Innovative Environmental Technologies in Automotive Painting: The Role of Suppliers

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Submitted to the Department of Civil and Environmental Engineering
in Partial Fulfillment of the Requirements for the Degree of

Doctor of Philosophy

in Technology Management and Policy
at the
Massachusetts Institute of Technology

June 1997

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Abstract

This dissertation examines the role of suppliers in developing and implementing innovations in automotive paints and coatings materials that make a difference in the environmental performance of automotive assembly plants. The research concentrates on innovations in cleaner technologies in automotive manufacturing, including material substitution, waste minimization, and closed loop systems and recycling. The role of suppliers in developing new environmentally beneficial materials for use in automotive painting is explored through a semi-structured survey of major U.S. automotive paint manufacturers and their primary customers, and an analysis of U.S. patents filed since 1955. The adoption of new materials and processes in automotive painting is evaluated through a set of four case studies, in two different large automotive companies, which focus on the challenges of introducing new materials with environmental benefits into technologically complex manufacturing systems. The environmental performance of these facilities is compared to determine the influence of the new materials on the overall emissions of the manufacturing plants.

The results of this research demonstrate the importance of suppliers in developing and implementing innovative environmental technologies. Achieving improved environmental performance through changes in materials in complex technological systems involves a number of different companies that must ultimately cooperate and share product and process expertise. New technologies must have the support of corporate and plant management to succeed. An integrated technology and management perspective is crucial in identifying and successfully implementing improvements in environmental performance that are sustainable over the long term. The most significant improvements are achieved when new, innovative technology and management priorities at the plant level are coupled with supplier expertise. This framework of integrating technological advances with innovative management approaches and strong partnerships with key suppliers leads to new thinking on how companies and governmental agencies should structure future environmental policies.

Thesis Supervisor: Professor Joel P. Clark
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Acknowledgements

While a doctoral dissertation is an independent and often lonely endeavor, there are a number of faculty and students at MIT, as well as others outside of the Institute who have helped me maintain my enthusiasm for research and my love of learning throughout this journey. First, my thanks to Professor David Marks for his continued support through all stages of this process and to Professor Joel Clark, a man of integrity without whom this work would not have been possible. Thanks also to Professor Jacqueline Isaacs, who was instrumental in establishing the research project under which the site visits were conducted and to Professor Isaacs and Dr. Richard Tabors, for the many hours spent helping me refine the presentation of my ideas and being willing to discuss any and all problems and questions that arose throughout this research. Their advice and encouragement has been invaluable and is much appreciated. To Dr. Elisabeth Drake, who served as a mentor and role model, thanks for your continuous encouragement and for providing me with precious workspace at MIT.

Thanks also to my many colleagues at MIT, without whom this research could not have progressed. Though there are too many to name specifically here, I would like to thank, in particular, Sandra Rothenberg for sharing the insights gained through her research and for introducing me to the IMVP. Without you, Sandy, this work would not have been as enjoyable or productive. Thanks also to Judy Cardell for her guidance in navigating the waters of the evolving TMP program and Renata Pomponi for her partnership in integrating technology management and innovation theory with an engineering-based curriculum.

This work would not have been possible without the many industrial contacts who willingly contributed their valuable time and insights to helping me conduct this research, or the financial support of the Battelle Memorial Institute and the Department of Energy. I would like to thank all of these people and organizations for their critical roles in this effort. I also want to thank my mentors outside of MIT. In particular, thanks to the late Dr. William R. Wiley, for believing in me and encouraging me to excel, for his commitment to education and for selecting me for this wonderful opportunity, and to Dr. Gerald M. Stokes, always willing to engage in intellectual discussions when I needed to refine my thoughts and arguments.

Finally, my gratitude and appreciation to my family, without whom this journey would not have been undertaken nor completed. To my father, who has always believed that education is the most important gift a person can receive and who instilled in me the value of continuous learning. My father has always encouraged me to reach for the stars, to go beyond my limits and set new standards of excellence in my life. And to my mother, always ready to catch me when I fell and remind me how far I had already climbed. Thanks also to my sons, who helped me maintain my perspective throughout this effort and put up with many nights and weekends of "Mommy's too busy to play right now....." Last, but not least, to my husband, who gave up his own opportunities to join me in this adventure and with his patient, uncomplaining devotion helped hold the family together through the roughest parts of this journey. Bob always loved a roller coaster.....

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Chapter 1. Introduction

Environmental management approaches in industry have been evolving since the 1960s.[a] In many instances, solutions to environmental problems consist of adding end-of-pipe technologies to production processes rather than preventing pollution at the source. Increasing costs of compliance and pressures on industry from investors, environmental interest groups and local communities have shifted industry attention to the challenges of pollution prevention and innovative environmental design. This research focuses on fundamental changes in the production process and materials used in automotive painting. Automotive painting is the primary source of environmental pollution in automotive manufacturing, generating millions of tons of toxic air emissions annually. Air pollution control costs for General Motors (GM) alone in 1992 were over 93 million dollars.[1] New approaches in product and process design are emerging that reduce the volume of materials required, increase recycling opportunities and result in "cleaner" technology options.[b] While there are still gains to be made in reducing wastes and improving processes from existing technology, many more advances will come from innovative technologies and processes.[2] The themes of an integrated systems perspective and the need for technological innovation are strengthened in a report from the Office of Science and Technology Policy that maintains innovative technologies are the key to achieving a sustainable future.[3]

The concept of "Design for Environment" is receiving much attention today among policymakers, researchers and environmental professionals. Theoretical constructs, such as industrial ecology, and analytical tools, such as life cycle analysis, are developing to enable the

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[a] See Colby's evolution, for instance, from "classic production economics" to "eco-development", in M. Colby, "Environmental Management in Development: The Evolution of Paradigms", World Bank Discussion Paper 80. The World Bank, Washington, D.C., 1990.

[b] A growing number of references document the actions that various companies and industries are taking to move ahead of the compliance curve in environmental issues. Some of these include: S. Schmidheiny, Changing Course, MIT Press, Cambridge, MA, 1992.; B. Allenby and D. Richards, ed., The Greening of Industrial Ecosystems, National Academy Press, Washington, D.C, 1994.; K. Fischer and J. Schot, ed., Environmental Strategies for Industry, Island Press, Washington, D.C, 1993.; and D. Smith, ed., Business and the Environment: Implications of the New Environmentalism, St. Martin's Press, NY, 1993.

application of these new ideas. Industrial ecology[a] (as a philosophy) focuses on understanding the systems nature of environmental problems, tracing the flow of materials and energy through the life cycle of a product. Highlighting the primary uses of nonrenewable or hazardous materials allows designers to begin thinking about ways to reduce or change material or energy requirements, and recycle materials and wastes. Material substitution in the design and manufacturing stages of a product is one of the more important mechanisms for reducing environmental impact.[4]

The extent to which these new approaches are actually being applied in industry, however, is not clear. Incorporating new materials into product designs is a major challenge. Large investments in research and development are required to successfully formulate new materials that meet the performance requirements of the old at a price that the end-users are willing to pay. Integrating these new materials into a complex technological system often requires modifications to existing production equipment, operating procedures, and supply chains. Integrated solutions to environmental problems that reflect the tenets of industrial ecology must consider complex manufacturing systems that extend across traditional company boundaries.

This dissertation examines the development and application of cleaner technologies in automotive manufacturing, specifically the painting process. There are two primary questions that must be addressed in exploring this area. The first relates to the development of the new materials or technologies. What are the incentives driving these investments and which companies have the technical competencies and market drivers to respond? Much of the research to date in understanding the shift from environmental compliance to pollution prevention and industrial ecology concepts is focused on the change process **within** a company.[5] Yet, in many cases, the upstream supplier may have more experience and knowledge in

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[a] Industrial ecology concepts borrow from the science of ecology of natural systems. Under this philosophy, the production process is reframed from a single-cycle, once-through approach to one of closed loops to reduce or eliminate waste, and reformulation of products and processes to reduce material and energy input needs. The most extensive version of the concept incorporates the idea of a network of industrial firms, where the waste products of one are the input materials for another.

environmental issues, and be better positioned to develop innovative materials, technologies, or even management approaches to help their customers achieve their environmental goals.

A major gap in understanding exists relative to the role of suppliers as initiators of innovative technological solutions to environmental problems. Manufacturers may have difficulty identifying fundamental changes to input materials or major technological innovations that provide environmental benefits. In the case where environmental improvements involve new technologies and materials and the primary technical expertise resides outside the manufacturing company, suppliers can be a major source of innovation.[6] The role of suppliers in developing new materials is explored through a survey of major U.S. automotive paint manufacturers and their primary customers and an analysis of U.S. patents filed since 1955. Understanding the importance of suppliers in developing and applying new environmental technologies can lead to novel approaches for improving the environmental performance of manufacturing facilities.

The second question relates to the implementation of new materials or technologies in manufacturing operations. Since there are a number of alternatives for meeting environmental requirements, a company may adopt a new material that requires product redesign, invest in more pollution control equipment, or move production operations outside the U.S. to avoid increasingly stringent environmental regulations. How are these decisions made, and what effect do they have on the environmental performance of the manufacturing plant? A limited set of studies to date have explored the importance of suppliers, customers and others in achieving environmental goals.[7] These have focused on meeting manufacturer-developed goals for items such as reductions in packaging waste, primarily through contractual specifications and education. This research explores the potential for dramatically improving the environmental performance of manufacturing facilities through innovation in materials and products driven by a partnership between manufacturer and supplier. The adoption of new materials and processes in automotive painting is explored through a set of four case studies, in two different large automotive companies. Each of the four automotive assembly plants has taken a slightly different approach to improving environmental performance.

Achieving improved environmental performance in technological systems that depend upon the talents and products of a number of different companies requires sharing of technical information and expertise. Mutual goals and supportive incentive systems are needed to make changes in technological systems that transcend individual company boundaries. In addition to technological changes, effective solutions must evaluate the economic incentives, organizational challenges and competitive implications for companies who need to work together in new ways.

This research illuminates the critical strategic factors and incentives that drive environmentally-related innovation among suppliers and manufacturers. The development of cleaner products demands attention to both materials and manufacturing processes. Reducing environmental impact through redefining the source materials used in products requires the development of new materials along the technology supply chain and the acceptance and use of those materials by manufacturers. Tracing the evolution of technology in automotive paints and coatings highlights important parameters necessary for the development of these innovative technologies. Implementing the changes in product design and manufacturing systems requires an understanding of the factors important to the acceptance and use of these technologies by automakers. Achieving environmental improvements through changes in materials involves a number of organizations, often from different companies, that must ultimately cooperate and share product and process expertise. An important contribution of this research is a framework for the design of more effective technological change programs across company boundaries.

Automotive painting has been chosen as the subject of this research for a number of reasons. First, there are strong environmental and competitive pressures on both the chemical and automotive industries in the U.S. Second, there is a dramatic amount of innovation and experimentation ongoing with automotive paint and coating materials and related technologies. The rate of change in these technologies provides a good basis for exploration of the important questions. Third, the ability to clearly identify the major suppliers and customers in automotive painting allows in-depth investigation of the dynamics in the relationships among suppliers and manufacturers, which are showing evidence of change.[8] At the same time, environmental issues are becoming more important to the competitive strategies and long term success of many companies. Illuminating the role of environmental factors in the ongoing change process and determining the influence of suppliers on the environmental practices of manufacturers has important competitive implications for these industries. Determining the strategic factors that encourage innovation in environmental technologies is also critical to providing more effective implementation tools to facilitate moving toward the system perspectives and goals of industrial ecology.

This dissertation is structured around the two primary research questions mentioned above. Chapter 2 provides a detailed description of the research problem and objectives to be pursued in this dissertation, and background material on automotive painting technology and related environmental regulations. Chapter 3 traces the sources of innovation in automotive painting and the incentives for adopting new paint technologies. Chapter 4 focuses on four in-depth case studies of automotive assembly plants, exploring the incentives for adopting new paint technologies at the assembly plant level and highlighting the challenges of introducing new materials with environmental benefits into technologically complex manufacturing systems. The environmental performance of these facilities is compared to determine the influence of the new materials on the overall emissions of the manufacturing plants. Chapter 5 consolidates the research results to examine the critical factors in decisions to develop and implement innovative environmental technologies and materials in automotive product design and painting operations. The tradeoffs considered in making these decisions and the impact of alternative strategies taken by different plants to improve their environmental performance are analyzed. The role of automotive paint suppliers in achieving environmental improvements in manufacturing facilities is highlighted. This research points to the importance of broader system perspectives in technological changes for environmental progress. The development of environmentally superior materials and technologies must be conducted with an awareness of the factors influencing changes throughout the supply chain, and of the complementary technologies that are needed to implement new technologies in production operations.

[1] General Motors Corporation, General Motors Environmental Report, Detroit, MI, 1994.

[2] U.S. Congress, Office of Technology Assessment (OTA), Industry, Technology and the Environment, OTA-ISC-586, U.S. Government Printing Office, Washington, D.C., 1994.

[3] Office of Science and Technology Policy (OSTP), Technology for a Sustainable Future, Washington, D.C., 1994.

[4] T. Graedel and B. Allenby, Industrial Ecology, Prentice-Hall, Englewood Cliffs, NJ, 1995.; B. Allenby and D. Richards, ed., The Greening of Industrial Ecosystems National Academy Press, Washington, D.C., 1994.; and J. Ehrenfeld, "Industrial Ecology: A Strategic Framework for Product Policy and Other Sustainable Practices", prepared for Green Goods: The Second International Conference and Workshop on Product Oriented Policy Stockholm, Sweden, September 1994.

[5] S. Schmidheiny, Changing Course, The MIT Press, Cambridge, MA, 1992.; P. Winsemius and U. Guntram, "Responding to the Environmental Challenge", Business Horizons (March-April 1992): 12-20; P. Shrivastava, "Corporate Self-Greenewal: Strategic Responses to Environmentalism", Business Strategy and the Environment 1, no. 3 (Autumn 1992): 9-21; J. Elkington, "Towards the Sustainable Corporation: Win-Win-Win Business Strategies for Sustainable Development", California Management Review, Winter 1994: 90-100; and J. Ehrenfeld and A. Hoffman, "Becoming a 'Green' Company: Cultural Change and the Greening Process", MIT Working Paper, presented at the Greening of Industry Conference Boston, MA, November 1993.

[6] E. Von Hippel, The Sources of Innovation Oxford University Press, New York, NY, 1988.

[7] Schmidheiny, 1992 and J. Makower, Beyond the Bottom Line: Putting Social Responsibility to Work for Your Business and the World Tilden Press, New York, NY, 1994.

[8] S. Helper, "How Much Has Really Changed Between U.S. Automakers and Their Suppliers?", Sloan Management Review, Summer 1991: 15-28.

Chapter 2. Research Objective and Background

This chapter provides the context for the research problem and background information on automotive painting technology. Emerging views in environmental management and the theoretical foundation of technology management and innovation are used to set the framework for addressing environmental innovation in product and process design. An overview of automotive painting technology and its environmental impacts is included in this chapter, along with a discussion of the major environmental regulations influencing the development and application of paints and coatings. The importance of paint quality to the sale of automobiles and the role of paints and coatings in the design and manufacturing process is highlighted in a discussion of the evolution of automotive paint technology over time.

In automotive paints, innovations in the chemical formulation of coating materials can significantly reduce the content of hazardous elements and volatile organics, leading to lower levels of pollutants for treatment or control. The objective of this research is to determine the role of suppliers in developing and implementing innovations in paint and coating materials that make a difference in the environmental performance of automotive assembly plants. This work concentrates on innovations in materials and related technologies that prevent pollution at the source, such as material substitution, waste minimization and closed loop systems and recycling. While changes to paint application equipment are also important to the performance of automotive paint systems, this analysis concentrates on innovations in the paints and coatings materials and related processes in automotive painting.

2.1. Problem Context

Developing "cleaner" technologies[a] that reduce or eliminate wastes through fundamental changes to production materials and manufacturing processes can provide more effective long term solutions to environmental problems than treating waste once it has been generated.[1] Most environmental technologies to date have been developed to treat or reduce waste streams from industrial processes as they leave the facility. These technologies often result in a transfer of pollution from one medium to another, perhaps reducing, but never eliminating, the existing environmental problem. For instance, scrubbers reduce emissions to air, but result in sludge that must be disposed of as solid waste in a landfill. Adopting technologies that require fundamental change, however, present profoundly greater challenges to a company, since they usually require system-wide changes to equipment, operating procedures and even worker skills.

Industry has incentives to look for new solutions to pollution control and waste treatment and disposal. The costs of traditional environmental control technologies are steadily increasing. The 1990 Clean Air Act Amendments are expected to add twenty to fifty billion dollars a year to pollution control costs in the U.S. that are already high.[2] Industrial investments in pollution control and abatement are now more than $100 billion annually, almost 2 percent of the U.S. gross domestic product; these costs are anticipated to double by the year 2000.[3] New environmentally-friendly technologies that reduce these costs can increase the competitive advantage for a company.

Consumers are demanding more attention to the environment in the design of products and the conduct of manufacturing processes. New sources of publically available information, including government data bases[b] and environmental interest group reports on the environmental

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[a] Cleaner technologies are defined here as those that eliminate or significantly reduce the amount of a hazardous substance or pollutant released to the environment by reformulating a product or related processes. The emphasis in this research is on technology changes that reduce the generation of wastes by changing the input materials to the manufacturing process.

[b] Such as the Toxic Release Inventory maintained by the Environmental Protection Agency.

performance of major companies,[a] have increased the focus on corporate treatment of environmental issues. Many companies now prepare and disseminate annual environmental reports in addition to their traditional annual business reports to respond to a broad group of stakeholders. Some companies are even forming partnerships with environmental interest groups to help foster an image of environmental responsibility and to gain a better understanding of environmental issues and how to solve them.[b]

In addition to reducing costs, innovative approaches to environmental issues can create marketing advantages and even new businesses for companies. In his latest work on competitive strategy, Porter suggests that effective management of resources, with a focus on environmental benefits, will be the competitive edge for companies in the 1990s and beyond.[4] In some markets, environmental factors are an important element of differentiating products and developing new product lines and businesses. The Western European market, in particular, has taken a strong stand on environmental issues, requiring companies to demonstrate environmental responsibility as a condition of operating in their countries. Requirements such as product takeback, ecolabeling, and recycling are examples of the new pressures on companies.[5] Products are often reformulated to avoid having a label of "hazardous" attached.[6] Other companies find new business opportunities through their own efforts to minimize waste and environmental impact. DuPont, for instance, has successfully built a new business out of their internal investments in environmental technology and pollution prevention approaches.[7]

Although many companies are able to achieve environmental gains by implementing pollution prevention programs in their own facilities, some problems can only be solved with a cooperative effort among suppliers, manufacturers, distributors, and even customers. For instance, General Motors (GM), in an attempt to meet an internal goal for reducing the amount of packaging waste sent to landfills, changed their procurement policies to require suppliers to

[a] Examples include the annual list of "America's Least Wanted" prepared by the New York-based Council on Economic Priorities and the 1993 article by F. Rice in Fortune on "Who Scores Best on the Environment".

[b] General Motors Corporation and the Coalition for Environmentally Responsible Economies (CERES) and McDonalds Corporation and the Environmental Defense Fund are two of the more well-known examples.

reduce packaging material volume and to make those materials more recyclable. This resulted in a reduction of almost two-thirds in the amount of packaging waste sent to landfill within the first six months of the program.[8] In this case, GM was able to direct their suppliers toward specific actions that would reduce waste and costs for the manufacturer. Environmental problems that require changes to complex manufacturing processes or innovation in production materials are not as readily solved. When products are part of larger supply chains, or one of a number of complementary products, the integrated performance of the chain must be evaluated and intervention strategies developed based on a total systems approach.[9]

The painting process is a major source of environmental pollution in automotive manufacturing.[10] Over eighty percent of all air emissions from assembly plants are generated from the paint shop. Reducing emissions from automotive painting may be accomplished by reducing the level of input chemicals (changing materials at the source), by changes to the manufacturing process, or by installing additional or more effective pollution abatement equipment. Abatement equipment is the solution chosen by most automotive companies today, incurring not only capital but also significant operating costs. More than 60% of General Motor's annual pollution control costs (which in 1992 were over $150 million for their U.S. automotive operations), for instance, are devoted to air emissions control.[11] Another alternative is to reduce pollution by changing the composition of the materials used in the manufacturing process. New paint and coating materials, such as waterborne and powder paints, can be specifically formulated to contain fewer volatile organics and other regulated chemicals. However, introducing new materials into the production process can impact the existing application equipment as well as related painting procedures used at a plant. New formulations must also be compatible with the material substrates used in the car body.

A schematic of the flow of chemicals through a painting process is shown in Figure 2.1 (next page). Coating materials containing a variety of chemical constituents are necessary inputs to the process. Other chemicals required for cleaning paint lines and application areas are also introduced to the process. Chemicals contained in the paint film on the vehicle exit the process with the final product. Waste materials, including paint overspray, waste paints, and used cleaning chemicals, are sent through the paint area washwater system for disposal or may be recycled for use as cleaning or purge solvents in the manufacturing process. Waste products are treated by environmental control technology to destroy toxic chemicals or reduce waste volumes. Some control technologies create solid materials as byproducts that can be reused as input materials in other manufacturing processes (for instance, the use of incinerator ash in concrete manufacturing). The treated material is then released to the environment, either directly through air emissions, or as transfers to outside waste handlers or treatment facilities.

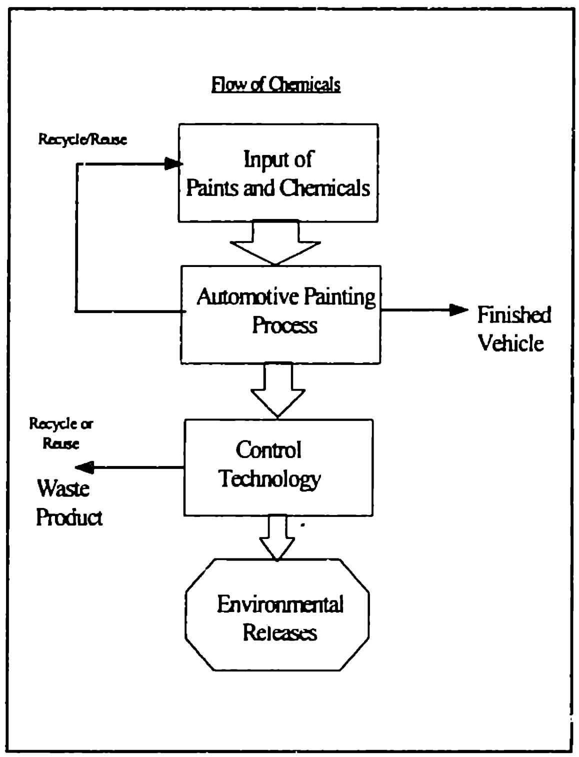

Figure 2.1. Schematic Flow of Chemicals in Automotive Painting[a]

From a systems perspective, cleaner technology design dictates changes to the product and the process that specify new materials as inputs to reduce potentially hazardous chemicals and/or greater use of recycling to create a closed loop system.[b] These changes are usually the most

[a] This diagram has been simplified to highlight key points.

[b] Another alternative is to reduce the materials and energy requirements for the manufacturing process.

radical for a company, often requiring revisions to product specifications, process equipment, and operating procedures that impact both suppliers and workers at a plant. Alternatively, the process might be redesigned to more efficiently use the same materials, resulting in less waste material for treatment and eventual release. Finally, improved control technology might be employed to reduce environmental releases from the facility and increase the potential for reuse of various waste streams by others.

