The following organizations were instrumental in the planning, preparation, prioritization, and/or review of the Electronics Industry Environmental Roadmap. Each organization recognizes the importance of addressing priority environmental issues and agrees in principle with the roadmap process, but also recognizes that the manner and timing in which the contents of this document are addressed will vary between organizations. These organizations do not necessarily agree with the contents of this document in its entirety.
3M - Electro and Communications Systems Group
Alcoa Electronic Packaging, Inc.
    Allied-Signal, Inc.
    Applied Materials
    Arthur Andersen, L.L.P.
    AT&T
Battelle, Pacific Northwest Laboratory
    Behr Precious Metals, Inc.
CALCE Electronic Packaging Research Center
    Circuit Center, Inc.
Computing Devices International
    Corning, Inc.
Decision Focus Incorporated
    Delco Electronics
Dell Computer Corporation
    DuPont Electronics
Eastman Kodak Corporation
    Envirocycle, Inc.
Environmental Health Center of the National Safety Council
Georgia Institute of Technology
    GM Hughes Electronics
    H-R Industries, Inc.
    HANDY & HARMAN
    Honeywell, Inc.
    Hurst & Hake, L.L.P.
Institute for Corporate Environmental Management, University of Houston
    Lawrence Livermore National Laboratory
    Lockheed Corporation
    Los Alamos National Laboratory
    MBA Polymers
    Northern Telecom
    Planar America, Inc.
    Polaroid Corporation
Pollution Prevention International, Inc.
    Printed Circuit Corporation
    Resource Concepts Enviro, Inc.
    Sandia National Laboratories
    Schumacher
    Sedgwick James of California
    Semiconductor Equipment and Materials International (SEMI)
    SKYLONDA GROUP, Inc.
    Techneglas, Inc.
The Institute for Interconnecting and Packaging Electronic Circuits (IPC)
    The Massachusetts Toxics Use Reduction Institute
    Thomson Consumer Electronics
    Tung Tai Trading Corporation
    Unisys Government Systems Group
    United States Display Consortium
    University of Houston
    Wellington Technology Group
    Zenith Electronics Corporation
For more than two years, the Microelectronics and Computer Technology Corporation (MCC) has been privileged to play a pivotal role in an aggressive voluntary effort by the computer and electronics industry to develop environmentally conscious processes and products. This industry effort has built on a series of meetings, workshops, and reports, developed by representatives of many corporations, government agencies, and universities.

The effort was initiated after an April 1992 meeting of the Chief Technical Officers of the Computer Systems Policy Project (CSPP), in which they were joined by representatives of MCC, other research organizations, and national laboratories. Several areas were identified as industry priorities, including the need for a comprehensive study of the environmental opportunities and challenges facing the industry. Based on the CSPP recommendation, MCC, one of the nation’s leading research and development consortia for the computer and electronics industries, began the process of facilitating and coordinating such a study.

Building upon sponsorship and support from the Department of Energy, MCC worked with industry and government to develop a work plan, adopting a life cycle assessment approach based on a “typical computer workstation.” An Advisory Committee, composed of industry, national laboratory, Department of Energy, and Environmental Protection Agency representatives, was formed to provide overall guidance of the effort.

More than 100 participants from forty organizations participated in an August 1992 workshop in Albuquerque, New Mexico, to launch “A Life Cycle Environmental Assessment of a Computer Workstation.” Seven Task Forces, consisting primarily of participants from leading corporations, were formed and over the next several months. Each prepared a report focusing on a specific component or business issue, and the reports were distributed for review and comment.

The initial study concluded with a conference in Washington, D.C. in March 1993. More than 140 people participated, including: Congressional members and staffers; representatives from government, academia, and national laboratories; and representatives from thirty-eight U.S. companies.

Following the 1993 conference, many who had participated in developing the report, joined by several others who had indicated interest or expertise in the environmental aspect of electronics manufacturing, launched an effort to extend the recommendations in the earlier report into an integrated industry roadmap. Working with other major industry associations involved in related efforts, and with the support of the Advanced Research Projects Agency (ARPA), the participants in this effort have prepared this report, submitted as a first step in the development of the comprehensive roadmap.
Following a workshop to kick-off the development of this full roadmap report, a draft outline of the roadmap sections with preliminary priority matrices was produced in April 1994. The draft outline was reviewed and agreed upon in principle by the following association/societies: the Chemical Manufacturers Association (CMA), the Electronic Industries Association (EIA), the Institute for Electrical and Electronic Engineers (IEEE), the Institute for Interconnecting and Packaging Electronic Circuits (IPC), SEMATECH, and the Semiconductor Industry Association (SIA).

The opinions and recommendations expressed in this report are those of the participants and authors, and have not been officially adopted by their respective companies. However, the report will provide a foundation for continued, proactive industry efforts to make computer and electronic manufacturing a model of efficiency and environmental consciousness.
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The substance of this report is the result of contributions from many individuals and organizations working primarily in topic-oriented task groups. MCC gratefully acknowledges their participation. The opinions expressed in this report are those of the participants and authors and have not been officially adopted by their respective companies or organizations.

**Business and Strategic Planning**

*Business*

The following individuals were extensively involved in the development of the business portion of this chapter: John Teets, Motorola; Elizabeth Hurst, Hurst & Hake, L.L.P.; Shawn Delorey and Lulu Yang, Arthur Andersen & Co., L.L.P.

In addition, the following individuals participated throughout the development of the chapter, offering key insights, expertise, and review: Irwin Carroll, Applied Materials; Bud Ward, Environmental Health Center; Anthony Veltri, Oregon State University; Jerry Coletta, Sedgwick James of California; Beth Beloff and David Shields, University of Houston; R. Darryl Banks, World Resources Institute.

**Design for the Environment (DFE)**

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**Printed Wiring Boards/Assembly**

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In addition, the following individuals participated throughout the development of the report, offering key insight, expertise, and review: John Lott, E.I. DuPont de Nemours & Co.; Chris Ford, Printed Circuit Corp.; members of IPC’s EHS&T committee.
Displays

*Cathode Ray Tubes (CRT)*

The following individuals were extensively involved in the development of CRT portion of this chapter: Bill Rowe, Zenith Electronics; Randy Kovalcin, Corning Asahi Video.

In addition, the following individuals participated throughout the development of the chapter, offering key insights, expertise, and review: Mark Taylor, Corning Inc.; Patricia Franco, Electronic Industries Association; Ronald Barber, Envirocycle; Jeffrey Lowry, TECHNEGLAS; George Burris, Thompson Consumer Electronics.

**Flat Panel**

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In addition, the following individuals participated throughout the development of the chapter, offering key insights, expertise, and review: Walter Worobey, Sandia National Labs; Kris Kidambi, Silicon Video; Bob Pinnel, U.S. Display Consortium.

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The following individuals were extensively involved in the development of this chapter: Jan Sekutowski and John Ciccarelli, AT&T; Erin Craig, BEAC; Don Walsh, Behr Precious Metals; Mike Biddle, MBA Polymers Inc. along with the American Plastics Council; Gary Minck, Northern Telecom; Patty Calkins, Xerox.

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**Regulations and Standards**

The following individuals were extensively involved in the development of this chapter: Stephen Greene, Polaroid Corporation; Dominique Cartron, MCC.

In addition, the following individuals participated throughout the development of the chapter, offering key insights, expertise, and review: David Rundle, AMP; Dani Tsuda, Apple Computer; James Converse, Eastman Kodak; Joe Cascio, IBM; Bill Hoffman, Motorola; Aimee Bordeaux, SEMI; Gary Jones, Siemens Corporation.

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Two of the defining trends of the late 20th century are the explosive growth of electronic and information technology products and the pervasive concern for environmental protection. Although apparently independent, these two trends are tightly interwoven—not only by technology opportunities that can address many of the environmental impact issues, but also by an industry that is actively striving to meet its responsibility for environmental stewardship while at the same time remaining competitive in the global marketplace.

The computer and electronics industry, which is the largest manufacturing industry in the U.S., has long been considered a relatively clean industry—computers and electronics contribute only about 1.6% of the total hazardous waste stream on an annual basis. However, the growing importance of the industry to national economic competitiveness (and the visibility that goes along with it), and the increasing recognition that many processes used to produce electronic systems do have environmental consequences as a result of the materials used, power consumed, or end-of-life product considerations, has led the industry to proactively examine its environmental practices and implement improvements.

This report is an important example of the electronics industry’s commitment. It results from several complementary efforts that have been underway in the industry for some time, including the efforts of over 40 companies who have participated in an ongoing effort, coordinated by the Microelectronics and Computer Technology Corporation (MCC), to explore a variety of issues related to environmentally conscious electronic systems manufacturing. This effort represents an important element of a comprehensive national technology focus, bringing attention to a complex set of issues that span the entire life cycle of electronic systems—from cradle to grave, or more hopefully, from cradle to cradle.

This report is the starting point for a comprehensive, focused roadmap for environmental management in the computer and electronics industry. The roadmap describes the process of building electronic systems, highlights those points of primary environmental sensitivity throughout the process, and identifies actions that should be taken to achieve the level of environmental excellence that is both an imperative for business success and a responsibility of corporate stewardship.

Four general conclusions and priorities have emerged from the overall effort:

*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. The development of a comprehensive information network and network services offers the potential to significantly impact this area. Software design and analysis tools are needed to transform the growing volumes of data and databases into new design approaches, enabling product and process engineers to design for the environment at all product development and manufacturing stages. The electronics and computer
industry is uniquely positioned to develop and use the software and hardware products to address these issues.

**Disposition is a business concern.** There is increasing recognition that used products have a value which needs to be recovered. The rapidly changing market makes valuable products and components obsolete long before their useful reliability life is reached. Many in the industry are actively seeking mechanisms that will allow their products to find either a second home, a new life in an upgraded product, or be recovered for the materials they contain. At present, there is a need to establish an infrastructure and the technology for capturing and directing used products toward the most useful economic and environmentally sound alternative.

**Manufacturing requires a focus on efficiency and understanding of new technologies.** New data on hazards and risk is effectively directing research efforts toward more efficient processes that generate less waste and therefore cost less, and toward less hazardous materials where substitutes are available or can be developed. There is a strong desire to be proactive in evaluating and working collaboratively with other stakeholders to minimize the impact of emerging technologies (such as flat panel display technologies) before they are broadly implemented in large scale manufacturing.

**Voluntary programs augment and surpass command and control approaches.** As a result of the previous life cycle study, the EPA initiated a voluntary collaborative project with the printed wiring board industry (PWB) and public stakeholders to identify, prioritize, and evaluate several alternative technologies to reduce environmental impact and maintain or improve performance, while reducing costs. A broader initiative within EPA, known as the Common Sense Initiative, is being launched to use common sense, innovation, and flexibility in order to achieve a cleaner environment at less cost. The voluntary 33/50 program has received pledges from industry to reduce releases of the 17 high priority targeted toxic chemicals by 355 million pounds by 1995. All of these efforts are examples of a more collaborative, voluntary approach between industry, government, and the public sector to accomplish real, positive change. The electronics and computer industry has encouraged and embraced these more flexible and effective approaches.

Each chapter in the report addresses a specific business or technical area with significant implications for environmental management in the computer and electronics industries. The chapters each include a “priority needs matrix,” identifying the priorities and approaches to be taken in order to address the concerns detailed in the chapter. The chapters are:

- **Business and Strategic Planning.** Environmental management must be infused throughout the corporate culture in the same way that quality and continuous improvement processes have been in recent years. Environmental excellence is a bottom-line issue, and cannot be left to the
more traditional approach of remediation, or “end-of-pipe” solutions. For example, the growing demand for “green” products, accelerated by national programs and requirements in Europe and the Pacific Rim, mean that environmental considerations may determine the ability to enter certain markets. When environmental management is infused in the corporate culture, the corporation can benefit from improved cost structures, better measurement systems, and more realistic decision-making. A foundation for comprehensive integration of environmental considerations is a formal, corporate policy that includes design for the environment (DFE) as a basic practice for the corporation.

- **Integrated Circuits (ICs).** The chapter incorporates by reference a substantial body of work developed by the Semiconductor Industry Association (SIA), in cooperation with its member companies, SEMATECH, and the Federal government. This environmental roadmap is part of a larger roadmap for integrated circuit technology, building on earlier work by the National Advisory Council on Semiconductors and the SIA. The SIA roadmap analyzes IC manufacturing processes, and recommends improvements in process technology, materials, and equipment.

- **Integrated Circuit Packaging.** IC packaging is the process of encapsulating and interconnecting integrated circuits so they may be reliably interconnected onto electronic systems. There are a variety of packaging approaches, but, to varying degrees, each share common environmental challenges: in the solvents used for cleaning circuits, the materials used in solders or other adhesives, and the chemicals used at various points in the process. Recommendations address the development of environmentally neutral substitute materials and more energy efficient processes.

- **Printed Wiring Boards (PWBs) and Assembly.** PWBs are the foundation upon which most electronic products are built. The boards, printed with electrically conductive pathways, hold chips and other electronic circuits together and allow them to operate as integrated electronic systems. From an environmental standpoint, they share many of the same types of issues as integrated circuits and IC packaging, i.e., the materials, chemicals, and solvents used in etching, plating, soldering, attaching, and cleaning. PWBs also offer opportunities for material reuse and more energy efficient processes. This chapter incorporates the Environmental and Safety Roadmap developed by the IPC, in cooperation with its member companies as part of a larger, independent interconnection technology roadmap.

- **Displays.** Displays are generally based on traditional cathode ray tube (CRT) technology, the same type of display found in televisions. CRTs represent significant environmental challenges, primarily in disposal, due to their size and the constituent materials incorporated into the CRT glass. Improved processes for production and recycling will help minimize this
Chapter 1

problem. Meanwhile, new flat panel display (FPD) technologies are starting to gain market share. These flat panel display technologies have their own environmental consequences, which are only now beginning to be understood, but are similar (in some of the technologies) in nature to semiconductor processes.

- **Disposition.** Recycling and reuse must be priorities in the electronics industry. The rapid obsolescence of computer and electronic products, combined with the plummeting prices for new generation systems, create a significant consumer incentive to dispose of old systems and buy new. This will continue to accelerate the entry of electronic systems into the waste stream unless viable technologies and infrastructures for recovery, and viable markets for the sale of recovered systems and materials, are developed. Designs that encourage recycling, purchasing systems that accept reused products and materials, and data tracking of product or component histories and performance are important developments in this area.

- **Regulations and Standards.** A variety of public and private organizations are working to develop new regulations and standards to guide environmental practices in industry. The aggressive efforts of various industry associations to develop voluntary guidelines and best practices offer the potential of meeting environmental requirements without the costs and inefficiencies often imposed by government-mandated regulations. Cooperative efforts among government, industry, and academia to conduct sound, life cycle analyses and propose technically valid and operationally viable standards offer the best approach to establishing a competitive, environmentally conscious business framework.

Appendix A includes a brief overview of some of the environmental activities taking place in Europe and Japan. This is included as a source for competitive benchmarking. In both Europe and Japan, environmentally conscious manufacturing, equipment and materials disposition, recycling, and related topics have not only ascended corporate ladders, they have given rise to cooperation, and sometimes conflict, between government, trade organizations and agencies, and industry.

Sandia National Laboratories has compiled a description of current flat panel display development projects underway at the National Laboratories, which is included in this report as Appendix B.

The overall agenda set forth in this report is an aggressive, far-reaching effort to make our domestic computer and electronics industry models of environmental excellence, while at the same time insuring environmental practices that contribute to, rather than complicate, international competitive success. This industry is truly vital to our national interests, and maintaining our quality of life
will depend in no small part on our success in pursuing and implementing these programs.
In the last few years, the electronics industry has become increasingly aware of the need to develop cost-effective, long-term solutions for environmental issues. Many organizations have invested resources to address environmental issues and business opportunities, and it has become apparent that a strategic, coordinated approach—a roadmap—is needed. Such a roadmap will help the electronics industry maintain a competitive edge in the international market and keep up with foreign competitors who benefit from well-established government/industry partnerships for addressing environmental issues.

The Microelectronics and Computer Technology Corporation (MCC) recognized the need for a strategic, industry-wide approach to environmental issues and launched the “Electronics Industry Environmental Roadmap” effort in November, 1993, with a workshop sponsored by the U.S. Department of Energy. Since that time, MCC has received funding from the Advanced Research Projects Agency (ARPA) and the EPA to continue working with industry task groups to compile information, digest the needs of industry, and suggest approaches.

Bringing key stakeholders together to set priorities, determine future needs, and leverage resources devoted to environmental challenges will result in cost-efficient strategies and solutions. These cost savings will allow companies to invest in other key business areas and products to enhance their worldwide market position.

The key issues and priority needs for the electronics industry are summarized in this “Electronics Industry Environmental Roadmap.” In addition, MCC has provided an analysis of the electronics industry environmental activities that are taking place in Europe and Japan (see Appendix A). This appendix is included to give perspective, showing that environmental activities are being undertaken globally that affect competitiveness and market entry.

The electronics and computer industry is the largest manufacturing employer in the U.S. This highly competitive, international industry accounts for nearly 11% of the U.S. gross domestic product, producing and distributing computers, communications, semiconductors, printed wiring boards, and consumer electronics. The industry is projected to grow at a rate of 4% per year throughout the remainder of the 1990s.

The building blocks of this industry (semiconductors, electronics packaging, printed wiring boards, assemblies, and displays) have typically been considered to be

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3 American Electronics Association estimates based on Department of Commerce data.
Chapter 2

relatively “clean” in terms of environmental impact, compared to other industry sectors. The electronics industry only emits 1.6% of total Toxic Release Inventory (TRI) emissions. Nevertheless, manufacturing by-products of the electronics industry and the disposition of electronic products are raising increasingly important technical, financial and environmental issues. Domestic and international air, water, ground and disposition regulations and standards now affect every step in the life cycle of electronic products, and are becoming an important cost consideration in electronic systems manufacturing.

Manufacturing wastes and the environmental impact of products are issues the electronics industry takes very seriously from both an environmental and a business perspective. Electronics manufacturing generates waste streams that are rigorously controlled and treated at a high cost to manufacturers, and the amount of waste that must be treated will increase if the current trend to expand the definition of hazardous waste continues.6

A Proactive Industry

Recognizing the environmental implications of its activities, the electronics industry has worked continually to align their business and environmental goals and to develop technologies and tools for environmentally conscious manufacturing. In 1992, over 40 organizations from various electronics industry segments worked together in a landmark study, coordinated by MCC, to identify the principal sources of waste in electronics production and address possible solutions and research needs. As a result of this study, the industry identified the generation and disposal of waste and disposition of end-of-life products as priority concerns, despite the fact that the waste generated by the electronics industry is only a small fraction of the more than 12 billion tons of industrial waste generated annually in the U.S.

Several prominent industry and professional groups have received national recognition for their efforts in the environmental arena:

- SEMATECH, for example, has been awarded $10 million from the Department of Defense to develop “pollution preventing, environmentally safe microchip manufacturing processes.” The consortia has also developed a 15-year Environment, Safety and Health Roadmap for the semiconductor industry, formed international partnerships for technology and information transfers, and conducted in-depth research and development in the environmental field.

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5 The TRI reports all emission into the environment of toxic chemicals. The EPA runs the program, which was mandated under Title III of the Superfund Amendments and Reauthorization Act of 1986.

6 For example, in 1992, Senate Bill S.976 proposed a technical amendment to the RCRA “mixture and derived from” rule, increasing amounts of solid non-hazardous waste that would have to be treated as hazardous waste by doing away with the distinction between low and high risk wastes. The amendment was not passed, but is indicative of a move toward more strict regulation of all waste. American Electronics Association, Comment to Senate Bill S.976 to amend RCRA, July 20, 1992.
The Institute for Interconnecting and Packaging Electronics Circuits (IPC) developed a technology roadmap for the electronic interconnect and assembly industry which addresses environmental issues, and has active industry committees focusing on the environment and environmentally conscious manufacturing.

The Electronic Industries Association (EIA) has worked for the development of sound environmental practices by promoting research, workshops, and tool development through a broad range of industry committees.

The Institute of Electrical and Electronics Engineers (IEEE) established an Environmental Health and Safety (EHS) committee and launched an annual “International Symposium on Electronics and the Environment” in May 1993, bringing together interested stakeholders from the electronics industry to share technical and managerial innovations for environmental issues.

The electronics industry efforts have benefited other manufacturing sectors as well. When the Montreal Protocol mandated the phase-out of chlorofluorocarbons (CFCs), the electronics industry joined together to develop alternatives to this critical component of electronics manufacturing. One industry group, called the Industry Cooperative for Ozone Layer Protection, has worked to facilitate the elimination of CFCs from electronics manufacturing processes. This group also developed an on-line database of alternative technologies called Ozonet that can be freely accessed throughout the U.S. These efforts and company commitments have allowed many electronics manufacturers to completely eliminate the use of CFCs in production, far in advance of the mandated deadline.

The wide variety of technical and collaborative efforts in the last few years have begun to bring both technology and business perspectives to environmental discussions and initiatives in electronics. In the last two years, major computer manufacturers have released a wide range of energy-efficient products whose innovative designs allow for major energy savings. However, one remaining obstacle is the lack of a national strategy for developing the infrastructure (including harmony between federal, state, and local regulations) and technologies for solving critical problems and developing appropriate solutions. A master plan for defining environmental goals and laying out realistic plans for achieving them has not yet been developed.

The Electronics Industry Environmental Roadmap effort will contribute to the continued “greening” of the electronics industry, offering an industry-defined strategy that follows a timetable based on industry objectives rather than government regulations. Furthermore, priorities will be based on an informed assessment of cost-effectiveness, and environmental benefit. The roadmap’s strategic, consensus approach, based on large-scale industry participation and partnerships with academia and government agencies, will help improve the
competitive posture of the entire U.S. electronics and computer industry. As the infrastructure and processes for sustainable and competitive manufacturing are put into place, more and more U.S. manufacturers will be able to implement environmentally conscious technologies in their manufacturing processes and benefit from the potential cost savings. Ultimately, the electronics industry will be able to offer not only environmentally friendly products, but also a model for collaboratively leveraging resources to address industry-wide challenges.

**Roadmap Process**

A series of activities and progressive steps occurred to develop the report with as much industry involvement and participation as possible. The following outlines the basic process in chronological steps:

1. **Launched roadmap effort through workshop.** A two-day workshop was held November 9-10, 1993 in Washington, D.C. to initiate the development of this industry roadmap report. This activity built upon the industry study entitled “Life Cycle Environmental Assessment of a Computer Workstation” that identified environmental challenges in the electronics industry.

2. **Formed task groups.** Industry task groups and leaders were formed along technology and business lines that follow the various chapters of the roadmap. A diverse set of industry professionals was sought to represent the various business and environmental aspects for each section.

3. **Generated draft outline.** A draft outline was prepared based upon the workshop results and the task group descriptions. The draft was submitted to ARPA in April for reference in a solicitation for research proposals. The draft served as a guide to organizations submitting proposals against BAA 94-29 (Broad Agency Announcement), on environmentally conscious electronic systems manufacturing.

4. **Regional presentations.** Presentations were made at various conferences and symposia, as well as at individual organizations, regarding the roadmap effort. These presentations broadened the awareness and involvement of industry participants.

5. **Task group work meetings.** Multiple work group meetings occurred across the country by teleconference, fax, and physical meeting to develop the content of each section independently. Each task group developed the background information and, more importantly, the short list of needs for each section. These needs were subsequently consolidated and prioritized during a series of regional meetings (see step 9).
6. **Analytical and research support.** In addition to organizing and participating in the task groups, MCC provide support to research the answers to specific task group needs and supply relevant analytical information for the formation of the roadmap sections.

7. **Compiled report for task group review.** MCC combined the various sections from each of the task groups and distributed the compiled report to the task group leaders and other active participants for the first view of the full document in advance of broader distribution.

8. **Revised and distributed report.** The draft document was distributed to over 200 contacts, requesting feedback and comments from a broader group than those that had participated directly in the development of the document.

9. **Regional feedback/prioritization meetings.** Three open regional meetings were held to discuss the content of the roadmap, and to consolidate and prioritize the needs for each section. Meetings were held in September in Austin, Boston, and Cupertino and were hosted by MCC, Polaroid, and Apple, respectively. Where appropriate, a ranking of priorities utilizing a “high, medium, and low” voting process was used.

10. **Revised report with selected task group leaders and volunteers.** MCC compiled the results and votes of the regional meetings along with the hard copy comments received by the reviewers submitting feedback. The revised priority needs were briefly reviewed with the task group leaders. Several sections were reworked by industry participants to reflect and incorporate the more significant changes recommended by the regional meetings.

11. **Distributed final draft for consensus.** In early November, the final draft was distributed to over 200 interested parties, for consensus sign-off. It was anticipated and expected that this would not be a board-level endorsement by each organization. This was an agreement in principle with the contents and the process, but not with the contents in their entirety.

12. **Prepared report for publication.** MCC performed a final edit of the document, incorporating minor edits and any changes required by the organizations providing consent.

13. **Published in December, 1994.** The final roadmap report was published, distributed, and made publicly available in December 1994.

14. **Continuing development of roadmap report.** The roadmap will continue to be refined in 1995 by MCC and industry participants. The key areas
of focus identified in the first roadmap will be examined in greater depth and more detailed plans of action developed.
The majority of this report focuses on environmental issues related to specific components in electronic systems, or at discrete stages of the electronics system’s life cycle. This chapter addresses the importance of integrating environmental principles throughout the corporate culture and business management process, beginning at the highest levels of the corporation. An organization that relegates environmental concerns solely to lower-level operating units cannot accomplish a comprehensive program of environmental excellence.

Environmental consciousness must be a fundamental part of the overall corporate culture, shaping corporate strategy, and contributing to the long-term competitiveness of the enterprise. When this cultural integration occurs, the corporation will reflect the economic and social logic of environmental awareness in its planning, product design and development, measurement systems, cost accounting, external relations, and strategic partnerships; in other words, across the entire value chain of the business. The result—measured not only in reduced waste, risk, and liability, but also in improved efficiency and products, and potentially even improved market share—will affirm the wisdom of the cultural evolution.

Perhaps in no other industry has the movement toward quality and continuous improvement been so totally embraced as in the electronics industry. Product life cycles are increasingly shorter, and customer expectations are increasingly tougher to meet. The pace of technology innovation continues to accelerate, and the global infrastructure of the electronics industry imposes enormous cost pressures and complex logistical challenges. High-quality is no longer a competitive differentiator, but a competitive necessity in the marketplace.

Similarly, electronics companies must embrace environmental quality objectives as part of strategic business planning processes and operating practices—including management systems, information management technology, performance measurement, and reporting—in order to understand the impact of environmental practices on business strategy. It is important that the corporate culture drive the integration of these environmental considerations into day-to-day corporate life. A company that fails to include environmental factors in its strategic decision-making process risks its corporate reputation as well as its economic survival.

Today, however, many companies still rely on end-of-pipe solutions and expend financial resources to meet requirements set by governmental agencies for waste handling. Competitiveness can be significantly enhanced by designing systems that are better, faster, smarter, and cheaper, reducing resource use and waste earlier in the cycle.

Enhanced risk management, compliance management systems, and pollution prevention initiatives have very real bottom-line consequences. These are most often reflected in terms of avoided costs and liabilities, but also directly through reduced material costs, lower risk and liability costs, faster permitting and approval, and process efficiencies. Table 3-1 provides a list of important
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environmental issues impacting the competitiveness of companies in the electronics industry.

