	conductivity/PWB, connectors
Antimony	0.0094	0.19	$0.02	0%	$0.00	$0.02	diodes/housing, PWB, CRT
Bismuth	0.0063	0.26	$0.02	0%	$0.00	$0.02	wetting agent in thick film/PWB
Chromium	0.0063	0.25	$0.02	0%	$0.00	$0.02	decorative, hardener/(steel) housing
Cadmium	0.0094	0.14	$0.01	0%	$0.00	$0.01	battery, blue-green phosphor emitter/housing, PWB, CRT
Selenium	0.0016	2.00	$0.03	70%	$0.02	$0.01	rectifiers/PWB
Niobium	0.0002	5.14	$0.01	0%	$0.00	$0.01	welding allow/housing
Yttrium	0.0002	5.00	$0.01	0%	$0.00	$0.01	red phosphor emitter/CRT
Rhodium	0.0000	650.00	$0.01	50%	$0.01	$0.01	thick film conductor/PWB
Platinum	0.0000	448.00	$0.07	95%	$0.07	$0.00	thick film conductor/PWB
Mercury	0.0022	0.09	$0.00	0%	$0.00	$0.00	batteries, switches/housing, PWB
Arsenic	0.0013	0.00	$0.00	0%	$0.00	$0.00	doping agent in transistors/PWB
Silica	24.8803	0.00	$0.00	0%	$0.00	$0.00	glass, solid state devices/CRT, PWB
	Subtotals		$50.92		$30.71	$20.21	

Appendix J. European Disposition Initiatives

This appendix discusses several initiatives to develop an infrastructure for the collection and processing of post-consumer electronics, focusing on public and consortial systems. Models from five Northern European countries are presented, including Austria, Switzerland, France, Germany, and the Netherlands. Based on several years of discussions and experience, these models represent industry's ideas on how to best manage the recycling of post-consumer goods given the constraints imposed by government. Whether "voluntary" or mandated, each of these models was spawned as a result of legislative activity, or in an effort to preempt mandates.

Collection systems that are fully operational (Austria and Switzerland) will be discussed first, followed by the proposals of the French, German, and Dutch electronics industries.

Austria: A Reserve Distribution Model

Austrian producers and importers established a country-wide recycling network for refrigerators, freezers, and air conditioners in response to a 1993 directive from the Austrian Environment Ministry. Managed by the Umweltforum Haushalt on behalf of 40 producers and importers, the system principally operates through a series of competitive partnerships among retail establishments, transportation firms, and recyclers. Additionally, in some regions of Austria—including Vienna, which accounts for almost 25% of Austria's population—the local authorities participate in the private system.

Customers return old refrigerators or freezers to retail establishments when they purchase a new unit, or to participating local authorities. Under contract with Umweltforum Haushalt, transportation firms privately negotiate with retail establishments for the collection of used equipment. The transportation firms in turn negotiate agreements with recycling firms. Competition between the nine transportation partners and the recycling firms ensures competitive prices.

In the Austrian scheme, consumers pay a fee of 100 schillings (approximately U.S. $10) at the time of product purchase, as a "down payment" for collection and recycling at the end of product life. As proof of payment, the customer receives a prepaid coupon that is affixed to the unit. At the end of life, the consumer returns the equipment to a retail establishment at which time he/she must pay a disposal fee equivalent to the current market price for recycling minus the down payment of 100 schillings. Five percent of the total recycling costs (down payment plus disposal fee) are turned over to Umweltforum Haushalt for administrative costs (currently 25 schillings, or U.S. $2.50 per unit). Total recycling costs are capped at 500 schillings/unit, which includes 10% sales tax.

Although under contact to Umweltforum Haushalt, transport and recycling firms are free to negotiate recycling rates with retail establishments. For example, lower recycling fees may be negotiated for higher volume retail outlets, similar to new product sales. Depending on the region of Austria, recycling a refrigerator or freezer currently costs 400 to 450 schillings, or U.S. $40 to $45. Recycling costs have dropped over 40% in 2 years as a result of both increased competition and experience. In fact, two months after switching from a monopoly with fixed prices to a competitive system, recycling fees plummeted 28%.