2.2. Theoretical Framework

Environmental management approaches in industry have been evolving since the 1960s, when environment first became a major concern for companies. Colby describes an evolution from "classic production economics" to "eco-development", where companies exhibit increasing levels of attention to environmental issues, ultimately incorporating environment as a criteria in product and process design.[12] This process of change has primarily resulted from increased government regulation and control on industry. However, more recently, a shift from reactive responses to societal goals and public pressure to more proactive responsibility for environmental concerns has been observed in some companies.[13] As environmental considerations expand from a focus on treating plant emissions to preventing emissions through new approaches to the design, use and disposal of manufactured products and materials, new models for thinking about industrial processes have emerged.

Industrial ecology concepts, which borrow from the science of ecology of natural systems, reframe the production process from a single-cycle, once-through approach to one of closed loops to reduce or eliminate waste, and reformulation of products and processes to reduce material and energy input needs. Industrial ecology is most often discussed as the way in which different industrial activities, their products and the environment interact. The most extensive version of the concept incorporates the idea of a network of industrial firms, where the waste products of one company are the input materials for another.[14] By shifting the focus from processes within a company to exploring those among a network of companies, industrial ecology provides an important framework of analysis for evaluating environmental change.[a] It expands the boundaries of solution sets to include upstream suppliers, customers, and other potential users of manufacturing wastes and byproducts.

[a] The primary analytic approaches used in implementing industrial ecology concepts highlight the importance of materials and related transformational processes as sources of environmental pollutants. By understanding material balances, changes to product design and manufacturing processes that most benefit the environment are identified.

Industrial ecology concepts signal an important shift in U.S. environmental policy. Rather than evaluating the outputs of an industrial process, it mandates an extensive analysis of the internal product design criteria and the manufacturing operations of a company. It requires an intimate knowledge of the materials and manufacturing processes used for making the products demanded by the market. It moves the evaluation of environmental impact from the "end-of-the-pipe", outside the factory boundaries, to inside the production facility, to be considered at every stage of product development and technology design decisions. In so doing, these concepts begin to shift environment from an added regulatory cost to a company to an integral consideration in business planning, product design and marketing. This integration also begins to link environment more closely with innovation in both product and process in addressing environmental issues over the long term.[a] Although there are still gains to be made in reducing wastes from existing technology, there are many more gains that will come from innovative technologies and processes.[15]

Technology management and innovation theories suggest that a successful transition to a new set of technologies based on the concepts of environmental stewardship requires strong incentives for change at industry and individual company levels, combined with the technical competencies and organizational commitment necessary for implementing such change. Some new technologies may also require the development of complementary assets (consisting of related technologies or business elements, such as marketing and distribution channels) before they can be utilized in the production process.[16] The innovation process (depicted in Figure 2.2 on the next page) requires both the development of new technologies (inventions) and the acceptance and implementation of these technologies (adoption) by industry. Decisions in both these areas are related to the overall strategy and structure of a business, and its commitment to technological innovation and change.[17]

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[a] The themes of an integrated systems perspective and the need for technological innovation are strengthened in a recent report from the Office of Science and Technology Policy that maintains innovative technologies are the key to achieving a sustainable future.

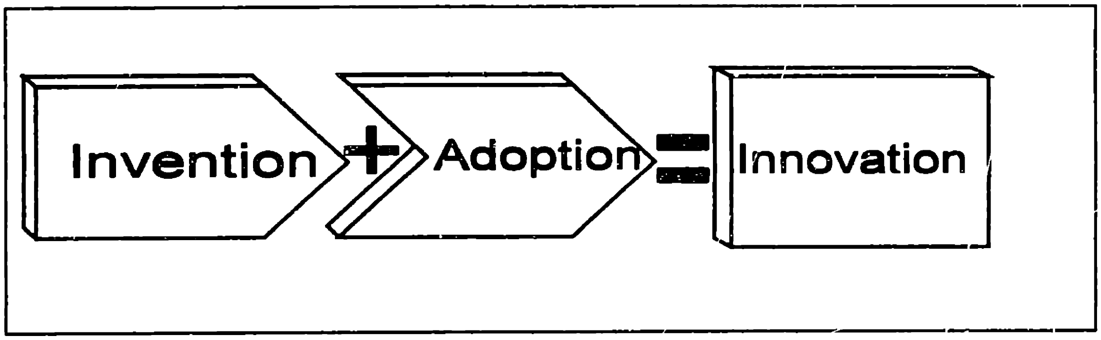

Figure 2.2. Innovation Requires both Invention and Adoption of a Technology

Research and development (R&D) activity, whether internal to a company, or accessed through the work of others, is critical to the process of invention. It is "the engine through which companies develop more environmentally benign products and processes, or develop 'new generation' products and technologies designed to improve environmental performance".[18] Early models of the innovative process suggested a linear approach, in which R&D investments led to inventions that were tested, developed and finally commercialized as innovations. More recent theory suggests that the process of innovation is iterative, and far less predictable than the linear model suggests.[19] Studies on innovation show that about two-thirds of the knowledge used by companies in innovation stems from their own product-specific R&D efforts and expertise. The other third comes from external sources (other companies, universities and government laboratories).[20] The largest single source of scientific and technological contributions to innovation from outside a company come from other industrial firms, especially users or suppliers.[21] Research on sources of innovation reinforces the view that innovative technologies can come from users and suppliers.[22]

Integrating inventions developed outside the company into internal manufacturing and production processes, however, can be problematic if the technical expertise to understand and utilize that technology does not exist within the company.[23] Even if it does, transforming the product of R&D activities into commercially viable innovations requires more than technical knowledge and skills. Commercializing a particular (outside) invention may depend on tacit knowledge of a process, where the innovation can only be fully developed and implemented through a partnership with the inventors.[24] Success requires the effective coupling of technical and market opportunities, and the development of an organizational construct through which the product can be further developed, manufactured and distributed.[25,26]

Inventions and resultant innovations can focus on products or processes. They can be incremental improvements of existing technology, or radical breakthroughs that change the nature of a product or process. Many inventions that succeed as commercially viable innovations are developed through incremental improvements to existing technologies. The experience and resource base of a company (in terms of existing plant and equipment, technical knowledge and management approach) play an important role in innovation.[27] Dosi's theory of technological paradigms explains why existing technology often defines the space of opportunities for further innovation.[28] Companies develop innovations through experience with a particular technology and through learning by doing. Thus, the experience base and technical knowledge built up by a business are important factors in successful innovation.[29] Incremental innovations present less risk to the adopting organization, and fit readily within existing production processes or require only minor changes to products.[30] Conversely, revolutionary (radical) innovation is built on new principles that require new technical competencies and skills, and often new organizational approaches to product design and marketing.[31] Radical innovations generally require significant adaptation of operating procedures, and/or investments in new equipment and processing technology.

These theories underline the importance of corporate strategy and top level leadership in encouraging radical innovation. The innovation must fit with the company's core business strategy and product lines and provide an opportunity to gain competitive market advantage.[32] Organizations with more flexible, decentralized structures and a focus on developing new product offerings are more likely to develop and adopt radical innovations.[33] Both an aggressive technology policy and a concentration of technical specialists is needed for adoption of radical innovations.[34] Large manufacturers, however, often have a number of production plants, geographically dispersed. Company policies must be transferred to and implemented by each of these operating units. These facilities must have the financial and policy support of the parent company, as well as the technical expertise and management capability to invest in and pursue radical technological change.[35] A lack of sufficient core capabilities in environmental skills and related know-how often is the reason why manufacturers are more likely to develop add-on innovations that can be easily incorporated into existing processes than invest in extensive modifications of existing products or processes.[36]

The framework of technology lifecycles and industry dynamics developed by Abernathy and Utterback provides a useful construct for thinking about the development of environmental technologies in the context of innovation.[37] New technologies develop through a process of experimentation and competition (often with radical innovations) that result in a dominant design, which sets product or industry standards. Once the standard has been set, most subsequent product innovations are incremental. Companies instead focus on improving their production processes to enhance efficiencies and cost-competitiveness. New performance parameters may emerge over time, renewing the cycle of product innovation in attempts to develop new standards.[38] This dynamic has been most evident in recent years in the continuous changes and product shifts in the computer and electronics industries.[39] The growing importance of environmental factors as a new set of performance parameters for a variety of products and manufacturing processes suggests that a similar dynamic is beginning to take place, potentially affecting a wide range of industrial activities. This shift may stimulate a new round of innovation in many products and related processes.

Environmental regulation historically has had a strong outside influence on the direction of technological innovation and change. The specific effect of new environmental standards on innovation depends on the form and timing of the regulation and the flexibility with which it is implemented. Government regulations are able to reorder priorities among dimensions (in this case, environmental criteria) that must be fed into the engineering design process.[40] Other studies indicate the ability of government regulation (specifically environmental regulation) to shift as well as narrow the path of technological innovation, directing company investments toward compliance needs and incremental innovations of existing, proven technologies. In situations where existing technologies cannot meet the needs defined by the standard, however, environmental regulation can prompt revolutionary change.[41] In the event of revolutionary, or radical change, the companies that have invested in understanding the elements of design important from an environmental perspective, and linking those to key market demands, are likely to take a leadership role in the next generation of product development. The organizational and technical capabilities of a company are critical in successfully identifying and responding to opportunities for innovation as new performance parameters develop.[42] Emerging automotive paint technologies such as powder, for instance, are based on entirely different chemistries and application techniques than the current industry standards (which are primarily liquid paints).

The systems perspective demanded to implement industrial ecology concepts in a company requires an evaluation of complex technologies that extend beyond traditional company boundaries. Some manufacturers may not have developed the systems knowledge and environmental expertise required to effectively integrate environmental considerations in reformulating their products. Although the research to date in technology innovation clarifies the importance of technical expertise and R&D investments in initiating the innovative process, it does not substantively address innovations that occur along the technology supply chains used by companies in designing and manufacturing their products. The research of this dissertation is directed at that gap, exploring the sources of innovation in cleaner technologies adopted in manufacturing processes and the rationale for and experiences in adopting these technologies.

2.3. Research Objective

The objective of this research is to determine the role of suppliers in developing and implementing innovations in paint and coating materials that make a difference in the environmental performance of automotive assembly plants. The research focus is on technological innovations that prevent pollution at the source, such as material substitution, waste minimization and closed loop systems and recycling. Although changes to paint application equipment are also an important part of the system, this analysis concentrates on innovation in the materials and processes relevant to the painting process for automobiles. Painting is the primary source of environmental impact from the manufacturing process, generating millions of tons of toxic air emissions annually. The major hypotheses tested are:

- **Innovation in environmental technology is being driven by paint suppliers to the auto industry**. Environmental regulatory pressures and competitive requirements on both suppliers and automobile assemblers are leading to changes in paint technology. The direction of technological change requires new technical competencies and management incentives for both suppliers and manufacturers. A strong supplier role in initiating the development of cleaner technologies suggests new approaches and incentive systems are needed in working with suppliers to fully benefit from their investments in new technological options.

- **Environmental performance in a manufacturing operation is improved through the use of new cleaner technologies and supplier expertise.** Innovations in paint materials and technology are expected to reduce environmental impacts from automotive painting through material substitution. However, in an integrated technological system such as automotive painting, other process elements or operational procedures may also contribute to total environmental impacts. This hypothesis is directed at understanding the influence of materials substitution on environmental performance in a complex manufacturing process.

In addition to these major hypotheses, this research explores the rationale for adopting radically new technologies at assembly plants. Determining the influence of suppliers on the environmental practices of manufacturers is an important part of developing a framework that can be used to encourage and promote environmentally beneficial technologies and practices in and across firms. Adoption of radically new technologies is expected to be more likely in those plants that have effective links with corporate policies that support innovation and environmental improvement. Given the complexity of automotive painting and the challenges in adopting new materials or process technologies at a production plant, strong partnerships among paint suppliers and automakers, supported by appropriate incentive systems, are expected to be an important element of success for innovative environmental technologies.

The previously cited General Motors example (working with suppliers to reduce solid packaging waste), while highlighting the importance of suppliers in solving environmental problems, dealt with a technological system that did not directly impact GM's primary product. Most automotive companies are primarily concerned about the environmental and safety impacts generated through the use of automobiles. Almost ninety percent of air pollution in cities and thirty percent of the greenhouse gases come from emissions during vehicle use.[43] The dependence of automobiles on gasoline as a source of fuel is another major environmental issue. Much of the current technology investment in automotive companies targeted for environmental improvements is devoted to redesigning the automobile to reduce its environmental impact as a product. Automaker R&D currently emphasizes improving the efficiency of engines, developing high performance emission control equipment for automobiles, and evaluating ways to improve the recyclability of the car.[44]

Yet, the environmental impacts of the automobile manufacturing process are also significant. Assembly plants are large generators of air emissions and hazardous wastes, eighty percent of which come from paint shop operations. The emissions generated from its assembly and parts plants in 1993 and 1994 place GM in the top ten companies in the U.S. with the largest total reported chemical releases.[45] The painting process is also a major cost element of the manufacturing process, with large capital investments and high material costs. Quality in automotive painting is critical to product sales. "For most new-car buyers, color and appearance are nearly as important as price".[46] Automotive assembly plants thus must balance reduction in environmental emissions and production costs with maintaining the quality of the vehicle finish.

While automotive companies have focused on improvements in engines, fuel systems, and vehicle recyclability, paint manufacturers have concentrated on new material chemistries and environmental performance. As early as 1967, environmental regulations targeted the paint industry with requirements for product labeling on Volatile Organic Content (VOC) and restrictions on product use. The chemicals industry, as the major source of industrial pollution in the U.S.,[47] has responded to increasing public pressure over time with an industry-wide agreement (initiated in 1988) to incorporate environment, safety and health concerns into their business and operating strategies. The Responsible Care program was developed in 1988 by the Chemical Manufacturers Association (CMA) to enhance the performance of the industry in the areas of environment, safety and health. Program participation is mandatory for all members of the CMA (all the major paint manufacturers are members).[48]

Collective actions by the chemicals industry that include specific codes of performance and broad-based sharing of expertise, as well as voluntary actions by specific companies, accelerated the progress of this industry in understanding environmental issues and tackling the challenges of pollution prevention through reformulation of products. DuPont, for instance, one of the larger paint and materials suppliers to the automotive industry, has made a strong corporate commitment to environmental leadership and product stewardship. This commitment, made publicly by the senior leadership of DuPont, is fully supported by investments in innovative technological solutions to environmental problems. DuPont works directly with customers to try to understand the environmental problems caused by their products and develop innovative solutions to address these concerns.[49] The results of these investments in new technology and processes are now available to customers and competitors as part of a broad offering of environmentally-oriented products and related technical services. PPG Industries, Inc. (PPG) is another company that offers a variety of materials (paints and coatings, as well as glass and plastics) designed to minimize environmental impacts. PPG has developed waterborne paints and coatings, and offers lead-free formulations and powder coatings to their customers. They also deliver waste minimization and environmental services based on their environmental knowledge to automotive paint customers. Broadening the range of product offerings through new environmental competencies enhances the long term competitiveness of these companies.[50]

This research postulates that the innovative technology needed to improve the environmental performance of automotive assembly plants requires skills and competencies from the suppliers (detailed knowledge of paint chemistry and environmental effects) and the assemblers (detailed knowledge of the final product requirements and assembly plant operations). Implementing new technology at the assembly plant is best done through a partnership arrangement that allows these groups to work together effectively. Suppliers to automotive assembly plants have traditionally been pressured to reduce costs while maintaining product quality.[51] With the relationship between supplier and manufacturer restricted to the sale and purchase of paint, the possibilities for innovative approaches to reduce costs across the broader technological system are limited. There are few opportunities for the supplier to provide input relevant to the environmental management of the plant. However, the nature of the relationship between assemblers and suppliers in the U.S. is changing, although it is not yet an acknowledged partnership arrangement.[52] In automotive painting, automobile assemblers are beginning to turn to paint manufacturers for cost-effective, high quality technological solutions to their environmental problems in addition to their materials needs.[53]

New programs are being developed to encourage suppliers to take more responsibility in production operations. But in addition to forming technology partnerships, the companies must develop new contractual mechanisms and incentive systems that encourage innovation and change. GM, for example, has established the Chemicals Management Initiative with suppliers to try to reduce the use of toxic chemicals at their facilities. The program pays suppliers based on the production levels at a plant, not the volume of chemicals sold, and includes incentives for reducing chemical use at the plant. Under the program, suppliers also provide technical expertise and on-site chemical services. Facilities with contracts in place (more than half the

North American plants) have realized an average reduction in chemical usage of 30%, and savings of up to $750,000 a year.[54]

Chrysler has also pioneered a program with chemical suppliers, the Solvent Management Program, to try and reduce the use of solvents at assembly plants and to increase efficiency (and reduce waste).[55] The program relies on the assignment of responsibility to a single supplier that manages and supplies all solvents and related cleaning materials for the paint shop. The supplier provides on-site technical support and training to the plant personnel, and is responsible for tracking material usage and resultant emissions. Chrysler attributes much of their success in reducing emissions at their plants to this program. Paint suppliers have initiated the "Pay as Painted" program which extends the concepts of the Solvent Management Program to paints and coatings materials. These new contractual arrangements assign a broader role to suppliers in the environmental management of the plant, utilizing the technical expertise of these companies in partnership with plant personnel to accomplish business and environmental goals.

In automotive paints, innovations in the chemical formulations of coating materials can significantly reduce the content of hazardous elements and volatile organics in the product, leading to lower levels of pollutants for treatment or control. The development of these new materials and related technologies (inventions) requires R&D investments by companies with technical competencies that include attention to environmental priorities. These new products must be accepted by the user community and integrated into their processing operations, however, to make an impact on environmental performance. Companies need to have some incentive for incorporating new paints into their product design and manufacturing processes. Theory suggests that decisions to adopt new materials are generally easier for companies if the products represent incremental changes from current practices, rather than a major shift that will require new investments, competencies and operations procedures. Yet, revolutionary changes in technology may be required as environmental criteria emerge as an important new parameter of product performance. The results of this research are expected to suggest that radical shifts in technological systems are more readily supported in partnerships where suppliers are encouraged to apply their technical expertise in a production environment.

While this research is explicitly directed toward U.S. companies, an important aspect of this work relates to differences in supplier-manufacturer relationships that generally exist among the U.S., Japanese and Western European companies. The U.S. and Western European systems are viewed as fairly similar, in terms of the overall business relationships between the suppliers and manufacturers.[56] Japanese firms have stronger partnerships with their suppliers than the U.S. or Western European systems. But the environmental goals, requirements and implementation mechanisms among these three regions are vastly different.[57] Determining the influence of the differences among these systems relative to the development and adoption of innovative environmental technologies is an important element of future research.

2.4. Overview of Automotive Paint System

Paints are coating systems that include not just the colored finish seen on the exterior of an automobile, but a variety of protective coatings that cover most automobile components, including engines, wheel covers, and even oil pans. The performance requirements are most stringent for the set of paints and coatings that are visible to customers, those which cover the main body of the vehicle. Automotive paint, initially a single product, has evolved over time to a complex layering of several products that work together as a system to provide the functions of color, appearance and durability. Each layer is comprised of four basic elements:

- pigments (for color);
- resins (for binders, holding all the paint constituents together in a continuous system, and enabling the paint to cure into a film after application);
- solvents (to lower the viscosity of the binder and allow application of the product--solvents then evaporate to permit the formation of a paint film); and
- additives (specific ingredients to improve the performance of the paint).[58]

Early automotive paints were based on materials that required many coats, with extensive drying times in between, to achieve an adequate film build on the vehicle. The development of lacquer paints in the mid-1920s, followed by enamels, provided significant improvements in drying times and durability of finish. These materials were used for many decades as the topcoat system for automobiles.[59] Advances in undercoatings for vehicle paint systems (primers and corrosion protection coatings) during the 1960s led to the introduction of electrocoating and dip application systems. Although the first electrocoating process was introduced by Ford in the 1960s, an improved process (cathodic deposition) introduced by PPG Industries, Inc. in 1976 soon became the industry standard, and remains so today.[60]

Until 1966, most paints had very low solids content and contained a high percentage of solvent. Most of the industrial coatings used at that time averaged about twenty to thirty percent solids, with the remaining seventy to eighty percent solvent.[61] The lacquers used in the 1970s were sprayed at roughly 10 percent solids and 90 percent solvent.[62] The solvents were relatively cheap and worked well as a medium for the other elements of the paint formulation (resins, pigments, and additives). But in 1967, the first U.S. environmental regulation limiting solvent emissions (Rule 66) was passed in California.[a] In 1970, the Environmental Protection Agency (EPA) was established, and the 1970 Clean Air Act (CAA) was passed, modeled after Rule 66. Regulated pollutants include particulates, sulfur dioxide, carbon monoxide, nitrogen oxides, lead and ozone, and chemicals contributing to the creation of these pollutants. Many of the elements of concern in paints are Volatile Organic Compounds (VOCs), regulated under the Clean Air Act as major contributors to urban smog.[63]

To meet the emission limits mandated by these regulations, automotive painting materials would have to be applied at nearly 60 percent solids content, by volume. Neither materials nor application technologies were available in 1970 to meet these limits and maintain the quality of finish required by the market. The approach adopted by the EPA focused on forcing changes in basic coating materials by restricting the use of key chemicals in paint formulations.[64] While encouraging the development of new products, these regulations simultaneously narrowed the design space for formulators, increasing the technical challenge and costs of innovation. These stringent regulatory standards combined with rising prices on solvents drove a dramatic technology shift in the paint industry.[b]

Paint manufacturers moved quickly to begin the lengthy process of product development for new materials to meet federal and state environmental regulations. Since 1970, technological development has progressed along three parallel paths, adding costs and complexity to the research process (see Figure 2.3 on next page). Today, the paints and coatings industry is simultaneously developing high solids, waterborne and powder coatings, with the gradual

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[a] Rule 66 restricted the use of specific chemicals in solvent blends, based on an assumption that some elements contributed more to tropospheric ozone air pollution than others.

[b] In addition to the regulatory pressures experienced at this time, the oil shortage in the 1970s precipitated a rapid increase in the price of solvents (which are derived from petroleum products).

elimination of lacquers and enamels in automotive applications. High solids coatings[a] were developed by increasing the solids content of the paint significantly (to 50 to 70 percent solids) and reducing the solvent content proportionally. The increase in solids content was accomplished by lowering the molecular weight of the resins in the paint formulation so they could still be applied by spray equipment.[65] Waterborne paints were developed through an entirely different chemistry, replacing most of the solvent with water, again lowering VOC content. Waterborne paints do contain some solvent, however, to improve the flow properties of the material.[66] The third major technological path of development was powder coatings, solid formulations that contain essentially no VOCs. In addition to high solids, waterborne and powder technologies, advanced research efforts are pursuing emerging technologies such as ultraviolet (UV) radiation cure and carbon dioxide spray.