Integrating environmental consciousness is most effective when focused on management systems and processes, rather than on specific initiatives such as eliminating a particular material by a given year, or increasing the recyclability of electronic products components by some percentage level.

| Global competitiveness will largely depend upon the ability to: | • Minimize waste.  
• Enhance productivity.  
• Minimize material costs.  
• Reduce hazardous materials usage.  
• Reduce energy consumption.  
• Re-engineer facilities processes, products, and management systems.  
• Understand current environmental cost structure. |
|---------------------------------------------------------------|
| Achieving environmentally conscious manufacturing systems and products necessitates: | • Collaboration between industry, government, and academia.  
• Regulatory policy and process changes.  
• Developing/applying new technologies.  
• Improved business processes and practices.  
• Broader education of all involved parties. |

Creating a balance between environmental stewardship and economic development requires acknowledgment that:

• Improved/higher environmental goals have real costs, as well as long-term benefits, which must be understood.

• These costs must be considered when evaluating shareholder value creation/presentation.

**Table 3-1.** Issues that impact the competitiveness of companies in the electronics industry.

Incorporating improved tools and methodologies early in the planning and design process will help decision makers working at the front-end integrate environmental concerns and product planning—the potential benefits will likely contribute to improved competitiveness. Figure 3-1 outlines how proactive planning can provide significant benefits.

<table>
<thead>
<tr>
<th>Planning Processes</th>
<th>Beneficial Results</th>
</tr>
</thead>
</table>
| • Effective partnerships with agencies and communities. | • Shorter cycle time for permitting of new facilities and more flexible permit parameters  
• Enhanced market penetration  
• Improved manufacturing capability/capacity/agility  
• Lower costs  
• Potentially higher ROIs/margins |
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**Figure 3-1.** Beneficial results of environmental planning.

Simply assuring compliance is not sufficient in a market that increasingly demands environmental protection. The accelerating pace, along with increasing complexity and stringency of regulatory requirements, necessitate that the electronics industry develop means to “get ahead of the curve.” Furthermore, the focus of the regulatory agenda has shifted from the facility-oriented “end-of-pipe” approach of the 1970s, to the process-oriented prescriptive standards of the 1980s. In the 1990s, products, as well as facilities, processes, and product stewardship, are the focus.

The mind-sets required for enhancing the quality of a product, improving the environmental aspects of a product, and ultimately increasing competitiveness are one and the same. All such initiatives require fundamental shifts in management and workforce thinking, practices, and standards, including:

- Deep level commitment and involvement by senior management;
- Empowerment of employees to act;
- Pervasive knowledge sharing, feedback, and communication;
- Aggressive goals and rigorous standards;
- Integration of environmental considerations at the earliest stages of design;
- Meaningful performance measures developed and applied on a systematic basis; and
- Effective partnerships with suppliers and customers.

The need for an environmental roadmap is made more significant by many different forces that influence environmental policy. Each of these influences must be individually understood, along with the linkages and interrelationships among them. Figure 3-2 illustrates the major environmental influences that impact the electronics industry and the need for a working balance between these elements.

**Issues and External Influences in the Strategic Decision-Making Process**
Figure 3-2. The electronics industry must first clearly understand the external influences and linkages between them, then create a balance accommodating to all.

These external influences can impact business success and environmental performance, often diverting attention from fundamental business goals. The impact and implications of these influences can be seen in several different areas, including:

- Enterprise (business) results;
- External influences/regulatory requirements;
- Behavioral practices/motivators; and
- Tools/methodologies (or lack thereof).

Table 3-2 presents a few examples of the ways that these influence groups affect corporate strategy. This information should not be considered comprehensive or exhaustive of the possible factors. Rather, the table compiles randomly selected comments from a quick review of recently published literature. This information emphasizes the need to invest in an environmental roadmap for the electronics industry—one that focuses on opportunity and/or risk recognition.

<table>
<thead>
<tr>
<th>Category</th>
<th>Key Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Suppliers</td>
<td></td>
</tr>
<tr>
<td>Shareholders</td>
<td></td>
</tr>
<tr>
<td>Regulators</td>
<td></td>
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<tr>
<td>Media</td>
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<tr>
<td>Public Interest Groups</td>
<td></td>
</tr>
<tr>
<td>General Public</td>
<td></td>
</tr>
<tr>
<td>Communities</td>
<td></td>
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</tbody>
</table>

Table 3-2 presents a few examples of the ways that these influence groups affect corporate strategy. This information should not be considered comprehensive or exhaustive of the possible factors. Rather, the table compiles randomly selected comments from a quick review of recently published literature. This information emphasizes the need to invest in an environmental roadmap for the electronics industry—one that focuses on opportunity and/or risk recognition.
Enterprise (business) results

- Potential market for products with improved environmental performance
- Loss of market share to offshore companies (global competition)
- Cost of waste management and remediation
- Increased competition
- Mounting cost of compliance
- Environmental liability issues have become quite significant
- Exemplary environmental performance is perceived as providing a competitive advantage
- Enormous business and investment opportunities for companies that can solve environmental problems
- Insufficient incentives for environmental technologies, materials, processes

External influences/regulatory requirements

- Liability issues during clean up
- Growing complexity of environmental business issues, regulations, legislation and standardization
- Growing number of environmental stakeholders
- Command and control regulations
- Public perception/scrutiny

Behavioral practices/motivators

- Environmental stewardship is emerging as key corporate responsibility issue of 1990s
- Lack of management/employee buy-in
- Change in corporate culture
- Building internal infrastructure to bring about change

Tools/Methodologies (or lack thereof)

- Environmental benefits difficult to quantify
- Environmental costs not identified to specific product/process for decision-making
- Lack of life-cycle approach
- Lack of reliable/quantifiable data for effective analysis/strategic policy formulation

**Table 3-2.** Factors that affect environmental performance.

Quick action necessitates a fundamental rethinking of the role that environmental considerations and professionals play in achieving basic business goals. Environmental considerations must be taken into account on a similar basis with any of the other factors that corporate leaders consider in day-to-day decision making and actions, and environmental professionals should have a seat at the table when these important decisions are being made. To make such a relationship successful, environmental professionals must come to the table prepared with business information as well as legal and technical knowledge, expertise, and materials required for a sound business decision. Environmental considerations must be integrated into the basic enterprise of an organization and become a thread in the fabric of the organization, not a button or ornament to be sewn on later.

There are at least seven attributes that are generally viewed as necessary for business environmental processes. Each of these attributes should be reflected throughout the basic value-chain of the electronics industry, represent integral

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**Focusing on the Business Issues**
components within any given segment, and provide logical transitions from segment to segment of the value chain. Figure 3-3 lists the desired attributes and suggests key initiatives needed at each step of the value chain.

**Environment Integrated into Life Cycle Thinking:** Environment is clearly understood and fully integrated within the organization, throughout the entire life cycle of the products and services, and across the value-chain of the business to include the extended enterprise of the organization (suppliers, customers, etc.). Environmental processes must be front-end integrated in order to play a key role in strategic planning and decision making, not “end-of-pipe reactive.”

**License to Operate:** Environmental processes assure and enhance an organization’s license to operate (e.g., permits) with: flexibility (operating parameters), shorter cycle times (efficiency), and cost-effectiveness.

**Capture Costs:** Environmental costs—both direct and indirect—are effectively captured to include a universal cost profile of environment-driven expenditures (capital and/or expense) throughout the life cycle and across the value chain. This profile should include costs related to the product as well as the operations (processes and facilities) and should be linked back to the activities that incurred the costs.

**Figure 3-3.** Desired attributes and link to the value chain.
Manage the Risks: Environmental processes effectively identify and manage the risks of the business, not simply in terms of regulatory compliance or remedial liability, but across the entire spectrum of business risks where environmental considerations may be a key driver.

Effective Advocacy: Environment-related advocacy and communications with all stakeholders should reinforce the environmentally conscious corporate culture.

Quality Linkage: Environmental processes must be directly linked to the central quality initiatives of the organization, where quality is generally viewed as conformance to specifications. This is highly analogous to compliance with regulatory standards or specifications. However, the linkage between quality initiatives and environment processes goes far beyond compliance.

Value-added/Bottom-line Oriented: Environmental initiatives and processes must add measurable value to the goals of the organization and be bottom-line oriented, but the time frames for these initiatives and processes may need longer pay-back periods.

The importance of considering the full product and process “life cycle” is commonly accepted as a critical aspect of integrating environmental and business strategies. However, there are at least two widely differing interpretations of the term.

1. Business life cycle: The product life cycle is a sequence of activity phases including the creation of a product concept, its development, launch, production, maintenance, maturity, re-evaluation, and renewal in the form of a next-generation product. (Similarly, the process life cycle is a sequence of activity phases including the development of facility and process designs, architecture and construction, operation and maintenance, and eventual upgrading or retirement.)

2. Physical life cycle: The product life cycle is a sequence of transformations in material and energy that includes extraction and processing of materials, product manufacture and assembly, distribution, use, and recovery or recycling of product materials. (Similarly, the process life cycle is a sequence of transformations in materials and energy that includes extraction and processing of materials used for process equipment and supplies, process operation and control, equipment cleaning and maintenance, and waste disposal or recovery.)

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This section is adapted, with the author’s permission, from a forthcoming book by Joseph Fiksel called *Design for Environment: Creating Eco-Efficient Products and Processes*, to be published by McGraw-Hill in May 1995.

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Note that a single process may be involved in producing a variety of different products, while producing a single product may involve a variety of different processes.

Figure 3-4 depicts how these dual life cycles are orthogonal yet interwoven. They intersect in at least two physical settings—in the laboratory where product and process concepts are created, and in the factory where full-scale production is performed. Yet they are very different in several respects:

• The time scale of the business life cycle is determined by the rate of technological change and other market conditions that determine product obsolescence; the time scale of the physical life cycle is determined by the length of service of a typical product unit, which may range from days or weeks for consumable products to years or decades for durable goods.

• The responsibility for the business life cycle and the business impacts (profits or losses incurred) are borne fully by the processing company; the responsibility for the physical life cycle and the associated impacts is distributed among many companies or individuals involved at different stages of transformation, and in some cases the responsibility for adverse impacts may be ambiguous (e.g., liability for waste disposal).

• The continuity of the business cycle depends upon the ability of a company to innovate by developing and delivering new product concepts that serve the needs of its markets; the continuity of the physical cycle depends upon the ability of various interested parties, potentially including the manufacturer, to refurbish used products and convert them to productive uses.

![Figure 3-4. Dual life cycles associated with a product.](image)

From a conventional product development perspective, interpretation 1 is the more meaningful one since it provides a framework for making business decisions
regarding desirable product features and cost or effort trade-offs. The concurrent engineering approach has always been based on this model of the business life cycle, with “ilities” associated with different phases.

On the other hand, the notion of the physical life cycle, interpretation 2, has been the focus of much work on life-cycle assessment (LCA) and has influenced recent efforts at environmental labeling, standard setting, and performance evaluation. While it is relevant to global sustainability, this approach to LCA is often unrelated to the business decisions addressed by product development groups, in which life-cycle analysis focuses on cost and performance trade-offs. For example, the increased cost of making a product more durable may be offset by reduced warranty costs. LCA results regarding environmental burdens, to the extent they reflect customer needs or corporate objectives, may certainly be factored into this type of business analysis, but the design decision framework must have a “return on investment” perspective. Therefore, electronics firms need to develop approaches to achieve integrated life cycle thinking, whereby financial, environmental and performance issues can be treated in a unified framework.

A fundamental requirement for an organization professing a cultural commitment to environmental excellence is a comprehensive design for the environment (DFE) program. Design for environment is defined as systematic consideration during new product and process development of design issues associated with environmental safety and health over the full product life cycle.8 In “concurrent” engineering, DFE is one of many design disciplines that address product quality at different stages of the life cycle (e.g., design for testability, manufacturability, and maintainability). These are often referred to collectively as DFX, or design for “ilities.”9

The goal of DFE, in simple terms, is to enable design teams to create eco-efficient products without compromising their cost, quality, and schedule constraints. An eco-efficient product may be defined as a product that both minimizes adverse environmental impacts, and maximizes conservation of valuable resources throughout its life cycle. There are a number of factors that have contributed to the growing interest of manufacturing firms in eco-efficiency:

- **Market awareness.** Both industrial and retail customers are increasingly conscious of the environmental performance of suppliers and products.

- **Differentiation.** Eco-efficient designs are generally superior in terms of elegance, energy conservation, and cost of ownership, and may sway a purchase decision if price and performance are comparable.

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- **Cost savings.** Eco-efficient products and processes can make a significant contribution to product line profitability through savings in production, distribution, and other life cycle costs.

- **Eco-labeling programs.** A number of product eco-labeling initiatives have arisen both in the U.S. and abroad, and the European Community is moving toward an eco-labeling standard.

- **Regulatory pressures.** Regulations governing the environmental impacts of products and production processes are becoming more stringent worldwide, especially with regards to waste disposal and recycling.

- **International standards.** The International Standards organization (ISO) has established Technical Committee TC207 to develop a global consensus on environmental management standards.

Perhaps the most important factor in changing industry attitudes has been the realization that paying attention to environmental responsibility can actually increase profitability. Reducing pollution at the source and designing products and processes in ways that enhance environmental quality generally result in higher productivity and reduced operating costs, and may also increase market share.

**Basic Principles of DFE**

The scope of DFE encompasses many disciplines, including environmental risk management, product safety, occupational health and safety, pollution prevention, ecology and resource conservation, accident prevention, and waste management. Figure 3-5 shows a hierarchical breakdown of DFE disciplines, most of which are routinely practiced by many manufacturing firms.

![Figure 3-5. A hierarchy of DFE principles.](image-url)
A variety of specific DFE methods have emerged to address the different areas of concern shown in Figure 3-5. For example, reducing the mass of a product can result in both energy and material conservation, which contributes to sustainability, and reduced pollutant emissions, thus contributing to health and safety.

This broad scope implies that the effort required for a company to practice DFE systematically is non-trivial. In order for DFE to be integrated into a new product development process, the following key elements are required:

- **Eco-efficiency metrics** are driven by fundamental customer needs or corporate goals and support environmental performance measurement.
- **Eco-efficient design practices**, based on in-depth understanding of relevant technologies, are implemented during the early stages of development.
- **Eco-efficiency analysis methods** are used to assess proposed designs with respect to the above metrics and to analyze cost and quality tradeoffs.

Throughout the process of integrating environmental issues into business practices, measurement tools and techniques are crucial for assessing performance and adherence to standards and other requirements. Product-, process-, and facility-certification initiatives (such as ISO standards) demand that the requisite management systems and processes are in place to ensure conformance to designated standards. To ensure the effectiveness of these systems and processes, meaningful performance measures, which reflect both in-process and end-of-process performance, must be developed and rigorously applied on a systematic basis.

Figure 3-6 reflects examples of the types of measures typically used at various levels in an organization. The mix of measures to be applied must make equal sense to the process operator and the CEO, and must be readily measurable and directly linked to fundamental business goals—it is only possible to manage what can be measured.
Environmental factors lead to substantial direct costs, as well as significant opportunity costs such as delayed decisions. Opportunity costs can lead to the potential loss of entire markets resulting, for example, from the impact of local environmental life cycle regulation (such as in Germany). In other cases, the absence of an environmental permit might delay the construction of a key manufacturing facility. Unfortunately, these costs are seldom, if ever, measured.

The total cost impact of environmental factors is very difficult to measure, especially for those organizations whose measurement systems are invested in past practices and habits. By focusing on both in-process and end-of-process measurements, companies can better assess their overall environmental performance, rather than simply determining the results of that performance, such as incidents, accidents, emissions, and waste treatment and disposal.

**Metrics**

A variety of eco-efficiency metrics are commonly used in the electronics industry. Some examples are listed below; many of these have been adopted by eco-labeling programs both in the European Community and the U.S.:

- **Energy metrics:**
  - Total energy consumed during the product life cycle.
  - Renewable energy consumed during the product life cycle.
  - Power used during operation (for electrical products).

- **Emissions metrics:**
  - Toxic or hazardous materials used in production.
  - Total industrial waste generated during production.
  - Hazardous waste generated during production or use.
– Air emissions and water effluents during production.
– Greenhouse gases and ozone-depleting substances released.

• Materials management metrics:
  – Useful operating life.
  – Product disassembly and recovery time.
  – Percentage of recycled materials used as input to product.
  – Percentage of recyclable materials available at end-of-life.
  – Percentage of product recovered and reused.
  – Purity of recyclable materials recovered.
  – Percentage of product disposed or incinerated.
  – Percentage of packaging or containers recycled.

• Economic metrics:
  – Average life cycle cost incurred by the manufacturer.
  – Purchase and operating cost incurred by the customer.
  – Cost savings associated with design improvements.

Once eco-efficiency goals have been expressed in terms of specific quality metrics, the next step in product development is to further delineate these metrics into quantitative parameters that can be estimated and tracked for a particular product design. An example is presented in Figure 3-7.

![Figure 3-7. Mapping general goals into measurable parameters.](image)

A confusing array of terms are used to describe activities that reduce the environmental impact of products and manufacturing processes. Pollution prevention, source reduction, waste minimization, design for environment, design for recycling, design for disassembly, life-cycle assessment, and industrial ecology are
just some of the commonly used terms. Many of these terms have multiple definitions, depending on the context in which they are used. Some of the terminology is used interchangeably even though each of the terms listed above has subtly different meanings.

The following are some of the more common DFE practices in industry today:

- **Material substitution**: replacing product constituents with substitute materials that are superior with respect to recyclability, energy content, or other metrics.
- **Waste source reduction**: reducing the mass of the product or of its packaging, thus reducing the quantity of waste matter per product unit.
- **Substance use reduction**: reducing or eliminating the types or amounts of undesirable substances (e.g., toxics or CFCs) that are either incorporated into the product or used in its manufacturing process.
- **Energy use reduction**: reducing the energy required to produce, transport, store, maintain, use, recycle, or dispose of the product and its packaging.
- **Life extension**: prolonging the useful life of a product or its components, thus reducing the waste streams (see design for re-usability).
- **Design for separability and disassembly**: simplifying product disassembly and material recovery using techniques such as snap fastening of components and color-coding of plastics.
- **Design for recyclability**: ensuring both high recycled content in product materials and maximum recycling, i.e., minimum waste, at the end of product life.
- **Design for disposability**: assuring that all non-recyclable materials and components can be safely and efficiently disposed of (e.g., ink/pigment restrictions).
- **Design for re-usability**: enabling certain product components to be recovered, refurbished, and re-used.
- **Design for remanufacture**: enabling recovery of post-industrial or post-consumer waste for recycling as input to the manufacture of new products.
- **Design for energy recovery**: extraction of energy from waste materials, e.g., through incineration.

**Analysis Methods**

Analysis methods are needed to assess the improvement expected from a new design with respect to the eco-efficiency metrics. Analysis methods may be either qualitative or quantitative. They can range from focused estimation of parameters (e.g., market surveys of expected recycling rates) to full-scale life-cycle assessment. Selected examples of these analysis methods are:
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• **Product design analysis.** A number of analysis methods currently under development seek to optimize the number and configuration of product parts or the robotic disassembly of products.\(^\text{10}\) These tools are focused on DFE practices such as design for recyclability, design for remanufacture, and design for separability and disassembly.

• **Life-cycle assessment.** Life-cycle assessment begins with a comprehensive accounting of the energy requirements and material flows associated with all of the stages of a product’s life, from raw material acquisition to product disposal.\(^\text{11}\) After an inventory of raw material, energy, and waste associated with a product has been assembled, the environmental impacts of these resource requirements and emissions are quantitatively assessed using any of a variety of approaches.\(^\text{12}\) As a final step, improvements are suggested.\(^\text{13}\) Although a number of software tools exist that assess material and energy use in commodity materials such as paper and plastic, no generic tools are currently available for products as complex as a computer workstation or a similar electronic product. The impact assessment and improvement analysis stages of life cycle assessments are only in the preliminary stages of development.

• **Qualitative and semi-quantitative life-cycle assessments.** A full life-cycle assessment is data intensive and results in the quantification of a variety of environmental impacts over all of the life-cycle stages, from raw material acquisition to product disposition. Organizing this information into a format that allows overall product assessments is challenging. One approach, outlined by Graedel and Allenby,\(^\text{14}\) is to qualitatively assess the impact of each environmental endpoint at each life-cycle stage. The matrix elements can be qualitatively evaluated without a complete life-cycle inventory and an overall assessment of environmental impact can be obtained by assigning rough numerical scores to each of the matrix elements.

• **Chemical-use mapping.** In order to identify candidate materials for substance-use reduction, it is necessary to build a structured model of the materials used directly in manufacturing and the precursors for these

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materials. This procedure is shown conceptually in Figure 3-8. Although material-use mapping provides a qualitative screening of potential concerns, its implementation is data-intensive. Hundreds of chemicals are used in a typical electronic product and many of those materials will involve precursor chemicals. Software capable of building these chemical-use trees is not currently available.

**Figure 3-8.** An example of chemical-use mapping.

- **Material-balance models.** Using process flow diagrams and material and energy balances, models of the flows of resources and emissions into and out of a facility can be constructed. These process flow models can be coupled with optimization tools to identify process configurations that minimize the water use, energy requirements, or the consumption of selected materials.

**Integration of DFE with Other Design Objectives**

Environmental objectives present just one set of constraints on the design of processes and products. Other constraints may be set by assembly, manufacturing, operability, reliability, serviceability, and testability goals. Therefore, the designer

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must be able to integrate DFE analyses with other design procedures to arrive at a design that optimizes a diverse set of objectives.

Integrating environmental considerations throughout the product life cycle begins with a visible, high-level commitment. DFE should be a normal part of doing business from product concept through end-of-life. The commitment to a comprehensive DFE program must begin at the most senior levels of corporate management, and be recognized by product and process designers, development and manufacturing managers, and marketing personnel as a key competitive advantage. An example of a DFE policy that can be used by a company is:

(1) **DFE as an operating principle**: It is our policy to conduct DFE as an ordinary part of our product design and review activity. We expect our design engineers and product managers to put the tools and concepts of DFE to use from product concept to product delivery and end-of-life. We will reward product and process designers who cut environmental costs, risks, and wastes from the life-cycle of our products.

(2) It is our policy that during the course of a product’s development cycle, our designers will utilize DFE as a method of:

- Understanding the environmental impacts of materials, product functions, and manufacturing processes.
- Adding alternatives to the choice of materials, product functions, and shop-floor processes.
- Evaluating the wider array of alternatives.
- Learning better ways to write and implement “green” specifications for others to meet.
- Measuring or receiving information about actual outcomes and feeding back the results to the next round of design decisions, on the same or future products.

In order to accept, agree, and support DFE, senior managers\(^\text{16}\) (along with others) will need a clear, consistent policy that explains:

- Why the company should implement DFE,
- What the benefits and impacts of DFE implementation are for the business and company, and
- What deliverables/value the senior managers themselves can expect to receive.

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\(^{16}\) In this context, senior managers refer to vice-presidents for product/process development and vice-presidents for manufacturing/operations, and vice-presidents for sales and marketing.
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To carry out DFE activities, product designers\(^{17}\) will need training, tools, and other resources. This roadmap recommends follow-up tasks that provide best-practice tools and resources to designers, including:

- Better information about the environmental impacts and benefits of materials, products, and technology systems. This information should be provided through DFE tools and/or awareness and skills training. For example, training might identify and explain how to access existing on-line environmental databases and incorporate the relevant information into existing CAD tools.

- Access to others who can interpret and explain the information that is received. While it is advantageous to build environmental expertise in the design community over the long-term, a guide on “where-and-how-to-go-for-more-information” is needed to improve the information flow from environmental and regulatory professionals to designers, at the request of designers, in the language of designers, and in the interest of improving designs.

- The ability to formulate effective recommendations and justifications for new alternatives.

Manufacturers require the same types of resources as product designers—the information that is provided, however, should apply to materials, technologies, options, and other resources that will improve manufacturing processes for the product.

Table 3-3 identifies several prerequisites to effective integration of environmental considerations that warrant further examination and development. These issues are intended to: (1) heighten the awareness of senior and operating executives about the importance of environmental issues to the electronics industry, and (2) provide the tools and information necessary to allow the environmental professional to provide meaningful business input, thereby helping the organization make an informed business decision.

<table>
<thead>
<tr>
<th>Culture</th>
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</thead>
<tbody>
<tr>
<td><strong>Management Commitment</strong>: Develop management buy-in on the importance of environmental issues to the electronics industry.</td>
</tr>
<tr>
<td><strong>Education</strong>: Educate key stakeholders to the implications of environmental activities.</td>
</tr>
<tr>
<td><strong>Product Stewardship</strong>: Address, in partnership with suppliers and customers, the environmental performance issues associated with a product throughout its life, including end-of-life disposition.</td>
</tr>
<tr>
<td><strong>Design for Environment</strong>: Include environmental impacts, implications, and considerations at every stage of the product design cycle, based on a visible, high-level commitment to DFE principles.</td>
</tr>
</tbody>
</table>

\(^{17}\) In this context, product designers may include engineers and scientists, development program managers, business strategists, and design team managers.
### Metrics

- **Metrics:** Conduct internal/external benchmark studies to develop metrics to achieve quality and competitiveness.
- **Performance Measures:** Develop performance standards, product certification and audit processes.

<table>
<thead>
<tr>
<th>Competitiveness</th>
<th>Quality</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Product Cost:</strong> Modify ways to account for environmental costs at product level.</td>
<td><strong>Standards:</strong> Participate in setting national, regional and business segment standards.</td>
</tr>
<tr>
<td><strong>Operational Costs:</strong> Understand ways to account for environmental costs such as energy consumption, disposition, and liability.</td>
<td><strong>Standards:</strong> Participate in international environmental/electronics standards development.</td>
</tr>
<tr>
<td><strong>Marketing:</strong> Demonstrate how environmental attributes directly/indirectly increase sales, profits, and market share.</td>
<td><strong>Legal:</strong> Monitor and analyze product take-back and other regulatory trends.</td>
</tr>
<tr>
<td><strong>Suppliers:</strong> Encourage supplier/customer partnerships for process/equipment/material development for “greener” manufacturing.</td>
<td><strong>Feedback and Communication:</strong> Develop systems to maximize efficiency and ensure consistency of approach throughout the organization.</td>
</tr>
<tr>
<td><strong>Technologies:</strong> Evaluate/analyze technologies and trends.</td>
<td><strong>Technologies:</strong> Evaluate/analyze trends, avoid end-of-pipe treatments, and support the development of pollution prevention technology.</td>
</tr>
<tr>
<td><strong>Trade:</strong> Identify and measure potential environmental trade barriers.</td>
<td></td>
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</table>

### Methods and Tools for Design for Environment

**Table 3-3.** Summary of important prerequisites for integrating environmental considerations into business planning.
### Chapter 3

#### Priority Needs and Approaches

<table>
<thead>
<tr>
<th>Priority Need (decreasing order of priority)</th>
<th>Approach</th>
<th>Selected Tasks</th>
</tr>
</thead>
</table>
| • Characterize elements of environmental decision making. | • Establish metrics for environmental quality management in design processes.  
• Forecast environmental expectations of the market. | • Conduct external benchmarking.  
• Develop internal performance/cost metrics to incorporate environmental issues into strategic planning processes. |
| • Incorporate environmental principles into existing business infrastructure. | • Integrate DFE into the organizational infrastructure.  
• Integrate DFE practices with existing business practices.  
• Influence supply chain to incorporate environmental principles. | • Establish environmental goals as a part of corporate strategic planning process. |
| • Develop tools to enhance voluntary implementation of DFE. | • Devise decision-making and analytical tools to support the understanding of design alternatives and tradeoffs.  
• Incorporate design for recycling (DFR)/design for environment (DFE) into product/process-design environments.  
• Incorporate DFE into existing product development processes.  
• Establish test and materials standards to enable uniform comparisons for DFE.  
• Generate and verify data to enable DFE.  
• Enable ready access to existing data distributed in multiple forms in a myriad of databases. | • Create software tools collaboratively between industry, academia, and government.  
• Define DFR and DFD needs in a manner such that they can be incorporated into existing CAD/CAM software.  
• Develop DFE “best practices” manuals utilizing existing knowledge.  
• Initiate a joint industry, academia, and government project to develop the tools to access and analyze the data through a public communications facility, such as the Internet. |
| • Help decision makers incorporate environmental information into planning processes and understand the financial implications of environmental decisions. | • Format environmental reports to be consistent with standard business practices.  
• Provide financial and accounting tools for decision makers. | • Assemble knowledge gained from data.  
• Develop environmental accounting practices that can be incorporated into existing systems. |
| • Educate stakeholders on the environmental implications of their decisions. | • Educate and disseminate information to stakeholders regarding the economics of environmental activities.  
• Educate staff on DFE and LCA considerations.  
• Educate environmental professionals on business implications of their decisions. | • Add environmental parameters as an element of the Malcolm Baldrige Quality Award. |
| • Encourage senior-level public policy intervention. | • Educate business leaders on environmental public policy issues. | • Get senior executives to testify on their commitment to voluntary environmental management. |
In 1992, the Semiconductor Industry Association (SIA) and SEMATECH facilitated the development of a Technology Roadmap for the semiconductor industry—the National Technology Roadmap for Semiconductors (NTRS). This was the outcome of a process that reevaluated the status and future of the U.S. in semiconductor technology and started with the creation of the Presidentially-appointed National Advisory Committee on Semiconductors (NACS). The subsequent NACS study and workshops raised the questions, “Was anything else needed?” and “Were current efforts sufficient?” The semiconductor roadmap was developed to answer these questions and includes a section on Environment, Safety, and Health (ESH) as part of the overall Technology Roadmap.