The ordinance requires Umweltforum Haushalt to establish a fund to pay for recycling costs when the product is disposed of in 10 to 20 years. The industry group is allowed to accrue the interest earned on the money during this lag period. When equipment is returned into the system, any accrued interest is credited towards recycling costs. This will act to increase the monetary value of the initial down payment, while lowing the end-of-life disposal charge.

Although the Umweltforum Haushalt system only "officially" covers products sold since enactment of the ordinance, the existence of the industry-established infrastructure facilitates the collection and recycling of pre-ordinance equipment. For pre-ordinance equipment, consumers in Austria can also opt to use municipal collection centers in lieu of the private system. By law local authorities must handle waste disposal, including the disposition of refrigerators, freezers, and air conditioners. Before 1993 the handling of these bulky items was absorbed in the municipal tax base. The ordinance for refrigerators and freezers gave municipalities the authority to charge consumers a discrete market-based recycling fee, payable at the point of collection, providing municipalities with an incentive to compete for refrigerators and freezers with the private system.

The current recycling infrastructure reflects an important change, resulting from two years of experience with appliance recycling. Amendments to the recycling ordinance in March 1995 changed the fee structure from an entirely prepaid system to the current down payment plus end-of-life fee. Under the previous system, consumers were required to pay the entire cost of disposal at the time of product purchase. As a result, Austria's retailers lost business to Germany and Italy, particularly in border regions. (Under the old fee structure, consumers could also use the fully prepaid coupon to recycle an old refrigerator. After moving to the partial payment scheme, coupons can only be used for recycling the new product at the end of its life in 10 to 20 years.)

According to the Umweltforum Haushalt and the Austrian Ministry, there are no reliable figures on the total recovery and recycling rates for appliances, since several systems are currently operating (i.e., private and public collection systems; equipment with and without prepayment stickers). The Umweltforum only collects data on the equipment recycled with prepaid coupons, which in 1994 accounted for half of the refrigerators recycled in Austria (75,000 of 150,000). These figures are misleading—they do not capture the pre-ordinance equipment recycled in the private system without coupons (i.e., consumer paid entire recycling fee at point of disposal). For the next several years, the Umweltforum also expects to see its figures decrease as fewer units are returned with coupons, reflecting the amendment to the ordinance. These figures will turn around when equipment sold since 1993 comes to the end of its life.

Switzerland: Private Prepaid Recycling System

The Swiss Economic Association of Information, Communication, and Organization Technology (SWICO) established a convention for the management of end-of-life equipment in April of 1994. Any member of SWICO importing or producing office equipment or computers can become a party to the convention. Signatories of the convention voluntarily commit to life cycle environmental responsibility, including: 1) avoidance of wastes, 2) reduction of harmful substances during manufacturing processes, 3) waste utilization through reuse or value material recycling, and 4) environmentally sustainable residual material disposal. Currently, 40 manufacturers are signatories of the SWICO convention. Only one major manufacturer has declined to participate.

The SWICO system utilizes three strategies to collect used equipment for recycling: 1) equipment distributors and dealers with the purchase of new equipment (any brand); 2) supplier-specified collection points, which may include on-site pickup; and 3) public drop-off sites located at Swiss railway stations (pilot starting April 1, 1995). In its first year of operation, the majority (90%) of equipment recovered by SWICO entered the system through direct supplier collection, mostly from large customers. Only 10 percent was recovered by dealer networks. In addition, the recovery rate from households was a disappointing 18%. The public collections sites are an attempt by SWICO to make the recycling system more accessible to household consumers. Equipment from any manufacturer weighing up to 50 kilos will be accepted, making the collection system user-friendly.