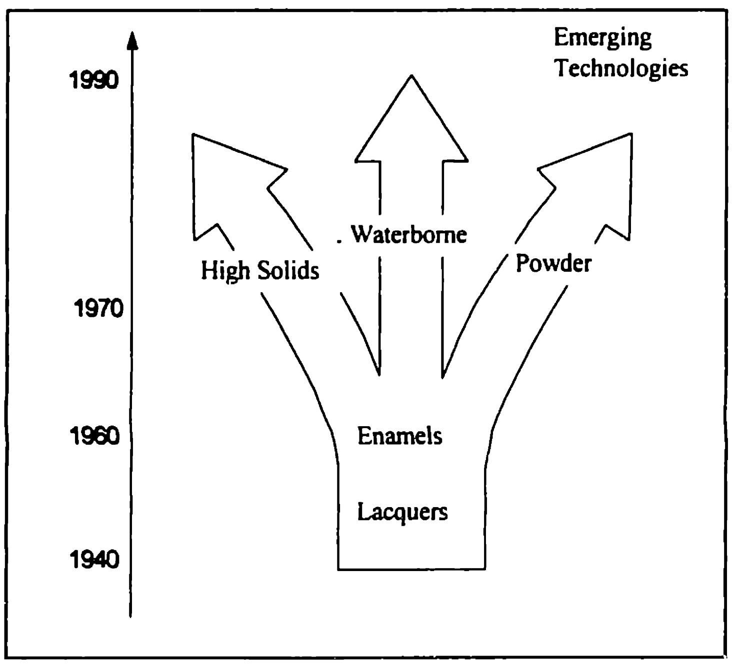

Figure 2.3. Technology Paths of Automotive Coatings

[a] This term is generally used in the industry to refer to solvent-based paints, even though technically a powder paint might also be considered "high solids".

Paint manufacturers must meet a number of environmental criteria in formulating new products. There is a maximum allowable solvent level and many elements traditionally used in paint formulation are now prohibited from use. Some companies provide checklists to their R&D groups and follow up with extensive product reviews to ensure that prohibited chemicals do not find their way into a new product. One of the early shifts in technology was the elimination of heavy metals from paints (cadmium, lead and molybdenum); organic pigments were developed to substitute for these materials. Restrictions on Hazardous Air Pollutants (HAPs) are the latest limitations in paint formulations, with formal regulatory guidelines for automotive assembly plants due in the year 2000. Paints and coating materials will require additional innovation to meet these emerging requirements. Limitations on coating material content are leading some companies to explore alternative technologies such as in-mold color, particularly as more automakers move to incorporate plastics in vehicles.

Automotive paints and coatings have experienced an increasing rate of change in the materials and technologies used since 1970 (see Figure 2.4 on next page). The advent of environmental regulation spurred a significant increase in the rate of invention in paints and coatings, as well as the development of new paths of technological advance. A competitive industry structure in the paints and coatings industry and continued demands for new, improved materials and processes by the automotive industry (particularly during the 1980s, as competitive and environmental pressures on automakers increased) encouraged significant investments in R&D. Automakers initially experimented with waterborne and powder technologies in an attempt to meet regulatory restrictions at assembly plants, particularly those where state requirements were more stringent than the federal regulations. GM implemented lower VOC waterborne paints for topcoats at two assembly plants in California in the early 1970s.[67] The thickness of the coating required,[a] and the difficulties in applying and drying the waterborne paints, led them to discontinue use of the technology shortly thereafter. Powder coatings were also explored at this time. Both GM and Ford established pilot powder facilities in their

[a] Note that the standard in the U.S. for automotive coatings at that time for topcoats was a monocoat system, rather than the basecoat/clearcoat system currently employed.

Framingham, MA and Edison, NJ assembly plants. Several thousand vehicles were color-coated with powder before the plants returned to traditional solvent-based paints.[68] The major problems encountered with powder were inconsistent film thicknesses, difficulties with metallics, and an inability to repair defects in the finish. Powder coatings found lasting application as primers and coatings for automotive parts, however, and were used again on exterior body panels as early as 1980.[a]

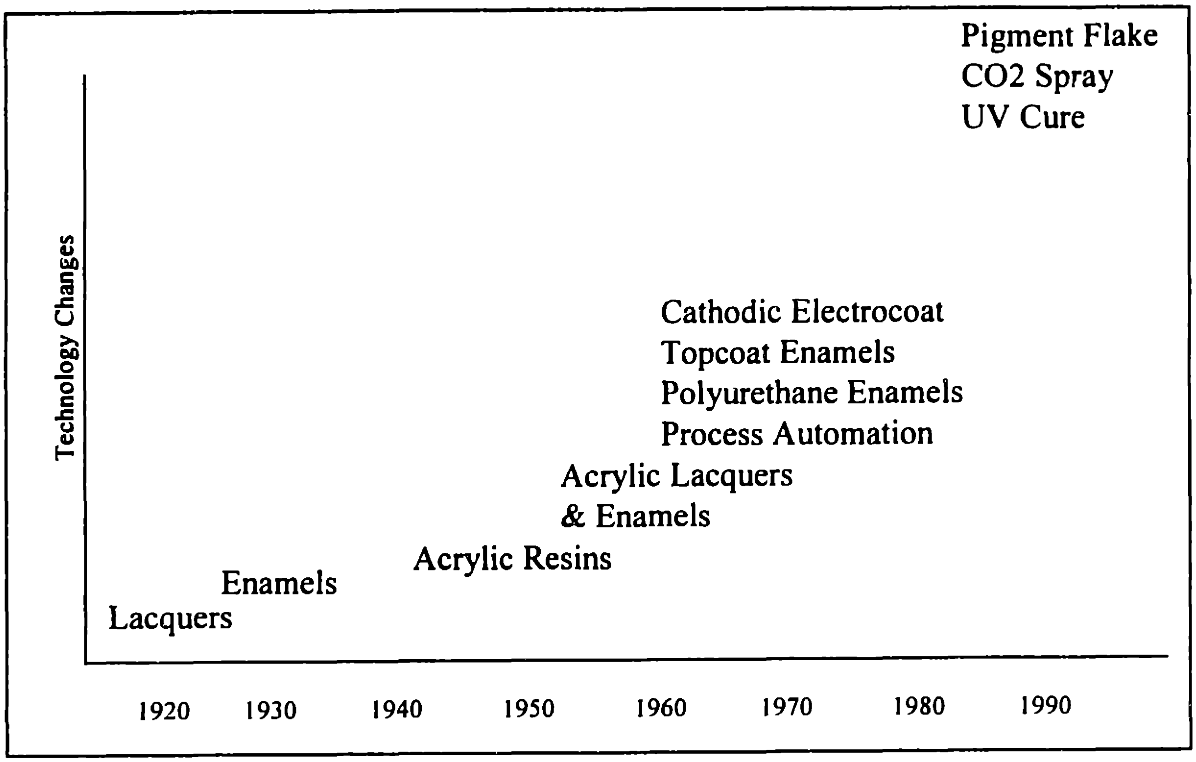

Figure 2.4. Technological Change in Automotive Paints and Coatings over Time

The difficulties encountered by automakers in employing the newer materials highlight the challenge of making changes to the automotive painting system. Paint materials, manufacturing processes and application equipment constitute a highly integrated

[a] When GM installed a powder primer facility in its Shreveport, LA truck plant.

technological system, comprised of a complex set of processes and materials that must function effectively together. In these systems, major changes to materials or product design demand technological shifts in the manufacturing operation. Innovation in paint materials requires related innovations in paint application equipment, plant layout and/or painting processes. Conversion to waterborne or powder paints almost always leads to major capital investments in paint shop lines and equipment.

Ultimately, automakers invested in incinerators and other pollution abatement equipment that allowed continued use of low solids, solvent-based paints well into the 1980s. High solids technology was gradually adopted in the mid to late 1980s as the environmental standards became more stringent and the technology was further developed. A related innovation, the basecoat/clearcoat system, developed in Europe, was adopted in the U.S. in the 1980s. The need to redesign paint systems and facilities to take advantage of this processing innovation (which required additional spraybooths and ovens) facilitated consideration of new painting materials by automakers. The basecoat/clearcoat process used different materials for the color coat (or basecoat) and the clearcoat, which was formulated for additional durability and protection against fading and weathering.[69] The high solids technology required relatively little change to existing plant and equipment, as opposed to the major facility modifications required for waterborne and powder coatings. Waterborne coatings were not used again in the U.S. for topcoat applications until the 1990s, when they were reintroduced as color basecoats.

The coating system currently used in automotive painting consists of up to six layers, applied in the following order: phosphate conversion coating, electrocoat primer, anti-chip coating, primer-surfacer, basecoat and clearcoat. Each of these layers has its own special performance requirements and must be formulated to bond with the next layer, to form a multilayered coating that will not flake or peel. The schematic of this layering system in Figure 2.5 (next page) shows the average thickness for each layer, with a total film thickness of five to eight mils. One of the challenges in automotive paints is that each layer is formulated separately, in many cases by different suppliers. The outer layers (antichip through clearcoat) could also conceivably be formulated based on entirely different technologies (i.e., either solvent-based, waterborne or powder).[a] Yet, the linking among the layers at the material interfaces is critical to ensure that the coating adheres to the vehicle substrate and to the additional layers. These layers must all work together effectively to provide the vibrant colors, durability and long life that the consumer expects.

Clearcoat	**1.8 to 2.5 mils**
Basecoat (colorcoat)	**0.6 to 1.0 mils**
[illegible]	[illegible]
Antichip Protection	**1.5 to 4.0 mils**
Electrocoat Primer	**0.8 to 1.2 mils**
Phosphate Conversion Coating	
Vehicle Substrate	**30 to 35 mils**

Figure 2.5. Typical Exterior Coating System for U.S. Automobile[70] (one mil = 0.001 inch)

Solvent-based coatings still comprise the majority of paints used at automotive assembly plants in the U.S., although that is rapidly changing. In 1995, market analysts estimated that 85 percent of automotive basecoats were solvent-based, with only 15 percent waterborne.[71] Both technological challenges and cost contribute to the slow adoption of the new technologies. Each of these technologies has a different set of advantages and disadvantages, some of which are highlighted in Table 2.1 (next page) and discussed below. High solids, solvent-based paints are the most commonly used for both basecoat and clearcoat in assembly plants today. They combine the advantages of reduced VOC content with high transfer efficiencies (up to 70 percent), minimizing both paint usage and solvent emissions through the use of electrostatic automated application equipment.[72] Solvent-based purge material used with these paints can be recycled. A growing number of suppliers are working with

[a] The industry standard for phosphate and electrocoat is currently a waterborne dip system.

automakers to collect and remanufacture the solvents for future use. High solids paints are much more sensitive to oil contamination or dust than are the low solids paints, however, and vehicle bodies must be extremely well cleaned before coating.[73] Also, resins used in the formulation of these paints require high cure temperatures or longer drying times if higher temperatures cannot be achieved. This results in a need to closely control oven times and temperatures in the application process.

Table 2.1. Characteristics of Various Automotive Paints and Coatings Technologies[74]

Product Technology	Challenges	Benefits
High-Solids	Lower solvent content narrows application parameters (curing time and temperature) in achieving high quality finish More expensive, customized resins required	Reduced solvent (and VOC) Recycle of process solvents Fit with existing plant & equipment
Waterborne	Material highly sensitive to temperature and humidity conditions Lower transfer efficiencies Purge materiais cannot be recycled Possible increases in paint sludge	Reduced solvent (and VOCs)-- although not VOC free. Improved appearance (although this is debated among experts)
Powder Coatings	High cure heat required -- tough on plastic substrates. Limits on resins that can be used Increases in solid waste if material not recyclable. High costs for material and related equipment	Improved durability Essentially VOC free technology High recycle potential, yielding relatively high transfer efficiencies

Waterborne paints are beginning to be used in the U.S. partly because of their lower VOC content, but also because of their improved appearance. The primary application is as a basecoat, followed by a high solids, solvent-based clearcoat. The use of waterborne paints creates a number of application challenges, however, since they are extremely sensitive to humidity and temperature fluctuations, requiring plants utilizing these technologies to install air conditioning and humidity control in the spraybooth. Implementing waterborne also results in lower transfer efficiencies, since it is difficult to effectively use electrostatic application techniques (most waterborne paints are conductive, transferring charge from the point of application down to the paint mix room). This leads to additional usage of more expensive paints, and more VOC emissions than originally expected. The purge materials used with waterborne contain too little solvent to make them attractive for remanufacture, and create additional water waste that must be treated and disposed of by the plant. Although the evidence is limited, some analysts believe that waterborne paints may lead to greater volumes of paint sludge, or a shifting of environmental burden from air emissions to solid (perhaps hazardous) waste.[75]

Powder coatings are of interest because of their durability and the potential to be essentially emission free. The material provides excellent protection against stone chips and corrosion, and is increasingly being implemented in U.S. assembly plants as an antichip primer. The powder can be applied electrostatically, achieving relatively high transfer efficiencies (some plants suggest up to 60 percent) and the overspray can theoretically be collected and recycled. The barriers to the use of powder technology are many, however. Converting paint shops to accomodate powder coatings is a major investment. Powder requires entirely different distribution systems and application equipment than that used for liquid coatings. It requires high bake temperatures to convert the powder into a flowable material that creates a film; these high temperatures cannot be used with most plastic panels.[a] Making color changes in powder is also extremely difficult, essentially requiring a total cleanout of the system. Adjustments to the material and process on-line (during production) is almost impossible.[76] Finally, the additional material cost for powder is currently prohibitive (at two to three times the cost of traditional high solids, solvent-based paint materials), especially if recycling powder overspray within the paint process is not achievable.

In addition to the overall changes in the technology, product specialization among the various layers of the coating system has emerged. For instance, powder technology is increasingly being used as an undercoat to give the vehicle improved durability and resistance to chips.

[a] Plastics are increasingly used in vehicles for reducing weight.

Lead-free formulations are being developed for electrocoats. Topcoats, although moving to some use of waterborne technology for basecoats, still predominantly use products with higher solvent content. Some of the current technology trends and challenges for key layers of the coating system are highlighted in Table 2.2. For the clearcoat layer, powder technology has great promise as a durable, high performance coating with many environmental benefits (at least from the standpoint of air emissions). The three major U.S. automakers have made a commitment to a jointly funded R&D effort to identify solutions to many of the current barriers to broader use of the technology.[a] Pigmented clearcoats are another area of research.

Table 2.2. Technology Trends for Different Layers of the Coating System[77]

Coating System Layer	Material and Technology Research Directions
Clearcoat	Powder coating still needs lower bake temperature to accomodate plastic parts Reduce film thickness Improve durability/performance/scratch resistance Pigmented and special effects clearcoats
Basecoat	Waterborne (to reduce VOCs) Improve application parameters Improve durability/performance
Primer-Surfacer	Color-keyed to basecoat (improves "depth of image") Improvements in chip resistance Reducing VOCs (waterborne or powder)
Electrocoat	Lead-free formulations Lowering bake temperatures Reducing VOCs (future goal is zero VOCs)

In the basecoat layer, waterborne technology appears to be the major thrust for the future, with research focused on improving the durability of the coating and ease of application in production environments. Primer-surfacers in both waterborne and powder technology are being explored, with the additional challenge of adding color to this layer of the coating system to enhance the image of the final finish. Electrocoats will likely continue as a closed-

[a] The Low Emission Paint Consortium (LEPC), a partnership of the three major U.S. automakers and the primary paint and equipment suppliers, was formed to conduct joint research to accelerate the availability of low emission painting technology. The focus of the research is on reducing emissions through fundamental changes in materials, with a priority effort on testing and evaluating powder paints for use in clearcoats.

loop waterborne system, with continued improvement in environmental performance (removing heavy metals and VOCs from the formulation). Trends in coatings reported by the annual economic survey of coatings manufacturers and finishers[a] suggest that powder and waterborne coatings will continue to increase their position in the market, with solventborne coatings (both low and high solids formulations) decreasing.[78]

In addition to the material formulation, the application and curing technology for each of these products plays an important role in achieving a finish that meets performance specifications. Application of the coating materials (through spraybooths and dip tanks) and curing (in bake ovens or air dry enclosures) must be completed for each layer of the paint and coating system. Phosphate conversion and electrocoating materials are applied using large dip tank systems. Primer-surfacer and other coatings and topcoat paints are delivered to spraybooths through a high volume, high pressure circulating system from a remotely located paint mix room. The application process generally utilizes some combination of hand-held and automated spray guns, rotary bells, and other advanced application equipment.

Most automotive painting processes employ electrostatic spray to increase the efficiency of the paint process and reduce waste. In electrostatic spray application, paint particles are atomized in an electric field, where they become charged and are drawn toward the vehicle to be painted.[79] The charging takes place on the nozzle of the spray gun or bell. Much of the paint is applied by robots, using spray guns, or through automated zones with high-speed rotating bells. Manually operated spray guns are used for areas that are difficult to reach, such as door openings. The flow of the material through the distribution lines, the pressure of the system, and the airflow in the spraybooth are all tightly controlled and monitored by computer systems at the booth to ensure the proper amount and thickness of paint is applied.

Film thickness, or build, is a critical performance parameter for automotive painting. It must be thick enough to provide the required durability and coverage, yet thin enough to be

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[a] This survey was performed in 1993 by Industrial Paint and Powder, one of the primary industry trade journals.

properly cured in a timely manner in high volume production lines. Film builds that are too thick lead to defects such as popping, orange peel, and sag. They also use more paint, and raise finishing costs through greater material usage if not additional rework costs. Each plant has detailed specifications for the thickness of each layer of the paint system.

Transfer efficiency measures the performance of the integrated painting operation (material, application equipment and processing techniques) in achieving the desired film build. Transfer efficiency, defined as the ratio of the amount of paint solids that actually stay on the vehicle panels to the amount of paint solids applied, is important to both production cost and environmental performance. There are a number of variables affecting transfer efficiency, including the type of spray equipment used at a plant, the paint flow rate, paint temperature, air flow in the booth, distance from the spray guns to the parts, and the number and frequency of color changes. Increases in transfer efficiency (usually expressed as a percentage) reduce the amount of paint necessary to coat a particular part. Reducing paint usage cuts cost of materials and reduces VOC emissions from two sources: those emitted from paint application and those from related cleaning chemicals (generally high in solvents) used to clean the process area. A major issue with waterborne paints is that plants have experienced much lower transfer efficiencies with these materials, yielding higher material costs and fewer improvements in VOC emissions than expected.

Every automotive assembly plant has a process that is somewhat unique to their facility, based on the product, the age of the plant, the equipment and paint formulations used in the facility, and the environmental requirements dictated in the operating permit. Some plants, for instance, do not use antichip coatings, or use them only on certain parts of the vehicle. Others do not use a primer-surfacer, preferring instead a product called "Uniprime", which provides the function of both the electrocoat and the primer-surfacer in a single process stage. Because the application equipment can dramatically affect their performance, paints are specifically formulated for particular equipment. Paints are surprisingly sensitive; a slight change in a pigment or a small shift in solvent content can affect color, ease of application or the curing time of a paint.[80] In spite of these variations in materials, there are a number of relatively standard process elements in automotive painting. The steps described in Table 2.3 are used as a baseline for comparison among the plants chosen for detailed case studies in Chapter 4. The primary environmental impacts of each step are also shown in Table 2.3.

Table 2.3. Baseline Elements and Environmental Impacts of an Automotive Painting Process in the U.S.

Process Steps	Primary Environmental Impacts
1. Cleaning and Pretreatment	Wastewater (requires treatment prior to release)
2. Phosphate Rinse	Wastewater (requires treatment prior to release) Some solid wastes
3. Electrocoating -- Dip System	Closed system High energy use Wastewater and solid wastes generated during periodic cleaning and recharging of system.
4. Oven Bake	Air emissions of VOCs and HAPs Air emissions of CO_2 from oxidation process High energy use
5. Primer-Surfacer	Air emissions of VOCs and HAPs Solid paint wastes Waste solvents (often recycled)
6. Antichip Protection	Air emissions of VOCs and HAPs Solid paint wastes Waste solvents (often recycled)
7. Sealer	Air emissions of VOCs and HAPs Solid wastes
8. Oven Bake	Air emissions of VOCs and HAPs Air emissions of CO_2 from oxidation process High energy use
9. Basecoat (color coating)	Air emissions of VOCs and HAPs Solid paint wastes Waste solvents (often recycled) Booth wash water (requires treatment)
10. Oven Bake	Air emissions of VOCs and HAPs Air emissions of CO_2 from oxidation process High energy use
11. Clearcoat	Air emissions of VOCs and HAPs Solid paint wastes Waste solvents (often recycled) Booth wash water (requires treatment)
12. Oven Bake	Air emissions of VOCs and HAPs Air emissions of CO_2 from oxidation process High energy use
13. Repair (full body -- high bake)	Basically a repeat through the paint process, generating all relevant impacts
14. Repair (spot -- low bake)	Low levels of air emissions of VOCs and HAPs

Achieving a high quality finish requires that each process step is carried out in accordance with detailed specifications. Cleaning and pretreatment of the vehicle (Step 1) is critical to ensure the removal of oils and dirt that might retard adhesion of coating materials. The phosphate rinse (Step 2) uses zinc phosphate to create a chemically developed surface coating that enhances corrosion protection and facilitates adhesion of electrocoating materials. The chemicals used for cleaning are captured in wastewater from the process, and treated at the facility before being sent to the local wastewater treatment plant. The next step in the process is electrostatic coating, or E-coat (Step 3), a process in which electricity is used to deposit paint film from a waterborne solution onto a metal vehicle body. E-coat paints provide highly effective protection against corrosion, and are applied using a dip tank system. Although E-coat application requires a large amount of energy, the system generates few other environmental impacts, operating as a closed system. Both wastewater and solid wastes (containing zinc) are produced during periodic cleaning and recharging of the system. After rinsing, the E-coat paints must be cured through an oven bake (Step 4).

The ovens in assembly plants (Steps 4, 8, 10 and 12) are large energy users, operating at temperatures of over 300 degrees Fahrenheit up to sixteen or twenty hours a day (depending on the number of shifts at a plant). There are two types of ovens used in automotive painting. Convection ovens are the most common, although infrared ovens are being installed in many renovated paint shops. Convection ovens heat the coating by first heating the oven air. Infrared ovens use a radiant energy that passes through the oven air without heating the air.[81] Infrared ovens are preferred for curing powder coatings, since there is no blowing air through the oven to disturb the position of the powder on the vehicle. The curing process is also where the majority of the VOCs and HAPs are emitted from the paint, as well as CO_2 from the oxidation process. Paint ovens are ducted to incinerators or other pollution control equipment to capture and destroy most of the volatile materials.[a] The amount of emissions from a

[a] High efficiency incinerators are most often used to destroy VOC emissions. Carbon absorption units are increasingly being used in newer automotive paint shops, although these systems require periodic treatment and recharge of the carbon bed. A detailed description of these devices may be found in the EPA Handbook on Control Technologies for Hazardous Air Pollutants, EPA/625/6-91/014, June 1991.

particular curing step of the painting process varies depending on the material used and the efficiency of the pollution control equipment associated with that oven.

Primer-surfacer coatings (Step 5) are applied to ensure a smooth vehicle surface for application of the topcoat. They are intended to "fill" or smooth any defects in the metal body from the stamping and assembly process. Surfacers are formulated so that they can be sanded after being applied to level out any minor roughness in the surface. Primer-surfacers also protect the vehicle substrate and corrosion protection coatings. Although some plants use a Uniprime system, which combines the E-coat and primer-surfacer steps, most plants use a high solvent material at this step, generating air emissions and overspray wastes. The cleaning chemicals used to clean equipment and paint lines also create waste solvents and air emissions. Additional protection from rocks and road salt is provided on an increasing number of vehicles by an antichip coating (Step 6). This coating, generally high in solvent content, is most often applied only to the lower panels and hood front of a vehicle. A growing number of assembly plants are using powder as an antichip, with some applying it instead of (or after) the primer-surfacer on the entire body of the vehicle.[a] Sealers (Step 7) are primarily used to enhance the adhesion of the topcoat and to prevent leakage into the vehicle body at the seams. These protective coatings are cured through an oven bake (Step 8). Both sealers and antichip material generate VOC emissions and solid wastes. Solvent-based antichip coatings can also create large quantities of waste, although at many plants these solvents are reclaimed and remanufactured by suppliers.