The entire semiconductor roadmap is being revisited by SIA in 1994, and the ESH section is being expanded. The revised ESH roadmap addresses fabrication and chip packaging and will have more metrics and time lines. The reader is referred to that document for a presentation of the integrated circuit chip manufacturing and packaging Environment, Safety, and Health Roadmap.18

Much progress has been made by the semiconductor industry in environment, safety, and health in the past, but the semiconductor roadmap identifies further aggressive goals and schedules for improvement. The ESH section is divided into five major topic areas: Design for ESH Tools and Methodologies (such as ESH cost of ownership, risk assessment, and mass balance), Hazardous Chemical Use Reduction, Emissions Reduction, Energy/Water Reduction, and Worker Protection/Ergonomics.

Progress has been made since the initial semiconductor roadmap was published in 1992. For example, hazardous chemical use has been significantly reduced. Ozone-Depleting Substances and ethylene glycol ethers are rapidly disappearing from use in semiconductor wafer and assembly manufacturing processes. Alternative chemicals and safer delivery methods are being sought for silane, dopants, and the hazardous solvents and degreasers used in equipment cleaners and assembly processes. Emission abatement technology, process optimization, and replacement chemicals are being sought for atmospherically long-lived process gases such as perfluoro compounds. Advanced wafer cleaning methods, using significantly less chemicals or no chemicals, have been demonstrated, although more research is still needed. The core strategy of the 1994 roadmap is to integrate preventative ESH solutions into process and supplier engineering. This “Design for Environment” paradigm shift is beginning to occur throughout the electronics industry.

The ESH portion of the 1994 NTRS will focus continuous improvements in hazardous chemical use reduction, energy and water use reduction, and worker protection/ergonomics programs. In order to successfully implement these improvements, tools need to be developed to manage chemical, energy, and water

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18 A copy of the 1994 NTRS, due to be released by the Semiconductor Industry Association in December 1994, may be obtained by calling (408) 246-2711.
mass balance; ESH cost of ownership; and risk assessment. As semiconductor geometries decrease, cost-effective, reliable, integrated chemical sensors, alternative cleaning processes, hydride alternatives, and additive process technologies become necessary.
As integrated circuit devices (ICs) become faster and more powerful, device packaging becomes a major limitation on computer speed. Packaging technologies combine the engineering and manufacturing capabilities required to convert an electrical circuit into a manufactured assembly, fulfilling four key technical functions: interconnect, mechanical support, heat dissipation, and device protection.\(^{19}\)

Packaging provides the electrical interconnection between the IC and the substrate, creating an assembly, controlling the efficient release of heat, protecting against moisture, and insulating against hot- and cold-temperature cycles and other effects of the environment. Most IC packages consist of the same basic elements: the IC device, wire bonds, the leadframe, and an encapsulant. The leadframe is connected to the chip using a very thin wire bonded to both the chip and the leadframe. The encapsulant or molding, usually made from plastic, encloses the chip, wire, and part of the leadframe, thereby protecting the IC from the ambient environment.\(^{20}\) Some ICs were packaged in ceramic packages, then hermetically sealed to protect the device from the elements.

IC packaging is available in seven basic family types: plastic, ceramic, plastic pin-grid array (plastic PGA), tape automated bonding (TAB), chip-on-board (COB), flip chip, and multichip modules (MCM). Plastic packaging includes dual in-line pin (DIP), small outline integrated circuit (SOIC), small outline j-lead (SOJ), plastic leaded chip carrier (PLCC), and plastic quad flat pack (PQFP), among many, many others.

After plastic packages (by far the most common), the next most popular package type is the ceramic DIP (CERDIP). A CERDIP looks similar to a plastic package, but is made of two ceramic halves joined at the leadframe by a glass frit. The chip is bonded to the leadframe, the wire connections are made, and the package is formed by placing the top and bottom ceramic pieces together and sealing them. The ceramic pin grid array (ceramic PGA) comes next in terms of market share, followed by the remaining families of packaging.\(^{21}\)

Ceramic packaging represents about 10% of the total dollar volume of the semiconductor materials market, and about 25% of the packaging materials market. By volume of packages, ceramic packaging is only about 1% to 2% of the unit volume.

The remarkable growth of the past few years in the IC market has led to innovative packaging techniques that offer low cost, low power consumption, high speed and high density. Ball grid arrays (BGA), MCMs, and chip-on board

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\(^{20}\) Ibid., p. 125.

\(^{21}\) Ibid., p. 127.
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(COB) all support high pin counts, which increase in relation to speed and available power. As the number of pins increase and available space decreases, reliable assembly, connection, and maintenance becomes a tougher technical challenge. The need for high-density technology is increasing the use of boards based on surface mount technology (SMT). Surface-mounted components are soldered directly onto the board instead of inserting leads or wires through holes in the substrate, as is traditional. Since holes are not drilled in the substrate, components can be mounted on both sides of the board, eliminating the need for loose wires and solders.

The ability to compress the size and double the component density suggests that this technology will continue to be in high demand for packaging chips until a reliable and cost-efficient “bare die” technology is available. Bare-die assemblies directly connect the die to the substrate without the use of traditional packages and leadframes. This technique reduces or eliminates the need for plastic and ceramic packaging and enhances the viability of MCMs. The MCM packaging technique is expensive and suffers from problems with device reliability, since it is not currently feasible to test each device individually before release from the manufacturer. Such issues hinder MCMs from being used widely in high-volume applications. Development of new and more efficient test methods are proving more reliable, which may contribute to eliminating the problem of bare-die testability, or “known good die.” However, until the bare die technology is more developed, traditional packaging techniques will dominate the market.

The IC’s performance, level of integration, and size will define the future packaging markets, applications, and ultimately, the environmental impact of IC packaging. Increased pin counts, which are necessary for harnessing higher-integration performance, will increase packaging costs and lead users to space-efficient surface-mount packages for loading high performance devices into a given board area. SMT packages are smaller and can be mounted on both sides of a PWB, thereby lowering PWB costs by up to 60% while improving overall system performance. It is estimated that SMT packages will hold 75% of IC units shipped in packages in 1998, up from 44% today.

Integration of more functions on a single IC will allow users to reduce the necessary number of devices, thereby reducing the number of packages. In fact, between 1994 and 1998, the worldwide compound annual growth rate (CAGR) of packaged-device shipments is expected to drop to 7% from 18% in the early

Semiconductor Packaging: Market Status

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22 The connecting system of the package is referred to as the pin. Pins provide mechanical support and electrical connection.
23 Op cit., note 19.
24 Op cit., note 19.
Through-hole packages will decline to 25% from 56% over the same period. DIPs will drop from 52% of total packages sold in 1993 to 23% in 1998.

However, SOIC package use will grow at a 19% CAGR to become 34% of total units shipped by 1998. SOJs will grow at a 33% CAGR to reach 17% of total units shipped over the same period. In 1998, 92% of consumed packages will be plastic, both SMT and through-hole. Although significant growth is currently projected in the ceramic pin-grid array market, due to the requirement for socketable packages with electrical and thermal performance needed by 32/64 bit microprocessors.  

Environmental issues in IC packaging generally parallel those in the rest of the electronics industry. The concerns primarily lie with the materials and processes for producing the plastic and the leadframes or ceramic packages and cover: solvents, photoresists, heavy metals, materials waste, and energy use.

**Process Flow:** The leadframe, a rectangular metal frame with leads, provides the connections for IC devices. Currently, leadframes are predominantly made by punching, or stamping, alloy 42 or copper from a metal sheet. Registration holes are then created with gang arrays of small punches that remove small sections of the metal sheet. After punching, the lead frame is typically cleaned. In the past, this has involved chlorinated fluorocarbons or other cleaning solvents, but now water-based cleaning systems are commonly used. Shrinking IC geometries are forcing leadframe manufacturers to use alternative production techniques, such as etching, in order to create very fine-pitch leads.

The formed leadframe is masked for plating and then cleaned to remove native oxide in either a mild hydrochloric acid (HCl) solution or with a brightener that contains sulfuric acid. Because hydrogen sulfide is a by-product of the sulfuric process, manufacturers tend to choose HCl. The mask process involves either a liquid photoresist or an aqueous dry-film. The latter offers significant environmental advantages over liquid resist, which requires trichloroethylene (TCE) for removal and contains solvents that, when baked out, become volatile organic compound (VOC) emissions.

**Environmental Issues:** Leadframe production, while producing some waste streams from plating and etching, contributes relatively little to the issues of materials waste and solvent cleaning. Some manufacturers create the leadframes by etching, in which case a heavy-metal-contaminated acid and solvent waste stream results. The alternative is punching, or stamping, the leadframe. In this case, there is virtually no waste stream, and there is a market for the scrap metal that remains.

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27 Personal conversation with John Prusak, IBM, Austin TX, 1994.
Once the leadframe is fabricated, the potential for waste and pollution comes from solvent cleaning and plating. This is a case in which a preferred process also benefits the environment. In order to protect silver-plated leadframe tips from contamination and bent leads caused by handling, leadframes are rarely cleaned before die attach. Therefore, whereas leadframes used to be cleaned with chlorinated fluorocarbons, they are now either plasma etched, cleaned with an aqueous solution, or not cleaned at all. If the leadframes are plated with palladium (Pd), which is solderable, good adhesion to the plastic package is possible without any additional plating except for a nickel (Ni) undercoat. Palladium is highly conductive and non-reactive, but brittle. Finally, although a deflash step is required, the media is recycled in sealed systems and is non-polluting.

Packaging Materials

Ovens used for high-temperature sintering of ceramics, curing of plastics, and testing of completed components consume large amounts of energy. Ceramics require high-energy processing. Although not much of the material is thrown away during the process, the material is quite expensive, averaging 10¢ to 15¢ per pin, compared to 1¢ per pin for plastic. Since ceramic packages are purchased pre-made, they do not require molds and mold presses for new devices and low-volume runs. Ceramic packaging generates more waste than plastic packaging because it has more processing steps, requires more chemicals, and consumes more energy. Also, some of the organic materials and solvents used in ceramic manufacturing, such as toluene, xylene, and binders (such as polyvinyl butyral) are suspected to cause cancer and/or miscarriages. As a result, they could be subject to further regulations.

Plastic is an attractive alternative to ceramic, particularly in terms of cost and weight. Currently, thermosets dominate, but produce significant material waste. In all plastic packaging types, however, epoxies, heavy metals, and flame retardants are used. These materials are often regulated as hazardous, thus making recycling difficult.

Punching the metal to form a “can” or “pocket” in flat metal (either aluminum or copper) plate with epoxied leads is another package possibility. The metal halves are epoxied together with a B-stage material—the intermediate cure stage of a thermoset resin in which the plastic is softened but does not fuse when heated. Metal packages produce little material waste and are similar to ceramic packages in that the plating is already in place, so that lead frames do not need to be plated to ensure good adhesion. Also, metal packages do not need any dam bars to halt the flow of package material, saving costs in tooling, energy, and material.

Package Molding

The molding process forms a given material around the device, wire bonds, and parts of the leads. The most common molding materials used are thermoset (epoxy) types, with some limited use of thermoplastics or reaction injection molding (RIM).
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Thermoset materials (epoxy) are used for plastic packages. They are made with fused silica as a filler (>60%), antimony trioxide or bromine as a flame retardant, cresylic novolac (Cresol Novalak) resin, and phenolic novolac (Phenol Novalak) resin as a hardener. A long-chain hydrocarbon, such as a low molecular weight polyethylene, is also used as a release agent. There are several concerns regarding the impact of this compounded plastic on the environment. The first concern is the disposal of waste. Since 90 to 95% of the cross-linking occurs during molding (when the material reacts and sets) the epoxy cannot be reused—thus, up to 60% of the material is wasted. As well, certain brominated furan flame retardants generate hazardous by-products when burned or incinerated. The issue of flame retardants and their disposal is becoming a pressing issue in Europe.

Thermoplastics, such as polyphenolene sulfide, have been in limited use for a decade as a molding material for passive and other non-silicon devices. A notable advantage of thermoplastics over thermosets is the ability to regrind and reuse the material. Although they are more expensive and more hygroscopic than epoxy, thermoplastics create virtually no material waste, have a fast cycle time, and they do not require a post-mold cure step, thereby offering significant energy savings.

Reaction-injection molding offers all of the advantages of thermoplastics and more. It is based on styrene, combining two liquids to create a thermoplastic, but has the positive characteristics of several package types. It has a very short cycle time (about 0.5 seconds), cures at a low temperature (90°C), and is an OEM product that does not require a mold or mold press for custom or low-volume devices. The styrene offers good thermal and mechanical control, and, being a thermoplastic, produces no material waste and allows the runner to be reused.

The molded package then goes through a deflash step—a finishing technique that removes excess material from the plastic package. Deflash is accomplished either chemically or mechanically. There are efficiency, hazard, and reliability issues associated with the chemical method. Most molding shops use media (powdered plastic), water jets (or a combination), or mechanical deflash. The exposed lead-frame is then cleaned in a mild HCl solution prior to solder plating.

Post-mold Deflash
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### Priority Needs Matrix

<table>
<thead>
<tr>
<th>Priority Need</th>
<th>Approach</th>
<th>Selected Tasks</th>
</tr>
</thead>
</table>
| * Reduce environmental burden of existing cleaning technologies. | • Develop alternative cleaning technologies.  
• Eliminate unnecessary cleaning steps.              | • Document and demonstrate alternative cleaning technologies.  
• Develop no-clean processes.                        |
| * Eliminate brominated furan flame retardants.     | • Find alternative flame retardants and flame resistant materials.       | • Collaborate with national labs on flame retardants.  
• Collaborate with European organizations in developing alternative flame retardants. |
| * Develop environmentally preferable alternative packaging technologies. | • Eliminate 1st-level packaging through bare die and other approaches.  | • Demonstrate known good die techniques.  
• Develop alternative packaging technologies.        |
| * Increase the use of recyclable thermoplastics over thermosets. | • Advance materials properties of thermoplastics for use as molding compounds. | • Reduce the hygroscopic characteristic of thermoplastics.  
• Reduce thermoplastic molding stress.                |
| * Delay increased use of etching technologies for leadframes. | • Maximize capabilities of punching technologies.  
• Eliminate leadframes in 1st level packages.         | • Determine the limits of punching technology.  
• Pursue alternatives to leadframes for fine pitch applications. |
| * Distinguish between the perceived risk and the actual risk of the presence of cyanide in gold plating and lead in soldering systems. | • Encourage dialog between industry, public policy, and community organizations on the actual risks associated with the use of cyanide and lead in electronics products. | • Prepare fact sheets from assembled industry data.  
• Conduct community workshops.  
• Perform risk/hazard study of lead in electronics.    |
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This section of the roadmap covers the electronic interconnection industry, which includes primarily printed wiring board (PWB) manufacturers and independent electronic assembly companies. Also included are the related equipment and materials suppliers to this industry, as well as the original equipment manufacturers (OEMs) that use PWBs and electronic assemblies in their final products. The information in this section was gathered primarily through two means: the IPC Industry Technology Roadmap Survey and the IPC Environmental Roadmap Survey.

The former was circulated to more than 1800 IPC member companies in 1993 to develop the first industry technology roadmap. This original survey included few questions on environmental and safety issues, so the 1994 Technology Roadmap Survey was revised to include a greater environmental and safety emphasis.

In addition to the general industry technology roadmap and survey, IPC members developed a specific environmental and safety survey and roadmap in 1994. This survey was circulated to more than 800 people in the environmental and safety fields, as well as members of related IPC technical committees such as the Assembly Committee, the Joining Committee, and the Base Materials Committee.

The results from this focused survey were combined with information from the general technology roadmap survey in order to develop an industry environmental and safety roadmap. Both roadmaps are also being used to steer research on environmentally friendly technologies by the Interconnection Technology Research Institute (ITRI) and MCC, and to guide work in the PWB and Assembly Design for Environment Program.

The printed wiring board is the platform upon which electronic components, such as integrated circuits and capacitors, are mounted. The PWB provides both the physical structure for mounting and holding components as well as the electrical interconnection between components. The combination of the PWB and the components that are mounted on it are referred to as an electronic assembly. This assembly is the basic building block for all of the larger electronic systems in the world.

There are approximately 700 independent PWB manufacturers in the U.S., and an equal number of independent electronic assembly companies. More than 90% of the U.S. independent PWB manufacturers have sales under $10 million. The global market for the electronic interconnection industry is about $40 billion. The U.S. controls about 29% of the market, a substantial reduction from 1980 when the U.S. held 40% of the world market (see Figure 6-1).

The total domestic market for all types of PWBs was approximately $5.5 billion in 1993. The market for these PWBs in the U.S. is shown in Figure 6-2. Approximately 80% of the PWBs produced in the U.S. are made by independent PWB manufacturers. The remaining 20% are produced in-house by OEMs.
Of all PWBs produced in the U.S., approximately 7.3% are flexible circuits and the remaining 92.7% are rigid PWBs. About 55% of the PWB market is multilayer boards, while 22% are single- or double-sided boards and the remainder are other types. With respect to the number of PWBs manufactured and the cost per board, that data is shown in Table 6-1. The basic manufacturing process flow for PWBs is shown in Figure 6-3.

![Graph showing historical world market share for rigid and flexible circuits.](image)

**Figure 6-1.** Historical world market share for rigid and flexible circuits.²⁸

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Figure 6-2. Market for PWBs in the U.S. in 1993.\textsuperscript{29}

\textsuperscript{29} IPC Technology Marketing Research Council (TMRC), “Market for Rigid PWBs in 1993,” June 1994, p. 35.
Chapter 6

1. Prepare photo tools for manufacturing. Prepare Numerical Control programs to control the drilling, routing, and testing equipment during production.

2. Manufacturer inner-layer cores with circuit designs: press cores together to form panels from which individual circuit boards will be cut.

3. Drill holes through board to establish a continuous electrical path between layers and to provide holes for customers to mount their components.

4. Dip panel in a sensitizing solution to promote copper deposition in the barrel of the drilled holes.

5. Electroplate panels in a copper solution to form electrical conductors on circuits and in holes.

6. Remove photoresist to expose copper. Remove unwanted copper, leaving isolated conductors in the circuit pattern.

7. Electrically test the panel for opens and shorts, using a custom-designed bed of pins to test conductivity.

8. Coat the circuit pattern with a solder resist ink and print a legend onto the panel to identify various components.

9. Dip the panel in molten solder, then blast with hot air to even out solder coating on which customers will solder-mount their parts.

10. Cut a cross-section of a sample board from each lot and examine the plated holes with a photomicrograph.

11. Cut the individual circuit boards out of the panel.

12. Electrical test, dimensional and visual inspection, and quality audit ensure compliance with customer requirements.

13. Package, label and ship the finished circuit boards according to the customer's specifications.

14. Packaging labeled boards according to specifications.

Figure 6-3. How to make a multi-layer PWB.
It is estimated that 293 million square feet of laminate and 322 million square feet of prepreg\(^3\) was used in manufacturing the PWBs that were produced domestically in 1993, with an estimated value of $835 million. That includes approximately 587 million square feet of copper foil, 52 million pounds of epoxy resin, and 60 million pounds of fiberglass yarn.

The value of other chemicals used in producing PWBs totaled about $519 million in 1993. These other chemicals include:

- Plating chemicals (electrolytic, etchback/desmear, oxide).
- Solder mask (dry film, photoimagible liquid, resist).
- Etchants (alkaline or ammoniacal, peroxide sulfuric, solder neutralizer/conditioner).
- Primary imaging products (dry film, photoimagible liquid, screen defined, resist).
- Imaging chemicals (aqueous and solvent developers and strippers).
- All other chemicals (fluxes, metal strippers, cleaners, anti-tarnish, de-foamers, waste treatment, metal alloys).

With respect to contract electronic assembly, the total estimated dollar value of that industry is approximately $6 billion. The primary markets served by contract assembly companies are shown in Figure 6-4. Table 6-2 gives information about how components were placed on the PWBs.

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31 Prepreg is the partially cured, resin-impregnated woven glass cloth mat used as the bonding layer between circuitized layers of a multi-layer PWB.
Overall industry data on energy consumption, total waste generation, and water usage are not available. However, an analysis done by MCC on a typical computer workstation yielded usable information, and is available in a separate MCC report.32

![Market for Contract Electronic Assembly](image)

**Figure 6-4.** Markets served in 1993 by all participating companies.33

<table>
<thead>
<tr>
<th>Type of Component</th>
<th>1992 (%)</th>
<th>1993 (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Through-hole components</td>
<td>69.0</td>
<td>55.4</td>
</tr>
<tr>
<td>Standard surface mount</td>
<td>30.1</td>
<td>43.5</td>
</tr>
<tr>
<td>Fine pitch (18 to 25 mils)</td>
<td>0.85</td>
<td>1.04</td>
</tr>
<tr>
<td>Ultra-fine pitch (&lt; 18 mils)</td>
<td>0.01</td>
<td>0.03</td>
</tr>
<tr>
<td>Chip mounted components</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

**Table 6-2.** Percentage and type of components placed on boards in 1992 and 1993.34

34 Ibid., p. 35.
There are a large number of environmental issues involved in PWB manufacturing and electronic assembly. To help organize these issues, they have been grouped under the following six topics: design tools, electronic equipment, materials, fabrication and assembly, purchasing and standards, and disposition and takeback.

Three key issues relating to design and design tools require priority attention: environmental data collection and management, data and design analysis, and integration of design for the environment (DFE) techniques into standard CAD and CAE systems.

DFE requires a large amount of environmental data to be incorporated into design decisions. Developing, disseminating, and integrating critical environmental information into product and process design decisions will require re-thinking what data are most important, how they are obtained, and from what sources. Some of this critical information includes: hazardous material usage, energy consumption, water usage, waste generation, and health hazards. In addition, information on alternative materials or processes—including relevant parameters such as cost, effect on product performance, and environment, energy, and economic impact—would be very useful.

With respect to data analysis, life cycle analysis can help identify the manufacturing process areas that produce the greatest emissions and consume the most energy and water. However, manipulating and analyzing the necessary data is costly, slow and usually incomplete. Small- and medium-sized companies often lack the necessary analysis tools and data-handling techniques even to attempt life cycle analysis.

For example, in the PWB industry, the costs of hazardous waste treatment, handling, and disposal are usually lumped into overhead costs. In some cases, these costs are not even accurately measured, nor are the primary sources or generators of the waste clearly identified. DFE tools that help companies accurately track all hazardous waste costs, as well as water and energy use, and allocate these costs properly to the departments or processes that generate them, may influence the development of more efficient, environmentally friendly process and material changes.

Finally, integrating DFE into traditional design schemes will require developing new standards and specifications. Traditional design and accounting systems will need to be modified. In addition, DFE integration will require cultural and organizational changes in management from the top down.

With respect to specifications in the design process, one crucial change would be the elimination of cosmetic requirements, which now dictate considerable chemical, energy, and water usage to insure that a PWB or assembly “looks” good, regardless of actual performance. Furthermore, the way product
performance and costs are defined in specifications or design standards could be revised to include the product’s environmental effects and disposition value.

Electronic Equipment

Electronic equipment issues focus on: communication/information, manufacturability and repair, and management/marketing approaches. In particular, communication and information are important because implementing environmentally conscious manufacturing demands better customer/supplier relationships between the OEM electronic equipment manufacturers and their PWB/assembly suppliers. OEMs will have to be more open and flexible in distinguishing between critical requirements (such as performance) and cosmetic ones (such as copper brightness). OEMs also will have to share information on how the circuit board or assembly will be integrated into the electronic equipment, and what disposition or re-use considerations lie ahead. At the same time, PWB or assembly suppliers must share information on their materials, manufacturing processes, and energy consumption.

In addition, product specifications and performance requirements can affect how manufacturable a product is. Therefore, OEMs and their suppliers will have to work on changing these specifications and requirements in order to increase manufacturability, decrease waste, and improve repairability.

Materials

The key environmental issues for materials are risk/benefit analysis, the role of suppliers, material characteristics, value/cost of waste materials, and the role of standards. In particular, customers, suppliers, and regulators must conduct sound scientific risk/benefit analyses in order to determine the true environmental and health impacts of various materials and their possible substitutes.

In many cases, PWB manufacturers and assemblers cannot substitute environmentally benign materials because they are not available. Thus, the role of the suppliers in material substitution is crucial. Suppliers will hesitate to develop new, environmentally friendly materials if they do not think a reliable market exists, especially if the new substitutes are more expensive than the original materials.

For example, many manufacturers would like to reduce or eliminate lead on an electronic assembly. Consequently, a nascent demand for a lead solder replacement is growing; however, few drop-in replacements exist. Lead solder is inexpensive, easy to handle, and has a long history of reliability and performance. Very few lead-free solders can match all of these characteristics. Other substitutes, such as conductive adhesives, may lack extensive reliability data or may require new equipment expenditures. Thus, the customer has few, if any, economical lead solder alternatives to choose from while suppliers are reluctant to invest heavily in developing alternatives if they are not sure of customer acceptance.

In looking at more environmentally neutral or safer material substitutes, this industry must consider all material characteristics—including quality, cost, and
reliability. If a new material is more environmentally neutral, but significantly shortens product life, then it is questionable if a benefit has been gained.

With regards to material use and substitution, companies must have readily accessible, low cost, sophisticated material management systems. These must include better data on the cost or value of “waste” materials. Waste materials can often have considerable value through recovery, reclamation, or re-use in another industry, or even within the same industry. All of the contaminated (or spent) solder pot dumpings, dross, or other waste in electronic assemblies, for example, are reclaimed and recycled into new solder.

Finally, some environmentally neutral material substitutions are not implemented because customer specifications or industry standards prohibit them. In these cases, it is incumbent on the manufacturer and the customer to evaluate such specifications and standards aggressively, revising them whenever possible to favor more environmentally benign solutions.

The many key issues in fabrication and assembly can be generally categorized into the following main headings:

- Management direction to integrate pollution prevention processes.
- Regulatory burdens and liability.
- Incoming toxic materials (prepreg, plating, photoresist, etc.).
- Defective raw materials that cause scrap (prepreg, laminate, mask).
- Materials whose value may be dependent on end-point requirements, e.g., lagging and back-up materials, brighteners, solder bath oil, cleaning chemicals.
- Processes whose value may be dependent on end-point requirements, e.g., surface treatment, stripping, desmear/etch, solder plating, conformal coating.