Following collection, used equipment is transported to recyclers that are licensed by SWICO. SWICO currently licenses 12 recyclers, either on a two-year or five-year basis depending on the processing technology. While there is no limit to the number of recyclers in the SWICO system, recyclers must meet the licensing quality standards, which are based on processing capabilities, technology, and environmental performance. Only 12 of the 40 companies applying for the license have received approval. Only one manufacturer, Digital Equipment Corporation, is a licensed recycler—all other manufacturers utilize third party recyclers. In their contracts with recyclers, manufacturers can arrange to recover valuable parts and components for reuse.

SWICO estimates that it captures the following discarded equipment in its collection network:

- Over 95% of copiers,
- 68 to 70% of personal computers, and
- 75% of mid- to high-end computers.

The collection and recycling system is funded through pre-payment fees, charged at the point of sale, lease, or rental, with no additional cost to the customer at the point of disposal. The following price list is based on a fixed amount per piece of equipment depending on the sales price (all costs in Swiss francs as of January 1995):

Sales Price	**Charge**[1]	**Charge**[2]
1 to 500	No charge	No charge
501 to 1500	21	10
1501 to 6000	53	10
6001 to 15,000	106	20
15,001 to 30,000	265	50
30,001 to 60,000	365	100
60,001 to 150,000	530	250

150,001 to 600,000	1060	500
above 600,001	1600	1000

1 Office equipment, copiers, facsimiles, workstations, printers
2 Personal computers, workstation peripherals

The compulsory fee must be openly and separately displayed on all price lists and invoices, and no discounting is allowed. Participating companies manage the pre-payment fee revenue, with guidelines developed by SWICO on the kind of expenditures that companies can bill to their pre-payment accounts. External auditors, on behalf of the signatories, must guarantee to the public that guidelines are observed. Semi-annually, participating companies contribute 2% of the pre-payment fees to SWICO for system administration, and to cover the cost of recycling non-member equipment.

France, Germany, and the Netherlands: Shared Responsibility Proposals

After several years of study and negotiation with their Ministries, the French, German, and Dutch electronic industry associations propose "shared responsibility" models for electronics disposition. Under these models, responsibility for the collection and processing of used electronic equipment would be shared by the chain of actors in the product life cycle, including product manufacturers, retail outlets, municipal authorities, and the waste management industry.

The proposals strongly argue for the continued role of municipalities as the principal entities for the collection of electronic goods, rather than establishing an independent industry-financed infrastructure. These municipal-based systems are intended to preserve and augment the current collection infrastructure, which provides collection points close to households and is familiar to consumers, in order to ensure a high level of product returns. Under contract with municipalities, the waste disposal/recycling industry would be responsible for the environmentally-sound processing of equipment and for ensuring adequate capacities. Certification of recycling firms and reporting systems (e.g., of recycling rates) would provide increased assurance of environmentally-sound recycling.

The expressed role of manufacturers in electronics disposition is two-fold:

1) The design of new products to reduce waste generation, avoid harmful substances, and enhance recyclability at end of product life; and
2) Information dissemination to customers and recycling firms to help ensure appropriate disposition.

In Germany and the Netherlands, industry proposes that consumers should pay for disposal at the end of product life, if needed, or municipalities should bear the cost through an increase in annual waste assessments to households. In Germany, industry proposes different financing mechanisms based on the size of the electronic equipment. For large electrical appliances and consumer electronics, municipalities could charge consumers a separate recycling fee, while no fee would be charged for small goods that fit in the trash bin (i.e., can be hidden in the trash). Industry proposes that municipalities assess each household an additional DM 15 (about U.S. $10) annually in their waste bills to cover the recycling costs for these small goods. Estimated recycling charges for several items are: washing machines, DM 20 (U.S. $13); refrigerators, DM 42- 62 (U.S. $26 to $33); and televisions, DM 40-60 (U.S. $25 to $38).