The topcoat system includes the basecoat and clearcoat paints, and is one of the largest sources of air emissions and solid waste of the painting process.[82] Basecoat (Step 9) is the color coating on a vehicle. It is most often a high solids, solvent-based paint, applied in one or two coats. Increasingly, however, waterborne paints are being used as basecoats in U.S. automotive assembly plants. The basecoat layer also contains any special effects, such as metallic flakes. It is the most noticeable and highly marketed element of the paint system.

[a] This process is termed "full-body powder" application.

The application of the basecoat is usually followed by an oven bake (Step 10), although some plants, particularly those using solvent-based technology, use a "wet-on-wet" process, applying the clearcoat over a basecoat that is not thoroughly dried. All waterborne paints must have a short bake cycle to flash off the water in the paint and prevent defects later in the process from water vapor escaping through the subsequent coating layers.

Spray application of paint produces a significant amount of waste paint through overspray (paint that does not adhere to the vehicle surface). Additional waste is generated through purging (cleaning) of paint lines and equipment during color changes.[a] This waste material has to be continually removed from the spraybooth to maintain a clean work area and minimize paint defects. A carefully monitored and controlled flow of air through the spraybooth is used to force overspray down through a grating to a waterwash system that runs under the booths in the paint shop. The waste material is treated with chemicals that attract the paint particles and allow separation of the solids from the water stream. The solids product of this treatment process is paint sludge, one of the largest waste streams from automotive assembly plant operations.[83] The water is generally reused in the waterwash system or sent to the local wastewater treatment plant for disposal.

Waterborne paints, while reducing the VOC content of the coating material, have created environmental challenges in other parts of the painting system. Purge materials from solvent-based paints are often collected by the solvent supplier for remanufacture and reuse, providing environmental "credits" for the automaker against calculated or measured emissions. With waterborne paints, however, the purge materials, while containing some solvent, have insufficient content for remanufacture, and become another waste stream for treatment. In addition, plants have experienced difficulties in removing waterborne materials from the booth waterwash systems. Foaming has been a particular problem in these systems, requiring

[a] Although some plants use a technique called block painting to minimize color changes, many plants change colors after every one or two vehicles, resulting in significant material waste and increased emissions.

additional chemicals for treatment. These chemicals, while reducing the foaming, result in higher solids contents of the resultant sludge (up to thirty or forty percent, by volume).[84] The clearcoat (Step 11) is the last material applied to the vehicle, and again, may be applied in one or two coats. The clearcoat, generally a nonpigmented, solvent-based paint, provides the final layer of protection to the overall finish, as well as the shiny appearance desired by the market. The application of clearcoat is followed by a final oven bake for curing (Step 12).

The last two steps in the process are used on vehicles requiring repair of defects. Paint defects may occur for five to twenty-five percent of production, and stem from a number of material and processing parameters. Dust and dirt are the most common source of defects, although sags, cratering, and orange peel effects in the finish may also occur. Paint viscosity, temperature, and variations in formulation among colors may impact the quality of the finish. Temperature shifts in the spraybooths or ovens, operating speed of the automated application equipment, and airflow in the booths are some of the operating variables that may be a source of paint defects. All assembly plants focus on reducing the amount of rework required, but at the same time accept only the highest quality products out of the paint shop. Vehicles may require either a full body repair (Step 13) or a spot repair (Step 14), depending on the extent and type of defect. Full body repairs basically send a vehicle back through the entire paint process. Spot repairs are done manually on small area defects, using special heat lamps for curing.

2.5. Overview of Major Environmental Regulations

Automotive painting operations are regulated at federal, state and local levels. The primary federal regulations and their focus are listed in Table 2.4.[85] Although the operating limits dictated by the Clean Air Act (CAA) and its related amendments are the primary concern for assembly plants, these facilities are also regulated by the Clean Water Act (CWA) for any wastewater discharges. Handling of solid and hazardous wastes are regulated by the Resource Conservation and Recovery Act (RCRA) and the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), otherwise known as Superfund. Paint manufacturers are impacted by these regulations as well as the Toxic Substances Control Act (TSCA), which regulates the development and commercial sale of new chemicals. These regulations have had a major impact on the development and implementation of paint technologies at automotive assembly plants.

Table 2.4. Federal Regulations Affecting Automotive Painting Operations

Federal Regulation	Area of Influence
Clean Air Act and related amendments	Facility and Process Design and Material Input
Clean Water Act	Treatment and Release of Wastewater
Resource Conservation and Recovery Act	Handling & Disposal of Hazardous & Solid Wastes
Comprehensive Environmental Response, Compensation and Liability Act	Disposal of Hazardous & Solid Wastes
Occupational Safety and Health Administration Standards	Regulation of Work Conditions at Manufacturing Facilities

The CAA and the related State Implementation Plans (SIP) developed throughout the U.S. have had a major impact on painting systems. The first regulation controlling solvent composition in the coatings industry was Rule 66, adopted in 1967 by the Los Angeles Air Pollution Control District. Rule 66 restricted the use of specific chemicals in solvent blends, based on an assumption that some elements contributed more to tropospheric ozone air pollution than others.[86] In 1970, the Environmental Protection Agency (EPA) was established and the 1970 CAA was passed. In developing the requirements of the Act, EPA used the model of Rule 66, which restricted the use of key chemicals. They added additional stringency, forcing changes in the formulation of basic coating materials and processes, attempting to reduce pollution at the source, while allowing the industries that applied the products some flexibility in how they would meet the standards through application of pollution control technology.[87]

The specific emission limits and control technology required for any one plant are determined on an individual basis through a negotiation process with the state and local agencies, and documented in the plant's operating permit. The emissions limits set for each plant are based on the control technology available when the permit was granted; major modifications to the facility affecting the process and related equipment require negotiation of a new permit. Existing facilities are required to use Reasonably Attainable Control Technology (RACT)[a] for VOC control. New sources, which include newly constructed facilities as well as those with significant changes to the paint process and related equipment since receiving their original permit, must meet the New Source Performance Standards (NSPS), which are more stringent. Many states have implemented more stringent emission limits than those specified by federal law. Operating permits for plants are structured to limit the VOC emissions for major steps of the painting process as well as overall emissions from the plant. The permits specify the pollution control equipment for the ovens and automated spraybooth zones, where the majority of the solvent emissions occur. Solvent incineration or carbon absorption are the two control methods most commonly recommended.[88]

The 1990 CAA Amendments added a new set of requirements and complications to assembly plant operations. The three major elements of the law that impact automotive assembly facilities are: new air quality classifications and requirements (Title I), including redesignation of ozone attainment areas; additional air toxics control (Title III); and new permit and reporting requirements under Title V. Title I establishes designations of "attainment" and "nonattainment" for geographic areas in the U.S. for the National Ambient

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[a] As defined in Section 182 (b) (2) (c) of the Clean Air Act Amendments of 1990. The EPA has established Control Techniques Guidelines (CTG) to help in defining appropriate control technologies.

Air Quality Standards (NAAQS) for criteria pollutants. In serious nonattainment areas, stationary sources are required to meet RACT standards, and must install equipment to reach Lowest Achievable Emission Rate (LAER) limits if they make major modifications to the facility. Currently proposed ozone standards would limit concentrations to 0.07 to 0.09 parts per million (ppm) measured over an eight hour period. The existing standard is 0.12 ppm measured over one hour.[89] Tightening this standard would place many automotive assembly plants in nonattainment areas, requiring additional restrictions on air emissions.

Title III establishes a list of 189 Hazardous Air Pollutants (HAPs), with associated plans for developing Maximum Available Control Technology (MACT) standards on major sources of HAP emissions. Many of these elements are also on the EPA list of seventeen priority chemicals for their 33/50 program, a voluntary program for reducing emissions of these key chemicals. MACT is defined as the "maximum degree of reduction in emissions...taking into consideration the cost of achieving such emission reductions and any non-air quality, health and environmental impact and energy requirements...achievable for new and existing sources".[90] For new sources, MACT must be at least as stringent as the level of control achieved in practice by the best controlled similar source in the industry. One interpretation of this requirement is that MACT could ultimately be more stringent than the LAER levels required for new automotive paint shops in the NSPS and more stringent than the RACT required for existing automotive paint shops. For existing sources, MACT is defined as the average performance of the top twelve percent best controlled sources in the source category, excluding recent LAER applicants.[91]

Development of the MACT standard for automobile and truck assembly began in 1996, with rules expected to be promulgated by the year 2000. Although MACT standards may be achieved through process and material modification, as well as installation of accepted control equipment or operational standards, they are expected to be primarily technology-based standards, with some provision for consideration of cost of control. In automobile and light-duty truck manufacturing, the principal focus is likely to be on HAP emissions from the major coating operations at assembly plants. The expectation is that the new emission limits will be set even lower than current limits.[92] However, there is a provision in Title III that stationary sources can obtain a six year extension on compliance with MACT standards is there is a significant reduction of emissions prior to the proposal of MACT standards for the source category. This option may encourage some automotive assembly plants to incorporate new technologies and materials prior to the development of the standard itself.

Title V requires states to implement a federal operating permit program. All major stationary sources will be required to obtain a new permit, and to update the permit every five years. The permit has three major requirements. First, facilities must compile and present detailed information on emissions from all significant sources. Second, the permit incorporates all federally enforceable requirements for each emission source into a single document. Finally, the facility must institute detailed monitoring and recordkeeping procedures for each applicable requirement on each emission source.

The upshot of the current regulatory requirements for air emissions is that the design space for formulators has been increasingly narrowed. There are fewer solvents available that can meet the increasingly stringent regulations, and the more effective solvents are likely to be further restricted from use through the HAPs regulations. Formulators must balance performance with regulatory status and cost-effectiveness, in an extremely competitive market. The continued proliferation of state and local regulations further complicate the way coatings are formulated, manufactured and sold. California, in particular, requires that finishers apply extremely high-solids coatings, or switch to waterborne or powder coatings.[93]

As important as the CAA has been and continues to be in driving technological change in paints and coatings, environmental regulations that cover the handling and disposal of hazardous wastes are other areas of concern. The implementation of RCRA and CERCLA have had a major influence on the strategies of assembly plants in dealing with their solid and hazardous wastes. RCRA mandates strict accountability for wastes from their generation through final disposal, while CERCLA is directed at cleaning up old, abandoned waste sites. These regulations focused attention on a broad range of chemicals as long term sources of environmental impact, and set in motion a move away from landfill as the disposal method of choice for solid and hazardous wastes.

The major purpose of RCRA is to control solid waste management practices and to encourage resource conservation and recovery. Solid wastes are defined in the Act to include any form in which hazardous or toxic substances may exist, including waste solids, sludges, and liquids. It establishes a strict set of permit requirements for operators generating or treating hazardous waste, and mandates a tracking system for accounting for wastes from generation through transport and final disposal. The new requirements established for landfills containing hazardous waste increased the cost of land disposal signicantly. Many traditional constituents of paint pigments, such as cadmium and lead, were totally banned from landfill. Paint sludges containing toxic chemicals were clearly identified as hazardous waste, and disposal of these materials was expected to become significantly more expensive. The elimination of many of the regulated and banned substances from new paint formulations has led to the classification of most paint sludges as solid, not hazardous wastes. Those that still contain hazardous elements generally require treatment before they can be disposed.

The costs of past practices for waste disposal became a major issue for all industrial facilities with the requirements established by CERCLA. This legislation placed the financial responsibility for cleanup of sites with the original generators of the waste. Amendments to CERCLA in 1986 established the Emergency Planning and Community Right-to-Know Act (EPCRA), which required companies to disclose to the public many of the chemicals released from their operations, even if those releases were within permitted limits. Some automotive companies see CERCLA as a bigger problem for them than the CAA, requiring the expenditure of millions of dollars in cleanup of old sites.[94]

The Toxic Substances Control Act (TSCA) impacts the paint manufacturers rather than the automakers. This legislation was directed at controlling the risks involved with commercial chemicals, attempting to determine potential environmental and health effects before allowing new chemicals to be commercialized. The review process required for new chemicals is onerous and expensive, making it difficult for paint manufacturers to include new chemicals in paint formulations.

Environmental regulations, while providing strong incentives for product change, also contain barriers to change through technology-based standards and restrictions on new product development. The requirements of the CAA, while not the only regulations to be considered in automotive painting, have been the most influential in encouraging technological change. The standards for VOC content in paints and coatings were established to force the development of substitute technologies and new coating materials such as waterborne and powder paints that could meet the performance requirements of the automotive industry with lower VOC emissions. However, until a more stringent standard was developed for the user community, the costs of switching to the new material seemed higher than the costs of installing pollution abatement equipment, much of which was required in any case based on the operating permits obtained for these facilities. The potential risks to product quality were also a factor in the reluctance to change materials, given the importance of the performance of the coating system (both in appearance and durability) in an increasingly competitive market.

Several major trends shifted attention away from the use of pollution abatement equipment to the adoption of new coating materials. First, there was an increase in the level of action by states in developing and implementing rules under specific State Implementation Plans (SIPs). This created a patchwork of regulatory requirements across the nation, some of which were more stringent than federal law (for instance, California), some of which were less stringent, and some of which were nonexistent.[a] Meeting many of these requirements with abatement equipment alone was extremely expensive and timeconsuming. Second, the CAA Amendments (CAAA) of 1990 shifted regulatory focus once more, further restricting allowable levels of VOC emissions in general, but also prohibiting the use of specific

[a] P. Portney provides additional detail on the difficulties in implementation of the regulations that this scheme created--not only for manufacturers, but also for achieving national policy goals relative to clean air. (See P. Portney, ed., Public Policies for Environmental Protection, Resources for the Future, Washington, D.C.,1990).

chemicals and solvents that were in the past designated as non-VOCs. For instance, 1,1,1-trichloroethane, which had achieved widespread popularity in coatings as a "compliant solvent", especially well-suited for spray applied, fast drying coatings (such as automotive paints) can no longer be used. A new list of specific compounds (HAPs) was singled out for emissions reduction activity. The list includes some of the most effective and widely used solvents in coatings systems, such as toluene, xylene and methyl ethyl ketone.[95] The new stringency of the CAAA and the increasing cost of pollution control equipment sparked the interest of automakers in new, lower VOC materials. Coatings manufacturers found that "the Clean Air Act caused us to form much closer partnerships with our customers to help them become environmentally compliant".[96] Third, new technologies (waterborne and powder) were gaining market share in Europe and were increasingly being tested and demonstrated in plants in North America. Improvements in the technologies themselves and their abilities to meet the performance needs of the automakers helped sell the new technologies.

While implementation of new regulations under the CAAA are developing along traditional paths, a series of innovative regulatory approaches are also being pursued by EPA to try to encourage environmental improvements by industry. Many of these programs emphasize voluntary partnerships with companies (such as the 33/50 program, which targets the reduction of releases of seventeen toxic chemicals to the environment[a]) or industry sector approaches to compliance, rather than media-specific standards. The Common Sense Initiative (CSI) is one of the industry sector programs, specifically designed to allow companies greater flexibility in how they meet the goals of environmental regulation. This program hopes to encourage more innovation in environmental technology that exceeds current standards while at the same time cutting costs.[97] While these approaches to compliance are still in the early stages of development, they do suggest potential future directions for environmental regulation.

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[a] This program is described in more detail in S. Arora and T. Cason, "An Experiment in Voluntary Environmental Regulation: Participation in EPA's 33/50 Program", Journal of Environmental Economics and Management, 28 (1995): 271-286.

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Chapter 3. Innovation in Automotive Paints and Coatings

This chapter is directed at the first hypothesis of this dissertation, which proposes that ***innovation in cleaner technologies is initiated by the supplier*** in automotive painting systems. New paint materials that provide environmental improvements are expected to develop as a result of research investments by suppliers with the technical competence and strategic interest in developing innovative products. Successful innovation, however, requires that inventions be integrated into production systems, or adopted, by the user community. The two components of successful innovation, invention and adoption, are explored using several methodologies (see Figure 3.1). An industry survey was used to provide primary data on inventions in automotive paints and factors important to their adoption in automotive assembly plants. Perspectives from the three major U.S. automakers and paint manufacturers were included in this survey. Patent analysis provided additional data on paint and coating inventions and was particularly useful in tracing changes over time. The first part of this chapter presents results on the source of inventions in automotive paint and coating technologies. The second part of this chapter highlights the important factors in decisions to adopt new coating systems.[a]

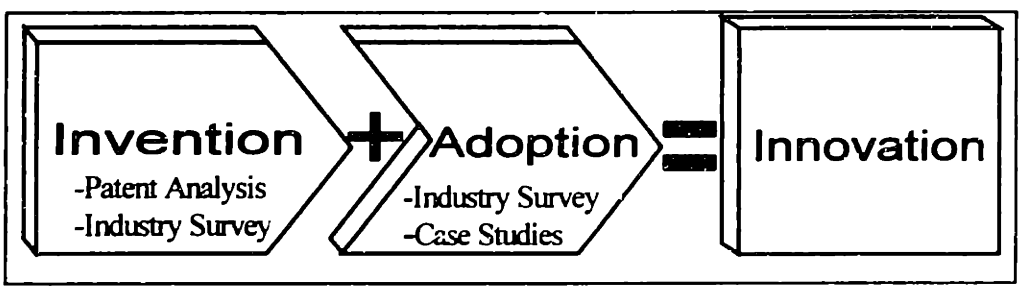

Figure 3.1. Research Approach for Tracing Innovation in Automotive Paints and Coatings

Von Hippel[1] points to the importance of accessing and tracing trade literature in identifying the source and path of innovations. His research often makes use of semistructured surveys

[a] Additional data on technology adoption decisions and their effects on environmental performance at assembly plants is provided in the case studies in Chapter 4, which address the second hypothesis, introduced in Chapter 2.

for defining the sources and motivations for innovation in particular technologies. His methods have been broadly tested over time in a number of industries, with a variety of technologies, and have been shown to be useful in clarifying the sources of technological innovation. Abernathy,[2] whose early work focused on the automobile industry, also used trade literature to understand the paths and timing of key innovations. In addition, he demonstrated the usefulness of patent data in exploring sources of innovation. An evaluation of patent activity at Ford Motor Company over time was used by Abernathy in his seminal work on technological innovation in the automotive industry.[3] The research approach used here includes both a semistructured survey and patent analysis to determine sources of innovation.

Industry Survey

Primary data on the sources of innovation in automotive paints and coatings was obtained through a technology survey of industry experts in automotive paints and coatings. The survey, a semistructured, open-ended instrument, was also one source of primary data on the decision process for adopting new technologies in automotive assembly plants and the role of suppliers in implementing change. Selected questions from the survey are shown in Table 3.1.[a] Survey questions were initially derived from an extensive literature review and modified to reflect input from experts on technology innovation, automotive assembly processes and environmental management. The form of the questions was refined through consultation with experts in technology management and organizational analysis research methods.

Participants in the survey were selected from the three major U.S. automakers (General Motors Corporation, Ford Motor Company, and Chrysler Corporation) and automotive paint manufacturers [b] (DuPont Automotive, PPG Industries, Inc., and BASF) to capture the views of both groups. Perspectives were obtained from individuals at three different levels in each

[a] The complete survey instrument is shown in Appendix A.

[b] This analysis focused on paint suppliers and automakers. Paint equipment suppliers, although important in designing paint systems and enabling the commercial success of many paints and coatings materials, have not historically been a significant source of innovation in paint formulations.

company: corporate; research and development (R&D); and assembly plant or product application. The primary targets were those involved in automotive paints and coatings R&D (inventions) and those involved in decision-making for developing or implementing new technologies (adoptions). All interviewees had extensive technical and operational experience (more than ten years in all cases, almost twenty years for many) in automotive paints. Access to individuals was generally obtained through a central contact, who directed inquiries to those most knowledgeable and able to provide the perspectives desired for the survey. Individuals agreed to participate in the survey on the condition that their responses

Table 3.1. Selected Questions from the Industry Technology Survey

Inventions and Technological Change
New Product Development: Have your R&D priorities shifted over the last 10-20 years? Are there new focus areas and specialties (for instance, environmentally-related competencies)? Has the interaction among automakers and paint manufacturers changed?
Ideas for New Products: How does the network of relevant firms (paint manufacturers, basic and intermediate chemical manufacturers, and automakers) work together in formulating new products? What are the roles of each of these firms? Are equipment manufacturers involved? If so, to what extent?
Incentives for Technological Change: What are the primary incentives leading to technological advances in paints and coatings? How have performance parameters for paints and coatings changed over the years? What challenges must be overcome to get broader use of emerging technologies (i.e., powder, radiation cure, in-mold color)?
Adoption of New Technologies
Primary Decisionmaker and Influencers: How are decisions about implementing new paint/coating technologies made? What role do paint manufacturers play in those decisions? What about environmental staff? Others? Do corporate level, industry or government voluntary programs (such as company environmental policies, the Responsible Care program, or the EPA 33/50 program) impact product decisions?
Critical Technology Factors: What are some of the key criteria and tradeoffs considered in selecting new paint formulations and technologies?
Role of Suppliers in Implementation: What role do suppliers play in implementing new technologies at assembly plants?

would be treated confidentially, and that company names and personal affiliations would not be included in the published results. Survey data is reported in the aggregate to maintain this confidentiality.

Data was gathered primarily through telephone interviews. Questions were faxed to the respondents several days in advance, and detailed notes were prepared following each interview.[a] Some interviews were conducted during site visits to assembly plants.[b] The sample size was insufficient to allow statistical analysis of the results. The consistency of responses across all target categories and companies, however, and the congruence of results with published government and industry sources suggests validation of the survey data as representative of the broader industry perspective. Results of the survey are summarized in this chapter in two sections. The first focuses on the development of new technologies in paints and coatings and includes data from the patent analysis. The second addresses the decision process by automotive companies in changing paint technologies and related materials and the role of suppliers in that process.

Patent Analysis

An evaluation of patents filed over time was performed to determine the locus of R&D activity in automotive paint and coating materials formulation and whether that locus has shifted over time. The analysis was conducted in a two-phase, iterative approach. First, the major inventions and associated patents in the field of organic coatings, segmented into categories as shown in Table 3.2 (next page), were reviewed for the years 1994 and 1995 to determine the appropriate U.S. patent classifications to be used for a more intensive patent search.[4] Each patent in the first six categories was reviewed to determine the nature of the invention, the company or individual to whom rights were assigned, and the major classification and subclasses under which the

[a] Interviews were about 45 to 75 minutes in duration.

[b] In some cases, the number of interviews was limited due to lack of access to company personnel, but was balanced overall between the automaker and paint supplier perspectives.

patent was filed. Patents that clearly did not apply to automotive coatings were deleted from further consideration. The remaining patents were reviewed to determine the primary patent categories for detailed analysis.

Table 3.2. Categories of Inventions Used to Determine Patent Search Classifications

Invention Categories
1. Pretreatment
2. Electrocoating
3. Ultraviolet Curable Coatings
4. Powder Coatings
5. Waterborne Coatings
6. Other Coating Formulations
7. Application and Curing Methods, Systems and Equipment
8. Paint Stripping
9. Testing and Control
10. Air and Water Pollution Control

The second step in the analysis was an intensive search of the broader U.S. patent data base, covering all patents filed from 1955 on.[a] The analysis was limited to U.S. patents for two reasons: first, companies that believe they have a potentially profitable invention will generally patent in several countries, including the U.S., to protect the invention;[5] and second, the focus of this research is on U.S.-based automakers and paint suppliers. The scope of the analysis concentrated on the years available in the computerized database of U.S. patents. The results of the patent analysis are discussed in this chapter in the section on inventions in automotive paints and coatings.