The key issues in this area are customer-supplier partnerships, research and development, and market promotion and standards.

Customer-supplier partnerships are critical because customers can only purchase those materials which suppliers can or will provide, and suppliers will develop and provide only those materials for which a profitable market exists or will exist. Thus, a customer cannot replace toxic process materials if alternatives do not exist on the market, and a supplier is not likely to research and develop alternatives without some indications that a profitable market will exist.

With respect to research and development, as well as market research, a supplier will naturally want to be prepared with a substitute product before phasing out any environmentally hazardous product. Therefore, considerable questions arise over
who drives the market for cleaner, safer materials. Customers may need to assist in new product or material research and development. Customers and suppliers may need to form partnerships to develop new material.

Phasing out CFCs is a good example. Years before the CFC ban took effect, suppliers were already researching and introducing alternatives. Furthermore, customers, suppliers, and the EPA all cooperated on research to define an acceptable cleanliness baseline and develop standard procedures for testing the cleaning effectiveness of alternatives.

Recycling

In-house recycling and reuse is the most straightforward and least complicated method used for environmentally conscious waste management. However, this step requires cooperation across the entire company in order to track and coordinate material use and handling. Since the electronics industry changes materials, products, and processes fairly rapidly, the re-use or re-manufacture of electronic materials and products can be complicated. However, secondary markets may accept recycled or “scrap” electronic products and materials.

Unfortunately, the regulatory and legislative network controlling the recovery and reclamation of materials can seriously hinder recycling. Many manufacturers are hesitant to initiate on-site material reclamation because of regulatory uncertainties. Furthermore, with respect to recycled or remanufactured products, many government purchasing regulations and other rules seriously hinder remanufacturing or reselling any reused products.

For example, in-house etchant regeneration systems for PWB manufacturers, which virtually eliminate material handling, packaging, and transportation hazards, exist. However, because the RCRA status of such regeneration systems is not entirely clear, many PWB facilities will not even consider such systems for fear they will become RCRA treatment, storage, and disposal facilities (TSDF). EPA’s Solid Waste Definition Task Group and the Common Sense Initiative (CSI) may generate new options to promote recycling/reclamation while still safeguarding the environment.

<table>
<thead>
<tr>
<th>Priority Need (decreasing order of priority)</th>
<th>Approach</th>
<th>Selected Tasks</th>
</tr>
</thead>
</table>
| • More efficient use, regeneration and recycling of hazardous wet chemistries. | • Extend life of electrolytic and electroless plating baths.  
• Develop chemistries and processes to allow recycling or in-house regeneration.  
• Eliminate formaldehyde from materials and chemistries  
• Promote on-site recycling and reclamation/regeneration. | • Research to extend baths.  
• Research in-line purification/regeneration.  
• Research alternative chemistries.  
• Modify RCRA and state regulations to promote recycling.  
• Educate line production on drag-in/drag-out problems. |
| **Reduce solid waste generated by scrap PWBs, leads, and components in the waste stream.** | **Develop and promote recycling of scrap PWBs, leads, and components.** | **Develop infrastructure to handle recycled material.**
**Establish enhanced process control and evaluation tools usable by small and medium size businesses.**
**Deliver consistently clean, solderable boards.** |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Establish better supplier relationships to enhance the development and acceptance of environmentally friendly materials.</strong></td>
<td><strong>Promote supplier, manufacturer, customer partnerships to implement environmental materials.</strong></td>
<td><strong>Develop a model Hazardous Materials Management System for small and medium sized PWB companies.</strong></td>
</tr>
</tbody>
</table>
| **Minimize the impact of hazardous materials use in PWB fabrication.** | **Reduce lead solder use when possible and/or reduce the lead content of the solder.**
**Develop alternatives to solder plating as an etch resist.** | **Change specifications to accept solder mask over bare copper.**
**Validate quality of lead plating alternatives.** |
| **Additive processes that are competitive with existing processes.** | **Develop simplified, cost effective, additive material and process technologies.**
**Seek alternatives sources and approaches for additive process capital equipment needs.** | **Collaborate on projects to establish novel additive dielectrics and metallization technologies and processes.** |
| **Eliminate hole smear in PWB fabrication.** | **Develop no-smear resins or drilling systems.** | **Investigate alternative laminate and prepreg materials.**
**Develop the use of laser and other alternatives to drilling systems.** |
| **Reduce water consumption and discharge.** | **Develop water use optimization and recycle system.**
**Reduce the number of cleaning steps in PWB manufacturing.**
**Eliminate parts handling and preparation to reduce recleaning.** | **Modify specifications to reduce cleaning requirements.**
**Investigate alternative parts handling methods.**
**Change or eliminate chemistries that require cleaning.** |
Chapter 6
The display screen is one of the most critical, and most volume-intensive, components of computer systems. The predominant display technology is the cathode ray tube (CRT), which provides a rich, high-resolution display well-suited to a wide range of user requirements. Advances in new display technologies are helping to position flat panel displays (FPDs) as viable alternatives to CRTs, particularly in applications where size, weight, or portability are concerns.

The CRT is the display of choice for both television and computer displays while other technologies (vacuum fluorescent, plasma panels, and electroluminescent panels) find significant use in industrial and instrumentation applications.

This chapter is divided into two sections—CRTs and FPDs. Each section discusses the strength of the market and the environmental issues for these two types of displays.

In the U.S., CRTs are produced primarily for the color-television industry and the monochrome industrial, military, and computer industries. Television dominates the installed display base, both in terms of size (the 19- to 27-inch viewing diagonal TVs dominate the marketplace) and ubiquity (saturation reached 98% of all households by 1988). Computer displays are also becoming pervasive with sales exceeding 8.8 million (one-third as large as the television market) in 1992. The industrial market and the instrumentation market (i.e., medical displays, automotive, appliance displays) number in the tens of millions of displays per year, but do not constitute an equivalent environmental impact because of their smaller size.

Although the color computer display industry is dominated by imports with negligible manufacturing in the U.S., the Electronic Industries Association (EIA) reports that color television CRT manufacturing in the U.S. grew by 43% from 1986 to 1992, while monochrome CRT manufacturing fell 84% (see Table 7-1).

<table>
<thead>
<tr>
<th>Year</th>
<th>1986</th>
<th>1988</th>
<th>1990</th>
<th>1992</th>
</tr>
</thead>
<tbody>
<tr>
<td>Color CRTs</td>
<td>11684</td>
<td>13747</td>
<td>14600</td>
<td>16741</td>
</tr>
<tr>
<td>Mono CRTs</td>
<td>3959</td>
<td>2580</td>
<td>1411</td>
<td>633</td>
</tr>
</tbody>
</table>

Table 7-1. Sales reported by EIA manufacturing companies (unit: thousands).

The market for CRTs will parallel the strong growth in the production of consumer and industrial electronics, particularly if the NAFTA agreement creates an advantage for CRTs manufactured in North America. TVs, computers, oscilloscopes, and other testing and measuring devices will continue to be a strong market, although future development of multimedia entertainment systems and high-definition television is also expected to drive the market for CRTs (see Tables 7-2 and 7-3).
Chapter 7

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Units</td>
<td>15,055.6</td>
<td>14,653.8</td>
<td>14,979.0</td>
<td>16,803.3</td>
</tr>
<tr>
<td>Dollars</td>
<td>1,510,844</td>
<td>1,552,463</td>
<td>1,541,258</td>
<td>1,704,056</td>
</tr>
</tbody>
</table>

Table 7-2. U.S. factory sales (thousands of units and dollars).\( ^{35} \)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Imports</td>
<td>122.2</td>
<td>274.0</td>
<td>239.9</td>
<td>264</td>
<td>303.3</td>
</tr>
<tr>
<td>Exports</td>
<td>79.2</td>
<td>103.2</td>
<td>86.2</td>
<td>143.6</td>
<td>161.4</td>
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</tbody>
</table>

Table 7-3. Trade trends of CRTs in the U.S. ($ millions).

The worldwide market for CRTs used in both consumer television and non-consumer equipment reached 168 million units valued at $13.6 billion in 1993.\( ^{36} \) The market is estimated to grow to 223 million units valued at $21 billion by the year 2000. The non-consumer segment, which includes computers and industrial equipment, represented 27% of the units and 34% of the value in 1993—these ratios are not expected to change by more than 1% over the forecast period.

The CRT continues to be the predominant display device because of its low cost per pixel and high-quality display. Although flat panel technologies are beginning to make their presence known in the marketplace, their share of the computer monitor market will still be approximately 30% of the total by the year 2000 (see Table 7-4).

<table>
<thead>
<tr>
<th>Year</th>
<th>CRT</th>
<th>LCD</th>
<th>Other FPD</th>
</tr>
</thead>
<tbody>
<tr>
<td>1993</td>
<td>11</td>
<td>2</td>
<td>0.1</td>
</tr>
<tr>
<td>1994</td>
<td>13</td>
<td>4</td>
<td>0.1</td>
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<tr>
<td>1995</td>
<td>15</td>
<td>5</td>
<td>0.1</td>
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<td>1996</td>
<td>17</td>
<td>6</td>
<td>0.1</td>
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<tr>
<td>1997</td>
<td>18</td>
<td>7</td>
<td>0.1</td>
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<td>1998</td>
<td>19</td>
<td>8</td>
<td>0.1</td>
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<td>19</td>
<td>9</td>
<td>0.2</td>
</tr>
<tr>
<td>2000</td>
<td>20</td>
<td>9</td>
<td>0.2</td>
</tr>
</tbody>
</table>

Table 7-4. Worldwide market for CRT and flat panel displays (FPDs) in computer equipment ($ billions).\( ^{37} \)

Technology of CRTs

A CRT uses high voltages to accelerate electrons toward a luminescent material called a “phosphor” that is deposited on the faceplate. The phosphor converts the


\( ^{37} \) Ibid.
kinetic energy of the electrons into light. In a monochrome CRT, the electrons are returned to the high voltage power supply via an aluminized film that connects the phosphor to the anode button. This film also increases efficiency of the CRT by directing all the light toward the observer. In a color CRT, the phosphors are patterned in dots or stripes of red, green, and blue phosphors. The electrons are emitted from three cathodes in the electron gun assembly and pass through an apertured metal “shadow mask” during their passage to the phosphor. Electrons from each cathode that are directed at the wrong color phosphor are absorbed by the shadow mask. This color selection method relying on three spatially separated sources and a shadow mask is described as the “parallax color selection method.”

Parallax color selection permits the brightness of each color to be controlled by modulating the current of the electron beam emanating from the appropriate cathode. Pictures are created by first focusing the electron beams into tiny spots, which are moved by deflecting the electron beams electromagnetically so that the spots move across the phosphor surface in a left-to-right and top-to-bottom raster. This system is extremely efficient in that it only requires three video drivers and connections instead of the 2000 or so in the most common flat panel display.

The electron guns require high vacuum to achieve long life and the bulb envelope must have sound mechanical integrity to resist the force of atmospheric pressure. The high voltages used to accelerate the electrons must be insulated from the external surfaces of the tube and the envelope must have excellent electrical insulating properties. The decelerating electrons produce X-rays and the envelope must also be a good X-ray absorber.

The CRT display is composed of a glass panel, a cathode ray tube, a casing, various connectors, wiring, shielding, and a deflection yoke. The tube ranges in weight from 40 to 70 pounds. Primary issues associated with the CRT display, other than its bulk, center around environmental and safety concerns. The end-of-life disposal of the unit is problematic due to the limited cost-effective disposal options for leaded glass, mixed plastics, and other components of the display. The poor quality of recycled CRT glass and lack of markets further complicate disposition alternatives.

It should be noted that the three types of CRTs (color, direct view monochrome, and projection monochrome) are different in their manufacture and envelope composition. The internal shadow mask of the color CRT requires an envelope that can be opened for deposition of the patterned phosphor screen, the contrast enhancement material (graphite), the reflective aluminum with its lacquer leveling layer, and the aquadag (graphite and silicate conductive coating). The two halves of the envelope are mated with the shadow mask and sealed together with a low temperature frit (a solder glass with organic binders) in a high temperature bake process called Lehr bake. The monochrome tubes for direct view or projection can be made from one-piece bulbs without resorting to the frit glass seal.
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Projection displays introduce additional components that have their own post-consumer implications. These include the lenses, CRT mounts, ethylene glycol cooling liquid, glass and plastic mirrors, and plastic projection screens, as well as significantly larger cabinets. However, the mass of the three monochrome projection CRTs is considerably less than that of a comparable direct view CRT.

Key Environmental Issues and Stakeholders

Although there are several issues of environmental concern in the manufacture of CRT displays, the primary issues concern disposal of end-of-life CRTs and the use of lead in the components. The lead content of the CRT is predominantly confined to the funnel of the CRT. The industry uses both a no-lead and a 2% to 3% lead faceplate composition with a trend toward increasing the use of the no-lead composition. Approximate lead content is shown in Table 7-5.

The control of dusts, wash water, etching solutions, and the careful disposal of industrial waste has made the industrial workplace environmentally conscious. During use, the CRT glass does not release lead. Thus, industry has identified post-consumer disposal as the key environmental issue, with lead leaching from the CRT envelope the primary environmental concern.

<table>
<thead>
<tr>
<th>Glass</th>
<th>Lead Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>Panel</td>
<td>2% to 3% (No-lead compositions were introduced in the past decade)</td>
</tr>
<tr>
<td>Funnel</td>
<td>24%</td>
</tr>
<tr>
<td>Neck</td>
<td>30%</td>
</tr>
<tr>
<td>Frit</td>
<td>70%</td>
</tr>
</tbody>
</table>

Table 7-5. Percentage of lead in glass used in TVs.

Because the CRT contains lead (primarily in the funnel, neck, and frit), the disposal of the display falls under the control of the “Land Disposal Ban Program” of the Resource Conservation and Recovery Act (RCRA), Class C materials. Thus, in order to landfill the CRT display in accordance with EPA regulations, it must first be dismantled, crushed, and micro-encapsulated. However, the lead in the glass is embedded in the glass matrix and is therefore stable and immobile. Release of the lead from the CRT display is directly proportional to the amount of surface area exposed. The surface area of the glass is greatly increased when the cullet (pieces of discarded glass used with new materials to create glass) is pretreated in the manner that the EPA requires for disposal (since crushing increases surface area), and therefore the potential level of leaching is likely to increase. Grinding the cullet also produces a lead-containing dust.

Cement encapsulation of the crushed CRT is the required method, but it has been postulated that cement actually disintegrates much more quickly than glass, releasing the lead sooner than if it had remained in the glass alone. Furthermore,
the EPA requirements for the disposal of CRTs involve a complex process that has overburdened the producers, the disposal facilities, and the EPA with requirements, paperwork, and has also reduced the number of available disposal facilities. The CRT industry believes that there are better disposal practices than the EPA-recommended microencapsulation disposal method.

It is certain that attaining 100% productive use of post-consumer CRT glass will require the development of new recycling strategies, including resmelting and downcycling (finding new users and markets).

The existing processing methods that conform with EPA regulations are costly, prompting manufacturers to consider recycling as an alternative to encapsulation. However, adequate technology for the cost-effective recycling of broken CRT glass by the manufacturer does not exist and the separation of component materials is a major challenge. Because so many of the various parts of the display contain glass of different sorts, different contaminants, and different chemicals, their mixtures are rarely pure and are often unusable. While most large CRTs consumed in North America are manufactured domestically, almost all of the computer monitor CRTs are imported, creating a source of recycled glass that is foreign to the North American manufacturing process. There are few alternative materials being used, and even fewer uses for reprocessed materials, which returns the manufacturer to the disposal dilemma once again. In order to resolve the problems of recycling, there are several issues that should be addressed:

- Simplification of mechanical disassembly.
- Avoiding self-contaminating combinations of materials.
- Standardization of component materials.
- Physical separation of high metal content items.

During the EPA Region I conference on Reduction of Heavy Metals in Municipal Solid Waste, several approaches to reduced introduction of lead from CRTs into the environment were presented. The primary approaches identified were recycling and downcycling to permit the continuing beneficial use of lead without creating any environmental impact. Also mentioned were the trend to use no-lead panels and the search for alternative lead free materials. Due to the high conversion and running costs for converting the 700-ton panel glass facilities, 100% use of no-lead glass will probably not be economically viable for many years. Corning estimates a running cost increase of about 6% for such a material substitution in their process.

The first recycling strategy is to use old CRT glass as a raw material for new CRT glass. This approach is limited by the shifting composition of glass over time and by the extreme risk of contaminating a large batch of glass. When the value of glass is about $1 per pound, a 700-ton tank load of glass spoiled by contamination represents over $1 million in wasted material and days of idle production capacity while the tank is cleaned and refilled. With JIT (just in time) manufacturing, no danger of tank upset is acceptable and the high dollar risk reduces the value of glass in the recycling stream. The recycling of broken CRT glass is being done by Dunkirk International Glass and Ceramic, who cleans and sorts the cullet by composition for return to the Thomson Consumer Electronics and Techneglas glass plants.

The second recycling strategy, practiced by Sony, is to return the whole tube to primary lead smelters as an ore for lead refining. The resulting materials are pure and highly salable as feed stock for the lead industries. The obvious drawback is that smelting must be followed by other processes before the materials become glass and the total processing cost may be higher than direct recycling. In any event, broken, mixed and dirty glass can be smelted rather than risking contamination of the glass making process.

Case Study: Sony USA Initiative for CRT Glass Recycling

Because scrap cathode ray tube glass is regulated as hazardous waste when disposed, Sony Engineering and Manufacturing of America (SEMA) developed procedures to reduce waste in their CRT manufacturing operation and reuse the remaining material in a beneficial way. To accomplish this objective, the company used a multifaceted approach.

The first step involved waste minimization. By controlling the handling and shipment of lead glass, the company could drastically reduce the amount of waste it produced in breakage during production, shipping, and handling. By using training, process changes, attitude changes, and employee involvement, the company began reducing the amount of waste generated.

The second step involved the initiation of an agreement between the company and its glass suppliers, which enabled the return of clean glass from Sony to be reused as cullet by the supplier. Because a single impurity in a 1,000,000 pound vat of molten glass can render the whole batch useless, trust had to be developed over time between the company and the supplier before they would allow the interchange of used glass.

After 63.5% of the waste stream was eliminated through minimization efforts, and 23.5% was removed through the recycling of cullet, the third step focused on the remaining 13% of the waste stream. The remaining percentage was classified as

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mixed, broken, and dirty glass. This remaining waste was utilized by running it through a smelting process, using the glass waste as a replacement for silica. This smelting process removes any lead or other heavy metals from produced glass, and, in effect, “cleans” the glass. Also, since the waste glass had been used in a beneficial way as a “substitute for a commercial process without first being reclaimed” it becomes an exemption to the “regulated solid waste” classification of RCRA, and can subsequently be disposed. By using these processes, SEMA is able to recover 100% of their lead glass waste stream and reduce glass that once would have been extremely expensive to dispose of in the traditional manner.

Identification of specific stakeholders in this process provides a basis for proposing industry alliances to address these challenges. Companies manufacturing CRTs in the U.S. include Zenith Electronics, Clinton Electronics, Thomas Electronics, Raytheon, Tektronix, Imaging and Sensing Technology, and Hughes Display Devices. Foreign companies with CRT manufacturing in the U.S. include Philips, Thomson, Matsushita, Toshiba, Sony, and Hitachi. Mitsubishi manufactures in Canada and several other companies are evaluating CRT manufacture installations in Mexico.

The industry is supported by three glass companies: Corning Asahi Video Products, Techneglas, and Thomson’s Circleville, OH plant. In addition, glass is imported from Asahi, NEG, Samsung Corning, Schott, Philips, China, and the former Soviet Union. It is supported by the U.S. shadow mask manufacturer Buckbee Mears and by imports from Dai Nippon Printing, Dai Nippon Screening, and other foreign CRT manufacturers’ integrated shadow mask facilities. Phosphors are supplied internally from vertically integrated manufacturing facilities and also by foreign manufacturers. The electron guns are made from precision metal parts manufactured by Premium Allied Tube and others fused into assemblies using low expansion coefficient electrical glasses made by Corning Asahi Video Products and Techneglas.

Another environmental issue is the energy consumption of the display itself. The public, the Administration, and the federal government are beginning to realize the importance of introducing components that use only fractions of the energy once consumed by the electronics industry, both during the manufacturing process and during later consumer use. Enactment of the Energy Star Program (see Chapter 9) and an Executive Order, which directs federal agencies to procure only Energy Star computers, acts as a huge incentive for the development of energy-conscious designs.

The Department of Commerce data for energy consumption and pollution abatement costs do not specifically give data for CRT and flat panel display manufacturing. It is nevertheless useful to look at the data reported for the 4-digit SIC codes that include these industries. Available SIC codes include: electron
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tubes (SIC 3671), semiconductor and related devices (SIC 3674), and electronic components (SIC 3679).40

Tables 7-6 through 7-8 give some idea of the energy consumption and pollution abatement costs and expenditures for the 4-digit SIC codes, which include the 5 and 7 digit SIC codes that specifically cover the CRT, flat panel, and LCD manufacturing sectors.

<table>
<thead>
<tr>
<th>SIC Code</th>
<th>Industry Group</th>
<th>Cost of Purchased Fuels and Electric Energy ($M)</th>
<th>Quantity (Million kWh)</th>
<th>Cost ($M)</th>
<th>Cost of Purchased Fuels ($M)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3671</td>
<td>Electron tubes</td>
<td>58.8</td>
<td>881.0</td>
<td>45.5</td>
<td>13.3</td>
</tr>
<tr>
<td>3674</td>
<td>Semiconductors and related devices</td>
<td>467.3</td>
<td>7487.0</td>
<td>420.7</td>
<td>46.6</td>
</tr>
<tr>
<td>3679</td>
<td>Electronic components, n.e.c.41</td>
<td>186.6</td>
<td>2592.9</td>
<td>158.6</td>
<td>28.0</td>
</tr>
</tbody>
</table>

Table 7-6. Purchased fuels and electric energy used for 1991.42

<table>
<thead>
<tr>
<th>SIC Code</th>
<th>Industry</th>
<th>Total PACE</th>
<th>Air</th>
<th>Water</th>
<th>Solid Waste</th>
</tr>
</thead>
<tbody>
<tr>
<td>3671</td>
<td>Electron tubes</td>
<td>2.0</td>
<td>(D)</td>
<td>(D)</td>
<td>(Z)44</td>
</tr>
<tr>
<td>3674</td>
<td>Semiconductors and related devices</td>
<td>49.8</td>
<td>28.7</td>
<td>17.6</td>
<td>2.9</td>
</tr>
<tr>
<td>3679</td>
<td>Electronic components, n.e.c.</td>
<td>5.6</td>
<td>0.9</td>
<td>2.9</td>
<td>1.8</td>
</tr>
</tbody>
</table>

Table 7-7. 1992 pollution abatement capital expenditures in millions of dollars.45

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41 n.e.c. stands for “not elsewhere classified.”
43 D stands for “withheld to avoid disclosing operations of individual companies.”
44 Z stands for “less than half the unit shown.”
Table 7-8. 1993 pollution abatement operating costs (PAOC) and cost offsets for 1992\textsuperscript{46} in millions of dollars. Cost offsets are pollution abatement costs that are recovered through the reuse or sale of recovered materials and energy.

<table>
<thead>
<tr>
<th>SIC Code</th>
<th>Industry</th>
<th>PAOC</th>
<th>Cost Offsets</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Total</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Air</td>
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<td>Solid Waste</td>
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<tr>
<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td></td>
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<td>3679</td>
<td>Electronic components, n.e.c.</td>
<td>51.0</td>
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<td></td>
<td></td>
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<td>0.8</td>
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<td>1.4</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Priority Need</th>
<th>Approach</th>
<th>Selected Tasks</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Establish infrastructure for post-consumer disposition of CRT glass.</td>
<td>• Survey and assess usability of existing systems for post-consumer disposition.</td>
<td>• Educate municipal waste handlers in proper CRT handling procedures.</td>
</tr>
<tr>
<td>• Reduce lead in CRTs.</td>
<td>• Look for alternative glass materials that meet the same safety/cost standards.</td>
<td>• Develop new frit, face plate and funnel compositions.</td>
</tr>
<tr>
<td>• Promote alternative uses for post-consumer CRT glass.</td>
<td>• Look for and/or establish alternative markets.</td>
<td>• Catalog existing uses.</td>
</tr>
<tr>
<td>• Increase processability of post-consumer CRT glass.</td>
<td>• Establish industry-wide acceptance of a single glass composition.</td>
<td>• Develop a single glass composition that meets industry needs.</td>
</tr>
<tr>
<td></td>
<td>• Develop processes for separating and cleaning broken, dirty glass.</td>
<td>• Investigate new bulb cutting techniques.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Develop rapid statistical assay methods.</td>
</tr>
</tbody>
</table>

Alternative Materials: The glass companies are developing lead-free frits, which may not be practical because of cost or performance considerations. Similarly, previous attempts to reduce the thickness of the funnel (required if the lead content is reduced) causes the bulb design process to fail because it lacks the proper implosion safety performance. Both of these technical problems should be placed with the national labs for evaluation from a new perspective.

\textsuperscript{46} Pollution Abatement Costs and Expenditures, [MA200(92)-1], Bureau of the Census, 1992.
Reduce Bioavailable Lead from CRTs: The current EPA-recommended disposal practice needs to be reevaluated and alternative practices approved for use and introduced.

Separation and Cleaning of Post-Consumer CRTs and TV Glass: The current method of separation is by scribing and thermal shocking to separate the CRT envelope into a panel and a funnel with a minimum of panel glass attached. Development of alternative separation methods (i.e., hydrocutting, sawing, laser assisted cracking) could increase both the percentage of materials that are recycled and ease of the recycling process. Contamination makes the recovered material worthless and cleaning methods must be developed to eliminate all risk of contamination. The companies currently involved in processing CRTs should be funded to explore processes they would not develop on their own.

Not all of the glass will be returned in complete bulbs with known history, composition, and easily separated materials. Much of the glass will be broken and dirty glass from unknown manufacturing periods and will have unknown (obsolete) composition. This glass represents the greatest challenge since it must be economically segregated into clean streams of a compatible composition glasses. New low cost separation methods will be necessary. Corning has recommended that Sandia Labs evaluate techniques such as heavy liquid, gravimetric separation techniques. Currently, UV and X-ray fluorescence technologies are being developed by DIGC for identifying the glasses being manufactured in 1994. Extension of these principles to automated sorting by applying machine vision and fuzzy logic will be a challenging technology development.

Recycled glass must be combined into large lots of known composition in order to make it valuable to the glass companies. Techniques for batch mixing and rapid assay of the resulting aggregate are not available and must be developed.

Downcycling Alternatives: Downcycling of the glass content requires formulating glass with other inexpensive materials to create useful glass and/or useful forms for the secondary uses of the glass. Acceleration of a downcycling industry requires identification of products (radiation shielding, optical glass beads, shot peening beads, etc.), experimental melting to demonstrate the manufacturing process, and evaluation of the samples by the ultimate customer.

The typical engineer today may not be sufficiently prepared to incorporate design for environment. The number of material choices is overwhelming and the information on materials is often contradictory or unavailable. It is anticipated that these tools will be implemented as they become mature. The challenge remains supporting tool development.

Lawrence Livermore National Laboratory has done significant research in developing in situ heavy metal sensors. These should be made available to create environmentally sound manufacturing and recycling facilities which maximize the
efficiency of recycling, protect workers from exposure to hazardous materials and prevent contamination of the environment. Compact chemical, spectroscopic, and piezoelectric sensors are ideal to track materials in liquid phase, gas phase and as particulate. ARPA should fund demonstration programs to evaluate these in situ sensors in industrial applications.