Pilot projects recently started in the Netherlands and France to further examine the model of shared responsibility. These projects will further assess the current infrastructure, needed changes in collection and processing systems, and the economics of recycling. In France, in particular, industry is eager to prove their hypothesis that electronics recycling "…can find its own economic equilibrium, and thus that it is not necessary to envisage further financial additions [to the recycling system]…" if responsibility for product design, collection, processing, and education is shared among manufacturers, retail, local authorities, consumers, and the federal government. In addition to sharing responsibility, each of these actors is responsible for seeking improvements in efficiency (e.g., processing and technology) within their domain over time. French industry further proposes to establish a "common agreement" among the actors in this "collective co-responsibility" scheme to formalize and detail the role, rights, and duties of each of the partners, and its relationship to upstream and downstream partners.

What Can the U.S. Learn from Europe?

Table 1 summarizes the features of the European models discussed above. In two models, Austria and Switzerland, industry established a collection and recycling infrastructure that operates independently of municipal collection systems. In Austria, local authorities can serve as an official collection point for the privately-operated system (i.e., collecting equipment with prepaid stickers), if they choose.

In contrast, France, Germany, and the Dutch consumer electronics industries (including large household appliances) have proposed collection programs that build on the current recycling infrastructure, namely, municipal-based collection with some involvement of retail establishments. Common to most of these models is the certification, or licensing, of recycling firms that meet minimum performance specifications.

Country	Manufacturer Role	Collection Point	Equipment Collected	Who Pays and When
Austria (Effective 1993)	Establish and administer collection system through Umweltforum Haushalt	Retail establishments; some local authorities participate	Refrigerators, freezers, air conditioners; proposed extension of recycling requirement to all electronic products	Customer; down payment at time of purchase plus disposal charge at end of life
France (Proposed; pilot projects underway in Fall 1995; full implementation expected 1997)	Advisory role in the development of a municipal-based program; product design; information on recycling to consumers and recyclers	Local authorities	Residential equipment, including major appliances, televisions, office equipment, computers, and consumer electronics	Consumer; disposal fee at end of product life, although French industry believes fees will be unnecessary

Germany (Proposed; effective 1996)	Ecological design; information on recycling to consumers and recyclers	Local authorities	Residential equipment, including major appliances, televisions, office equipment, computers and consumer electronics	Consumer; disposal fee at end of product life with the exception of small appliances; small appliance funding through annual tax assessment by local authorities[1]
Netherlands (Proposed; pilot projects started June 1995; implementation expected 1997)		Retail outlets or local authorities	Residential equipment; including major appliances, small appliances, televisions, audio/visual equipment	Consumer; disposal fee at end of product life[1]
Switzerland (Effective April 1994)	Establish and fund voluntary collection and recycling system administered by SWICO	1) dealer networks; 2) supplier collection points or pickup; and 3) railway stations (pilot project)	Commercial and residential office equipment and computers, including copiers and facsimiles	Customer; recycling fee at time of purchase

1 Conflicts with Environment Ministry view that recycling costs be internalized in new product price. Final outcome will be influenced by EU Priority Waste Stream.

Table 1. Brief summary of European recycling models.

Some important lessons for U.S. industry, as well as public policy, emerge from these European experiments: as with any product or service, customers are best served by a competitive marketplace.

- In geographic areas with access to other markets, high recycling fees tacked onto the purchase price of new products drives consumers across borders, resulting in depressed product sales in border regions.
- Commercial and residential electronic equipment should not be treated the same when devising end-of-life disposition schemes. Existing commercial transactions provide adequate channels for the recovery of used equipment.
- Reverse distribution networks are not recovering sufficient quantities of used equipment from households. For example, the Swiss industry system is only capturing approximately 18% of used products, which led the organization to establish "public" collection points at railroad stations. In Germany, the industry association proposal aims to preserve and improve the municipal-based collection infrastructure, which currently recovers 80% of used equipment.

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