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[a] Patents filed after August 1996 are not included in this analysis.

3.1. Inventions in Paints and Coatings

Results from the industry survey on technology developments in automotive paints and coatings provide evidence that the primary sources of inventions today are the paint manufacturers. A summary of survey results on sources of innovation is shown in Table 3.3 and discussed below.[a] Historically, both suppliers and automakers maintained research groups in paint formulation and application. As automotive companies began to focus their resources on areas of expertise considered core to their business, they began to increase their

Table 3.3. Summary of Industry Survey Results on Inventions and Technological Change in Automotive Paints and Coatings[b]

Survey Questions	Automaker (A) Respondents (%)	Paint Supplier (P) Respondents (%)
New Product Development Primarily by:		
Paint Suppliers	100	92
Automakers		8
Ideas for New Products Come From:		
Paint Suppliers		
Automakers		
Both Suppliers & Automakers	100	100
Environmental Criteria Primarily Considered in:		
Material Formulation	100	80
Plant Application		20
Incentives for Technological Change		
Environmental Regulations	100	100
Improved Performance	75	100
Competitive Advantage	62	58
Pressure from Automaker	25	33
Cost	12	25

[a] Industry affiliations of survey respondents will at times be noted in the discussion with the shorthand notations of (A) for automotive companies and (P) for paint manufacturers.

[b] Responses to survey questions are shown in terms of percentages of respondents providing that answer. Many questions allowed more than one response, and may show totals of more than 100%.

reliance on suppliers for product innovation, performance testing and quality assurance.[a] When looking for cost reductions in R&D departments, the paint shops were a particular target due to the duplicative nature of the work, according to one interviewee who had held a senior position in both paint manufacturer and automotive R&D groups during his career. The automotive companies retained their expertise in paint application however, focusing their research and development efforts on understanding the critical parameters of the painting process within the assembly plant and identifying new performance needs. Improvements in transfer efficiency, film builds and finish quality are some of the topics explored in their research, as well as advances needed in equipment and related process control to implement some of the newer paint technologies. Research in paints at automotive companies is also focused on testing supplier innovations for performance and operational issues. The effects of changed formulations on amount of paint overspray is a major concern, for example.

The paint manufacturers have focused on building the technical competence in chemistry and paint formulation required in support of their core business, creating new materials and coatings products to meet the needs of a variety of customers. The invention of a new coating is an expensive and complicated effort. The color, reflection, corrosion protection and other performance parameters of paint products are achieved through an intricate recipe of combinations of certain chemicals under specific curing conditions. Innovation in products is an important mechanism for gaining market share in an extremely competitive industry.[6] A senior manager of paint applications (P) says that "as paint makers, we need to develop new products--constantly. That is how we make money. We are always looking for unmet needs." Paint manufacturers have traditionally made the major investments in research, development and product testing necessary to develop new coating materials, colors and innovative paint products. They maintain currency on environmental requirements and provide a range of products to support different corporate strategies and environmental policies. New chemical

[a] The divestment of research groups in paint formulation has occurred at different times for each automaker. Ford maintained an internal paint formulation and development group until the mid-1980s, when they sold that part of the business to DuPont. Chrysler has traditionally outsourced most of their research needs in this area. GM continues to support research in paint processes, but currently relies on suppliers for most of their formulation work.

formulations have to be approved under the Toxic Substances Control Act (TSCA) before they can be marketed, a costly and timeconsuming process.

All survey respondents agreed that the primary capability for developing new, innovative products in paints and coatings currently resides with the paint suppliers.[a] Automaker respondents at all levels (research, corporate and assembly plant) viewed the paint manufacturers as the locus for innovation in materials and coatings. An R&D manager (A) said that "the major source of new ideas and innovation in paint formulation is the suppliers; they do a lot of initial development and testing of new paint formulations before they come to us". This view is echoed by corporate managers (A) who stated that "suppliers formulate the new products. Then we work with them to test for processability". This is particularly the case with dramatic improvements in basic materials properties, such as improving durability of a paint, according to R&D staff with the paint manufacturers.

The ideas for new products, however, come from both the supplier and automaker staff. The process of identifying needs for new products is highly interactive. "New ideas for products come from both the paint suppliers and the automakers--there is always an ongoing discussion between us, and it is never just one or the other driving the innovations", according to managers of R&D in both paint and automotive companies. Paint manufacturers conduct their own research, working on a variety of innovations, from basic chemistry breakthroughs to products that are targeted toward a specific customer. Many of the new colors and special effects developments in automotive paints are a result of supplier-initiated research. The new generation of lower solvent paints and shifts from inorganic, heavy metal pigments to organic elements is also the result of extensive research by paint suppliers. Paint suppliers will often develop a new product that they believe meets current or future customer needs, presenting the new ideas in formal meetings or informal discussions with automotive companies.

[a] A minority of paint supplier staff located at the assembly plants felt that automakers determined the direction of product development, but agreed that the paint manufacturer has the primary capability for new formulations.

New product needs are also identified by the automotive companies, which share results of market research on customer needs or specific performance improvements with suppliers to accelerate development work. The data from warranty claims and customer surveys are used to identify new product performance requirements. For instance, both corporate and R&D managers in automotive companies referred to market data that shows people keeping cars longer than they used to, leading to needs for paints that retain their quality and durability over longer time periods. Research managers in both automotive and paint companies stated that "the life of a paint system today is seven years; we need to extend that to ten years." Another new customer driven demand is the emerging desire for a scratch resistant paint system that stands up better to the brushes used in automatic car washes. This has prompted research on the mechanisms of scratching, which will lead to the design of molecules that can provide better scratch resistance.

Another source of ideas is the process and performance R&D conducted by the automakers. They do invest in research on film durability and process-related issues, and, according to R&D managers (A), "often discover things related to materials formulation that we pass back to suppliers. We discover things, for instance, about paint failure mechanisms, which support better understanding of crosslinking mechanisms and help develop basic knowledge of formulations". Paint company R&D managers agree that, while the suppliers are the primary developers of new products, the automotive companies have significant technical capabilities and large research budgets. "When they target a particular technical area, they can uncover things we do not know."

The development of new products often takes place jointly between the automaker and paint supplier. There are close linkages between these groups at all levels, with frequent communication among companies and their research groups, and an intimate knowledge by the suppliers of the needs of the automakers. The interdependence of the paint product and the application process has served to strengthen these links. As put by one R&D manager (A), "paint suppliers not only understand the needs of the automakers, they are very responsive in finding solutions and providing innovative approaches through new formulations". Several respondents from automakers credited the paint manufacturers for the significant reductions in emissions from automotive assembly plants over the last decades through the use of new paint technologies. They achieved these results, working with their customers, while improving the performance and appearance of the product at the same time.

The process of innovation in paints is extremely interactive. Many of these companies have a very disciplined process for working together. In addition to the technical and/or marketing people that the paint supplier locates onsite in an assembly plant, there are also detailed project review meetings held several times a year. All of the major paint suppliers now have satellite facilities located near their customers, and larger facilities near the corporate decisionmakers in Detroit. Paint company managers highlight the importance of staying close to the customer and continually improving their products. The competition in the industry makes it important to have a close connection with the customer and to offer new, improved products that meet market needs and/or reduce production costs. The level of guidance given to suppliers in what those needs are seems to vary among companies. Some automakers give specific direction on the areas in which they are looking for improved performance or new products; others give suppliers more general input. The challenge of developing a material that meets environmental needs and can be successfully and cost-effectively applied in a plant environment has required continued dialogue between these groups.

The importance of application equipment in the successful application of new coating systems led respondents from paint companies, particularly in research positions, to suggest that a stronger link between paint formulators and equipment developers would be useful earlier in the formulation process. There is currently not much interaction during development with equipment suppliers. Part of the reason for that, from an R&D manager's point of view (A), is that although processability of the material is important, "we haven't yet learned how to design molecules for better sprayability". Formulations are developed, then adjusted based on the equipment at particular plants with which they need to work. Managers of R&D (P) suggested that the interface with the equipment suppliers is "one we don't emphasize enough--especially now with the increased demands on paint products". The sensitivity of the coatings to the design of the application equipment makes a stronger link with equipment suppliers important, particularly in the latter stages of product development.

Environmental criteria for paint and coating materials are for the most part considered in the formulation stage. The suppliers are relied upon for understanding the environmental requirements for paints and coatings, and developing new materials that will meet the additional requirements mandated by emerging regulations.[a] Any new product is expected to have been thoroughly tested before the formulation is ever brought to the automaker. According to research managers at automotive companies, "a supplier wouldn't even bring in a formulation that didn't meet basic regulatory requirements". The suppliers incorporate environmental criteria very early on in the development process for new formulations and colors. Research managers in paint companies reinforce the importance of environmental criteria in the development of all new products. There are maximum allowable solvent levels, which cannot be exceeded. There are specific solvents that may not be used at all. There are targeted materials (other than solvents) that have been restricted from use by company policy, in addition to those regulated by the EPA. "Looking for more environmentally friendly products is a big driver for us", say R&D managers (P).

The new product regulations under TSCA create additional pressures and constraints for paint manufacturers. The EPA approval of new materials is a lengthy process, and often a barrier to the introduction of new products. The restrictions put on new chemicals prevent the introduction of new products that might lower HAP emissions, say some R&D managers (P). All materials sent offsite from the paint manufacturing plant must be registered under TSCA, either as an R&D material, a new product with previously registered constituents, or as a new material with new chemical elements, requiring permit for sale. According to the paint manufacturers, "these restrictions force us to make conscious decisions on the materials we use in our formulations".

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[a] For instance, the Clean Air Act Amendments of 1990 mandate the development of new emission standards for VOCs and HAPs at automotive assembly plants. These standards are currently scheduled to be issued in 2000.

Paint manufacturers design products for a number of customers. "Ultimately, what we do depends very much on the strategy of our particular customer, the automaker", say paint manufacturers. They will work with the customer to formulate products according to their needs. Paint manufacturers have experts in applications that analyze the entire coating system to determine what is needed for a particular plant, and how to take solvent out of the various layers of the coating system. Products are then formulated for those specific plants. In working with a customer to determine the appropriate set of products for a plant, suppliers need to understand the local regulations, the facility layout and equipment, and then look at each layer of the system to identify where they can most effectively reduce solvent and still retain the performance properties of the system. They may decide to reduce solvent in the primer-surfacer, rather than reducing solvent in the clearcoat. There are a number of tradeoffs that can be made effectively when dealing with the set of products as a paint system rather than as separate materials. All automakers are interested in having a coating system that complies with the regulated limits for their plant. Some customers want to achieve the compliance limits with minimal product change. Others are interested in going beyond compliance to dramatically improve environmental performance.

One issue in developing new technologies raised by paint manufacturers is the balance between the need to offer new products and the expected return in the market. Each paint manufacturer has different strategies that drive their investments in new product development, as do the automakers. The paints and coatings industry is extremely competitive, and suppliers must meet the demands of a large diversity of customers. There are relatively low margins for many products, and investing the millions of dollars in R&D and testing for a new product is done only with some certainty that a customer is interested in the output. New formulations often demand new polymers and fundamental shifts in chemistry that drive up the costs for raw material inputs. Paint manufacturers see a large difference between customers in the U.S. and those in Western Europe. "In general", they say, "our European customers are much more willing to pay for higher environmental performance. For them, it is a marketing tool and advantage. Over here [in the U.S.], few companies are willing to pay more for environmentally better paints. They'll take it if we offer it--but are not willing to pay". Responses from both automakers and paint manufacturers suggested that while environment is an important design factor, the additional costs in using new, environmentally improved materials were often a barrier to adoption, particularly if there is any debate about product performance or durability.

Survey respondents viewed environmental regulations and increased performance requirements as the primary incentives for technological change in automotive paints and coatings. The opportunity for companies to gain competitive advantages from new technologies were also cited as a major incentive for change. A small number of responses suggested that product advances were also directed by requests from automotive companies for particular product features or the need to reduce costs, but agreed that the ability to meet performance and quality needs and satisfy environmental requirements at a competitive price is the major incentive for product development in paints and coatings.

R&D managers (A) said that the paint suppliers feel environment is a key factor of importance. To the automaker (both research and applications staff), however, it is simply one of a number of factors that must be considered, and one for which they cannot sacrifice performance. "The first application of powder paints, for instance, was driven by its performance qualities. The fact that it also had environmental benefits was helpful, but not the primary driver". Corporate managers (A), on the other hand, saw environmental regulations as major drivers for change. The uncertainty of the regulatory requirements in the future is an important issue for them. "As the list of chemicals and constituents of regulatory interest grow, we may need to change technology again in the future--we never know what will appear on that list from day to day". Substitutes now need to be found for many of the HAPs used in waterborne paints that are being prohibited by the CAA Amendments.

New performance demands from vehicle buyers are another major driver of technological change. Marketing studies by the automaker and by paint manufacturers, customer surveys and vehicle warranty claims are some of the mechanisms used to identify new consumer demands. Customers today want more durable paint finishes, in a variety of colors, with good resistance to chipping and scratches. The paint must be able to retain its color and shine over long periods of time. New color schemes and improved durability require new chemical formulations. The advent of metallics in paints, for instance, led to the need for new chemistries in paint products. One of the challenges in developing new paint products stated by corporate level survey respondents from both automakers and paint manufacturers is that the performance parameters of yesterday's technology have become the minimum expectation for the next product. Changes made in a formulation to improve environmental qualities or durability cannot negatively impact other important product characteristics, such as resistance to fading. These difficult tradeoffs encourage continous evolution and innovation in paints, because both automakers and suppliers are always looking for a better product.

The ability to gain competitive advantage in the marketplace was another reason given by respondents for the development of new technology. Both paint manufacturers and automakers can gain market share with the development of a new, innovative product. Novel colors or visual effects in paints are an important part of the marketing strategy for many automakers and suppliers. Color includes a range of special effects, beyond just the color itself.[a] Some paints show as different colors when viewed from different angles, or include metallic or pearlescent effects. These special effects can have a major impact on the sales of a vehicle. Industry studies indicate that over thirty percent of prospective car buyers will switch models and makers if necessary to obtain the color they want.[7] Development of new colors can also revitalize lagging sales of a vehicle in the later years of production. New paint technologies that focus on the development of special characteristics or visual effects also represent high margin products for paint manufacturers. Automakers are likely to pay higher prices for these innovative products, since they can more easily pass the costs onto consumers.

Paint manufacturers play a lead role in the development of color. They track color trends and develop color shows for automotive designers, who select colors at least three years in

[a] That in itself can be quite complex. One respondent talked about having to choose among twelve shades of black for a fascia, each with subtly different basetones (reds, blues, yellows). These all have to match the final exterior body color and match or coordinate with the interior plastics, seat covers, and accessories.

advance of being used on a particular vehicle. Suppliers are closely involved with color decisions and increasingly with technology choices (solvent-based or waterborne, for instance) to ensure that a particular color can actually be manufactured to meet the customer's performance needs and facility requirements. Paint manufacturers that develop new technologies to either increase market appeal or reduce production costs have advantages in an increasingly competitive marketplace.

Results of the patent analysis provide additional insight on the source of innovation in automotive paints and coatings. Patents do not measure innovations directly, since many patented inventions do not become commercial successes. They are a primary indicator for inventions, however, and are also extremely useful for indicating the direction of technical research within a company. "On average, more patents would be anticipated in areas of greater technical activity and vice versa."[8] Patents can thus serve as indicators for helping to understand the shifts in investments in automotive paint and coating technologies by suppliers and automakers over time. Shifts in R&D focus are expected to be reflected by changes in patent activity.

There are differences among industries in the competitive advantage of patents. For a company to have the incentive to invest in R&D, they must be able to appropriate the returns, and ideally, prevent their competitors from accessing the new technology. Patents are only one mechanism for protecting the R&D investments of a company, and are not necessarily appropriate for all technology types. Research by Levin et al. shows that R&D managers consider patents for specific products to be more effective than patents for processes. Secrecy is more often used to protect process innovations. Secrecy is not as effective in protecting products because information on the products and the technology it embodies is often critical to successfully marketing the new product.[9] Some industries do not invest in the considerable costs to get a patent because it would inform competitors of ongoing research directions, perhaps giving them an early lead. Many patents do not provide the protection desired by a company, either because they can be circumvented or because there are strict and onerous legal requirements to prove that they are valid or that they are being infringed. For some industries, initial innovative activity in technology may be less important as a competitive advantage than focusing on gaining product development lead time, exploiting learning curves, or building on complementary assets such as marketing and customer service.[10]

For the chemicals industry, however, patents are viewed as a key mechanism for protecting and marketing inventions.[11] Patents can raise the imitation costs of a product by 30 points for major new chemical products and by 25 points for typical chemical products. This compares to raising costs by 7-10 points for electronics and less for other industries.[12] The standard use and effectiveness of patents in the chemical industry and related products supports the usefulness of patent analysis as one measure of tracing the levels of innovative activity in paint formulation. Patents are particularly effective for chemical products because relatively clear standards can be applied to assess the validity of the patent and to defend against infringement. "The uniqueness of a specific molecule is more easily demonstrated than the novelty of, for example, a new component of a complex electrical or mechanical system."[13]

Two groups of patents (listed in Table 3.4, next page) were analyzed to identify the primary sources of inventions in automotive paints and coatings and any shifts in activity by companies over time. The Group A classifications focused on new coating compositions and application processes. Group B classifications included a greater number of patents in new paint and material formulations. The category of electrical and wave energy primarily included new electrocoating materials and techniques. Key words (including automotive, motor vehicle, paints, coatings, electrocoating, primer, clearcoat and basecoat) were used to search the title, basic abstract, and primary classification of patents in these groups to identify those relevant to this research. The resultant data sets were the primary focus of this analysis.[a]

[a] Although possible that other relevant patents were filed in other classifications and categories, a detailed review of a subset of the specific patents produced by the computerized sort and an additional review of patents by company suggests that this process captured the vast majority of the relevant patents.

Table 3.4. Categories of U.S. Patent Classifications Reviewed

Group A Classifications *	**Group B Classifications**
Coatings & Compositions--Apparatus & Processes	**Chemistry & Synthetic Resins, Wave Energy**
# 106: Compositions: Coating or Plastic # 118: Coating Apparatus # 427: Coating Processes	# 204: Chemistry: Electrical & Wave Energy # 523: Chemistry: Synthetic Resins or Natural Rubber # 524: Chemistry: Synthetic Resins or Natural Rubber # 525: Chemistry: Synthetic Resins or Natural Rubber

* Categories # 148 (Metal Treatment) and # 239 (Fluid Sprinkling, Spraying & Diffusing) were also reviewed for completeness, but did not yield additional patents of interest.

The top twenty companies in each patent group (A and B) are shown in Table 3.5 (next page). While paint manufacturers constitute a majority of these companies, automakers, including Ford Motor Company and General Motors Corporation, are also represented in the top ten. Japanese paint and automotive manufacturers constitute a significant percentage of the total patent activity in this area, as do European paint companies. These data represent total patent activity over four decades. To understand whether the R&D priorities of a company shifted over time (using patents as proxies for levels of investment), this data was analyzed over time. Patent activity in four time periods was analyzed for each of the target companies (the three major U.S. automakers and paint suppliers). These time periods were selected to reflect key events in the industry (i.e., the period prior to environmental regulations; the advent of environmental regulations for paint manufacturers in the mid-1960s; the increased pressure on manufacturers in the 1970s to reduce environmental emissions; and the passage of major environmental legislation on hazardous waste and new clean air standards in the last decade). Results of this time-phased analysis are shown in Figures 3.2 and 3.3 (pages 80 and 81).

Patent activity over time for Group A classifications is shown in Figure 3.2. Although both Ford Motor Company (Ford) and General Motors Corporation (GM) show some R&D investment in most time periods, the paint companies (DuPont, BASF and PPG Industries, Inc.) show a much higher level of R&D activity, as measured by number of patents granted. The data also suggest an increase in new inventions in the later time periods, particularly in the last decade. This data seems consistent with the hypothesis that the suppliers are the source of inventions in paints and coatings, and that the increasing pressure from environmental regulations is certainly an influence on the priorities of this industry. Ford is the only automotive company showing a significant increase in patent activity during the period 1976 to 1985. But that is followed by a decline in patent activity since 1986, signalling a shift from research in paint formulation and materials.

Table 3.5. Top Twenty Companies and Numbers of U.S. Patents (1955-1996)

	Group A	Group B
Rank	**# of Patents/Company**	**# of Patents/Company**
1	36 / DuPont	164 / DuPont
2	16 / Ford Motor Company	46 / Ford Motor Company
3	16 / PPG Industries, Inc.	29 / BASF
4	14 / BASF	26 / PPG Industries, Inc.
5	13 / Honda	13 / Dow Chemical
6	12 / Toyota	13 / Nippon Paint Co.
7	11 / Nissan	8 / Inmont Corp.
8	10 / Mazda	8 / Kansai Paint Co.
9	6 / General Motors Corp.	7 / 3M
10	6 / Herberts	7 / Nissan
11	6 / 3M	6 / Ciba-Geigy Corp.
12	6 / Nippon Paint Co.	6 / Shell Oil
13	6 / Nordson Corp.	5 / Herberts
14	5 / Behr-Ind. GMBH	5 / Imperial Chemical Industries
15	5 / Gencorp	5 / Mitsui Toatsu Chemicals
16	5 / Inmont Corp.	5 / Takeda Chemical Industries
17	5 / Kansai Paint Co.	4 / Sherwin-Williams
18	4 / Akzo	4 / Shinto Paint Co.
19	4 / Ciba-Geigy	4 / Toyota
20	4 / Hoechst	3 / Akzo

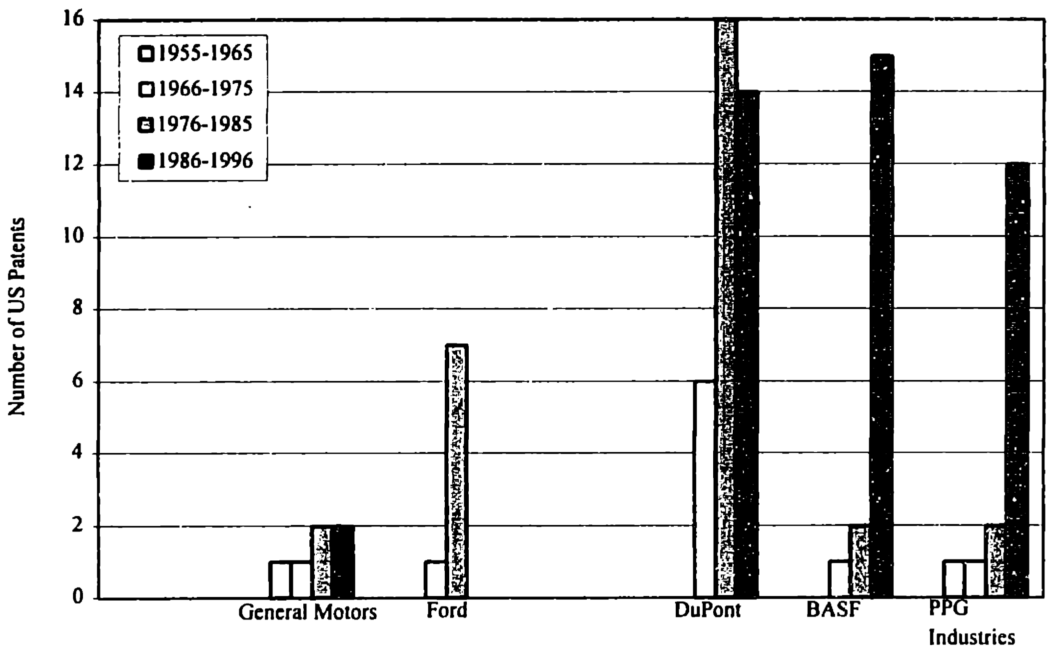

Figure 3.2. Patent Activity in Coatings and Compositions Categories Increases over Time

Patent activity over the same time periods is shown in Figure 3.3 (next page) for Group B classifications. All the paint companies show significant increases in numbers of patents filed over time. The pace of R&D activity (as reflected in numbers of patents granted) grows substantially in the two later time periods (1976 to1985 and 1986 to 1996). Ford is again the only major automotive company with a significant research investment in paint and coating formulations. A relatively high level of patent activity by Ford in the 1970s (almost 50 patents over that time period), however, dropped to less than ten patents granted in the last time period. The patent data for Group B classifications again supports the hypothesis that the paint suppliers are the primary source of inventive activity in paints and coatings.