**Regulatory Revision:** Current regulations effectively prevent experiments by imposing unnecessary permitting requirements. These come about when new chemicals appear in the exhaust stream from a factory and new permits would be required. Streamlining the permit practice to a basis of increased/decreased/experimental emissions of all types would speed reasonable experimental evaluations.

Further research is needed to refine the EPA risk assessment procedures in order to compare eventual environmental outcomes of disposal practices with respect to heavy metal bearing glasses. This work would allow recommendations for the safest disposal practices for post-consumer materials.

FPDs are suitable for application in a wide range of markets—they may be used for applications traditionally using cathode ray tubes, or they may enable equipment manufacturers to develop products that use a flat panel’s unique characteristics for a specific purpose, such as a laptop computer. Table 7-9 provides a list of FPD applications and indicates the scope of the market place for flat panel products.

### Background of Flat Panel Displays

#### Markets

| Consumer      | • Television  
|               | • Games       
|               | • Appliances  |
| Transportation| • Automotive   
|               | • Aircraft    
|               | • Entertainment
|               | • Traffic control |
| Business      | • Copiers/Fax 
|               | • Tiled displays 
|               | • Videophones 
|               | • ATMs/vending machines |
| Industrial    | • Lab/analytical 
|               | • Process monitoring 
|               | • X-ray security |
| Medical       | • Lab equipment 
|               | • Surgical assistance 
|               | • Diagnostic imaging |
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<table>
<thead>
<tr>
<th>Computers</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Desktop monitors</td>
</tr>
<tr>
<td>• Portables displays</td>
</tr>
<tr>
<td>• Personal digital assistants (PDAs)</td>
</tr>
</tbody>
</table>

Table 7-9. Flat panel display applications.

Worldwide sales of high-information content FPDs will continue to grow rapidly. Liquid crystal displays (LCDs) will dominate the market with a 75% market share. [This figure includes all types of LCDs, not just active matrix LCDs (AMLCDs)] Between 1993 and 1998, reduced AMLCD manufacturing problems will help sales reach $2.3 billion. Some estimates place the FPD market in 2003 at $13 billion—when AMLCDs will account for approximately 38% as other emissive technologies (e.g., electroluminescents, gas-plasma, field emission cathodes) achieve widespread commercialization. Other sources estimate that the worldwide market for LCDs will be between $10 billion and $15.6 billion by 2000.

The 1990s saw a huge increase in demand for portable products, thus increasing the demand for the FPDs. A once stagnant market became a boom, leaving the Japanese with a virtual monopoly on production. In 1994 the Administration announced its plan to award grants in excess of $600 million dollars to help stimulate active pursuit of flat panel display production in the U.S. The first of these awards went to Optical Imaging Systems, the only U.S. manufacturer of active-matrix liquid crystal displays. Researchers believe that the introduction of these grants will stimulate development and help the U.S. corner at least 15% of the world FPD market.

FPD manufacturers worldwide offer a range of products for application in military, consumer, and industrial products. Flat panels offer tremendous advantages over cathode ray tubes for many products because FPDs can be designed to be thin, light-weight, and low power consumers. U.S. manufacturers offer a wide range of flat panel products and have been developing manufacturing capabilities to meet demand for FPDs.

Technology of FPDs

Many technologies exist to produce flat panel products including plasma display panels (PDPs), AMLCDs, field emission displays (FEDs), electroluminescent displays (ELs), vacuum fluorescent displays, light emitting diodes, and micromirrors. The Task Group is composed of representatives of the four major display technologies today—AMLCDs, PDPs, FEDs, and ELs. Each of these technologies are described below and Table 7-10 summarizes their advantages and disadvantages.

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- **Plasma Display Panels (PDPs):** PDPs are based on the plasma discharge that occurs when an ionized (usually noble) gas undergoes recombination. Electrons are removed from atoms to produce ions, later recombining with the ions and releasing energy in the form of light. A certain trigger (or priming) voltage is required to start the ionization process, after which the process will continue at a lower voltage, and the brightness of the emission will depend directly upon the current passing through the ionized gas, known as a plasma. The predominant technology is an AC driven display that obtains color by using the ultraviolet emission from a combination of He-Kr-Xe or Ne gases to excite red, green, and blue phosphors.

- **Electroluminescent Displays (ELs):** ELs are solid state devices with the active layer of manganese-doped zinc sulfide sandwiched between two insulators, which in turn is sandwiched between an indium-tin-oxide (ITO) column electrode and an aluminum row electrode. The phosphor layer (manganese-doped zinc sulfide) emits light when it is excited by the introduction of electrons between the row and column electrodes.

- **Field Emission Displays (FEDs):** Cold cathode field emission arrays contain a cathodoluminescent device that relies on extremely high field strengths at each element of an array of structured microscopic cathodes to relieve them of their electrons. The electrons then are accelerated to the anode where they strike a phosphor and produce light. No focusing structures are used, since the space between the cathode and phosphor/anode is extremely small.

- **Active Matrix Liquid Crystal Displays (AMLCDs):** AMLCDs are composed of a rear glass substrate patterned with thin-film transistors (TFTs), a front glass substrate with color filters, and a liquid crystal material filling the mid
<table>
<thead>
<tr>
<th>Technology</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plasma Display Panel (PDP)</td>
<td>• Established technology&lt;br&gt;• Wide viewing angle&lt;br&gt;• Proven to be rugged and reliable&lt;br&gt;• Multiple sources&lt;br&gt;• Simplified driving circuit&lt;br&gt;• Simple construction lends itself to low-cost, high volume production&lt;br&gt;• Color is feasible&lt;br&gt;• Long lifetime</td>
<td>• High-voltage driver requirements&lt;br&gt;• Washout in bright sunlight&lt;br&gt;• Low resolution</td>
</tr>
<tr>
<td>Electroluminescence (EL)</td>
<td>• Very thin and compact&lt;br&gt;• High writing speed&lt;br&gt;• Good readability and brightness&lt;br&gt;• Gray-scale ability&lt;br&gt;• Low-voltage operation&lt;br&gt;• No catastrophic failure&lt;br&gt;• Multi-color display available&lt;br&gt;• High contrast ratio&lt;br&gt;• Wide viewing angle&lt;br&gt;• High volume manufacturing</td>
<td>• High voltage drivers required&lt;br&gt;• Higher cost than standard LCD</td>
</tr>
<tr>
<td>Field Emission Displays (FEDs)</td>
<td>• Technology based on cathode luminescence (mature)&lt;br&gt;Wide viewing angle&lt;br&gt;• Potentially high luminous efficiency&lt;br&gt;• Long history of phosphor development to draw from&lt;br&gt;• High-speed addressing and response&lt;br&gt;• No temperature sensitivity&lt;br&gt;• Analog gray-scale and full color capability&lt;br&gt;• Limited multilayer photolithography requirements&lt;br&gt;• No filament to heat - no warm up time&lt;br&gt;• Potentially scalable to large screen displays</td>
<td>• Efficient low-voltage phosphors not yet developed&lt;br&gt;• Optimum manufacturing process not yet developed&lt;br&gt;• High voltage drivers are required&lt;br&gt;• Large area photolithography is required&lt;br&gt;• High temperature fabrication equipment needed&lt;br&gt;• Critical mass of participants not yet reached</td>
</tr>
<tr>
<td>Liquid Crystal Displays (LCD)</td>
<td>• Low driving voltage&lt;br&gt;• Very thin display&lt;br&gt;• Readable in direct sunlight&lt;br&gt;• Available from many sources&lt;br&gt;• Advanced technology</td>
<td>• High processing costs for active matrix types&lt;br&gt;• Defect free TFT panels difficult to manufacture&lt;br&gt;• High capital equipment investment for TFT-LCDs&lt;br&gt;• Low transmissivity of color filters requires strong backlight&lt;br&gt;• Polarizer set required</td>
</tr>
</tbody>
</table>
The array of thin-film transistors on the rear substrate is attached to electronic drivers that receive impulses from a computer chip attached to the host system. Each TFT acts as an on/off switch to activate a pixel, force the liquid crystal to twist, and allow light to pass through and form images on the display. Most AMLCDs use either an amorphous silicon or poly-silicon layer of semiconductor material within the TFT array. Metal layers and insulator layers are also patterned and deposited on the rear substrate.

Most U.S. display manufacturers are in research and development or start-up phases; thus, their focus is on technology development, deployment, and manufacturing capacity. Justifiably, business concerns such as raising capital and developing cost-competitive, viable products are the industry’s primary objectives. In this early state of maturity, the flat panel industry will be hard pressed to initiate environmental management strategies beyond traditional pollution control or end-of-pipe solutions to waste management that meet permitting and other statutory-regulatory requirements. Nevertheless, efforts to consider environmental issues during the design stage of industrial development will pay off in the longer term.

Fortunately, many manufacturers may already be familiar with pollution prevention techniques, such as source reduction measures, that prevent waste or use less toxic materials. Companies that take advantage of such strategies may benefit from reduced materials costs, disposal costs, insurance costs, risk to workers and local communities, and improved corporate image. See Appendix B for a listing of environmental research initiatives underway at the National Laboratories.

The entire life cycle of the FPD product system must be addressed in order to accurately assess the environmental burden attributable to the FPDs. FPD producers should make every attempt to evaluate the total environmental burden associated with all phases of the product life cycle—the extraction of raw materials, the production of bulk and engineered materials, the manufacture of the product, use of the FPDs, disposal and retirement of the product. In addition, by considering the life cycle of the product, stakeholder analysis and competitive business issues that may affect flat panel manufacturers become evident.

Although FPDs offer several environmental advantages over cathode ray tubes—such as reduced weight-volume, energy consumption, and lead content—manufacturers can still make improvements in environmental performance in a number of areas, including manufacturing, use/service, and end-of-life management. (Note: a full life cycle analysis would consider earlier stages such as raw materials

Table 7-10. Advantages and disadvantages of various display technologies.50

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Processes that are common among FPD manufacturers include photolithography, deposition, metallization, cleaning, sealing and encapsulation, clean room environments, and deionized water usage. The processes and materials used throughout the manufacture of FPDs that contribute environmental burdens include:

- Process chemicals throughout photolithography steps.
- Dopant and process gasses for deposition.
- Wet and dry etchants.
- Cleaning substances/techniques.
- Metallization processes.

Table 7-11 summarizes materials that are used commonly by FPD manufacturers. Quantitative data was not obtained and the information has been condensed to simplify the presentation of the results. This table illustrates that many of the materials/processes and concerns in the manufacturing stage of FPD production are similar to that of integrated circuit manufacturing.
Beyond life cycle assessment, the FPD Task Group also recognizes the need to incorporate environmental requirements into the design of FPDs. Design approaches such as life cycle design (LCD) and Design for Environment (DFE) are state-of-the-art approaches for identifying and managing environmental issues over the product life cycle. These approaches enable manufacturers to reduce environmental burdens by changing the design of their products.

Table 7-11. Key environmental issues over the product life cycle.
A number of companies have instituted proactive programs of pollution control, energy conservation, and resource conservation and are attempting to capitalize on pollution prevention opportunities. Three examples of these types of activities are provided here:

- An AMLCD manufacturer installed an acid neutralization system, a recirculating DI water system, and a combination of gas and oil chillers operated by an energy management software tool to conserve energy. The acid neutralization system was not required under permit conditions but was nevertheless installed at the facility. The DI water system and energy management plan were pursued because of the cost-saving opportunities.

- In response to a toxics use reduction program at the State level, a manufacturer of ELs created a source reduction committee that meets periodically to review pollution prevention options. To date, the committee has worked on eliminating CFCs, recycling solvents, and communicating with equipment manufacturers about tool designs that would improve environmental performance.

- At a manufacturing facility for FEDs, care is taken to select what is determined to be the most environmentally benign solvents. In addition, filtration processes, re-circulation systems, and shallower acid baths are used to reduce waste from the facility.

**Stakeholders**

Internal and external stakeholders must be considered throughout the product system supporting the manufacture, use, and end-of-life management of FPDs. Table 7-12 summarizes the varied stakeholders identified by the Task Group.

<table>
<thead>
<tr>
<th>Stakeholders</th>
<th>External</th>
<th>Internal</th>
</tr>
</thead>
</table>
| Manufacture  | • U.S. Display Consortium  
• OEMs  
• Equipment Suppliers  
• Material Suppliers  
• EPA/State Dept. of Env. Protection  
• U.S. Administration  
• Localities/State Economic Offices  
• Community Environmental Groups | • Management  
• Engineers  
• Facilities Staff  
• Designers  
• Marketing  
• Accounting  
• Purchasing  
• Environmental Professionals |
| Use/Service  | • Consumers  
• OEMs  
• Government Agencies (e.g., FCC, FTC) | • Service Technicians |
| End-of-Life  | • Waste Handlers  
• EPA/State Dept. of Env. Protection  
• Community Environmental Groups | |

**Table 7-12.** Internal and external stakeholders to FPD industry.

**Priority Issues and Needs**

Priority environmental issues and needs in the FPD industry are, in many cases, directly related to technological advances made in the production process. Several
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priority issues relating to process improvement require attention to accomplish environmental objectives in the FPD industry.

- The U.S. Display Consortium (USDC), recognizing the importance of equipment and materials, issued requests for proposals in a number of areas including color filters, inspection and testing, dry etching, and proximity lithography. As these technologies are developed and semiconductor manufacturers leverage their know-how to support the FPD industry, the flat panel industry will significantly improve its manufacturing efficiency and environmental performance. Technologies that lead to higher material usage rates, higher yields, energy efficient clean rooms, and other process design advancements will result in significant improvements in environmental performance throughout the industry.

- Environmental performance improvements at the FPD manufacturing level are impacted by the ability of equipment manufacturers and material suppliers to develop more efficient and environmentally conscious tool designs and materials that are environmentally benign. FPD manufacturers must specify design requirements that consider key environmental issues, communicate these specifications to equipment and material suppliers, demand tools that meet these specifications, and test the processes so that the improved tools can be installed in full-scale manufacturing lines.

- Advancements in environmental performance also hinge upon how well manufacturers and suppliers of equipment and materials can identify product, process, distribution, and information management related issues that affect environmental performance. Product-related issues include all materials that go into the final product. Process-related issues include all materials and energy that are used to transform product components. Distribution-related issues include all packaging and transportation issues. Lastly, information management includes all of the data needed to monitor, track, and provide continuous feedback on product and process performance.

- FPD manufacturers need to focus on product design requirements that lead to environmentally conscious displays throughout the life of the product. First, screens must use glass that contains the least amount of harmful substances to human health and the environment. Designs must strive for the least weight, volume, sealants, and toxic heavy metals. Moreover, displays should operate at maximum energy efficiency and provide as high a luminous efficacy as possible. Potential user health concerns should be investigated. Lastly, reuse or recycling of displays needs to considered to avoid disposal.

- Process design considerations must be considered concurrently with product design specifications. Environmentally safe solvents, resists, color fil-
ters, and dopant gases should be used where feasible. Acid etchants, ozone depletors, and global warming substances need substitutes where feasible. In addition, energy efficient and water conservation measures must be implemented.

- On a regulatory level, FPD manufacturers must work more closely with government agencies to establish consistent classifications of facilities that are conducting similar operations. FPD industry representatives must work with government and environmental groups to educate these stakeholders on the processes used in production of displays as well as issues associated with other life cycle stages.

The FPD industry is faced with a number of challenges in terms of environmental improvement. Specifically: (1) what strategies will lead to reduction in pollution and are cost-effective and (2) which areas of manufacturing, use/service, or end-of-life management are environmental priorities? Human health and land use impacts occur in several categories, including:

- Energy consumption.
- Resource use/depletion.
- Global climate change.
- Ozone depletion.
- Water quality impacts.
- Solid and hazardous waste.

The following section will briefly review each of the impact categories and describe efforts already underway within the industry to reduce environmental burdens.

**Energy Consumption**: Energy use is one of the most important environmental issues facing FPD manufacturers and other semiconductor and electronics producers worldwide. Energy consumption at FPD manufacturing facilities is substantial in order to power the process equipment, clean room machinery, waste disposal equipment, and the facility’s daily requirements for computers, lights, etc.

- Clean Room Design: Clean rooms are mechanically-intensive facilities that consume enormous amounts of electrical power.

- Chillers: Chillers cool the water and air conditioning systems for the facility. Both gas and oil powered chillers are used throughout the industry.

- Product Use Over Lifetime: Energy requirements over the lifetime of displays will also result in environmental impacts. Whether the products are powered by fossil fuel or battery power, the efficiency of its power use will impact the environment.

**Resource Use/Depletion**: The primary resource of concern used in FPD manufacturing is water. Water is provided by public water systems for use in DI water
systems and process equipment cooling. The rate of consumption of FPD manufacturers results in a huge demand for municipal water over the lifetime of the facility. The impact of this demand is relative to the area in which the facility is built and the capacity of local water systems to supply this rate of flow.

As described above, non-renewable energy is consumed throughout the production of FPDs due to the power requirements of clean rooms, process equipment, etc. The impact of this consumption includes the emission of CO$_2$ and sulfur dioxide, and the impacts range from global warming to acid rain, affecting populations at local, regional, and global levels.

Global Climate Change: Global warming gases such as carbon tetrafluoride or tetrafluormethane (CF$_4$), hexafluorohane (C$_2$F$_6$), nitrogen trifluoride (NF$_3$), sulfur hexafluoride (SF$_6$), methane (CH$_4$), C$_3$F$_8$ (Freon 38), and nitrous oxide (N$_2$O) are used for a variety of purposes, including chemical vapor deposition, etching, and cleaning chambers. These chemicals have each been determined to have a Global Warming Potential (GWP) based on the atmospheric lifetime of a chemical and its infrared absorption spectrum relative to carbon dioxide. Table 7-13 presents the GWPs for a group of compounds including those listed above.

<table>
<thead>
<tr>
<th>Chemical</th>
<th>Lifetime (years)</th>
<th>GWP (100 years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CF$_4$</td>
<td>&gt;50,000</td>
<td>10,900</td>
</tr>
<tr>
<td>C$_2$F$_6$</td>
<td>&gt;10,000</td>
<td>11,500</td>
</tr>
<tr>
<td>NF$_3$</td>
<td>&lt;179</td>
<td>24,200</td>
</tr>
<tr>
<td>SF$_6$</td>
<td>3,200</td>
<td>21,000</td>
</tr>
<tr>
<td>C$_3$F$_8$</td>
<td>&gt;10,000</td>
<td>N/A</td>
</tr>
<tr>
<td>CO$_2$</td>
<td>120</td>
<td>1</td>
</tr>
<tr>
<td>CH$_4$</td>
<td>10.5</td>
<td>11</td>
</tr>
<tr>
<td>CFC-11</td>
<td>55</td>
<td>3400</td>
</tr>
<tr>
<td>CFC-12</td>
<td>116</td>
<td>7100</td>
</tr>
<tr>
<td>N$_2$O</td>
<td>132</td>
<td>270</td>
</tr>
</tbody>
</table>

Table 7-13. Global warming potentials for industrial chemicals.$^{51}$

Ozone Depletion: These compounds contribute to ozone depletion by releasing CFC molecules into the atmosphere. Cleaning operations have historically made use of harmful CFCs; however, most manufacturers have eliminated the use of these chemicals due to Clean Air Act and Montreal Protocol requirements.

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Facilities still emit ozone depletors (i.e., HCFCs) through industrial chillers used to produce air conditioning and process cool water.

**Water Quality Impacts:** Water used on-site for the manufacture of FPDs is ultimately discharged into the publicly owned treatment works (POTW) or water bodies located near the facility. The effluent from the FPD facilities also includes neutralized acids and metals generally via treatment by a neutralization system. Effluent discharges are subject to POTW or Clean Water Act regulations.

**Solid and Hazardous Waste:** Solid waste streams generated from FPD manufacturers include scrap glass and packaging materials. Hazardous waste resulting from the manufacture of FPDs include solvents used as cleaning agents, photoresist materials, and process solutions such as spent IPA. Manufacturers are responsible for storing the hazardous wastes and hiring permitted waste handlers to transport the material to either a registered disposal site or other acceptable use such as a chemical refinery. Waste streams may also be generated throughout manufacturing steps if displays are defective. In addition, after a display is retired by the consumer, its disposition in a landfill or other disposal site could result in environmental burdens.

**Strategies for Reducing Environmental Impact and Risk**

Manufacturers have numerous opportunities across the life cycle of a product to reduce environmental impact. The following lists examples of proven strategies:

- **Product Life Extension**
  - Extend useful life
  - Increase durability
  - Ensure adaptability
  - Increase reliability
  - Expand service options
  - Simplify maintenance
  - Facilitate reparability
  - Enable remanufacture of products
  - Accommodate reuse of product

- **Material Life Extension**
  - Develop recycling infrastructure
  - Examine recycling pathways
  - Use recyclable materials

- **Material Selection**
  - Use substitute materials
  - Devise reformulations

- **Reduced Material Intensiveness**
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– Conserve resources

• Process Management
  – Process substitution
  – Process energy efficiency
  – Process materials efficiency
  – Process control
  – Improved process layout
  – Inventory control and material handling
  – Facilities planning
  – Treatment and disposal

• Efficient Distribution
  – Optimize transportation systems
  – Reduce packaging
  – Use alternative packaging materials

• Improved Management Practices
  – Using office materials and equipment efficiently
  – Phase out high impact products
  – Choose environmentally responsible suppliers or contractors
  – Encourage labeling and advertise environmental claims

<table>
<thead>
<tr>
<th>Priority Need (decreasing order of priority)</th>
<th>Approach</th>
<th>Selected Tasks</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Determine the feasibility of reusing display parts or components.</td>
<td>• Develop cost-effective recovery mechanisms.</td>
<td>• Assess existing recovery systems.</td>
</tr>
<tr>
<td></td>
<td>• Assess disposal rates and volumes.</td>
<td>• Study consumer disposal trends and options.</td>
</tr>
<tr>
<td></td>
<td>• Assess consumer and technological trends affecting disposal.</td>
<td>• Develop models to predict optimum component recovery.</td>
</tr>
<tr>
<td>• Institute processes to minimize hazardous materials use and releases.</td>
<td>• Evaluate containment and reuse/recovery systems for PFCs and certain glycol ethers.</td>
<td>• Generate list of alternatives to glycol ethers and PFCs.</td>
</tr>
<tr>
<td></td>
<td>• Recovery of spent solvents.</td>
<td>• Install closed-loop materials recovery systems.</td>
</tr>
<tr>
<td></td>
<td>• Eliminate chemical glass-cleaning processes.</td>
<td>• Determine areas for reducing hazardous materials use through risk management techniques.</td>
</tr>
<tr>
<td>• Strengthen relationship between FPD suppliers and manufacturers to focus on environmental needs.</td>
<td>• Establish FPD manufacturer/supplier environmental design teams.</td>
<td>• Establish joint task group with SEMI.</td>
</tr>
<tr>
<td></td>
<td>• Increase environmental information flow on hazardous materials used.</td>
<td>• Establish a system for retrieving all chemical and materials data.</td>
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<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Provide DFE training.</td>
<td>Transfer technology and approaches from semiconductor industry, where appropriate.</td>
</tr>
<tr>
<td>Optimize use/service performance.</td>
<td>Decrease power consumption.</td>
<td>Research manufacturing methods for more efficient displays.</td>
</tr>
<tr>
<td></td>
<td>Extend useful life, durability and facilitate serviceability.</td>
<td></td>
</tr>
</tbody>
</table>
Personal computers and other electronic products are becoming increasingly pervasive in our homes, workplaces, and schools. Each one of these products will eventually reach the end of its useful life, and will require disposition of one sort or another. The sheer number of electronic products currently in the marketplace has caught the attention of solid and hazardous waste policy makers, companies concerned with appropriate disposition, and business entrepreneurs who see value in the purported waste. In addition, technology improvements consistently result in less expensive, more powerful products, and thus may hasten the replacement and eventual disposition of electronic goods.

The concerns most frequently raised about electronic product disposal are their bulk, and the hazardous constituents some of them contain. In many parts of the U.S. and the world, landfill space (and the difficulty in siting new landfills even if space is available), is a sufficiently important concern to warrant close examination of the growing electronic component of the waste stream. In addition, electronic products carry the added burden of a variety of hazardous constituents, from lead solder to batteries. Ensuring appropriate disposition of such hazardous constituents is a challenging problem.

The economic opportunities inherent in the electronic waste stream have not gone unnoticed by business entrepreneurs and large companies. Unlike mechanical systems, electronic components do not “wear out.” The cost of some new components is so high as to provide significant incentives to identify sources of used, less expensive components, especially in cascading uses. There is a healthy and growing independent secondary market for used computers and components, and many computer manufacturers are looking for ways to capture some of this market, and the value of their products, for a variety of their own uses.

Added to this mix of concern and opportunity is a very fluid regulatory situation, in which a few countries are starting to create models for controlling the disposition of electronics products. Companies are thus faced with a difficult array of influences which they must balance to address product disposition.

There are a number of different schemes which can be implemented, either through legislation or company action, that would address product disposition concerns. These include reverse distribution (product take-back), third-party product collection and disposition (public or private), outright disposal restrictions, and others. Reverse distribution schemes have received much attention, in part due to the German government’s support for such a system. The German “electronic take-back” law has been circulated widely throughout the electronics industry, although it is not in effect in Germany at this time.

The complicated nature of a reverse distribution scheme makes it a vivid case study of the policy and logistical issues associated with any disposition scheme; therefore, the discussion below focuses on this option. However, it should be noted that it is only one of many choices available, and the relative lack of attention given to other options in industry and the government is itself an issue of
concern. The discussion below highlights the myriad issues a company or policy maker must address when adopting any disposition system.

There are four major issues that need to be taken into account before an infrastructure for a product end-of-life disposition industry can be established. First, some form of a product return system needs to be available and convenient to all customers. Two methods could achieve this: one approach would be to use existing dealer networks as customer return centers and store the old equipment until sufficient volumes require shipping to a recovery (recycling) center or original manufacturer. Another approach would be to develop a toll-free 1-800 number and contracts with various types of carriers for shipping discarded equipment.

The second issue is determining who will pay for this service. One approach considered by industry is a discrete recycling fee charged to consumers at the time of purchase. In this way, the product user pays the cost of recycling and disposal. This differs from the current practice in most of Europe and the U.S., where product disposal is financed through municipal revenues and, therefore, distributed among all taxpayers. The rate of technological advances makes it very difficult to predict future recycling and recovery costs. Paying recycling costs at the time of product purchase presents a challenge to any industry that replaces “technically” obsolete products with new ones. Subsequently, product takeback offers from the manufacturers may be delayed.

The third issue is marketing these products. Since most returned products will be based upon outdated technology, critical service parts could be removed, certified, and then sold for use in some other industries (see Figure 8-1). Another approach is to sell the products for a lower price to customers who do not need leading-edge technology. Used products are often the most cost-effective source of replacement parts, particularly for discontinued products. With proper service and support, the

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Figure 8-1. Disposition life cycle.\textsuperscript{54}

\textsuperscript{54} Used with permission from MCC.
used products often provide profitable opportunities to reuse equipment subassemblies, circuit boards, or components. Plastics and the metals that are recovered could be recycled for reuse or sold.

The fourth issue is the calculation of the environmental burden of end-of-life options. It may be that certain options (e.g., recycling) are more burdensome to the environment than land disposal.

Disassembly and Recyclability Challenges

All manufactured products sooner or later develop defects, wear out, or simply become obsolete, thus becoming waste themselves—electronic products are no exception. Historically, the majority of these wastes made their way to landfills or incinerators. Groundwater contamination from leaking landfills, toxic emissions from incinerators, natural resource depletion, and disposal costs associated with diminishing landfill space, have brought “recycling” to the forefront of methods to address these issues.