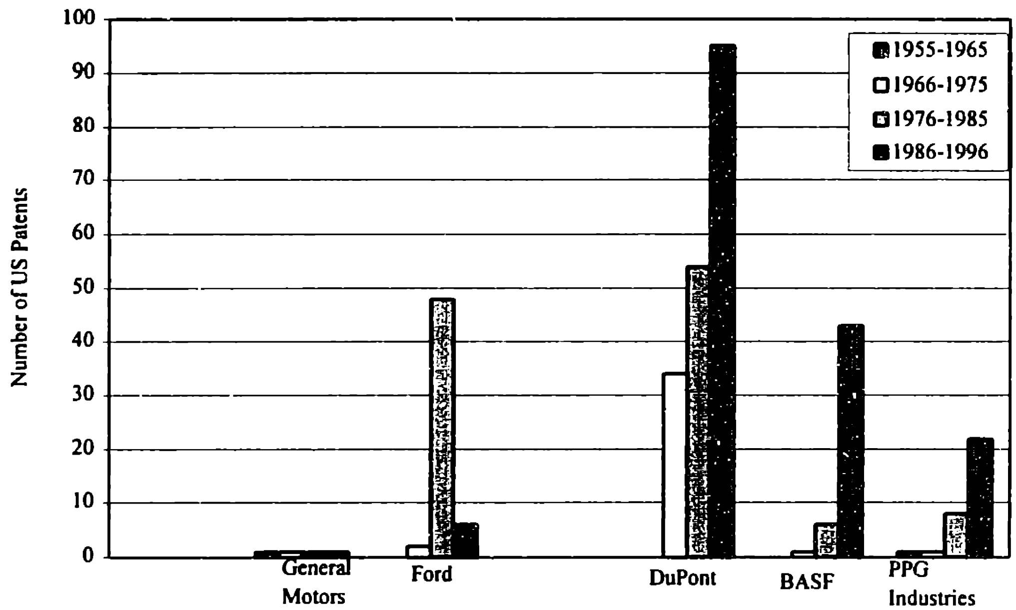

Figure 3.3. Patent Activity in Chemistry and Synthetic Resins, and Wave Energy Categories Dominated by Paint and Chemical Companies

The analysis of the patent data suggests two high level findings. First, the R&D priorities related to formulation of automotive paints and coatings, as reflected by numbers of patents, are higher in the paints and coatings companies overall, although clear differences among companies do exist. A shift in patent activity from automakers that had earlier been involved in paint formulation to the paint companies is observed in later time periods. Second, the level of overall activity in patents seems to increase markedly with the period beginning in 1966 (the advent of environmental regulations for paints and coatings products), as new technological paths in paints and coatings emerged.

Results from the patent analysis are consistent with and supportive of the findings on sources of innovation from the industry survey. They also point to different strategies among automotive companies in paints and coatings. Chrysler, for instance, showed no patent activity in any of these categories for the time periods examined. Ford was highly active in formulation of paints and coatings until making a corporate decision to focus on painting processes. Ford sold its paint division (which included a research department in paint formulation) to DuPont in 1986. GM has always maintained a research group in paint and coatings, but has over time refocused that group on process and performance issues rather than formulation.

The survey results highlight an interesting dynamic between the paint supplier and the automaker, with contributions from both parties required to achieve production goals. Although the automaker is clearly viewed as an important and powerful customer by the paint supplier, there appears to be mutual respect and understanding of each industry's competencies and talents in developing ideas for and investing in new materials and products. The automaker is somewhat dependent on the paint manufacturers for expertise in color and paint materials, a critical product attribute. Paint manufacturers, on the other hand, must design for specific plant equipment and processing attributes, which are controlled by the automaker. In this integrated production system, sharing of information and ideas is important to cost-effective design of products, whether developed for environmental or quality improvement.

The market power of the automakers leads to the assumption that innovation on the part of the paint manufacturers occurs simply in response to the specifications and requests dictated by the automakers. The need to design paint materials to meet the requirements of individual plants and application equipment would support this view. One of the findings of this research, however, is that suppliers do not simply respond to the mandates of their customers in designing new products. They also innovate on their own, developing new products with improved environmental performance in response to international market drivers and company strategies at a broader industry level.

3.2. Adoption of New Materials and Paint Technologies

New products must be accepted by the user community and integrated into production operations, or adopted, to make an impact. The survey described at the beginning of this chapter was used to obtain primary data from industry experts on technology adoption decisions for new paints and coatings systems. Survey questions (highlighted in Table 3.1) focused on identifying the primary decisionmakers and influencers in technology change decisions, the timing of those decisions, and the critical factors analyzed as part of the decision. The role of suppliers in implementing new technologies was also explored.[a] Survey questions primarily addressed decisions relating to dramatic shifts in technology, such as from high-solids solvent-based to waterborne or powder materials, rather than relatively minor changes in coating systems. A summary of survey results is shown in Table 3.6 (next page).[b]

Respondents provided consistent views on the decisionmaking process for shifting to new materials and technologies. Decisions on adopting new paint and coating materials and technologies are made at the corporate level, and are highly dependent on specific company strategies. Suppliers have a major influence on the choices made, particularly in decisions to switch to new paint technologies. New technologies are rigorously evaluated for performance as well as environmental benefits. Cost is an important factor in decisions to switch technologies. The capital cost of adapting facilities to accomodate new materials and processes is as important a consideration as the added material costs of new products. The technology strategy and environmental policies of a company are critical in framing the decision elements. Automotive company respondents believed decisions to adopt new technologies were based on preparing to meet future environmental regulations. Paint company respondents saw current regulations as a somewhat higher priority for automotive companies, with the quality and performance of the coating being more important in adoption decisions. Automotive companies agreed that performance is important, and demand

[a] The complete list of industry survey questions is included in Appendix A.

[b] Responses are reported in the aggregate to protect the confidentiality of participants.

extensive testing of any new material or process before adopting it for use. Suppliers, influential in the adoption decision, are also beginning to take on greater roles in the implementation of these new technologies, and are still viewed by the automotive companies as responsible for making any new material work successfully in the production environment.

Table 3.6. Summary of Industry Survey Results on Adoption Decisions for New Materials and Paint Technologies[a]

Survey Questions	Automaker (A) Respondents (%)	Paint Supplier (P) Respondents (%)
Primary Decisionmaker		
Corporate Management (Automaker)	100	80
Plant Management (Automaker)		10
Purchasing (Automaker)		10
Primary Influencers		
Corporate Environmental Goals/Programs	50	100
Plant Management (Automaker)	85	100
Corporate Management (Paint Supplier)	75	100
Environmental Staff (Automaker)	75	15
Purchasing (Automaker)	10	30
R&D Staff (Automaker)	10	
Timing of Decisions		
0 - 2 Years	25	0
2 - 4 Years	50	40
4 - 6 Years	25	60
Critical Technology Factors		
Demonstrated Technical Performance	100	100
Environmental Benefits	75	100
Compatibility with Existing Facility	60	90
Cost	60	90
Other Critical Decision Factors		
Meeting Current Regulations	65	80
Preparing for Future Regulations	100	60
Quality and Performance of Coating	85	100
Market Appeal (new colors or effects)	85	50
Cost	85	80
Role of Suppliers in Implementation		
Onsite Problem Solving	85	90
Material & Inventory Tracking	100	40
Product & Process Testing	100	100
Cost Reduction in Plant	70	35
Environmental Performance Improvements	55	35

[a] Responses to survey questions are shown in terms of percentages of respondents providing that answer. Many questions allowed more than one response, and may show totals of more than 100%.

Decisions on new paints and coating technologies are made at the corporate level, according to all respondents. The paint colors are chosen by the design and styling groups responsible for developing new vehicle models. Decisions on technology types are made by the engineering staff at corporate responsible for production equipment and techniques. Automakers make these decisions at the corporate level to ensure that they are made by a group that understands the characteristics of the total plant population for that company and is able to balance the needs of one facility against another. Plants are placed on upgrade schedules consistent with the direction the company has chosen to go, whether it be implementation of full-body powder antichip and waterborne basecoats, or updated incinerators and pollution control equipment. At the corporate level, the automakers are always looking ahead in making technology change decisions, asking questions about upcoming changes in environmental regulations that might affect operations, or about the effect of proposed production rate changes on facility emissions and abilities to meet existing permits. These decisions are also tightly integrated into the technology strategy and environmental policies of a company, and are made at the corporate level to support consistent implementation of these policies. The goals and targets of these policies were viewed by paint manufacturers as being highly influential in technology adoption decisions, while somewhat less so by the automaker respondents.

Plant managers and suppliers were mentioned by both groups (A and P) as highly influential in technology adoption decisions. Plant managers can be an important element in moving a technology from approved status to use in a plant. One manager (P) describes a new technology that, while approved by corporate and purchasing managers (A) for plant use, has not yet been accepted by plant personnel. But the paint suppliers also play a large role in making decisions to adopt new technologies. A manager of applications (P) states that "we have to show that changes in technology will add value to the automaker, and that the new product has a high probability of being successfully applied on their production line--that it will work!" Corporate managers (A) agree that suppliers have "a huge role in these decisions. They have to prove the durability of the new products. They must meet the necessary cost parameters. They are also responsible for ensuring that their product meets environmental requirements".

The influence of environmental staff on paint materials decisions varied among the companies surveyed. In general, automotive companies saw environmental staff as highly influential in the decision process, while paint manufacturers viewed them as more important in the implementation of decisions already made by product teams. This may be a result of the different roles assigned to environmental staff in the automotive companies. Some are involved early in the decisionmaking process, but may or may not have a strong interface with the supplier staff. Others are involved only once the colors and materials have been chosen and test samples developed by the supplier. At this point, many of the environmentally-related decisions for the formulation have been made. All respondents agreed, however, that environmental staff play a major role in the implementation of technologies at the plant.

Views on the timing of decisions to adopt new technologies also varied among automaker and supplier groups. Automakers finalize paint decisions about two years in advance of product launch. Decisions related to paint technologies that might require plant modifications are generally made about three years in advance. From the paint supplier perspective, however, paint decisions need to be made four to six years in advance, given the extensive testing required for new products. It generally takes at least two years after a full body application test before an automotive company will accept any dramatically new material at their plants. Getting a new product to the point where it is ready for a full body demonstration takes the paint manufacturer about five years. For fundamentally new products, then, the time from prototype to commercial application can be as much as seven years. That does not include the basic R&D required prior to the development of the prototype. The paint suppliers are continuously developing new products to ensure that they are ready on the timescale desired by their customers.

Respondents from automotive and paint companies were in fairly close agreement on the critical technology factors important to technology adoption decisions. The need for new materials or technologies to have a record of demonstrated performance is essential before adoption in an assembly plant. Environmental benefits are also important, although not as high a priority for some automotive companies as product performance. Compatibility of the material with the equipment and processes in existing facilities is also an important factor, particularly as it relates to the final criteria considered in adopting a new technology, the cost of the new material and any related capital investment requirements.

New products must meet exceedingly strict performance and quality requirements. Gaining approval by the automakers of new paint formulations is a lengthy process. It takes years for new formulations to be tested and to reach mutual agreement by suppliers and automakers on its readiness for use. There are entire books of technical and performance standards set by the paints and coatings industry that new products must meet.[a] Each automotive customer also has their own list of specifications. Even relatively minor changes to a formulation are put through a battery of specified tests. Extensive testing is conducted by the supplier, with additional or duplicate testing sometimes performed by the automaker as well. All the primary suppliers have full scale demonstration and test facilities, as do the automakers.

"The cost for doing this is tremendous", according to R&D managers (P and A). But the costs to the automaker of warranty claims in the event of performance problems are extremely high. Automakers are reluctant to use products that have not been demonstrated in production volumes. As stated by a corporate manager (A), "even with a new technology that might get us lower VOCs, we would not take it on until that technology has been proven". Paint suppliers echo that "it probably takes two years after a full body trial before a car company would adopt [a new technology] at any of their plants". Most application managers (P),

[a] See, for instance, J. Brezinski, ASTM Manual on Determination of Volatile Organic Compound Content in Paints, Inks, and Related Coating Products, 2nd ed., 1993; the EPA Procedures for Certifying Quantity of Volatile Organic Compounds Emitted by Paint, Ink and Other Coatings , 1984; and the standards for paint engineering referenced in R. Diem, "ASTM Methods and the Original Equipment Manufacturer", ASTM Standardization News, October 1995. In addition to VOC Content, these standards include testing methods for viscosity, hardness, gloss, adhesion, and weather resistance, among other parameters.

however, while agreeing that it is difficult to gain acceptance for major changes to materials and coating systems, see minor formulation adjustments as more readily implemented.

The ability of the new product to meet environmental requirements is another major criteria for new technologies. All automotive assembly plants are facing the need for further reductions in air emissions in the future, and many are considering waterborne and powder paint technologies as one element of their strategy for meeting these requirements. Other companies are specifically looking for materials that eliminate key chemicals. For these companies, new materials need to be at least as good from an environmental perspective as those they replace.

Compatibility with existing plant and equipment is another critical factor for new technologies, although difficult to deliver. Each assembly plant has a different physical configuration and set of in-place equipment. The paint systems and technologies must be designed by plant to accomodate and work with those realities. "For instance, paint shops have ovens in place, of certain lengths, with the ability to deliver specific temperature ranges. Paint formulations that need higher temperatures or longer curing times and ovens may not be suitable for a particular plant", according to R&D managers (A). Also, the material substrate of a vehicle must be considered. Some plastic panels cannot be heated past a certain temperature limit, to avoid sagging and deformation of the part itself, presenting a design constraint for the paint formulator. A balance must ultimately be achieved between the chemistry and performance parameters of the paint, the facility and vehicle constraints, and the cost. Because each of these factors varies from plant to plant, suppliers must be able to design paints and paint systems specifically for a particular plant.

The major challenge is to maintain the properties and performance required from paint and conform with the environment, safety and health laws, all within specified cost constraints. It is difficult to reformulate paints and retain their key performance properties. The complexity of the problem is summarized by research managers (A and P): "Going to a new chemistry can present problems. It is a game of not wanting to give up what you have already got, and adding something new. At the same time, you can't just grab anything. There are operational problems and facility constraints that have to be considered". If it was just a problem of formulating a low VOC paint, that could certainly be done. But the challenge is more one of developing a new formulation that has all the properties of the old (in terms of gloss, depth of image, durability, resistance to acid rain and other environmental stresses, etc.) and the new performance needs. Even with the chemical molecules and formulation mix to meet these needs, the new materials must be balanced with the realities of the facilities in which they need to operate.

Formulating a product to work effectively in any particular plant is difficult. Paint R&D managers give an example of a white basecoat product. It is not just one product. The supplier may be working with eight or more different plants that want to paint cars white. "Each of these plants receives a white paint, but there may need to be eight or more different formulations created (tailored) to specifically meet the needs of each plant (their application equipment, the vehicle they are producing, their environmental restrictions, etc.)," according to R&D managers (P and A). Paint suppliers work hard to develop technologies that fit in with and can accomodate flexibility in the processes in place at assembly plants. A manager of R&D (P) says "We cannot expect the plant to invest in new equipment just to make a particular product work--that is a major capital investment. We simply have to find ways to make our formulations work with a variety of equipment types". Application managers (A and P) echoed the importance of understanding the tradeoffs involved in implementing new technologies in the production environment.[a] From the supplier standpoint, this is why working from a systems perspective is preferable. Designs that consider the total coating system allow greater efficiencies among individual products.

Cost is an important factor in the acceptance of new technologies, although it was mentioned more by paint manufacturer respondents than automakers. Cost is not [illegible] cost of new

[a] Research staff at the automakers agreed with this view. Corporate and assembly plant staff at some automakers, however, believed there was more transferability of materials among plants, and were not as cognizant of the uniqueness of formulations to the specific production factors at a plant.

materials, however. "From the customer's perspective, they are concerned about material cost, capital investment required, and operating cost", say paint manufacturers. "Ultimately, everything comes down to cost", according to one applications manager (P). The paint suppliers are trying to encourage broader use of the more environmentally benign products (waterborne, for instance, and powder), but recognize that all their customers may not have the equipment and process technology to apply it. Their primary focus is formulating something that the customers can use and will be happy with. Cost is certainly a major issue for suppliers. They say that "the price of the newer materials is still a huge barrier. The new, environmentally friendly paints require more expensive input materials, increasing our costs of production. Yet, the automakers are still not very willing to pay for price increases--especially if they cannot see the differentiation in the product". Another paint supplier says that "it is a competitive advantage for a paint company to be able to get a customer in compliance with the required regulations without making them spend capital funding. This has led to greater use of high solids systems than the newer technologies."

An example of the importance of total cost for technological shifts is given by paint suppliers in the reluctance to implement waterborne systems. "The capital investment, as well as the operating cost, required to provide humidity and temperature control is a major disincentive. In addition, the material cost is higher (maybe 20 % or more) and the transfer efficiency lower, giving you a 'double whammy'--you need more of a more expensive material!" Another applications manager (P) adds that if the facility has been designed to accomodate the equipment needs of waterborne, fine. But adding the ovens and other equipment needed for dramatically new technologies is a difficult challenge for many. "With greenfield plants, you can design these things in; it is much tougher for older plants". Another says "the expense is what is holding the newer technologies back. Switching from solvent to waterborne systems is a very expensive proposition, costing up to $25 million for such a conversion".

Adopting new technologies is ultimately a decision that incorporates a number of tradeoffs. Several questions in the technology survey were directed at getting more data on what drives these tradeoff decisions for companies. Automakers have several alternatives for achieving environmental improvements, including new materials, new process equipment, and new pollution abatement equipment. They must make complicated tradeoffs among product quality, environmental performance and costs (operating and capital). Any changes must be integrated with existing plant and equipment with a minimum of downtime in production. The way in which each company balances these tradeoffs differs, and is influenced in part by their environmental strategy.

The willingness of a company to invest in major facility modifications depends, according to survey respondents, on their technology strategy, and in some cases, on their environmental policies. It is also affected by the regulatory pressures at a facility, the age and condition of existing equipment, the vehicle(s) produced at that plant, and the ability of the workforce to implement any new procedures required for that technology. Some plants don't have the physical space required for major expansion, and are thus somewhat limited in their choice of technology. Particularly for these plants, the integration of new materials with the existing equipment and procedures at a plant is a major cost issue.

In making decisions on facility upgrades all respondents provided a similar list of key considerations. The more important ones included: the amount of investment required and the future lifetime of the plant (that is, can they achieve a reasonable return on their investment); the product being produced at the plant, or planned for new launch (does that model have a sufficiently high profit margin to allow recovery of the investment); and any specific regulatory requirements that would require a change in the operation just to continue production at that facility. For instance, many state laws are more stringent than federal laws. A plant may receive a high priority status for upgrade based on the need to continue production and increasing pressure from local regulatory agencies to reduce emissions.

Each company and each plant has its own set of priorities. There are tradeoffs between investing in some of the newer paint technologies that might require major capital investments in the paint shop and investing in other technologies, such as high solids, or the emerging super solids formulations, that have higher per gallon costs of materials, but lower capital investment requirements. Paint suppliers understand this, and work with the customer to try to identify the best overall package for them. Some companies find that by using high solids paints (with some level of solvent reduction), electrostatic application equipment to increase transfer efficiencies, and advanced abatement equipment in their processes they can attain the necessary emission limits to stay in compliance with their operating permits. These strategies are not necessarily lower cost strategies, given the expense of pollution abatement equipment, but can be accomplished without major downtime of the facility and loss of production.[a] Other automakers are driven by corporate environmental strategies that dictate elimination of certain chemicals or pollutants at the source, and are willing to pay more for technologies that help them achieve these goals. The suppliers work with the automakers on a basis of total cost to develop a paint system that will meet their economic and performance needs.

Interestingly enough, automaker respondents say that cost is not always the critical hurdle for new technologies. If the new material offers dramatic performance or market advantages, the automaker may invest in the facility modifications necessary to use that material at a particular facility. Some companies implement newer paint technologies (such as powder for antichip protection) not because of the environmental properties of the material, but because the performance of the material is superior to that which it replaces. The environmental benefits help in finalizing the decision, but the primary consideration is often the performance attributes of the material. As mentioned earlier, other companies have a specific strategy to improve environmental performance and will adopt new technologies that contain fewer or less toxic chemicals, even if they are already below their operating permit limits. These companies believe that implementing the newer technologies will provide them environmental benefits and long term competitive advantage.

Waterborne paints are a good example of the kinds of considerations involved in these decisions. Waterborne paint is more sensitive to dust and application problems, demanding

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[a] Downtime is an important element of cost for most automakers, with potentially significant impacts on product timing and resultant market share.

tighter control of cleanliness and operating parameters in the spraybooth. Imperfections that are easily covered with solvent-based paints are harder to hide with some waterborne formulations. Implementing waterborne requires stainless steel piping and distribution systems, as well as air conditioning, because the paints are so sensitive to humidity and temperature. Installing air and humidity control in these large facilities is a major capital investment, as well as a commitment to continued operating expenses in energy use. In some plant locations, even the installation of such equipment may not yield sufficient process control to ensure high quality performance of the system. In hot, humid regions, such as Florida, Louisiana or Texas, the outdoor temperature and humidity fluctuations can dramatically affect the internal operating conditions for some of these sensitive waterborne materials, even with full facility air conditioning. For plants located in these areas, waterborne paints may never be a viable option.

A portion of the technology survey centered on the role of suppliers in implementing new technologies. All survey respondents agreed that suppliers have been taking on increased responsibilities in the automotive painting process, although the extent of this involvement varied among companies. Suppliers are heavily involved with automakers during product design in choosing colors and special effects. Paint and chemical suppliers are also increasingly providing additional technical services to assembly plants to help improve the quality of the paint finish. In addition to product and process testing and onsite problem solving, some companies provide inventory and usage tracking of paints and related materials. Automakers agree that the involvement of suppliers within the assembly plant has increased significantly. There is no longer a single sales associate visiting the plant. More often now there is a technical team that includes chemists and engineers located permanently onsite. This increased level of technical competence and skill is critical to the supplier being able to perform a broader set of functions in the plant. In some plants, automakers have moved to single source suppliers (Tier 1) for all their paint system needs. This places the responsibility for all materials used in the paint system with one supplier, rather than purchasing E-coat, basecoat, clearcoat, and related paint shop chemicals from different suppliers. Some automakers have involved suppliers[a] directly in their environmental management programs, giving them specific responsibilities to improve the environmental performance of the plant.