One approach consists of voluntary and/or mandatory recycling programs at all governmental levels, worldwide. Moving away from a “throw-away” society will require the cooperation of everyone from the producers of products to the end-users. Product designers in particular have an important role to play since they can strive to design both toxic or other hazardous materials out of, and better recyclability into, products.

Product “takeback” and recycling laws, “eco-label” programs, and customer requirements impact the way we look at a product’s end-of-life design considerations. For example, the German Blue-Angel program requires modular design to promote recyclability and also requires that producers takeback their old products from customers. As recycling becomes mandatory, the question of how to do it in an environmentally-friendly and cost-effective manner arises. The greater a product’s recyclability, the more economical the extraction of the valuable materials that make up that product. Product recyclability can be enhanced through the judicious choice of materials and the incorporation of certain design features.

The trend toward increased recyclability in products has led to the concept of design for recyclability (DFR). Since the initial design of a product has been shown to lock in an estimated 80% to 90% of the product cost because of material and process selection, the most cost-effective place to address recyclability is in this initial design stage. Addressing the problem at the design stage is consistent with Total Quality Management (TQM) models. Recycling is recognized as a very effective resource management tool when materials can be recovered several times before they degrade and can no longer be reused. Recycling can be enhanced by:

- Ease of disassembly
- Material identification
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- Simplification and parts consolidation
- Material selection and compatibility

In many cases disassembling and segregating various parts of the products increases the scrap value and promotes recycling—hence the similar need for design for disassembly (DFD) to maximize this value.

The typical individual product turnover rate in the electronics industry is so high that companies have developed highly sophisticated computer-aided design (CAD) tools to simplify and standardize the design process. The designers must not be burdened with the need to input or interpret the environmental impact data on which the analyses will be based, nor is there time to turn every designer into an environmental specialist. Rather, data on materials, as well as DFR and DFD considerations, should be incorporated into the CAD software so that the most appropriate choice is made automatically for the task at hand.

This automated process would use the existing design tools to access databases on environmental data, on environmental impact, on trade-off analyses, and on full life-cycle risks. These tools must be developed while keeping in mind that these are additional criteria the designers must incorporate into an already highly constrained solution space.

These tools will also allow for additional analyses to increase the recyclability of products including:

- Costs/savings for recycling versus disposal options.
- Review of ease/completeness of segregation.
- “What if” evaluations for different design options.

Policies and regulations associated with product takeback requirements promote the sharing of information between companies regarding the materials content of products and the disassembly instructions. These DFR and DFD tools and databases will provide the information necessary to meet government requirements for performing accurate life-cycle assessments. These tools will also support the efforts to move toward more modular designs that will enhance recyclability and improve the longevity of products.

A final area to be considered is the present state-of-art of the recycling industry. Most recycling operations consist of shredding products, some separation of materials, and the recycling of these materials for their raw material or energy value. This process results in the lowest recovery of the initial investment of the product, short of disposal. Modular design, DFD, and DFR can allow for the reuse of sub-assemblies, components, and housings, among other items, which can return a higher value than the inherent value of the item based on its materials composition.
Although the option always exists to recycle the raw materials from items that are no longer reusable, the alternatives may often be preferable (i.e., more cost-effective or profitable). However, the infrastructure and industries that are required to capture and reuse the higher value items are not yet in place. Therefore, design considerations will need to be made adaptable to keep pace with, as well as influence, the changing opportunities for enhanced reuse and recyclability.

The three major materials used in the manufacture of electronic products are glass, metals, and plastics. The technical challenges of recovering these materials are discussed below.

**Glass:** The electronics industry generates glass cullet for product applications such as color television picture tubes, color computer monitors, and monochromatic monitors. The CRT displays of television sets and computer monitors contain heavy metals, making the sets difficult to recycle. Glass constitutes about 50%, by weight, of the material in TV sets and represents a major recycling potential. Modern video displays contain at least six different glass elements, each with unique compositions and engineering requirements. In general, mixed glass is unsuitable for recycling. Although some CRT market share is moving to flat-panel screens, CRTs remain the predominant display technology. Issues of recycling CRTs are now coupled with those of flat-panel screens, which significantly reduce materials and energy usage, but pose environmental issues that are still being examined.

**Metals:** Lead is commonly used in the electronics industry, primarily for CRT manufacturing and soldering. Its usage is strictly regulated by OSHA and the EPA. Although no cost-effective alternative for lead has yet been discovered, research is ongoing in several organizations to develop lead-free solder and glass alternatives. Concerns remain about the toxicity, long-term availability, and limitations of substitute materials such as conductive adhesives to replace lead and tin solder.

**Plastics:** One of the problems with plastics recycling and recovery is the difficulty in getting high-quality material. While thermoplastic materials are recyclable, mixtures are unacceptable (15 to 20 types of plastics are used in producing a television set), so there is a need to reduce the variety of plastics used in specific products to a single material. Because of the incompatibility of various plastics, the parts disassembled from old products must be identified and sorted in order to separate different types of plastic. Current plastics-marking practices offer little help, as the type of additives, fillers, or flame retardant materials is not supplied. Further studies are necessary to establish the most appropriate treatment for each type of plastic: recycle, regenerate, or incinerate.

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Reverse distribution and product takeback initiatives could force manufacturers to consider environmentally-sound designs and disposal strategies for their products. Furthermore, these concepts also offer a closed-loop recycling system. More research should be conducted on this subject in order to derive an economically and environmentally feasible solution.

Voluntary asset recovery systems for electronic equipment are currently offered by many companies through warranty, repair, trade-in offers, and other return incentives. Some companies vertically integrate the collection, storage, repair/refurbishment, and/or shipment to recyclers, while others utilize third parties for any combination of these operations. Once disposed, components or scrap materials collected may eventually fall under the RCRA solid waste definition. Because no electronic equipment takeback mandate currently exists, except for batteries, these programs are instituted by the companies purely from a business stewardship perspective.

Some European disposition programs have seen the OEM as the responsible party for equipment collection and/or stewardship under mandatory takeback programs. Whether the program is instituted as a result of a government mandate or voluntarily by industry, it must ensure environmentally sound final disposition.

Building a cost-effective and responsible equipment collection infrastructure within municipal solid waste guidelines requires that several issues be addressed:
• Recycle Methods, Capacities, and Markets: Electronic equipment is currently being recycled using several methods, namely de-manufacturing and segregation into like materials for recycle/reuse; shred and post-shred into like materials for recycle; and refurbish and resell. Recyclers have the capacity to handle current volumes, but may not be able to absorb the added quantities resulting from mandated or organized product distribution programs. Also, markets need to grow at the same rate as recycling so storage does not become a problem.

• Business/Industry Electronic Equipment: Some end-of-life electronic equipment disposed of by business/industry may be regulated under RCRA. These entities must substantiate and verify the sound environmental final disposition of the equipment, incurring costs associated with managing materials classified as “hazardous.”

• Consumer (household) Electronic Equipment: The objective is to remove end-of-life electronic equipment from municipal trash through reuse and recycling of material, thereby preventing its disposal in landfills or consumption in municipal incinerators. All household waste is currently exempt from regulation under RCRA. Municipal waste disposal prohibitions may require the development of collection, inventory, and transportation methods to accommodate equipment discarded by consumers.

• Municipal Curb-Side Pickup: One viable collection system is municipal curb-side pickup and subsequent shipment to recyclers. This will avoid having the OEMs develop parallel collection programs that will inevitably be financed by the consumer via initial product cost increases. Municipal management may result in an increase in local taxes to support the added burden if the scrap value is insufficient to cover management costs.

Potential deterrents to implementing voluntary product disposition initiatives include:

• Regulations, especially state-to-state variations, that inhibit, rather than encourage, environmentally sound programs.

• Defining end-of-life electronics products as “hazardous” and in need of close regulation—and, thus, having higher costs for handling—even if no firm evidence of hazardous effect exists.

• Federal and/or state regulation of consolidation points.

• The environmental costs (e.g., energy and waste).

• The financial costs.

Options for addressing voluntary asset recovery initiatives are as follows:

• The electronics industry, in conjunction with electronic product users, should form a working group to prepare a model program aimed at
ensuring the environmentally sound stewardship of end-of-life electronic equipment.

- The electronics industry should lobby to have end-of-life electronic equipment exempted from the RCRA “solid waste” definition and, instead, identified as a raw material/commodity if it is being collected, stored, transported, and managed for recycle/recovery (this is being done by the IPC and the Electronic Industries Association).

Traditional electronic products are not manufactured with a view towards after-use recycling. Although salvaging only a small portion from the available volumes of obsolete electronic scrap, most reclaim efforts currently focus on recovering selected components and valuable metals. Full service metal and component recycling requires a knowledge of resale values, recovery techniques, and environmentally sound metal purification and separation techniques. Available services offer combinations of manual, mechanical, chemical, and pyrometallurgical capabilities. Segregation, value, and volume all affect the net return. Until now, glass and plastic have largely been considered non-recyclables.

To facilitate disassembly and sorting of parts and materials, several key issues must be addressed:

- Increasing the recyclability of all components.
- Easing the disassembly and identification of component parts.
- Protecting OEM sensitive/confidential information.
- Encouraging OEMs to support creative applications for recycled products.
- Developing global and cross-industrial recommendations and initiatives—including parts and material reuse.

Potential deterrents for the disassembly and sorting of parts and materials are:

- Recycling, and/or the disposal of non-reusable materials in an environmentally correct manner, is expensive. This cost will continue to grow if the volume of non-recyclables is not reduced. Recycling must be profitable in order to succeed.
- OEMs must be willing to incorporate, and consumers must change their perception of, used parts (especially electronic components) in new products. Unless the quality and reliability issues associated with these parts are overcome, manufacturers will continue to pay the costs for new products (using virgin materials) plus face the probable future expense created by recycling and disposal regulations on obsolete products.

The following are recommended for implementing a disassembly and sorting procedure:

Disassembly and Parts/Material Sorting
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- Design for disassembly should include input from recyclers to assure ease of break-down, shipment, material segregation, and secondary market acceptance. Lower costs associated with time and effort will increase the likelihood of value in the secondary arena.

- Internationally accepted, generic codes on all components would allow instant scanning. This would alleviate the current difficulties associated with component/material identification, sorting, treatment, or recycling.

- Global education programs should offer a coordinated scheme for the benefits of recycling and reuse issues. Such programs could aid the marketing of products utilizing recycled parts and, equally important, help alleviate the public pressure for environmental policies that have too often been expensive, counter-productive, or unnecessary.

**Part Refurbish/Remanufacture**

At equipment end-of-life, many potentially reusable parts currently enter the waste stream. While in some cases material value is recovered, greater value can be realized if parts are reused for their originally intended function.

However, incorporating used parts back into new equipment requires highly reliable technologies to ensure that refurbished parts meet the same quality standards as new parts. This is especially important to dispel the current negative public belief surrounding used parts (and machines). Alternatively, parts that are not expected to meet the same performance standards as new ones can be redistributed in other products and markets. In this case, less rigorous standards may apply, thus permitting less extensive refurbishing and repair processes.

To facilitate parts reuse, the following major areas need to be addressed:

- **Customer-vendor cooperation:** Many parts contained in electronic equipment are purchased by equipment manufacturers from parts vendors. Electronic equipment manufacturers need to work cooperatively with the original part manufacturers to facilitate the reuse of parts. Parts manufacturers must design parts for refurbish/remanufacture and provide refurbish/remanufacture technical expertise. Equipment manufacturers need to specify used part requirements in purchasing contracts and provide the used parts for refurbish/remanufacture.

- **Parts design for refurbish/remanufacture:** Robustness needs to be designed into parts. Additionally, design should incorporate reparability. Potential failure sources should be identified up front and then designed out. Alternatively, the part can be designed for easy access and repair.

- **Test procedures to ensure reliability and performance:** Parts life needs to be established and demonstrated to a high confidence level. Reliability test procedures need to be developed to ensure that reused parts will meet the desired performance standards. These technologies should provide information on life expectancy and component aging characteristics.
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• Technologies for tracking parts life and number of turnovers: Inexpensive means for tracking parts life and the number of turnovers can serve as a simple means for identifying parts that can potentially be reused. In some cases, reliability testing can provide enough data to predict expected reused part performance to an acceptable level of confidence. In these instances, parts life and the number of turnovers may be sufficient quality assurance information. This would reduce any costs associated with extensive performance testing.

• More environmentally acceptable cleaning technologies: Most refurbishing processes include at least one cleaning operation. Current technologies still rely heavily on cleaning solvents such as halogenated organics, and more recently, semi-aqueous and aqueous materials. More work needs to be conducted on alternative cleaning technologies such as carbon dioxide blasting and supercritical applications.

Potential deterrents to parts refurbishing and remanufacturing are:

• Procurement policies that specify new: While the federal government is attempting to incorporate environmental considerations into their procurement practices, many states continue to specify that office equipment be completely new. These contracts prohibit the use of reused parts.
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- The belief of used as inferior: It is generally believed that all used products are inferior to new ones. Education and awareness are important to dispel this perception and build customer confidence. Additionally, economic incentives could serve as a means for promoting purchase.

The following are recommended for implementing the use of refurbished and re-manufactured parts in products:

- Incorporate the consideration for reused parts content into government and industry procurement practices: Frequently government practices set the stage for private organizations. In addition to considering used part content when purchasing their own office equipment, federal and state procurement offices can also require that their contractors and vendors adopt the same practice.

- Parts and equipment manufacturers need to work cooperatively: Cooperative efforts between part and equipment manufacturers would be most effective in maximizing part value. In addition to part design, standard test methods for evaluating used parts condition in terms of reliability and expected performance could be addressed.

- Develop parts reliability database: Part reliability data correlating life with performance could provide enough information on a specific part design to allow reuse without extensive testing. This effort would most logically be undertaken by parts and equipment manufacturers.

- Develop low-cost parts tracking technology: A rapid low cost means for determining the life status of a part could be used in conjunction with the reliability database. This would provide a method for dismantlers to sort reusable parts from scrap.

- Develop more environmentally acceptable cleaning technologies: More development work needs to be conducted to make non-chemical cleaning technologies both technically and economically feasible. For example, while carbon dioxide cleaning technologies are being used in limited applications, economics currently present an obstacle to widespread use.

Recycling Technologies

Some materials—such as precious metals—have been recovered from electronic equipment for years because of their value. Others, such as ferrous metals, aluminum, stainless steel, glass, and plastics are just beginning to be recycled as the required technologies and infrastructures become available.

This section will focus primarily on plastics, because they are typically the most valuable materials in the electronics waste stream after the precious metals, and because they are being recycled in very limited amounts because of the technical and economic challenges. The economic challenges are mostly associated with the collection, disassembly, and market development issues. The technical challenges are just now beginning to be addressed.
The recycling of plastics from post-consumer packaging, particularly bottles, has become fairly well-established. While the engineered plastics typically found in electronic equipment streams have higher potential market values, their recovery and recycling present unique challenges compared to the recycling of plastics from shipping packaging. Some of these challenges include:
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- A much greater number of different plastics, some with various types of fillers and additives that make their separation both more difficult and more important.
- More items constructed of multiple plastics.
- Opaque pigmentation and thick walls making polymer identification and sorting more difficult.
- Paint and metallic coatings on some plastics.
- Significant amounts of attached metallic items (e.g., labels).
- The abundance of other non-plastic items such as natural rubber, synthetic elastomers, and glass.
- Parts containing attached foam, fabric, or plastic films made of different materials.
- Larger (and more variable thickness) wall sections, increasing the challenges associated with efficient size reduction and control.

Some of the most important issues with regards to plastic recycling are:

- Plastics identification and sorting technology.
- Size reduction and liberation technology.
- Separation technology (for plastic and non-plastic foreign material).
- Paint and coatings removal.
- Upgrading.
- Re-use (particularly of older plastics containing flame retardants or other “undesirable” additives).
- Customer-added contamination such as labels and paints.
- Identification of post-consumer plastics that contain undesirable additives.

The two major potential “show stoppers” are getting the material back into a recyclable form economically and generating sustainable markets for it once it has been purified. Collection and dismantling of plastics from end-of-life electronic equipment is perhaps the most costly component, and must be addressed industry-wide to spread the capital and operational costs associated with such an undertaking. Individual company initiatives will likely be cost-prohibitive except in very targeted areas.

Market development is critical to making the activity economically viable. The revenue generated by the sale of the raw materials produced by the recycling activity must pay for that activity. The quality of the material will be one factor in
determining its value. The development of adequate recycling technologies will help increase the quality of the product and reduce recycling costs.

Another factor in determining value is the supply of the raw material. Increased supplies will tend to decrease values and make the recycling activity less viable; therefore, finding high value markets for the recycled materials—preferably in closed-loop scenarios—is very important. The OEMs play a vital role in creating the demand for these materials by specifying recycled material content in new applications. Many OEMs still require 100% virgin materials while at the same time espousing recycling in response to perceived customer requirements.

In addition to technology breakthroughs, closed-loop and cross industrial application development for recycled materials needs to be conducted to increase the market for recycled materials.

The electronics industry should continue to work with the plastics industry, which is funding significant work in the area of technology development. It can also help ensure continued work in this area through its association with other groups, such as the National Center for Manufacturing Sciences (NCMS) and the National Institute of Standards and Technology (NIST), to encourage additional funding to these needed areas.

The focus of materials science has been on developing new virgin materials for new uses. To facilitate product disposition, the focus must include material properties of used materials. How these materials can be used in products must be better understood.

To facilitate the re-use of materials, the following major areas need to be addressed:

- The basic properties of used materials need to be better understood. These properties are, in general, degraded in comparison with those of virgin materials. The effect on material properties of preparing for reprocessing (e.g., shredding) needs to be established in order to determine how materials can be reused. The effect of typical contaminants on the properties of materials for reuse also needs to be understood.

- Once the basic material properties of re-used materials are established, the technology of mixing various materials to come up with a final material with the desired properties needs to be developed. The goal is to develop the technology of mixing recycled materials to yield a final material with the properties of a virgin material.

- Processing technologies need to be optimized for recycled materials. This may require changing processing conditions to accommodate the different properties of recycled material.
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- Better material separation technology needs to be developed to ensure streams of materials with less contamination for reuse.
- There needs to be an investigation of ways to increase the compatibility of materials so that materials can be reused without rigorous separation.

Potential deterrents to developing the field of materials science for reused materials are:

- If the costs associated with technology development and new equipment are too high, companies will be reluctant to invest in these areas.
- There must be good cooperation between academia, material suppliers, equipment suppliers, product producers, regulatory bodies, and recyclers and associations. If such cooperation does not exist, there will be little progress in this area.
- Regulations and purchasing guidelines specifying that new equipment contain no reused or refurbished parts need to be changed. If there is no motivation for buying products with recycled content, then there is no reason to develop the field of material science for reused materials.

Two recommendations address the key materials issues in an effective program:

- A coordinated research program on the properties of materials for reuse should be instituted. This research program could be a consortium, composed of major material suppliers, major material users, universities, recyclers and associations, or it could be a part of the new mission of the National Laboratories.
- A coordinated effort is needed to educate and convince consumers to buy products containing recycled material.

The biggest remaining question is whether customers will accept products with recycled contents. Frequently recycled material can affect the appearance of a product and it is not known whether a customer would be willing to forego a better-looking product made of virgin material in favor of one made of recycled material that performs the same function, yet may not have the same appearance as the product made of virgin material.

New Design Technologies

The handling of scrap electronic equipment to encourage recycling and materials recovery can be enhanced by incorporating or introducing features into new designs that facilitate material identification, segregation, toxic content, and disassembly. Designers traditionally select materials and design products based on factors such as proprietary designs, raw material price and availability, customer needs, and assembly time. This freedom of material selection and design latitude provides the consumer with a wide variety of products from which to choose—based on color, materials durability, aesthetic appeal, size, personal
preference, cost, and optional features. However, the wide variety of materials, components, and assembly techniques required to allow this freedom, along with the need to handle and process each material separately, reduces recyclability and increases operation costs. To reduce this variability and enhance recyclability, designers may consider incorporating features and materials selection that will facilitate end-of-life disposition.

Some of the key issues to consider when developing new design technologies are:

- **Attachment Technologies**: To facilitate disassembly by recyclers, designers may consider the use of “snap fit” features in lieu of self-tapping, machine, and/or sheet metal fasteners. Where fasteners are necessary, designers may consider standardizing on one type of fastener head, such as a Phillips head, to avoid the need for a disassembler to constantly change tools. Permanent attachment methods (i.e., epoxies, welds, and hot staking) should be designed out of the assemblies.

- **Marking for Ease of Identification**: Disassemblers encounter a wide variety of materials, some of which are difficult to identify for proper segregation. Designers may consider marking various components to facilitate this identification. Plastics may have the international materials identification abbreviations and chasing arrows molded into the part; wire and cable may be marked to differentiate thermoplastics from thermosets; components may be marked to identify metallic content, (such as copper in coils and precious metals in mounted components); and printed circuit boards may be marked to indicate the use of lead based solders.

- **Aesthetic Quality Technology**: Customers demand aesthetic perfection on visible surfaces. This cosmetic requirement seriously inhibits the use of post-consumer materials. However, designers may consider specifying post-consumer recyclable materials for any non-visible parts. Designers may also consider changing surface texture requirements to hide surface imperfections resulting from the use of post-consumer materials.

- **Material Properties/Characteristics**: The physical, chemical, mechanical, and performance requirements of the materials often demand virgin raw materials. Efforts should be made to add post-consumer recyclable materials in concentrations that do not compromise the material and product integrity and functionality.

Potential deterrents to the development of new design technologies are:

- Consumers may reject products with imperfect surface features.
- Customer and regulatory agency requirements for materials may demand characteristics that can be obtained only by the use of virgin raw materials.
- Manufacturers may not be receptive to revealing the material identity of components, housings, subassemblies, etc.
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- Attachment alternatives may involve time-consuming and expensive pre-production testing to evaluate the efficacy of alternative mechanisms.

- Designers may be reluctant to accept attachment methods that differ from individually preferred techniques and may resist criteria that inhibit their individual creativity.

Recommendations for the adoption of new design technologies are:

- A list of materials used for the manufacture of electronic equipment should be developed. This can be accomplished by electronic equipment representatives to trade associations.

- Manufacturers should agree upon a program to convince consumers that purchasing products manufactured with post-consumer materials may result in surface imperfections without sacrificing quality and/or functionality.

- Specification requirements should be reviewed to determine the extent to which chemical, physical, electrical, and/or mechanical properties can be changed to accommodate post-consumer materials without sacrificing quality.

- Electronic equipment and product manufacturers should meet within trade associations to develop standards for an acceptable universal identification program.

- Designers should be rewarded for innovative technical substitutions for use in lieu of traditional fastener systems.

- Industry standards and manufacturing specifications should be reviewed to identify requirements that inhibit reuse.

Market Pull

Electronic equipment disposition has the potential to encourage the development of several innovative market opportunities and enhance traditional markets already in place. In reality, this “market pull” (development) for the disposition of electronic equipment is a critical factor in the electronics industry environmental roadmap. Opportunities to provide value from electronic products and subsequent market development include:

- Performance-sensitive (early) reuse: Sell or lease used electronic equipment while its technology is relatively current.

- Price-sensitive (later) reuse: Sell or lease electronic equipment with adequate, but not cutting-edge, technology at attractive pricing.

- Service and support: Source or replacement parts for warranties and service as well as discontinued equipment.

- Component reuse: Use of component parts in new or refurbished equipment either by equipment manufacturer or third party.
• Residual material recovery and recycle.

To facilitate the market development for electronic equipment, the following major areas need to be addressed:

• Manufacturers of electronic equipment must begin to integrate product reuse opportunities into the business’ strategic plan.

• Manufacturers of electronic equipment must begin to integrate product life cycle management (PLCM)/DFE into the product design.

• An infrastructure for collecting and returning equipment must be developed.

• Association of quality with reused equipment, parts and materials by both the electronic equipment manufacturer, third party purchasers for resale/reuse, and the customer must be more firmly established.

• Entrepreneurs must be recruited to invest and develop innovative electronics disposition markets globally.

Potential deterrents to the facilitation of market development for electronic equipment are:

• The inability for electronic equipment manufacturers to align their strategic business plan with potential reuse/resale opportunities and PLDM/DFE platforms.

• The inability of the manufacturer and customer to demonstrate that used equipment, parts, and materials are of acceptable quality standards.

Key recommendations for accelerating market pull include:

• Provide high-level consumer awareness programs to encourage the reuse of used electronic equipment, parts, and materials, with specific emphasis focused at overcoming perceptions relating to inferior quality.

• Incorporate requirements for used equipment, parts, and material content into both corporate and government procurement practices and strategies, which in turn will effect strategic business planning and potentially lessen regulatory control initiatives.

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<th>Priority Need (decreasing order of priority)</th>
<th>Approach</th>
<th>Selected Tasks</th>
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Priority Needs Matrix
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| • Create design guidelines to enhance electronic product recyclability. | • Provide designers with a list of materials that are easier to reuse/recycle. | • Implement research on the properties of materials for reuse and recycle. | • Assemble and disseminate information on disposition options. | • Develop information networks and sources to facilitate disposition decisions. | • Create and populate databases to enhance disposition decisions. | • Establish product disposition strategies and capabilities. | • Define an efficient electronics product disposition system. | • Examine the success/failure of existing disposition approaches. | • Improve product recycling strategies and capabilities. | • Establish collaboration strategies in conjunction with suppliers to enhance recycling efforts. | • Develop low-cost part tracking technology. | • Develop markets for recycled products. | • Establish corporate and government procurement policies that encourage reuse and recycling. | • Define requirements for recycled-product content. | • Educate consumers about benefits of products containing recycled materials and/or reused components. | • Establish a coordinated, multi-industry effort to educate and convince consumers to accept recycled/reused products. | • Institute programs to educate consumers on products containing recycled materials. |
| • Promote cooperation between equipment manufacturers, suppliers and recyclers. | • Establish a feedback loop between recyclers, suppliers, and OEM designers to affirm design decisions. | • Encourage CAD/CAM suppliers to incorporate DFE/DFD in their programs. | • Establish analytical approaches for making disposition decisions. | • Institute a mechanism for disseminating information on product content. | • Develop a model electronics disposition system, leveraging off of existing systems. | • Define requirements for recycled-product content. | • Promote R&D to find new uses for recycled plastics. | • Take back and utilize used equipment, parts and materials into procurements. | • Examine technology needs at various recycling stages (e.g., separating, grinding). | • Develop parts reliability database. | • Incorporate requirements for used equipment, parts and materials into procurements. | • Educational programs to educate consumers on products containing recycled materials. | • Develop global education programs on the costs/benefits of recycling and reuse issues. |
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Regulations and Standards

Background and Status

The regulations and standards roadmap represents an effort by the electronics industry to clearly identify an industry approach to regulations and standards over the next 10 years. Because environmental regulations and standards will increasingly become an integral part of doing business in the electronics industry, the industry will benefit by developing a strategy for maximizing environmental performance and minimizing costs. Regulations can require companies to change processes, alter materials used, and expend significant resources for employee training and environmental clean up. Standards can have similar impacts, even affecting access to foreign markets. The electronics industry must work collaboratively with regulatory and standards creating bodies and other stakeholders to ensure that future regulations and standards effectively protect the environment, while avoiding excessive economic burden on the industry.

Although regulators understand, in a general sense, that traditional command and control regulation is overly costly and does not often result in the desired environmental improvement, it still dominates the regulatory landscape. Nevertheless, regulators are attempting to move toward a more collaborative approach and, as a result, have identified “pollution prevention and voluntary programs” as the preferable approach to solving environmental problems. This approach, however, has not supplanted the traditional command and control regulatory regime under which all companies must operate. Thus, while the electronics industry has been a pioneer in participating in voluntary initiatives, it must still contend with, and adhere to, the command and control system that continues to grow in scope and to increase costs of doing business. The objective of this industry roadmap effort is to delineate initiatives that will benefit the environment and reduce costs to the industry.