Paint suppliers are moving into new areas of technical service, building on their environmental expertise, among other capabilities. Some companies offer waste minimization services as part of contracts they receive for providing materials and/or chemical products to a customer. Others offer waste handling services, recycling used solvents, for instance. New contracts that require continuing cost reductions are one incentive for these services, offering a broader spectrum of savings opportunities. New programs such as "Pay as Painted" are also being developed by suppliers to try to shift the cost per gallon mentality of the automakers and provide incentives to reduce material waste in the paint shop. These programs not only save the automaker money by reducing waste, but also improve environmental performance through such reductions. They allow the supplier greater latitude in applying their expertise to solve process and product-related problems at the plant. This increase in breadth of product offerings is one way to provide customers with unique benefits, giving a competitive advantage to a supplier in an increasingly competitive market.

The extent to which suppliers are involved in these activities varies significantly across the automotive companies, according to survey respondents. Some companies see a benefit to developing a longer term relationship with their primary suppliers, but have not yet made any change to their purchasing or operating practices. The companies that have given more responsibility to paint and chemical suppliers at their plants find that they get better and more timely data on their operations and their environmental performance, and faster identification and resolution of process problems. The plants that have implemented innovative contractual arrangements, such as "Pay as Painted", are achieving cost savings and reduced waste volumes. Suppliers appreciate the opportunity to develop a longer term relationship with their customers and provide additional technical expertise. These facilities appear to be very much

[a] To date, these contracts have primarily involved suppliers of water treatment and cleaning chemicals and/or purge solvents and booth cleaners.

in the minority at present. Although current trends support a move toward additional partnering,[14] the nature of most relationships at present are far from the partnerships ultimately envisioned as the model of the future.[a]

One of the benefits that paint suppliers identify from a closer working relationship with the plant operations is the ability to make changes to the process on a real time basis to achieve higher quality, more cost-effective results for the customer. "It basically gives us more latitude to put our expertise to work for the customer", says one onsite supplier. Another corporate manager (P) says that "if we are given more responsibility, we can change the technology and the process to match AND create something that sells the vehicles better. Our incentive, after all, is for them to sell more cars." It also gives companies an opportunity to continue to build their expertise, bringing an improved understanding of the paint process and the application conditions at a site to their next product cycle, improving the quality of the product for that customer.

[a] Note that there is a major difference among automakers in their relationship with suppliers, with some relying much more upon major suppliers for a broader set of responsibilities than others.

3.3. Summary

The results of the technology survey and the patent analysis demonstrate that the technical expertise and, increasingly, the product understanding necessary for formulating new, innovative paints and coatings that meet emerging environmental and technical performance needs resides with the suppliers. The histories related by survey respondents, however, suggest that this has not always been the case. Initially, many of the automakers had important capabilities and extensive research investments in new paint formulations. As the regulatory complexities and technological challenges of paints and coatings development grew, the requirements for investment in R&D increased to develop the new materials and related technologies. Forced in the 1980's to make choices about investment focus, automakers began to divest their paint formulation capabilities.

The larger paint and chemical companies had the research budgets necessary to pave the way toward new technologies.[15] They have used these resources strategically to strengthen their technical competencies and the scope of product offerings in response to declining investments by the auto companies. The paints and coatings manufacturers have always seen product innovation and market penetration as key challenges for their industry.[16] The industry leader, PPG Industries, Inc., was a leader in developing a set of expanded product offerings and technical services for their automotive customers. They have also used partnerships within the larger chemicals industry to their advantage. Although each of the large paint manufacturers is backward integrated to some extent, none produces all the chemicals needed for any particular paint or coating product. As the importance of resins and pigments has grown in the development of new, innovative products, the major producers have taken more of a cooperative, systems approach to new product development. The core competencies of the paint manufacturers in chemistry combined with a traditionally high investment in R&D and innovation led to significant technological advances. Automakers began to rely more heavily on the paint suppliers for expertise in chemistry, product testing and environmental regulatory requirements.[17]

Automakers have retained an important capability in paint application and related processes, however. Historical links among these parties, reinforced by the technological links demanded between the paint material, the vehicle substrate and the application environment, have maintained a strong, interactive partnership among these companies. While the paint manufacturers are focusing on improving materials characteristics to meet the increasing demands of the marketplace, the automakers are focusing their attention on trying to develop process improvements for cost efficiencies and waste minimization. Two major areas of investment are improvements in transfer efficiencies (particularly for waterborne technologies) and reductions of paint sludge volumes. Both parties must work together to achieve high quality results in this integrated production system.

Environmental regulations have created additional complexities for the painting process and placed new costs on automakers. The painting process results in a high level of emissions of VOCs. As the requirements for reducing VOC emissions from automotive manufacturing facilities became more stringent, the costs for achieving incremental improvements in environmental performance increased dramatically. Automakers became more interested in exploring alternatives to traditional environmental control measures, particularly in an industry climate of increasing competitive pressures and needs to improve productivity and reduce costs.[a] At the same time, technology changes in paint application techniques and continued improvements in innovative coating materials made these more attractive options for automakers. Although investments in improved pollution abatement equipment continued, the industry became more willing to explore other options for improving environmental performance at lower costs, including changes in operations, investment in more efficient application equipment, and the use of new paints and related products with lower VOC content.

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[a] Recall that the 1980s were a difficult time for the U.S. automotive industry, with increasing cost and quality pressure from foreign competitors, particularly Japan. For additional insight on the competitive pressures facing the industry at that time, refer to J. Womack, D. Jones and D. Roos, The Machine that Changed the World, Harper-Perennial, New York, NY, 1990.

Results of the survey indicate that paint manufacturers are continually investing in the research and testing necessary to develop new products. Although not all U.S. customers are willing to pay for environmental improvements, most of the major paint suppliers also serve Western European and other international markets, where these innovative products have added value. The performance of the paint system continues to be the primary criteria in choosing to adopt these innovations. Some U.S. automakers see environmental performance as a critical parameter as well, however, and are willing to pay the additional costs to adopt new technologies that they believe will position them advantageously for the future. The specific technology strategy and environmental policies of each company are major determinants of the decisions to adopt new paint and coatings technologies.

The survey also highlighted the implementation challenges in adopting new technologies. Paint products must be designed for the particular vehicle being produced, the facility layout and available application equipment at a plant. Not all companies have the ability to invest the resources required for plant modifications to accomodate these new technologies. Upgrades to plants are made on a particular timetable, as determined by corporate decisionmakers. Although suppliers have increasing influence on decisions in color and special effects, they are not always involved as closely in decisions on plant process technology and paint material. The survey showed a wide range of levels of involvement of suppliers at assembly plants, from those integrally involved in material tracking, process improvement, and even environmental performance, to those relegated to more traditional sales and service roles.

Automakers have a number of alternatives for meeting the increasingly stringent and costly requirements for environmental performance at their manufacturing facilities. Lower VOC products are only one option among many (including additional pollution control equipment) that companies are using to keep their plants operating at or below permitted limits. The survey suggests that the technology strategy and environmental policies of a company are one important set of variables that drive a decision toward controlling pollution at the source through specially designed products. The influence of suppliers with environmental and systems expertise in the decision process is also important. The case studies in Chapter 4 evaluate these factors in more depth. Equally important, they attempt to provide insight into the ability of these innovative products to provide environmental performance improvements at an operating facility, where product and process technology must be effectively integrated to achieve desired results. The technical expertise of suppliers in product design and environmental requirements and automakers in process issues and application equipment suggests the need for both groups to work together to support innovation. The case studies examine the implementation of new paint technologies at the plant level, comparing the environmental performance of plants using the new technology to those retaining solvent-based paint systems. These cases also explore the role that supplier relationships may have on the level of innovation and successful performance of the new technology at the facility.

[1] E. Von Hippel, The Sources of Innovation, Oxford University Press, Oxford, 1988.

[2] W. J. Abernathy, The Productivity Dilemma: Roadblock to Innovation in the Automobile Industry, The Johns Hopkins University Press, Baltimore, MD, 1978.

[3] Ibid.

[4] M. Murphy, "Technical Developments in 1994: Organic Coatings, Processes and Equipment", Metal Finishing (February 1995): 10-23; and M. Murphy, "Technical Developments in 1995: Organic Coatings, Processes and Equipment", Metal Finishing (February 1996): 47-58.

[5] Personal comments from Mr. Steven Bauer, Partner, Testa, Hurwitz, Thibeault, at a lecture on "Protecting Intellectual Property: Patents and Beyond", October 5, 1995, Cambridge, MA.

[6] J. Dean, "How They Compete in the Coatings Market", Chemical Week, October 5, 1983, Special Advertising Section.

[7] D. Winter, "Uh, Oh, Colors and Fabrics of the '70s are Making a Comeback", WARD's Auto World (September 1996): 39.

[8] Abernathy, 1978.

[9] R. C. Levin et al., "Appropriating the Returns from Industrial Research and Development", Brookings Papers on Economic Activity, 3 (1987): 783-831.

[10] D. Teece, "Profiting from Technological Innovation: Implications for Integration, Collaboration, Licensing and Public Policy", Research Policy, 15 (1986): 285-305.

[11] E. Mansfield, "Patents and Innovation: An Empirical Study", Management Science, 32 (February 1986).

[12] Ibid.

[13] Levin et al., 1987.

[14] M. Flynn et al., The 21st Century Supply Chain: The Changing Roles, Responsibilities and Relationships in the Automotive Industry, Chicago, IL, A.T. Kearney, Inc., 1996.

[15] Tim Triplett, "Resin Manufacturers 'Struggling for Answers'", Industrial Paint and Powder (November 1994): 27.

[16] "Annual Industrial Finishing Survey of Coatings Manufacturers and Finishers", Industrial Finishing (January 1993): 28-31.

[17] Personal communication with Eugene Praschan, AMVA, and formerly with GM (in paints) and DuPont.

Chapter 4. Implementing Innovative Technologies: Case Studies of Assembly Plant Performance

This chapter is primarily directed at the second hypothesis of this dissertation, which proposes that ***environmental performance in a manufacturing operation is improved through the use of new cleaner technologies and supplier expertise.*** Innovations in paint materials and technology designed to reduce environmental impact are expected to significantly improve the environmental performance of automotive assembly plants, particularly when supported by onsite technical expertise from suppliers. This chapter presents the results of case study research on the adoption of innovative environmental technologies at selected U.S. assembly plants. The case studies explore both the relevant factors in technology adoption decisions and the level of success in implementation. The methodology used for structuring and selecting cases is described in the first section of this chapter, followed by the four case studies. The cases are structured to explore the primary factors important to decisions to adopt innovative materials and technology (identified in Chapters 2 and 3): technology performance; fit with corporate strategy and environmental policies; and plant management and organization, including the role of suppliers. Data is provided for each plant in each of these three areas, with innovative technologies, materials and projects highlighted. This is followed by environmental performance data from each of the plants, used to measure the outcome of the technology choices made. A comparative analysis of the four plants is presented in Chapter 5, with the overall findings of this research.

Automotive paint process technology and materials have changed dramatically since the 1970s. Environmental regulatory pressure has encouraged most automotive assembly plants in the U.S. to shift from low solids to high solids, solvent-based paints. Other materials, however, designed specifically to provide significant environmental benefits through reduced volatile organic content, have only recently been adopted by some automotive assembly plants. The majority of automotive companies have continued to invest in pollution abatement equipment rather than risk potential problems in the paint shop by introducing a new material, or incur the capital costs (and production losses from downtime) required to install new production equipment. In the case of automotive paints, the development of new materials designed to address environmental problems by reducing hazardous constituents has not guaranteed their commercial application.

Why do some companies choose to invest in new materials and technologies as a strategy for improving their environmental performance? The adoption of new materials for paints and coatings is only one approach for reducing the environmental impact of automotive manufacturing. This research evaluates and compares the environmental performance of automotive assembly plants implementing innovative paint technologies to those using traditional paint systems to understand the benefits and challenges of using new technology for improving environmental performance. The importance of understanding the context in which the technology is introduced and the strategic factors influencing adoption led to the selection of the case study approach for this portion of the research. Case studies allow a detailed investigation of the factors encountered in integrating new technologies into the plant and provide a rich set of data (both qualitative and quantitative) for evaluating the results in terms of environmental performance. They are particularly appropriate as a research methodology for exploring questions of "how" and "why", facilitating a detailed examination of the decisions made at a specific facility.[a] This flexibility and depth in approach is important to address the complex questions relevant to choosing environmentally-preferable technologies and materials, and evaluating resultant plant performance.

The key variables of interest in the case studies were identified from the technology survey (Chapter 3) and a review of relevant literature in technology management and innovation (Chapter 2). The results of the technology survey identify technical performance, environmental benefits and cost as major factors in decisions to change coating materials. These factors must be measured at the assembly plant level, since achieving high quality technical performance in automotive paints is highly dependent on the equipment and

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[a] R. Yin, Case Study Research: Design and Methods, Second Edition, Sage Publications, Thousand Oaks, CA, 1994.

procedures used at the assembly plant. The environmental performance of a plant is also dependent on local variables, including the content of hazardous or regulated chemicals in paint and other materials used at that plant (chemical input) and the effectiveness of specific operations in the paint process and of the pollution abatement equipment. The costs to implement a new system will also differ by plant, being based on the extent of facility modification required, the price of the new material, and the form of the contract under which the material and related services are procured.[a] Because these factors all differ among companies, plants and geographic areas, this research focused on investigating particular plants in depth.

The survey also highlighted the influence of corporate technology strategy and environmental policies on material selection and product design decisions. Although the implementation of corporate strategy does vary to a certain extent among plants, these factors are assumed to be fairly consistent among plants with the same corporate parent.[b] This allows some comparison among plants using different technologies, but having the same corporate drivers, as well as evaluating the effects of different corporate strategies at plant levels. Research on technological innovation and change points to two other variables of importance in evaluating technology adoption decisions. The willingness of a company to adopt innovations that represent more fundamental change (such as shifting from solvent-based to waterborne or powder technology) has been shown to be related to its organizational structure, the management approach used at the facility, and the level of technical expertise available to support the change. A flexible, open culture and work environment is important, for instance, in encouraging innovation.[c] Based on this work, the other variables chosen for exploration in these case studies are the management approach and culture at the plant and the extent to which they support innovation. The plant management approach is also important in

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[a] Payment on a material volume basis ($ per gallon) as opposed to payment for a fixed amount per vehicle that includes both materials and related technical services (Pay as Painted).

[b] The case studies showed good consistency among plants relative to corporate strategy factors.

[c] J. Ettlie et al., "Organization Strategy and Structural Differences for Radical Versus Incremental Innovation", Management Science, 30, June 1984, 682-695.

understanding how corporate policies are implemented at the plant level. Finally, the role of suppliers at the facility was included as a variable, since suppliers were identified in the technology survey as a major source of technical expertise in paints and coatings, particularly the newer materials.

Four automotive assembly plants, two each from the same corporate parent, were selected for detailed case study,[a] with a focus on understanding the paint process and materials used and the environmental performance of the facility as measured by chemical releases. The case studies were structured to allow a comparison among plants of several important variables: differences in paint materials and technology; corporate strategy and plant management approach; and level of supplier involvement. A matrix showing the similarities and differences in these three major parameters among the cases is shown in Figure 4.1 (next page). Plants A and B, for instance, have the same corporate strategy, but different technologies and management approaches. Plants C and D also have the same corporate strategy, and (for a period of years) the same technology (waterborne basecoat paint) but have different environmental strategies and management approaches at the plant level. Plants B and D share both technology and plant management approach (prior to Plant D implementing waterborne), although their corporate policies are somewhat different. Plants A and C provide a similar comparison, after the shift at Plant A to waterborne.

Primary data was obtained from site visits and extensive interviews with plant managers and environmental staff at each assembly plant.[b] Quantitative plant data includes a description of: the relative contributions of key elements of the paint process to total plant environmental

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[a] The cases were restricted to the U.S. to ensure consistency in the regulatory framework and environmental priorities applicable to each plant. Another selection criteria was that plants have relatively continuous operation during the years 1987 through 1994, the timeframe for which environmental data was available. The support of parent companies and plant management in allowing access to the plant and its staff for site visits and interviews was another factor in the final selection of companies and assembly plants included in this research.

[b] The automotive companies and the specific plants involved agreed to participate in this study on the condition that their responses would be treated confidentially and that company names and personal affiliations would not be included in the published results. Details on plant history and performance data are generalized in some cases to maintain this confidentiality.

releases; a history of any new paint formulations and related materials adopted; and data on the handling and disposal of paint sludge. Data on environmental performance was obtained from an analysis of the EPA Toxic Release Inventory (TRI) database (described in more detail in Appendix B). The TRI data includes releases (emissions) and waste transfers from each plant for a list of specific chemicals for the years 1987 through 1994.[a] Production data for each plant was collected to allow comparisons among plants on a per vehicle basis.[b] Releases for each year of interest are evaluated both by total quantity and by quantities normalized by annual production figures for each plant. These data are used in conjunction with plant data to

Figure 4.1. Matrix of Comparative Case Studies

Plant A	Plant B
Technology: Shift to waterborne and powder **Corporate Strategy:** Innovation a corporate priority Proactive environmental policy **Management Approach:** Open, flexible Proactive environmental policy Suppliers as partners	**Technology:** Solvent-based **Corporate Strategy:** Innovation a corporate priority Proactive environmental policy **Management Approach:** Hierarchical, structured Compliant environmental policy Supplier role limited
Plant C	**Plant D**
Technology: Waterborne **Corporate Strategy:** Corporate support for innovation Proactive environmental policy **Management Approach:** Open, flexible Proactive environmental policy Suppliers as partners	**Technology:** Shift to waterborne **Corporate Strategy:** Corporate support for innovation Proactive environmental policy **Management Approach:** Hierarchical, structured Compliant environmental policy Supplier role limited

[a] The database covers the years 1987 through 1994.

[b] The database constructed for this work includes details on models produced and volumes, units per hour, and numbers of shifts per day for various assembly plants.

analyze overall environmental performance. Results are summarized in text, supplemented by various charts, tables and graphs. An important part of the analysis is the evaluation of trends in total emissions, emissions per unit of production, and differences among plants adopting waterborne or powder technologies and those retaining traditional high solids solvent-based systems. One benefit of the TRI data is the opportunity to trace changes in plant technology and environmental releases over time, providing some evidence for assessing the effects of new materials on the environmental performance of assembly plants.

Determining an appropriate measure for environmental performance is somewhat problematic. There is no concensus on what elements of environmental performance should have priority (for instance, biodiversity or toxic waste), what constitutes "best practice" in environmental performance, and how that is integrated with the other performance targets of a company. Nor are there generally accepted methods for measuring across multiple dimensions of environmental performance. For the purpose of this research, however, which is focused on whether changes in source materials result in reductions in environmental releases from plants, the TRI database is useful for evaluating environmental performance. Although TRI data have some limitations (described in Appendix B), these can be effectively managed if coupled with first-hand knowledge of the specific facilities being investigated. This research focuses on an analysis of four facilities and targets a few listed chemicals of major importance to paints and coatings, which can be traced from year to year in the TRI data. An emphasis has been placed on site visits and contacts to ensure a thorough understanding of the facility and its equipment, materials and processes. This knowledge helps put the TRI data in context and identify any anomalies in reporting. The production data was obtained from published sources and verified with the facilities themselves.[a] For the purposes of this research, the TRI data is a valid and useful source of information on environmental performance as measured by changes in chemical emissions and waste disposal methods.

[a] Such as WARD's Annual Automotive Data Books and the data published by the Motor Vehicle Manufacturer's Association.

4.1. Case Study: Plant A

As with many automotive assembly plants, this facility, originally built in the 1960s, has been used to produce both large and small vehicles during different periods in its history. In the late 1980s, the plant was entirely gutted and rebuilt to produce large luxury vehicles. New conveyors and pipes were installed, new equipment was brought in, and new processes developed to streamline assembly. The paint shop was part of that renovation, rebuilt to accomodate the technology necessary for producing a high quality luxury car. This included a dip E-coat system, spraybooths and ovens to accommodate a two phase basecoat/clearcoat topcoating system and high solvent paint materials (to achieve the quality finish desired). A full line for repair was installed as well. In 1990, the plant switched to a high solids formulation for basecoat (a high solids formulation for clearcoat was initiated the following year) and installed powder equipment for providing additional antichip protection on the rocker panel and sills of the vehicle.

During the period of 1988 through mid-1993, the plant operated continuously, after which it was shut down for six months to implement a number of major process and system changes. The plant introduced new paint materials specifically designed to reduce VOC emissions as part of this shift in technology. Powder coatings for the hood and front of the vehicle took the place of high solvent antichip coatings. Waterborne materials were introduced as substitutes for high solids basecoats and a deadener material that had a high solvent content. In-mold color was adopted for front and back fascia, eliminating painting entirely for those parts of the vehicle body. All new automation and a convection oven were installed at the plant to accomodate waterborne materials and an innovative sludge drying process was adopted to reduce the volume of paint sludge sent annually to landfill disposal. The shift to new paint materials also required major modifications to system piping and application equipment. Stainless steel piping and new application equipment and bells were required for the waterborne basecoat. The spray booths had to be temperature and humidity controlled to accomodate the new paints. Although new equipment throughout the plant had been installed only five years earlier, the company committed to the change in materials and invested in the required capital upgrades.

In addition to these technological changes, the plant adopted an important change in management systems. An experimental program that gave suppliers greater responsibility for key production chemicals[a] and elements of the paint process had been established late in 1992. In 1993, this program (having achieved both cost savings and reductions in environmental emissions at Plant A), was extended to include topcoat materials. A similar program was developed for the nonproduction solvents and cleaning chemicals in the paint shop. An important part of both programs was the mandated presence of supplier staff onsite at the plant and an increase in key process and material management responsibilities to the supplier.

Plant Process Technology and Operations

The plant runs two shifts, five days a week, producing about 1100 vehicles a day. The painting process used at Plant A, compared to the baseline process described in Chapter 2, is depicted in Table 4.1 (next page). The process begins with a thorough cleaning of the vehicle with a water and surfactant rinse, followed by a phosphate rinse to prepare the vehicle for the electrocoating process (E-coat). After E-coat, the vehicle goes through a dryer to remove the water and cure the E-coat layer. This facility uses powder (instead of a primer-surfacer), applied in a dry-on-dry process to provide chip protection at particularly vulnerable locations (i.e., the rocker panels and sills, hood and front fenders). Powder overspray is collected and reused, either within the painting process or by outside buyers. Waterborne paint is used for the basecoat, applied manually on the more contoured areas around the doors and fenders, followed by automatic spray from bells. The air directly around the nozzle of the bell is charged to provide some electrostatic effect (and improve transfer efficiency). Spraybooths are air conditioned and controlled for temperature and humidity. Infrared and convection

[a] Production chemicals and materials are those that remain as part of the vehicle when it leaves the plant; nonproduction chemicals and materials are primarily those used for cleaning or equipment and process operation.

ovens are used to flash water out of the coating. The clearcoat is a high solids, solvent-based system, originally installed for producing the earlier luxury model. It was retained because of the high costs to remove it, and the added benefits in final appearance and quality of the finish. Cleaning chemicals and purge materials constitute a large portion of the VOCs at Plant A. A water-based purge material is used for the basecoat area, and is treated with the booth waterwash effluent. A solvent-based purge is used for the clearcoat system. It is a HAPs free material, formulated with chemicals that are not reportable under the Superfund Amendments and Reauthorization Act (SARA). The solvent-based purge material is collected in purge pots in the spray booth area, transported to a holding tank in the paint mix room and used by outside vendors in fuel blending.