In order to understand what must still be done to ensure maximum environmental benefit and cost-effective regulations and standards, and in order to understand the logic of the recommendations listed in this section of the roadmap, it is important to review examples of the many voluntary, standards, and regulatory initiatives underway where the electronics industry is participating.

Common Sense Initiative: The EPA is working with selected industries and important stakeholders in the regulatory process to improve the environmental results and reduce the economic impact of its programs. “Individual Sector Teams” will undertake activities in six categories.56

1. Conduct a retrospective review of existing rules to identify opportunities to make improvements, and improve the development of future rules through greater coordination across EPA’s Media Programs;
2. Promote pollution prevention and other voluntary, environmentally sound practices;

56 EIA Memo May 11, 1994 from Melissa Carey to Environmental Issues Council.
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3. Simplify and improve the effectiveness of record-keeping and reporting requirements;
4. Undertake compliance and enforcement initiatives to provide increased predictability, greater information, compliance assistance, and greater overall compliance;
5. Identify and implement permit streamlining opportunities; and
6. Promote innovative environmental technology.
Environmental Leadership Program: The EPA has requested proposals for Environmental Leadership Program (ELP) pilot projects with the objective of determining the feasibility of a future, full-scale ELP to help improve environmental compliance. There are numerous benefits from the proposed program, including greater industry self-monitoring, improved compliance, pollution prevention and environmental protection. Full-scale programs will be consistent with the Administrator’s Common Sense Initiative.

EPA is focusing on seven criteria for acceptable proposals:

- State-of-the-art environmental management systems that assure compliance and compliance histories demonstrating a commitment to go beyond compliance.
- Established environmental management and auditing programs.
- A willingness to divulge audit findings to the public in a manner that improves public confidence.
- Existing and proposed pollution prevention activities.
- Willingness to set an example for others with their environmental programs.
- Compliance and pollution prevention tracking with quantitative and/or qualitative measures.
- Employees and community involvement in program development.

Green Lights: Green Lights is a program sponsored by the U.S. EPA that encourages major U.S. corporations and state and local governments to install energy-efficient lighting. Using new technologies, participants reduce energy consumption while delivering the same or better quality lighting. Under this voluntary, non-regulatory program, participants upgrade their facilities with energy-efficient lighting wherever it is profitable and maintains or improves lighting quality. Green Lights will produce multiple national benefits by addressing critical issues of energy-efficiency, pollution prevention, and economic competitiveness. Corporations and governments that make the commitment to Green Lights will profit by lowering their electricity bills (by an estimated $20 billion), improving lighting quality, and increasing worker productivity. They also will reduce the air pollution caused by electricity generation, which includes carbon dioxide, sulfur dioxide and nitrogen oxides.57

Energy Star: The EPA Energy Star Computers program is a partnership effort with computer manufacturers to promote the introduction of energy-efficient personal computers and other electronic products. Energy-efficient products will reduce air pollution caused by power generation. The program was introduced on

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Earth Day, 1993, by Vice President Al Gore and is based on a simple concept: computer equipment capable of going into an energy-saving “sleep” mode when sitting idle earn an EPA “Energy Star.” These new personal computers will save enough electricity to power Vermont and New Hampshire each year and save ratepayers up to $1 billion in annual electricity bills. Since last April, what was a novelty corner’s worth of hibernation-capable desktop PCs and printers has swelled to a storeful. The first partnerships were signed June 17, 1993 with leading manufacturers that are responsible for 35% of all U.S. computers, including Apple, Canon, Compaq, Digital Equipment Corp. (DEC), Hewlett-Packard, and IBM. Over 75 companies are already offering such products—in many cases entire product lines.

Electronics Industry Roadmaps: Several electronics industry organizations have launched significant efforts to develop roadmaps for environmental issues in particular industry sectors. These roadmaps are collections of concerns, efforts, and a collective outline of the intended direction and initiatives that are needed in the particular electronics industry sectors. They will contribute to a greater understanding of environmental issues in electronics and improved regulations and standards:

- SEMATECH has had an ongoing technology and Environmental Health and Safety (ESH) effort for the semiconductor industry underway in the last two years. A revised version of the ESH roadmap will be released in November, 1994.

- The Institute for Interconnecting and Packaging Electronic Circuits (IPC) has been working with printed wiring board manufacturers to develop an environmental initiative as well.

- The IPC has had an ongoing technology and environmental safety effort for the electronics interconnection industry in the last several years. The Interconnection Technology Research Institute (ITRI) was formed to implement many initiatives that were identified by the IPC roadmap.

- The Microelectronics and Computer Technology Corporation (MCC) has been actively promoting and coordinating an industry-wide roadmap effort designed to address environmental issues across the full life cycle of an electronic system.

International Standards Activities: The International Organization for Standardization Technical Committee (ISO/TC207) represents the most significant collection of standards activities. The technical committee (TC 207) is divided into six sub-committees, each working on a separate element of the environmental management standard that will be voted on in the next year. Because the ISO

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activities are so critical and will directly impact how U.S. manufacturers make and sell products abroad, the major initiatives are briefly reviewed below.

- **Environmental Management Systems:** This group is in the process of developing two documents. The first is a specification standard for registration purposes, listing core elements of any acceptable environmental management standard. The second is a guidance document intended to give good examples of environmental management practices, discussing the core element with illustrative “ways to get started” and “tool kits.” The second document also contains information on risk, integration, performance, and improvement. Anticipated release for balloting is September 1995.

- **Environmental Auditing:** Three sections of the environmental auditing segment have been completed for discussion. The first includes general principles of environmental auditing. The second section outlines procedures for auditing environmental management systems, addressing audit objectives and procedures for initiating, preparing, executing and reporting the audit. The final section lists qualification criteria for environmental auditors. This section evaluates roles and responsibilities of the audit team, qualification criteria for education and work experience, training, personal attributes and skills, maintenance of competence, due professional care, and language of the individual auditors. This chapter is also anticipated for balloting in September 1994.

- **Environmental Labeling:** This sub-committee has divided into three working groups. Group one is focusing on the principles/practices of third party (private and government) certification and verification programs. Group two is developing standards for environmental self-declarations and claims, including terms and definitions, symbols, and testing and verification methodologies. Group three is developing basic environmental labeling principles which will serve as the foundation for development and implementation of all environmental labeling programs. Drafts are targeted for mid-1995.

- **Environmental Performance Evaluation:** Unlike the others, this group has faced an initial problem of having no existing guideline or format to follow. Therefore, their first initiative was to develop a framework document on definitions, principles, and general approach to environmental performance evaluation. This document will contain standard development principles, application principles, and possible applications and uses of environmental performance evaluation. Three areas of evaluation are described: management, operations, and environment. Management includes compliance, systems development and implementation, and integration into general business functions. Operational process categories include efficiency in the use of natural resources, energy consumption, waste generation, and incidents. Environment includes air emissions having global, regional, or local effects; water discharges with regional or local effects; soil contamination;

- **Life Cycle Assessment (LCA):** There are five working groups established under the subcommittee on life cycle assessment. These are:
  - General Principles and Procedures
  - General Inventory Analysis
  - Industry Specific Inventory Analysis
  - Impact Assessment
  - Improvement Assessment

Issues that have developed in group one are data quality, LCA applications, presentation and communication, and critical review. Groups two and three are jointly developing a framework, general issues and practices, reporting and communications, and goal definition and scoping. Groups four and five are working to develop a better understanding of what is currently practiced in impact assessment and improvement assessment respectively. The draft is not yet prepared.

- **Environmental Aspects of Product Standards:** This group submitted a draft document entitled “Guide for the Inclusion of Environmental Aspects in Product Standards” to the TC207 May 1994 meeting. The Guide is intended for standards writers. Its purpose is to raise awareness about the effects of standards on the environment, outline the negative and positive impacts of standards on the environment, address the balancing of priorities, and recommend the use of recognized scientific methodologies in developing product standards. The Guide emphasizes that environmental effects must be considered in Product Standards Development (such as material inputs, energy inputs, emissions to air, effluents to water, waste, and noise and vibration).

**Examples of Other Standards Groups and Activities:** Several other standards activities are also currently underway:

- **American National Standards Institute (ANSI):** Serves to represent the U.S. in the ISO organizational scheme.


- **British Standard:** Created by the Environment and Pollution Standards Policy Committee to Technical Committee EPC/50 of the British Standard Institute. Served as a basis for the first ISO TC 207 Environmental Management Standards.

- **Canadian Standards Association (CSA):** Canada’s oldest and largest standards development and conformity assessment organization. Currently there is an agreement of sorts with the CSA and the National Sanitation
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Foundation to make the Canadian standards available to the U.S. in order to facilitate expedient development of a similar document in the U.S.

- **Committee of European Normalization (CEN):** BT WG 64 “Environment” is their version of the Environmental Standards.


- **National Sanitation Foundation (NSF):** Proposing a US-EMS standard similar to BS 77-50 to go into effect in 1995.

- **Semiconductor Equipment and Materials International (SEMI):** Creates international consensus-based standards and safety guidelines specific to the semiconductor and flat panel display industries. The SEMI Standards Strategic Plan has been aligned to meet the requirements contained within the National Technology Roadmap for Semiconductors (NTRS).

**State Toxics Use Reduction Programs:** Toxics use reduction programs have been labeled by some as source reduction aimed specifically at toxic chemicals. A report, titled “Toxic Substances—Advantages of and Barriers to Reducing the Use of Toxic Chemicals,” states “Whereas source reduction focuses on reducing all types of waste at their point of origin, toxics use reduction focuses on reducing or eliminating toxic chemicals in manufacturing and commerce before the chemicals are used to create products and eventually become hazardous waste.” State laws range from requiring reporting on and reductions in use, fines or fees on companies using certain chemicals, and limits on the amount of materials that can be present in products. Though there is potential for industry to benefit from toxics use reduction, it can limit manufacturers in the high-tech industry, and is not always perceived as the most cost-effective and efficient means to handle environmental concerns.

**Universal Waste Rule:** The Environmental Protection Agency proposed the new rule, 40 CFR 273, in an attempt to remove regulatory impediments to the safe and efficient management of hazardous wastes. Under the rule, “certain post-user waste items would be collected under greatly streamlined requirements, to facilitate separation of these materials from the municipal waste stream and to encourage proper treatment and/or recycling.”

Common characteristics of “universal wastes” are that they are frequently generated in a wide variety of settings, usually associated with hazardous waste; they are generated by a vast community, the size of which poses implementation difficulties for both those who are regulated and the regulatory agencies charged with implementing the hazardous waste program; and they may be present in significant volumes in the municipal waste streams.

Goals of the program for universal waste are to encourage resource conservation, while ensuring adequate protection of human health and the environment, and to improve implementation of the current subtitle C hazardous waste regulatory pro-
gram. By simplifying the requirements and encouraging collection of these hazardous wastes, EPA hopes to provide incentives for individuals and organizations to collect the unregulated portions of these universal waste streams. The wastes can then be managed using the same system developed for the regulated portion, thereby removing the wastes from the municipal waste stream and minimizing their input of hazardous constituents to municipal landfills, combustors, and composting projects.

Clean Air Act Amendments: The Clean Air Act Amendments (CAAA) and the implementing regulations, especially Title V permitting requirements, will continue to have a major impact on the electronics industry. The CAAA reflect the importance and need for pollution prevention in developing and implementing programs to meet air quality objectives. Many opportunities exist to instill a pollution prevention approach to implementing the CAAA which will lead to greater overall environmental benefits and better use of our limited resources. Proposed permitting requirements could be a major barrier. The great significance of the programs required by the CAAA suggests that our ability to incorporate pollution prevention policies in the Act will be a true test of our ability to implement pollution prevention as a national policy. The electronics industry is working hard to make sure that the CAAA Title V program will have the necessary flexibility to maintain a competitive strategy that includes rapid product and process changes.

Priority Issues and Needs

After having reviewed the various issues affecting the electronics industry, the Regulatory Roadmap Group has selected five key priority issues:

- Regulatory streamlining.
- Partnerships between industry/EPA and state and local regulatory agencies.
- Information access and dissemination within industry.
- Collective trade association network.
- National and international standards activities.

Priority Needs Matrix

The following matrix outlines the recommended roadmapping initiatives. One general issue is that emerging product life cycle regulations and standards—such as the banning of key chemicals, process-based standards, and minimum content requirements for products—could seriously impact competitiveness.

<table>
<thead>
<tr>
<th>Priority Need (decreasing order of priority)</th>
<th>Approach</th>
<th>Selected Tasks</th>
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<tr>
<td>• Minimize regulatory constraints on innovative approaches to environmental problems.</td>
<td>• Support government/industry efforts to streamline regulations.</td>
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<td>• Increase flexibility in environmental permitting.</td>
<td>• Work with state and federal agencies to secure flexibility.</td>
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<td>• Harmonize federal/state environmental legislation.</td>
<td>• Bring federal and state regulatory and legislative bodies together to reach agreement.</td>
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<td>• Change from the use of SIC Codes for environmental classification of industry sectors.</td>
<td>• Work with the U.S. EPA to devise a different system for classifying industrial sectors.</td>
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<tr>
<td>• Change RCRA by legislation or regulation to encourage recycling.</td>
<td>• Work with EPA to develop infrastructure necessary for efficient electronic products disposition without undue burden on industry.</td>
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<td>• Streamline access to information from EPA.</td>
<td>• Improve electronic data storage and delivery mechanisms.</td>
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<tr>
<td>• Modify standards affecting reuse.</td>
<td>• Encourage standard-setting organizations to review standards affecting product and component reuse.</td>
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<tr>
<td>• Coordinate trade associations within the electronics industry and between this industry and other industry sectors.</td>
<td>• Establish an inter-trade association council.</td>
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- Establish sunset clauses for certain regulations.
- Streamline process for fixing unworkable or conflicting regulations.
- Establish a fast track review for new technologies.
- Establish a public review process for agency interpretation and guidelines.
- Get legislation calling for performance rather than prescriptive standards.
- Assure that all sectors within EPA are in accord prior to entering into cooperative agreements.
- Industry should sponsor key workshops to start this process.
- Establish appropriate classification for each emerging technology, e.g., flat panel screens, at the federal level.
- Redress the efficacy of the household exemption for post-consumer products.
- Encourage the electronics industry to lobby to exempt end-of-life electronic equipment from the “solid waste” definition.
- Develop an accessible international regulatory database.
- Develop a “super bulletin board” of EPA actions.
- Review industry/government standards and manufacturing specifications to identify requirements inhibiting reuse.
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<th>• Minimize the potential for trade barriers resulting from standards activities.</th>
<th>• Harmonize environmental standards between the U.S., Canada, and Mexico under NAFTA.</th>
<th>• Promote industry involvement in NAFTA environmental negotiations.</th>
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<tr>
<td>• Assess the potential effects on trade from standards such as ISO 14000, Environmental Management Standard.</td>
<td>• Increase industry involvement with the U.S. TAG on TC-207/ISO 14000 standards development process.</td>
<td>• Monitor and analyze product take-back and other trends.</td>
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A roadmap for environmental action in the U.S. electronics industry is enhanced by a knowledge of global activities, which provide an important source of competitive benchmarking. In both Europe and Japan, environmentally conscious manufacturing, equipment and materials disposition, recycling, and related topics have not only ascended corporate ladders, they have given rise to cooperation, and sometimes conflict, between government, trade organizations and agencies, and industry. In some cases, environmental actions are led, or instigated, by legislation or threatened legislation—such actions are sometimes encouraged by a growing environmental concern among consumers. There are several reasons for the effort currently put forward by European and Japanese companies to assess the environmental impact of processes and equipment waste and no two regions are driven by the same set of factors. The following sections discuss highlights of activities in Europe and Japan and some of the driving forces behind them.

Europe is often used as an example of commercial and governmental activities for a more environmentally conscious electronics industry. Examples range from the proposed German law for electronics waste take-back to cooperation between national governments or the European Commission (EC) and companies for enhanced development of environment-related infrastructure and technologies. While it is important to be aware of activities in Europe for market access and competitiveness issues, it is likewise important to view such activities in the appropriate context. Europe not only has a different relationship between industry and government than that in the U.S., but the need to address waste—in this case electronic waste—is driven significantly by severe limitations of landfill space. Also, given that tourism contributes over 5% of the gross domestic product (GDP) for the EC, the environment is taken very seriously. However, the environmental issues are vast, ranging from eroding statues due to air pollution, contaminated beaches, and dying forests. As a result, awareness of environmental issues is on the rise. Inhabitants of such countries as Germany, The Netherlands, and Denmark are increasingly sensitive to environmental damage.

As a result of the growing concern over the environment, as well as over the likelihood that Germany will pass some form of legislation forcing electronics waste to be taken back and recycled, many companies, industry trade groups, government entities, and universities across the European Union (EU), within the European Commission, and in countries that are not yet members of the EU, are launching studies of business and trade issues related to the environment, technologies, legislation and standards, infrastructure, and training.

The efforts made by European companies to create greener images range from establishing corporate environmental policies and programs to carrying out environmental audits (or developing other means of internally measuring environmental performance). A recent survey of German companies indicated that almost two-thirds have conducted, or plan to conduct, an environmental audit. Other methods of measuring environmental performance (metrics) allow comparisons between companies, set measurable goals for improvements, and assess environmental im-

Appendix A

Activities in Europe and Japan

Europe

Corporate Policy and Business Implications
Appendix A

Impact on Common Market Trade

An underlying characteristic of the EU is harmonization or uniformity to avoid trade barriers—deliberate or de facto—resulting from activities in EU member countries. As with almost every issue in the European Union (EU), cultural, historical, socio-political and socio-economic factors vary across member countries and are part of the decision-making processes. Differences in environmental regulations could lead to de facto trade barriers. A number of EU countries consider the stringent environmental laws in Germany as a means of blocking exports from other EU countries into Germany—contrary to the mission of the European common market.

Differences in interpretations of environmental issues and the omnipresent concern over trade barriers have become a top issue for discussion among industrialists, economists, academicians, and governments. The advisor to the French Environment Minister, for instance, is leading a recently established think-tank composed of 15 members from academia, science, and industry. Its goal is to strategize new environmental regulations at national and international levels. “Environmental issues are very closely related to competitiveness,” he states, and points out that the EU’s effort to standardize packaging-waste regulations will expand to include electronic equipment.

On a even larger scale, environmental regulations were the subject of a February 17, 1994 meeting, sponsored by the United Nations. Ninety-four representatives from 17 nations met to discuss the need for common ground between trade and...
environment. Although no consensus was reached, most of the 17 agreed that the role of the Environmental Committee of GATT should be expanded. Such an expansion may be possible when the World Trade Organization (WTO) replaces GATT in 1995.

IC Packaging: In Europe, particularly in the Nordic countries, “green” electronics packaging and assembly often include the effort to replace lead-based solders with conductive adhesives and find the best alternative to CFCs for cleaning boards. In the past two years, several collaborative European studies have researched the viability of conductive adhesives and issues of debonding to facilitate recycling.

Norad, a joint Nordic project consisting of 22 Finish, Danish, Swedish, and Norwegian companies, is conducting a comprehensive study on the replacement of solders with adhesives for surface mount technology (SMT). Norad was set up to provide information deemed crucial for assessing the potential of adhesives in SMT. In this first known study of its kind, the Danish Toxicology Center is the Norad participant responsible for carrying out the majority of study on the environmental aspects of adhesives compared to lead-based solders. Study results, expected in late-1994, will contain: ecotoxicological and toxicological profiles on chemical components of several commercially available adhesives; an estimate of the volume of lead-based solders used in electronics production in Denmark; the potential for replacing these solders with adhesives, including advantages and disadvantages; and some life cycle assessment (LCA) of electronic-product manufacturing.

Based on the premise that lead must be phased out, the Fraunhofer Institute in Germany has conducted a study of conductive adhesive applications and has published results relating to debonding components that have been mounted with adhesives. Although the study shows that it is possible to debond these adhesives, performance requirements call for metal flakes containing lead as the conductive element in the adhesive. Future studies at the Fraunhofer Institute will look at the use of reducing the size of metal powders—down to a grain-size in the nanometer range—and the development of intrinsically conductive polymers. Another example of research into conductive adhesives is at the Helsinki University of Technology, the VTT (Technical Research Center of Finland), in the UK, and at IVF in Sweden.

Displays: Displays are as much an environmental problem in Europe as in the U.S., considering the number of television sets and computers sold per year and the challenges of CRT-glass recycling. Once again, a collaborative effort was undertaken to look at these challenges. Vision 2000, a Eureka project, was launched to resolve technical and infrastructural issues. Vision 2000 allows companies from across Europe to cooperatively establish an infrastructure that will help: 1) ensure a high quality of recycling, 2) support markets for recycled materials and products, 3) guarantee a system for equipment recovery and disassembly, and 4)

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Eureka is a pan-European umbrella for a wide variety of research and development.
set take-back prices. Several other Eureka projects dealing with the environmental impact of CRT manufacturing and disposition are: Eureka 1112 for CRT separation techniques; FLAIR for CRT recycling techniques; and the Green-TV project, the goal of which is to design a completely recyclable television.

Disposition: Of all the activities surrounding environmentally conscious electronics manufacturing in Europe, the disposition of used equipment is probably the most extensive. Companies, research institutes, and governments are working to establish an infrastructure for the major elements of electronics dispositioning: disassembly, material recovery, recycling, assessing markets for used/recycled equipment and components, technology development to support recycling, and information exchange and training. Such activities take place at the national level as well as through collaborative European efforts. Countries such as Germany, the UK, and The Netherlands already have a sector of private recycling companies and, in some cases, major electronics firms are establishing markets for secondary materials and equipment, disseminating information to facilitate recycling, and preparing future engineers.

The volume of electronic waste has raised concerns over the ability to handle the growing volume of equipment and provided business opportunities to recycling companies. The German BDE, a trade association for the private-waste industries states that electronic equipment recycling is the “wave of the future.” There are currently 18 electronic and electronic scrap recycling facilities among BDE members and another 31 are either planned or already under construction. In the UK, the Industry Council for Electronic Equipment Recycling (ICER), in response to a January 1991 request by the British Trade and Technology Minister, is devising a plan to recover and recycle used equipment in the UK. Once a plan is accepted, it is likely that legislation will follow that will encourage the entire industry to adhere to the scheme, and ICER will develop a center for recycling expertise to include such equipment as computers, telephones, and televisions. ICER members include: Digital Equipment Corp., IBM UK Labs, ICL, Northern Telecom Europe, Thorn EMI, and British Telecom.

On a much broader scale, approximately 42 companies, institutes, and governmental organizations are participating in Vision 2000. Vision 2000 goals include: 1) using an information system to promote the electronics-disposition process, and 2) creating design concepts, QA methods, and recertification standards and processes for recovered and recycled modules and components. The project has established three task forces to deal with economic, marketing, and logistical issues, the members of which include such companies and institutes as ICL (computer-systems manufacturer, UK), TME (Institute for Applied Environmental Economics, The Netherlands), the Technical University of Delft (The Netherlands), NEC, and Philips.

A successful and widespread recycling program requires the disclosure of information pertaining to the chemical and material composition of equipment
and components. A major effort in Vision 2000 is the development of recycling-support tools: an identification (ID) unit, disassembly techniques, and design tools. The proposed identification unit—a distributed and standardized information system in the form of a memory unit (green port) for each electronic product—will contain and register data necessary for re-use and recycling. Data contained in the identification units—such as product type, date of production, and the specification and location of hazardous materials—can be used to improve recycling operations and the recovery of modules and materials. Life-history data relating to the use of each product through its total life cycle will berecorded to enable the partial re-use of modules and components. The ID unit will also store life span data and may have an integrated sensor that measures overheating, emissions, extreme humidity, mechanical and electrical stress, overload and excessive voltage, as well as the number and duration of occasions when thresholds have been passed. The data, accessible via a standardized interface will be protected from tampering with appropriate memory media and such mechanisms as encryption.

Support tools, documentation, and mechanisms for exchanging and disseminating information are crucial for full-scale, efficient electronics dispositioning. Software plays an important role in design-for-disassembly, something that Siemens knows from experience. This company, already known for its environmental policies, has developed software to analyze the environmental impact of various electronic assembly processes which assists manufacturers in ensuring a desired level of recyclability. The company is also writing its Environment-Compatible Products guide for product development, which will reportedly cover every aspect of environmentally conscious manufacturing, recycling, and disposition. Philips is also preparing an Environmental Design Manual in which the chemical content of components and materials will be provided.

Not only will technologies such as the Green Port (Vision 2000 project) be crucial for disposition/recycling systems, but databases containing information on product compositions will also facilitate recycling and perhaps encourage the purchase and use of recycled materials. This infrastructure is helped by such efforts as IVF’s (the Swedish Institute for Production Engineering Research) definition of electronic products in terms of composition: printed-board assemblies (PBAs), metals in PBAs, plastics, ceramics including glass and metal oxides, CRTs, mercury, PCB, brominated flame-retardants, cadmium, lead, and possible areas for future problems (organic liquid crystals in LCDs, beryllium in copper alloys and microwave components, and optical materials such as gallium, arsenic, indium, and MCT (mercury/cadmium/telluride).

No two countries in western Europe approach the problem of electronic and electronics-related waste at the same pace or in the same manner. Germany and The Netherlands, for example, have already drafted legislation on electronics-waste avoidance; the German and British governments foster widespread efforts to create electronics-industry associations that address the need for recycling.
Appendix A

infrastructure; and France generally contends that market forces should drive waste reduction activities. Such disparities present a challenge to the goals of the European Common Market, and will likely force the European Union to streamline standards and regulations through EU-wide legislation.

The legislation proposed in Germany and The Netherlands share the same fundamental goal: to reduce the waste generated by electronic equipment primarily by designing for easier recycling and greater reuse of components and materials. The German legislation, the Elektronikschrottverordnung, was put forth by the German Ministry for the Environment to deal with the estimated 800,000 tons of electronic waste produced annually in Germany. Originally scheduled to go into effect by January 1, 1994, it is expected to be passed in 1995 once the dust settles after the fall 1994 German elections. The proposed law is far-reaching and strict, affecting manufacturers and retailers, including mail-order houses and targeting a broad range of equipment for take-back and recycling. It would apply to any company that manufactures, or puts its brand name on, electronic equipment in Germany, or that commercially introduces electronic equipment into the German market. “Electronic equipment” as defined by the proposal, includes: office equipment, such as personal computers and fax machines; televisions with screens larger than 30-cm; calculators; and medical equipment, among other items.

The law, as currently drafted, requires the following actions:

- Products must be manufactured from “environmentally compatible” and recyclable materials;
- Products must be designed and manufactured for easy disassembly and repair;
- Used-equipment collection centers must be easily accessible to the end-user (the consumer returning the product); and
- Parts deemed non-recyclable must be disposed of safely.

The scope of the proposed Dutch legislation is similar to its German counterpart, but functions more as a framework for subsequent legislation in electronic sectors. The Dutch environment ministry has categorized the electronics industry depending on the product use and size (such as washing machines and TV sets versus portable computers and phones), and will require draft legislation for the recovery and recycling of electronic equipment from each of these areas. The legislation will provide quantitative targets for product and materials reuse: 90% for such items as washing machines and dishwashers; 70% for televisions, video recorders, telephones and similar electronic equipment; and 95% reuse of metals and 30% of polymers in certain high-grade applications.

Industry groups in the European Union, particularly the UK and Germany, play an integral role in drafting the final legislation. The British ICER (Industry Council for Electronic Equipment Recycling) has responded to a January 1991 request by the British Trade and Technology Minister and is devising a plan to recover and
recycle used equipment in the UK. Once a plan is accepted, it is likely that legislation will follow that will encourage the entire industry to adhere to the scheme, and ICER will develop a center for recycling expertise to include such equipment as computers, telephones, and televisions.

In Germany, electronics-industry trade groups have an active voice in the process of drafting the Elektronikschrottverordnung. The German Ministry for the Environment and several working groups—such as VDMA/FG Bit (the German Business Machines and Information Technology Manufacturers’ Association) and ZVEI (the Central Association of the German Electric Industry)—are currently hammering out the details on criteria for safe disposal, recyclability, environmentally compatible materials. They are also planning a large-scale recycling system and developing methods for enforcing the law.

Strong DFE elements in Europe are life-cycle assessments (LCAs) and the development of support tools to determine the environmental impact of existing equipment and processes. For example, the three major divisions of Nokia Telecommunications have undertaken an analysis of products and processes, with the goal of emphasizing environmental efforts in the worst offending areas. Components under investigation are pulled from various products and analyzed, with a concentration on the manufacturing processes, raw materials, logistics, and packaging. Also, a Swedish model for Environmental Priority Strategy (EPS) is a tool for the impact assessment stage of an LCA. The LCA in the model is broken into four main parts: 1) define goals and scope, 2) analyze inventory, 3) classify impact assessment and evaluate characterization, and 4) assess improvements. The EPS takes data from the inventory and other databases (perhaps using data from the IVF component listing) and calculates an environmental load unit (ELU) for materials or processes. In Denmark, the Environmental Design of Industrial Products (EDIP), a joint project with five different Danish companies, is seeking to develop processes to profile and inventory products according to environmental impact.

Outside of the Nordic realm, where the need to minimize waste is strong, some German companies are designing environmentally friendly processes for manufacturing electronic subassemblies. In Siemens, for example, efforts began in 1988 to develop more environmentally sound materials for electrical products. Since then, Siemens has undertaken a guide for environment-compatible products, and has established specialists teams to create a standard for recycling products, to include rules for material preferences and marking. The company has also developed a halogen-free, flame-retardant printed circuit board (PCB) material that will increase PCB costs by approximately 1% at full-scale production.

Software tools exist to facilitate the analysis of the environmental impact of various electronic assembly manufacturing processes to ensure a desired level of recyclability. Two significant tools have been developed by Siemens and by EMPA (the Swiss Federal Laboratories for Material Testing and Research), whose software for LCA includes fuzzy logic.
A review of worldwide environmental activities must look at the context of drivers in Japan. Japanese companies are fiercely competitive and are responsive to consumer demands, and the relationship between the Ministry of International Trade and Industry (MITI) and Japanese industry creates a different situation for environmental activities than that in the U.S. or Europe. The following section on environmental activities in Japan is broken down by various company initiatives and includes brief discussions of displays and regulations to illustrate the relationship between Japanese companies, between industry and MITI, and between companies and the marketplace.

**NEC:** NEC’s philosophy that it is best for industry to independently set goals for environmental production drives the company’s initiatives in the environmental arena. Such initiatives include organizing workshops, assessing performance, and developing recycling technologies. NEC’s Eco-Management Committee, established in September 1993, has run five workshops, one of which, the Environmentally Friendly Product Composition Workshop, was designed to formulate concrete goals and strategies. Other workshops cover industrial-waste reduction and recycling, elimination of ozone destroying agents, distribution and product recovery, and energy efficiency.

For internal assessment of environmental performance, NEC established its Eco-Action Plan 21, which divides the company’s overseas plants into four geographical blocks. Each block is to conduct an environmental assessment once every two years. Plans also call for reducing the nitrogen oxide emissions generated by the company’s transportation fleet by 20% by fiscal 2000 from fiscal 1992 levels, and reducing industrial waste output by 30% by fiscal 1995 from 1990 levels. The Eco-Action Plan also sets goals for reducing the use of packaging plastics, increasing recycling, and reducing overall energy consumption.

The company has also developed recycling processes for materials and PWBs. In February 1993, NEC’s Resources and Environment Protection Research Laboratories developed a system for recycling liquid fluoride chemicals used as etchants in semiconductor production. The system removes metal particles from the solutions, lowering the metal content to less than 0.01 ppb (parts per billion). The system effectively removes copper from the solution by using electrode metal separation silicon; silicon particles covered with gold attract copper ions to the gold surface. The labs have discovered that the adsorption efficiency of silicon increases more than 100-fold when coated with gold. They claim that the system helps increase the life span of chemicals sevenfold—to more than one year. NEC intends to use the system in commercial semiconductor production one year from now.

NEC has also tackled PWB recycling by developing a technique to separate up to 97% of the copper from PWBs by shredding them into pieces or into a powder form and centrifuging the powder in a gaseous environment. The PWB waste material that is fed into this process for recycling is the residual portion of PWBs after the main portion is punched out for production. NEC has evaluated various
methods of shredding PWB waste for copper collection rate. The most effective method to separate copper from the rest of the plastic was a combination of slicing, shredding, and impulse force on PWB pieces. Since this method requires only physical energy and not chemicals, toxic gasses are not generated and a facility for neutralizing waste liquid is not required (see Figure A-1). Assuming a process capability of 135 kilograms/hour, NEC estimates that a dedicated facility of ¥71 million ($710,000 @ ¥100/$) would recover their initial investment within 3 to 4 years. However, this system does not take PWBs with chips, although the company plans to make a system that will handle them in the future.

![Figure A-1. NEC’s process for removing copper from PWBs.](image)

**Matsushita:** One of Matsushita’s strategies is to establish an infrastructure for environmental management. In April 1991, the company founded its Ecology Oriented Management (EOM) program, which it hopes to extend to external business partners and members of the Matsushita Electric group. Matsushita Electronic Components also plans to create a network database to promote the effective use of surplus materials and waste generated at its domestic and overseas production bases. The “scrap database” fits into the company’s overall strategy by assisting the EOM program with reductions in energy and natural resource usage and increased recycling. Both efforts support the stated opinion of Matsushita Electric Work’s “Green Strategy, Five Themes.” As President Toshiyo Miyoshi
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stated, “A corporation that is indifferent to environmental protection, resources, and the protection of nature will crumble away.”

**Fujitsu:** Fujitsu’s efforts have resulted in the development of non-CFC cleaning processes and environmental monitoring—both activities are seen to create a green corporate image. Fujitsu and Fujitsu Lab jointly developed a new non-CFC cleaning agent made of hydrocarbons, polar solvents, and acetic acid. The solvent reportedly has better dissolution power than trichloroethane for flux wastes produced during the soldering of semiconductor devices. It can also can be used to clean supercomputer CPU elements, a capability that other substitute solvents have lacked. Japan will discontinue trichloroethane production at the end of 1995, but the switch to substitute solvents has been behind schedule. This solvent may speed up the transfer from CFCs to alternatives. Initially, the new solvent was to be used in Fujitsu’s consumer electronic parts and computer production operations. However, responding to favorable user needs in June 1994, the company signed a contract with Nitto Chemical, which will sell this product under the name “Perclean.”

Beginning in October 1994, Fujitsu will implement its environmental monitoring system to forty of its primary domestic group companies, ahead of ISO’s planned Global Standard Monitoring System, which is scheduled for next year. Fujitsu hopes to improve its corporate image by establishing environmental protection policies featuring unified measures. A total of seventy items are addressed in the program, including protecting the ozone layer, recycling, and industrial waste management. Environmental management departments at group companies will handle implementation, and Fujitsu’s Environmental Technology Promotion Center will provide support.

**Toshiba:** A year prior to Fujitsu’s breakthrough, Toshiba, along with other companies, developed a vapor-phase cleaning agent, Techno Care™, as a substitute for CFC-113 and chlorine-based cleaning agents. The main features of the Techno Care™ series are reduced cleaning and drying time and a no-water cleaning process, thus eliminating the need for a wastewater treatment facility.

In addition to research on CFC alternatives, Toshiba has developed detoxification technologies for chlorinated organic compounds, such as chlorofluorocarbons and trichloroethylene. Toshiba’s research group used ultraviolet light irradiation to decompose chlorofluorocarbons concentrated in alcohol. The results showed that decomposition to harmless salts (NaCl, NaF) occurred within a few minutes. A solid-acidic catalysis method under a wet atmosphere was also studied to decompose trichloroethylene at relatively low temperatures. It was found to decompose completely at 600°C. These technologies reduce costs and are safer than conventional incineration methods. Toshiba is now designing a test apparatus to enable the practical introduction of these technologies within a few years.

**Displays**

Displays provide an interesting insight into the effort expended by the Japanese to address environmental concerns. Display manufacturers have successfully
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reduced energy consumption and materials use (as the product size decreases) while increasing battery lifetime. The incentive for increasing display panel efficiency comes primarily, if not totally, from consumer demands for longer lasting, higher quality displays.

NEC provides a brief, but instructive, case study. They have made steady progress in panel power efficiency through significant reductions in power requirements for backlighting units and driver ICs, and through improvements in aperture ratios, which determine the panel brightness. Between 1992 and 1993, the total power dissipation of the company’s 9.4-inch color thin-film transistor liquid crystal displays (TFT-LCDs) went from 6.1 W to 3.6 W; the backlight unit consumption almost halved, from 5 W to 2.6 W; and the IC power consumption dropped 0.1 W to 1 W. The aperture ratio played an important role in the reduction in backlight-unit power consumption. Because the aperture ratio and panel brightness are directly related, an increase in the light transmittance and in the aperture ratio lowered the backlighting enough to provide sufficient brightness. As a result, the overall power consumption can be substantially reduced.

NEC’s next goal, set for sometime in 1995, is to reduce total power consumption to 2.0W—1.3 W for the backlight unit and 0.7 W for the driver ICs. In order to achieve this, certain technical requirements must be met. The IC threshold voltage must drop by 30% and the power source must be optimized to result in a 0.45-W power consumption in the LCD driving block. NEC plans to implement 3.3-V devices for the logic block, which would consume about 0.25 W, resulting in a total power consumption 0.7 W.

In spite of increasing efficiencies, the issue of display-related waste remains. MITI stated in its Environmental Vision for Industries, published 6/27/94, that 25,000 tons of raw material is used for computer displays in Japan every year. This document also states that production of CRTs for personal computers totals 1.51 million units, and for LCDs, 1.59 million units. Currently all disposed CRTs go to a landfill.

The primary regulatory avenues in Japan are the Recycling Law and strong encouragement from MITI to conserve energy. The Recycling Law has added PCs, word processors, camcorders, cordless phones, cellular phones, and others to the existing list that includes automobiles, refrigerators, washers, unit air conditioners, and televisions.

The Japanese government has also developed strong incentives in its tax system to encourage environmental consciousness:

- Waste recycling facility taxation measure.
  - Application of special depreciation system (2-year extension)
  - Reduction of fixed property tax (2-year extension)

Regulations and MITI
Appendix A

- Pollution prevention facility taxation measure.
  - Application of special depreciation system (2-year extension)
  - Tax exempt of fixed property tax (2-year extension)
  - Reduction of fixed property tax (2-year extension)

The omnipresent MITI is trying to encourage corporations to invest in energy, labor-saving, and environmentally friendly equipment by increasing the tax credit from 7% to 10% this fall; an extra ¥1 trillion investment from private sectors is expected, totaling ¥100 billion. MITI’s Agency for Natural Resources and Energy will introduce new standards on conserving energy in fluorescent lights, TVs, and copy machines. The standards are designed to reduce the power consumption of fluorescent lights by a maximum of 7.1%, TVs by a maximum of 25%, and copy machines by an average of 3.0%. MITI estimates that the energy conservation efforts will conserve about 3.7 billion kW/hour, which is equal to 900,000 kiloliters of crude oil by 2000. This new call for standards is one of a succession of regulations.

MITI is also approaching the environment in a more hands-on manner with its sponsorship of a major study of the “Ecofactory.” This Ecofactory will employ “ecologically harmonized” process technology for production and recycling. The teams conducting the study includes researchers and engineers from private-sector Japanese manufacturing firms, research institutes, and MITI’s own laboratories.

As defined by the Mechanical Engineering Laboratory, the Ecofactory is a manufacturing/recycling infrastructure that maximizes productivity, performance, and economy, and minimizes the global ecological impacts of such factors as ozone depletion/global warming gas emission, energy consumption, and the generation of pollution. The Ecofactory places emphasis not only on energy-efficient manufacturing, but also on the structural design of products so that disassembly, material separation, and recycling processes are less costly.

Fundamentally, the Ecofactory is a closed-loop system. It resembles a traditional facility for product design and production of goods. However, it includes capabilities for used-product disassembly, recycling, and the generation of materials useful in the fabrication of new products. Manufacturers accept used products from customers, examine them for design and material characteristics, and then tag them for disassembly, recycling, or disposal. Products that are to be reused or recycled are broken down into their components. Depending on the outcome of an inspection of these components, they may be reused directly in other products, or be recycled for use in lower-quality products.

The Ecofactory aims to avoid pollution generation throughout the manufacturing process. In order to achieve this goal, the Ecofactory must incorporate environmental considerations in each of a plant’s four main areas of operation:

- Product design,
- Manufacturing,
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- Disassembly, and
- Separation and recycling.

It is important to understand the status of activities in leading electronics companies and in countries that play a major role in defining aspects of environmental behavior. Such information facilitates benchmarking, competitive analyses, marketing forecasts, and other tools that are indispensable in today’s business arena. Any analysis or information delivery is more valuable when provided in an accurate cultural, governmental, and social context. Without such a context, the information can be misleading and the analysis faulty.

MCC is expanding its information gathering to include Korea, Taiwan, and the Pacific Rim countries (PRC). It is realized that worldwide analysis of environmental activities must not be conducted without consideration of regions with a large manufacturing base, such as Singapore, Malaysia, and Thailand. Therefore, when possible, MCC will collect information on environmental standards and regulations of particular countries, as well as companies operating in those countries.

MCC’s International Liaison Office (ILO) tracks developments in foreign technology, policy, and company strategies. This organization has, and will continue to, provide much of the information needed for worldwide analysis. The summary provided in this Appendix was gathered by the ILO from visits to and from European and Japanese companies, literature searches, and long-distance conversations. This appendix was designed to provide an overview of environmental activities, rather than an exhaustive review. For more information, please contact Colleen Wilson at Tel/Fax (512) 338-3391/3898 or email: cwilson@mcc.com.

Conclusion
The following is a description of current flat panel display development projects underway at the National Laboratories, compiled by Sandia National Laboratories (SNL):

**Project Evaluation and Optimum Selection Methodology for the SNL/New Mexico Pollution Prevention Program.** The Project Evaluation and Optimum Selection Methodology for the SNL/NM Pollution Prevention Program is a consistent method for evaluating, scoring, and prioritizing waste minimization proposals, based on a cost/risk/benefit analysis. The methodology has three distinct parts. First, a hierarchy of evaluation criteria is developed and relative weights are assigned to these criteria using expert opinion quantified with the assistance of the Analytic Hierarchy Process. Second, the results of a given Pollution Prevention Opportunity Assessment are collected and evaluated using scoring schemes in conjunction with the weighted criteria. Third, the optimal set of waste minimization proposals to be funded with a fixed budget are selected using a Zero-One Linear Program. The methodology is currently available and is partially computerized.

**Evaluation and Qualification of Environmentally Conscious Soldering Processes for Commercial and Military Applications.** Traditional soldering processes for electronic products use rosin flux to remove oxides and other contaminants from the surfaces to be joined—this process enhances solderability. However, if the flux is not removed after soldering, it can attract moisture and lead to corrosion and possible failure. Rosin flux residue is typically removed with solvents that contain ozone-depleting chemicals (ODCs), mainly CFCs. Low-residue (no-clean) soldering technology uses alternative flux materials that do not require post-solder solvent cleaning. Work has been completed to determine a low-residue technology capable of producing reliable hardware comparable to the traditional rosin flux/solvent cleaning process hardware. Elimination of solvent cleaning not only minimizes waste emissions but also significantly reduces energy use; process turnaround time; and the costs associated with cleaning equipment purchase, operation, maintenance and solvent purchase, storage, and handling. Success of the project resulted in the formation of a 19-member Low-Residue Soldering Task Force, established and coordinated by Sandia, to evaluate and qualify the technology for military and commercial use and to transfer the technology to industry. Sandia is also involved in an internal effort to couple low-residue technology with lead-free solders and to evaluate the reliability of hardware manufactured with the combined technologies. In addition, the National Labs have partnered with industry to establish the feasibility of, implement, characterize, and optimize low-residue technology for specific manufacturing applications.

**Solvent Reduction Through the Use of Fluxless and No-Clean Solder Processes.** No- and some-clean soldering fluxes need to be more fully characterized to ensure long-term functional reliability for electrical and electronic products. Considerable effort has been expended by industry to develop “no-clean” residual soldering flux materials and processes, primarily for economic considerations.
Similarly, considerable chemical, environmental, and electrical/electronic testing and evaluations have been performed to qualify the materials and processes. However, the major emphasis on these activities has been for printed board assembly applications, and very little data has been reported for the next levels of electronic packaging, such as sub-assemblies, equipment, and small systems. The use of no- or some-clean soldering fluxes needs to be characterized to establish the reliability of electrical/electronic products for higher levels of assembly. The goals for this project are to evaluate the use of no- and some-clean solder fluxes in electrical/electronic products in order to minimize or eliminate the need for removing residual solder fluxes using volatile organic compounds or semi-aqueous cleaners, and to meet the electrical/ electronic product’s functional requirements.

**Exhaust Stack and Process Gas Emission.** The purpose of this ISRD-funded research is the demonstration and development of planar thin-film micro-electro-chemical sensors for gas sensing applications. The sensors are comprised of solid electrolytes layers that transport certain ions \(X = B1\) selectively and are coupled to metal/metal -(X) reference electrodes and catalytic measuring electrodes. Catalytic measurement electrodes enable the sensing of a variety of gaseous species such as: oxygen, chlorine, fluorine, hydrocarbons, sulfur dioxides, nitric oxides, and carbon monoxide. The sensors may be designed to operate in either a potentiometric broad range logarithmic output mode, or an amperometric linear output mode.

This class of devices generally operate at elevated temperature, therefore thick-film platinum strip heaters may be incorporated into the sensor design. Thin-film deposition techniques, such as electron-beam and sputter deposition, are used to synthesize the other device layers. The project has lead to further co-development of internal combustion engine exhaust manifold sensors with the U.S. car industry.

**Polymer Filtration for Recycling Metals in Process Waste Streams.** Polymer filtration (PF) is a new technology for metal-ion recovery. It uses water-soluble polymers that selectively bind metal ions. The polymer-metal association is filtered and concentrated using off-the-shelf ultrafiltration equipment. Metal is recycled to process or sent off-site for recovery. Metal use is thus reduced because it is returned to the process. Water discharge meets all regulatory requirements and available technology can be used to recycle water. Commercial demonstration of polymer filtration has been successful.

**The Virtual Factory: Computer Simulations in Support of Environmentally Conscious Manufacturing.** The Virtual Factory is a computer program developed jointly by a National Lab and an industry partner to simulate the operation of the integrated circuit manufacturing facility. Engineers use simulations to explore the interactions linking the various stages of manufacture in order to:

- Predict the effects of changing the operation of any stage,
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- Evaluate the economic and environmental impact of new technologies without the need to physically alter the structure of the manufacturing plant,

- Identify opportunities to reduce chemical use,

- Reduce the consumption of critical resources such as water,

- Assure that components can be manufactured in an environmentally conscious manner, and

- Focus research and development efforts on particular operations or processes.

The “virtual factory” created by the computer simulation will allow the factory to operate its integrated circuit plant in a more environmentally benign and economically competitive manner. By exploring various options and alternatives, plant managers will be able to reduce not only the amount of chemicals and solvents, but also the amount of water used in manufacturing. Because of reductions in the amount of waste that must be treated, the factory will have reduced operational costs.

Alternatives for Hazardous Solvents used in Cleaning. More than 70 alternative cleaners have been studied as potential replacements for CFCs, halogenated hydrocarbons (e.g., trichloroethylene and trichloroethane), hydrocarbons (e.g., toluene and Stoddard Solvent), and volatile organic compounds (e.g., acetone and alcohol). Tests were performed using more than 45 proprietary formulations on bench scale testing equipment and in more than 60 actual shops and laboratories. Cleaning applications included electronics fabrication, machine shops, optical lenses and hardware, and general cleaning.

Both qualitative and quantitative cleanliness tests were performed for selected applications using the following techniques to measure the amount of impurities remaining on the cleaned surface: 1) optical scanning, 2) ionography, 3) X-ray fluorescence, 4) Fourier transform infrared (FTIR) spectrometry, and 5) gas chromatography/mass spectrometry (GC/MS). Other techniques have been used elsewhere to determine surface cleanliness. For example, Los Alamos National Laboratory has used ellipsometry. Oak Ridge National Laboratory used electron spectroscopy chemical analysis (ESCA), and Allied-Signal, Kansas City Division used measurement and evaluation of surfaces by evaporative rate analysis (MESERAN). Battelle developed measurement with stable (non-radioactive) isotopes for the Aerospace Guidance and Metrology Center.

The scope of work also contains a brief discussion of some techniques that have been used to examine the materials’ compatibility and the long-term effects of using alternative cleaners. This project was completed and a formal report was released in January, 1994.

Non-Halogenated Cleaners. A major program was established to identify and qualify alternates to chlorinated solvents for cleaning. A variety of cleaners have
been examined to replace the chlorinated cleaners used in electronics manufacture. Cleaners that were examined fall into the categories of aqueous, semi-aqueous, and solvent-based. Initial screening of the cleaners was performed using cleaning efficacy on copper, solder, aluminum, polyimide, and stainless steel with a variety of soils. The soils included rosin-based fluxes, mold releases, hand creams, common resins such as epoxies and acrylics, and other materials frequently present in electronics manufacturing operations. Selected cleaners were evaluated for compatibility with a variety of metals, inks, and polymeric materials to insure that no detrimental effects were introduced through the use of the substitute cleaners. An extensive evaluation was also performed on the cleaning of metal piece parts using aqueous cleaners. Other cleaning processes examined include super-critical carbon dioxide and carbon dioxide snow. Sandia’s cleaning program is an ongoing activity that is exploring the processes required to maintain cleaning technology that is up to date.

**Aqueous Dry Film Developer.** In mid-1993, Sandia decided to make a change in their dry film image department from using semi-aqueous dry film and developer to full-aqueous dry film and developer. The change was virtually painless. The motivation for making the change was to reduce the hazards related to working with and disposing the developer used to develop the dry film. The semi-aqueous developing solutions were a mixture of sodium hydroxide and 2-butoxyethonal. Due to the solvent in the solution, Sandia was required to have an air quality permit which required keeping usage records with annual quantity limits. The presence of 2-butoxyethonal in the solution also added to the waste disposal requirements. By changing the full-aqueous dry film and developing solution, Sandia eliminated the need for an air quality permit and the record-keeping associated with the permit. The full-aqueous developing solution is 1% sodium carbonate and water. Sandia now sends the spent developer solution to their retention tank system. This system is treated when it is full by an off-site transportable treatment unit. The cost of the solution is lower and the cost of disposal has been eliminated. An unexpected bonus from using the full-aqueous film was that their fine-line capabilities improved from 5 mil lines and spaces to 2 mil capabilities. Overall, the change has been a positive move. It is more cost-efficient, has improved the quality of Sandia’s work, and is an environmental plus for the Lab and the operators working with the materials. This project was completed early in 1994.

**Aqueous Dry Developing.** In 1990, Sandia changed over from solvent processing of photoresists to a full aqueous process using various commercial dry film resists. They have characterized several commercial products and have now chosen a DuPont resist (9000 series) for their major photoresist. The developing solution for this photoresist is a 1% sodium bicarbonate solution which is pH adjusted to 11 with sodium hydroxide. The control system on the developer maintains the pH at 11 by the addition of NaOH. The level of the solution is maintained by the automatic addition of water. This system has been improved and can now routinely produce a 5-mil pitch product with high yield and uniformity on 18-inch x 24-inch substrates. This system is also used to develop
solder mask by slowing the belt speed down. No adverse affects have been noted in over a year of dual use. Solutions are changed out on a weekly basis or more often as product requirements dictate.

Non-Cyanide Electroplating Solutions. The metals that are commonly plated from cyanide chemistries include copper, gold, silver, and cadmium. Increased environmental safety and health awareness has promoted government legislation which could severely limit, if not totally curtail, the use of cyanide throughout industry because of its acutely hazardous nature. Presently, dealing with cyanide’s hazardous waste is very costly to the electroplating industry. Many local governments are imposing zero cyanide discharge limits to sewage systems. Considerable effort is being expended by many companies to find and qualify suitable substitutes for the cyanide solutions. Sandia has evaluated a number of commercially available non-cyanide plating solutions used for gold, copper, and silver plating. Work was done to replace the standard cyanide solutions in many industrial type applications which include protective coatings and fine line patterns for microelectronics.

High-Reliability Circuit Assembly Using Low Solids Flux and Plasma Cleaning. Prototype circuit assembly for high-reliability applications, such as weapons, medical, and space electronics, generally use large amounts of flux during soldering. Most applications currently remove this flux using solvent defluxing. The solvents, often ozone-depleting chemicals that will not be manufactured after December 1995, are expensive to dispose of after processing. Hence, a number of environmentally responsible alternatives for high-reliability circuit assembly are needed in a short period of time—this process represents one such assembly alternative. This project offers an electronic assembly method that still uses rosin-based flux as a wetting agent for soldering, but the clean-up involves all dry processes, thus reducing the solvent waste stream. The new process uses commercially available low solids flux for solder assembly followed by plasma removal of the small amounts of post-solder residue (<1 micron thick) to ensure long-term storage reliability and good adhesion of the protective encapsulating compounds applied to many electronic circuits after assembly. In addition, this process uses traditional solder resins, thus making it applicable to repair work on systems previously made using standard flux assembly processes, such as the nuclear weapon stockpile, without changing current specifications. Laboratory results have shown that tinned circuits (no components attached) are cleaned to within two monolayers of the surface by this method in less than eight minutes using a sequential, in situ application of oxygen-90%/tetrafluormethane-10% plasma followed by an argon plasma.

Lead-Free Solder Development Capabilities at the Center for Solder Science and Technology. A wide variety of equipment is available for lead-free solder research in the laboratories associated with the Center for Solder Science and Technology. Some of the major research capabilities are described below:
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- The Solder Center’s Wettability Assessment Laboratory has the capability of evaluating the wetting behavior of solder alloys on a variety of base surfaces. Wetting balance, meniscometer, surface tensiometer, viscometer, area-of-spread, and capillary flow apparatus are available to study the effects of processing and materials on solder wetting properties.

- The Solder Center is involved in the development of various laser soldering processes. A recent effort involves fluxless soldering under a protective inert gas atmosphere. This system uses a dedicated 100-W CW Nd:YAG laser for soldering applications.

- A Solder Analytical System is designed to define solder wetting with respect to the variables encountered in soldering: solder compositions and effects of impurities, the gaseous environment and the substrate, its cleanliness, its roughness, and chemical activity with the solder. Data will be taken via photography and digitized for analysis of wetting characteristics.

- To permit the realization of fine-pitch technology, the particle size of solder powders must be significantly reduced. Much finer powders can be made by a new solder powder production approach: high pressure gas atomization (HPGA). This technique has been developed in an existing lead-free, high-temperature solder paste development project supported by the U.S. Department of Energy. The HPGA technique appears well suited to the processing of fine powders of lead-based and lead-free solders, so this atomization process should be highly efficient in the production of low-temperature, lead-free solders in fine powder form because of the similarity of melting temperature, surface tension, and melt viscosity.