Table 4.1. Painting Process Steps and Technology for Plant A

Process Steps -- Baseline	**Process Steps -- Plant A**
Cleaning and Pretreatment	Yes
Phosphate Rinse	Yes
Electrocoating -- Dip system	Yes, using Uniprime system
Oven Bake	Yes
Primer-Surfacer	No
Antichip Protection	Yes, using powder coating
Sealer	Yes
Oven Bake	Yes
Basecoat (color coating)	Yes, using waterborne (after 1993)
Oven Bake	Yes, to flash-off water
Clearcoat	Yes, using high solids, solvent system
Oven Bake	Yes
Repair	Spot repair -- low and high bake systems

The plant utilizes about eight different colors, delivered on a "just-in-time" basis to the mix room in ready-to-spray condition from the supplier satellite nearby.[a] About 80% of the production uses solid colors rather than metallics (this also facilitates color matching with the

[a] Plant A had eliminated the process of cutting or thinning paints in the paint mix room in the late 1980s, requiring suppliers to deliver the paint premixed in ready to spray condition.

inmold color fascias). White is the most popular color, followed by green, red and blue. Block painting is prevalent, with block sizes of 10-20 vehicles or more not uncommon, although the standard block size at the facility is said to be closer to three to five vehicles.[a]

In-mold color is used for the front and rear fascia in about 60% of the production units; the balance of the production parts are received prepainted from another facility. The color match of the in-mold materials is excellent. Scrap material is reused (if white) or sold to outside users for reuse. For instance, waste material from purges between colors is sold to toymakers for use in making plastic toys. The use of plastic fascia saves weight in the vehicle and saves the company $60-$65 per vehicle by using in-mold color as opposed to traditional painting.

The plant also has traditional pollution control and abatement equipment, although they have not invested in new abatement equipment for over eight years. The new investments have gone to projects they believe will reduce pollution at the source. There are six incinerators at the plant (although facility personnel stated that they could easily meet their regulatory limits without running these incinerators with the shift to waterborne materials). There is an onsite water treatment system, where water destined for discharge is treated before being sent to the local Publically Owned Treatment Works (POTW). A sludge dryer system (which has an incinerator connected) has been installed specifically to treat and dry paint sludge. The dried material is sold to asphalt producers as a filler, supporting the corporate goal of zero landfill in the future.

Air emissions and wastes related to the operation of the paint shop represent over 80% of the environmental problems at Plant A. The operating permit for the plant was negotiated in the late 1980s, and remains in force, notwithstanding the recent facility modifications. This permit allows annual VOC emissions of 3400 tons. Over the years, the technological changes implemented at the plant have dramatically reduced the level of VOC emissions and

[a] While at the plant, I observed continuous production of large blocks (minimums of ten, and at times up to thirty vehicles in a block). Production staff fight against larger block sizes, since they feel it makes it difficult to correct against defects in a paint batch or process problem and can result in more repair work.

other environmental wastes. Air emissions of VOCs in 1995 were about 600 tons; yet the plant continues to work to reduce emissions even further, even though they are well below compliance limits. Plant A staff feel they have benefited from a relatively cooperative relationship with the local regulatory agency. The local agency has proven willing to work with the plant in implementing innovative technologies and approaches to reducing emissions. They are willing to grant extensions to permit deadlines, if necessary, to allow for testing of new products, equipment or processes. Some of the specific operations at the facility regulated by federal, state or local agencies are listed in Table 4.2.

Table 4.2. Operations and Waste Streams Subject to Federal, State or Local Regulation

Operations and Waste Streams	Primary Regulatory Guidance
Water Treatment and Discharge	Local Water Treatment Rules
Sludge Disposal	State Solid Waste Disposal Regulations
Toxic Chemical Use Restrictions	SARA
Hazardous Waste Disposal	RCRA
Solid Waste Restrictions or Reduction	Pollution Prevention Act of 1990
Air Emissions: Visibility	Opacity (Boilers)
Air Emissions: Urban Ozone or VOC	New Source Performance Standards (CAA)
Air Emissions: Acid Rain	CAA

The plant continues to explore how it can improve its processes, from an environmental perspective. A new full-body powder antichip facility is currently under construction, planned for start-up in 1997. They are working with their suppliers to test a lead-free E-coat and low or no VOC materials for booth cleaning. The E-coat material is completing a two year testing period and is anticipated to utilized at Plant A following approval by corporate. A nonchrome rinse is also being developed by the supplier. New bells and automation are being installed (in 1996) to try and improve the transfer efficiencies of applying waterborne basecoats. A primary driver in all these changes is improving the quality of the finished vehicle. As one environmental manager stated in regard to powder, "the reason we are going to powder is for better antichip protection. It happens to help us environmentally--which is certainly a positive. But we are making the change to make better cars". Similarly in moving to waterborne paints. "When we went to waterborne, we found we got better quality--better gloss and better appearance. We thought the paint would be more expensive, but that has not been true. It is about the same price. You do have to use a little more because the solids content of the paint is lower--but the improvement in appearance we get is well worth the cost". Although there is a high level of judgement in measuring the quality of the finished product (in terms of paint), this facility also uses a number of quantitative measurement tools to check and control the quality of the finished vehicle as it exits the paint shop.

The focus on quality first and a long-term perspective on cost and waste reduction is also evident in the planned upgrade of the paint shop automation. The new bells for the basecoat spray booths were recommended based on a study driven by a quality team at the platform level. Improving transfer efficiency for waterborne materials was expected by this team to improve film builds and lower material costs. Although the environmental staff at the plant doubt the project will achieve projected levels of improvement, any improvement in transfer efficiency certainly improves environmental performance, through reducing VOC emissions (less paint used) and cleanup chemical volumes (less overspray to clean). The ongoing investments in new technologies reflect a continuing commitment by this company to improve their overall performance through innovation in both process and product dimensions.

There are a number of projects ongoing at any one time to find new products or new ways of operating that achieve cost savings and reductions in VOC emissions. Ideas for these projects come from a number of sources. Some are dictated by corporate, either through the environmental staff, or through design or process changes determined by the platform teams. Others are developed at the plant, initiated by suppliers, plant managers and staff, or workers on the line. Most of these projects, while benefiting the environment, also have a strong element of cost savings, through reduction of materials input or waste output. Most of them require some initial investment and approval from corporate for implementation. Corporate level investments also provide opportunities for environmental improvements. The corporate strategy for eliminating hazardous constituents from materials has spurred suppliers to develop new coating materials free of heavy metals.

Corporate Strategy and Environmental Policies

The corporate strategy is based on integrating environmental considerations into the business planning process through a detailed understanding of the costs of pollution or noncompliance. In addition to traditional costs of compliance (permitting, labelling, reporting), the company also evaluates costs or operating restrictions that may be imposed by proposed or existing regulations. Emerging regulations are monitored to ensure that investment decisions anticipate future trends that may restrict production or limit sales. The increasing importance of recycled content in vehicles (particularly for European markets) is one such trend. Translating these trends into specific decisions on material content in a vehicle and manufacturing processes at an assembly plant are an important part of the company strategy for achieving competitive market advantage. Investments in innovative technologies that reduce or eliminate regulated materials are encouraged, and preferred to those that rely on advanced pollution control equipment to meet permit requirements. The company believes that investments in new technologies that eliminate pollution problems will provide more operational flexibility and competitive advantage in the future.

Implementation of the strategy is ensured by controlling decisions on product design, material content, and manufacturing process at the corporate level. Platform teams make material and technology decisions for specific vehicle models. For the paint process, key decisions include paint formulation, colors, and use of recycled materials. Environmental staff at corporate must also approve decisions on materials (including nonproduction cleaning chemicals) and will reject new materials that have higher VOC or HAP content than those being replaced. The commitment to waterborne paints and powder coatings was made by the platform team, based on the demonstrated performance of the finish and the environmental benefits and cost savings at facilities where those technologies have been employed. The company has made a commitment to spending over $4 billion (since 1994) to build and install new paint shops and equipment in all their facilities. Upgrades to facilities are made in a phased approach, to ensure maximum learning from early adopters and allow system modifications for later adopters of technologies to improve performance.

The environmental strategy for Plant A is closely tied to corporate environmental policies. The parent company attempts to provide consistency of direction and priorities across all plants, yet allow for individual goals and projects based on the needs of particular facilities. At the corporate level, an important element of the environmental strategy is reducing the impact of vehicle manufacturing on the environment through source reduction of polluting materials and elimination of landfill as a disposal option (by the year 2000). Decisions in product design and selection of manufacturing technology are made at the corporate level to support this strategy. Plant priorities are set by plant managers and corporate managers working within the broader corporate strategy. However, at the plant level, the more immediate concerns of compliance with existing regulations and permit requirements must also be considered in setting specific plant goals. The implementation of projects and activities to meet this combination of goals takes place primarily at the plant level.

Superfund legislation has had a major impact on corporate environmental policies. Plant A's parent company has spent $8 to $10 million over the last decade on remediation projects for a number of old waste sites discovered from the 1960s. According to the environmental staff at the plant, "that is one of the reasons we are so concerned about reducing and eliminating waste from our facilities!" The site is located near a public source of drinking water and there are continuing concerns about possible leakages into the groundwater system. The early approaches to remediation efforts at the site were to use technologies such as pump and treat systems for dealing with groundwater contamination. However, the ongoing expense of such approaches has led them to try technologies that lead to more permanent solutions. The regional EPA office has given the plant a lot of freedom in trying innovative technologies to deal with remediation problems. For instance, a biocell was used to incinerate fifty thousand yards of contaminated dirt at one site. They were able to get a permit for this project in less than 48 hours and had support from both the local community and the regulatory agencies.

A philosophy of avoiding future liabilities has driven many of the environmental policies and practices within the company. Reductions in material use and shifts to materials with fewer hazardous constituents are also important elements of the company response to environmental legislation. Corporate level goals encourage continuous improvement in environmental performance. A corporate level "stretch" goal of 216 tons per year VOC emissions has been set for nonproduction solvents. This is based on a proposed EPA rule currently under discussion that will limit automotive assembly plants to 216 tons VOC per year for certain cleaning operations, including body wiping, paint purging and line cleaning, and general cleaning (cleaning spray booths constitute a large part of this category). In 1995, Plant A achieved a level of 190 tons VOC emissions in these use categories (down from 1560 tons in 1988), at fairly consistent production levels (248,100 vehicles in 1988 and 247,480 in 1995). There is a commitment by both the supplier and the plant staff to do at least that well this year (although they both admit that this will be tough to accomplish).

Over time, Plant A has shifted its waste disposal practices from a focus on landfill to a focus on reuse and recycle of materials. Releases to groundwater and land are essentially nonexistent now for this facility. Water use and discharges to the local Publicly Owned Treatment Works (POTW)[a] are tracked very carefully. The environmental staff at Plant A, working with environmental and design staff at corporate headquarters, and production staff at the plant, are continually looking for ways to not only meet the current environmental requirements, but to improve the environmental performance of the plant to enable it to readily meet future requirements. New coating materials and lower VOC cleaning and purge chemicals have been introduced into the plant. New management systems that allow plant staff to draw on the expertise of suppliers and outside sources in achieving reductions in emissions and cost have been adopted. New equipment is introduced as necessary to improve the performance of the newer, aqueous-based chemicals.

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[a] Discharges to local sewer systems and water treatment plants fall under this categorization.

Management Approach and Plant Culture

The plant manager has the responsibility of translating the broader environmental goals set by corporate to specific performance measures that can be used in guiding the operation of the plant. In addition, the plant must comply with all existing environmental regulations and the requirements specific to their local operating permit. However, the primary focus of the plant manager is still on meeting production quotas with high quality vehicles. He is also challenged to continually reduce production costs. To support the plant manager in his environmental responsibilities, and to ensure attention to the corporate strategy, each plant is assigned an onsite corporate level staff member, called an Environmental Coordinator. This person's job is to help the plant manager in improving the environmental performance and overall efficiency of the facility. They supervise the environmental specialist at the plant and provide a link to corporate strategy and activities. They also share information through a network of all the onsite corporate environmental staff, meeting monthly to discuss new projects, challenges and successes they are having in their facilities. There is corporate support for visiting other plants to learn from their successes (and failures) and to try to share the best practices of the company across all its facilities. The environmental coordinators are also the primary contact point for suppliers and facilitate information sharing about the performance and sources of expertise for major suppliers. The environmental coordinators have a strong relationship with and responsibility to the plant managers at the facilities to which they are assigned. Working with the plant manager and staff at Plant A, they translate the general corporate environmental goals into implementable performance objectives.

At Plant A, a major environmental goal is to reduce the emissions of VOCs from the plant and to reduce the use of HAP chemicals. Another is to reduce reliance on landfill as a disposal mechanism, increasing the volume of material that is recycled or reused. Goals are developed after analyzing the major source of environmental problems, based on data from plant operations. Joint agreements are made to develop goals at the plant level with those directly affected in processing to reduce wastes, materials use, or cost where they can achieve the greatest gains. For instance, the plant goal for reduction of VOC emissions from nonproduction materials (cleaning and purge chemicals) is set jointly by the corporate liaison environmental coordinator and the supplier responsible for solvents, after working with the production and paint shop managers to understand their performance needs. Projects to help achieve these goals are implemented at the facility level.

Although many of the product-related decisions are made at corporate, the plant manager is the individual responsible for ensuring cost-effective and timely production at the manufacturing facility. He has a major influence on the priorities and projects at the plant, and is critical to implementing any new technology or project. At this facility, the plant manager is an advocate for new technologies, new operational procedures, and innovative approaches to working with suppliers. He also supports a flexible, informal work environment. The line workers have a good attitude toward their jobs, as reflected by their comments during the interviews and the cleanliness of the workplace. Line workers are focused on their jobs, but feel comfortable in approaching management or environmental staff with ideas for improvement. This approach has encouraged the development of new ideas by all staff and the implementation of many new projects (some of which are described later in this section). This facility has consistently been one of the top performing plants in the company, from an environmental perspective and on key production parameters. Maintaining this level of performance is very important to the employees, the management, and the supplier staff at the plant.

Worker awareness of the hazards of solvents and other hazardous materials has been developed through consistent training. Every worker receives hazardous materials training--and is made aware of the costs to the company of using (and misusing!) these materials. The workers at this plant enjoy a profit-sharing arrangement with the company and cost issues impact some of them more strongly than environmental ones. Yet all of them are aware of the importance of environment. Many of the projects in the plant directed at eliminating hazardous waste and solvents from the facility have been initiated by the workers, who would prefer not to be exposed to the odors and hazards of these materials.

The suppliers play a very important role at Plant A, both in productivity improvements and environmental performance. The plant has a unique arrangement with its suppliers in the paint shop, relative to other automotive assembly plants. First, it has committed to using a single supplier for its entire paint system. That is, one company is responsible for providing the materials and paints to supply the entire paint process, from pretreatment, through E-coat, antichip, and topcoat. This is a major shift for this plant, which not too many years ago had as many as five suppliers providing the various materials required for the paint and coating process. The same supplier also provides the cleaning and purge chemicals for the paint shop and the treatment chemicals for the paint sludge system. Moving to a single supplier has allowed the plant to consistently track chemicals use and find ways to achieve plant-wide efficiencies. It has also facilitated the development of a closer relationship with the supplier. One way in which this relationship is demonstrated is by the extension of the plant attitude for excellence to the supplier staff. The onsite person who is responsible for managing solvents says that it is a source of pride to him and others at the plant that this facility is used as an example for the rest of the corporation. "I view it as a personal challenge to make this program work and maintain our high rating".

Secondly, the paint shop is run under what is termed a "Pay as Painted" system, where the supplier is responsible for tracking the use and quality of the paint and related materials, which are delivered on a "just-in-time" basis. Generally, no more than one day's worth of production materials is housed onsite. The supplier is paid based on a set fee per vehicle painted. The fee is set using historical data for the process, or using estimates from similar operations. Any savings achieved by the supplier are retained, as long as a high quality finished vehicle is produced. Savings based on process efficiencies help both the supplier and the automaker. This program was implemented in two stages at this facility, first with the phosphate chemicals and the uniprime system, and later expanding to include the powder coatings and topcoat system. There is ongoing discussion of further expansion of the program to include all paint shop materials (purge and cleaning chemicals, solvent wipes, covers and finish materials, such as sandpaper).

Implementing "Pay as Painted" at Plant A drew increased attention to the volume of materials used in the painting process, by both the automaker staff and the supplier. It required the supplier to develop a stronger understanding of the painting process and the use of their materials in that process. "Our goal as a supplier is to know the system better than the customer. We also want to be the ones to know where big improvements can be made, and push for those. We have pushed hard, for instance, to get more block painting here". Having an onsite presence and increased process knowledge allowed the supplier staff to provide better technical support for solving production problems. The supplier developed a detailed material tracking system that has led to an improved understanding by both parties on how to maximize the efficiency of the painting operation. From the perspective of the automaker, the program was adopted as part of an overall strategy for working with suppliers to draw more effectively on their unique areas of expertise in identifying and implementing process efficiencies. The program also supported a movement to consolidate the supplier base and get suppliers more involved in product development and process efficiency, and through this knowledge, help in cutting production costs. From the supplier perspective, the program provided an opportunity for longer term business in a very competitive market, and improved possibilities for introducing new products. It also provided the supplier first hand knowledge of the performance of their product in the application equipment and working environment of the facility and feedback on how to improve the product to enhance its performance.

According to both the automaker and the supplier, the program has met expectations. In the first year of operation, the supplier saved over $1 million for the plant in improved efficiencies and reduced waste. The presence of suppliers in the facility, with responsibilities for material inventory management and tracking, helped Plant A obtain better and more timely data on material usage. Having a single supplier responsible for materials in a process also facilitated problem-solving. Instead of having to deal with several suppliers, all of whom were trying to avoid blame for a particular nonperformance issue, there was a single point of contact for dealing with problems. The supplier found it easier to get decisions for resolving problems, through weekly meetings that include all the relevant management staff. Having all the decision makers in the room at once helped to get decisions made expeditiously. Both parties developed a greater understanding for what it takes to produce a high quality paint job.

Automaker staff in Plant A also feel that they are getting more innovative products as a result of the program. They believe the supplier feels more ownership for the problems in the plant, and is more willing to share some of the ideas that in other situations they may have held back (due to competitive concerns with other suppliers also present in the plant). The security of a longer-term relationship focuses the supplier on the needs of the automaker, and the opportunity to develop a good reputation through this arrangement was viewed as a positive business asset by the supplier. The program has also reduced the amount of time spent on paperwork. According to suppliers, "We can avoid the bureaucracy of writing up separate procurements when new material is needed. With us owning the materials, the customer doesn't have to worry about placing orders. Our job is to see that the right colors are there in the right amounts when needed by the production team."

Another innovative program includes all purge solvents, thinners, cleaning chemicals and related solvents. It is run by the primary solvent supplier (which at this plant, is also the paint and coatings supplier) who is responsible for tracking and reducing usage and/or VOC content of these materials. Rather than established targets as in the paint program, the solvent program is based on a continuous improvement philosophy where yearly goals are established jointly by the supplier and the automaker. The solvent supplier usually does not manufacture all the products needed at the facility. He is, however, responsible for working with other suppliers to find improved, lower VOC products at competitive prices to achieve the reductions in cost and VOC emissions desired by the plant. The onsite solvent manager has a dual reporting relationship, to both the environmental coordinator and the plant manager, ensuring that both priorities will be important. At this plant, this relationship has developed into an effective working team. Both automaker and supplier staff talked about the trust in their relationship. The supplier is viewed as extremely customer-oriented. "They are as invested in fixing the process and getting a quality car out as we are", say plant supervisors.

This relationship and the commitment of both parties to the success of the plant has led to a number of innovative projects for improving environmental performance (described below).

Presaturated, Prepackaged Wipes

Vehicle assembly requires cleaning of the body and parts at various stages of the manufacturing process. Cleaning before and during painting is particularly critical to achieving a high quality finish. The plant had traditionally used pure acetone for wiping down the vehicle. Workers dipped rags into open buckets of solvent and then wiped the vehicle, resulting in high solvent usage (and creation of VOC emissions) and loss through evaporation. Prepackaged wipes were identified as a possible solution to this problem. The workers were supportive of the new wipes as a way to reduce their exposure to solvents in the workplace. The supplier trained the line workers to ensure that they understood how to use the wipes most effectively. Going to the prepackaged wipes resulted in a signficant reduction in VOC emissions and supported a plant-wide effort to eliminate acetone from their operation.

New Deadener Materials

Deadener materials are used in vehicle assembly to reduce noise during operation of the vehicle. These materials are high in solvent content and applied manually, much like other coating materials. Plant A, working with its supplier, identified two potential changes to the high solvent deadeners they had been using. One was to use sheets of preconstructed materials for the floor of the vehicle, laid in the body at various locations to reduce noise. The sheets are more expensive than using the solvent-based spray, but the company feels that they are worth it. "They are better environmentally, and they are better from the worker standpoint". The second change was to switch to a waterborne deadener, developed by the supplier, for the underbody spray. Applying deadener is a high labor job; line workers were one of the main supporters in the material change to reduce odors and irritation from solvents. Plant A is one of very few plants in the U.S. using waterborne deadener.

Redesigned Cleaning Stations

A myriad of handtools are used at an assembly plant to perform a variety of functions. Historically, tools had been cleaned at stations located throughout the plant where buckets of solvent were standing and available to workers. A supplier for handling solvent wastes came up with an idea for integrated tables that would take the place of the old stations. The tables include lighting, self-contained low-VOC cleaning fluids, and other materials needed for cleaning tools. The supplier owns and maintains the tables and fluids, replacing the material as needed and disposing of or reformulating the used fluids. There are thirty of these stations now at Plant A. It has benefitted the plant through reducing the use of solvent-based chemicals, cutting costs, and ensuring the stations are maintained appropriately. It has also allowed them to obtain this service and the related equipment without investing capital money. Although some workers initially had concerns about this shift, particularly about potential job impacts, the union workers in the stamping plant were highly supportive of the reduction in exposure to solvent odors. The environmental coordinator championed the idea with the plant manager and team supervisors, playing an important role in the implementation of the project.

New Floor Cleaners

Cleaning the floors, walls and grating in and around the spray booths is a particularly challenging problem in automotive paint shops. Traditionally, high solvent cleaners have been used in booth cleaning because they are extremely effective and fast. However, the workers at Plant A objected to the odors and related health effects of the solvent-based materials.[a] The supplier brought in a number of products with lower VOC content, but had difficulty finding a substitute that would deliver the performance required to clean the booths in the time available between production shifts. After a number of experiments with plant environmental staff and line workers (most of which had to be conducted during the graveyard

[a] Volatile organic compounds have a variety of health effects on workers, from causing dizziness and disorientation, to permanent neurological damage. Some of these chemicals are also known or probable carcinogens. For more information on the health effects of specific organic chemicals used in coatings, refer to the US EPA 1994 Toxics Release Inventory Public Data Release document, EPA 745-R-96-002, June 1996.

shift to avoid impacting production), it was determined that heating the material and using a mechanical scrubber could yield better results. Implementing this solution, while requiring investment in a new piece of equipment and the development of new procedures, has the potential to substitute a material containing 0.75 pounds of VOC per gallon for one that contains 5.5 pounds of VOC per gallon. Plant A has decided that the potential benefits of this project warrant adoption, at least on a trial basis. This solution required the support of plant management in allowing the supplier to experiment with options for both cleaning products and process. It also required resources (which were obtained from the corporate pollution prevention program) to invest in a mechanical scrubber. It required line workers (who are all union staff) who were willing to explore options that might require changed duties. And, it required a supplier who was dedicated to achieving results for the plant, whether the new product was manufactured by his company or not.

The philosophy at the plant is to reduce the use of solvents and hazardous chemicals wherever possible, "protecting rather than cleaning equipment". At times that has led to solutions that have the potential to increase the volume of solid waste from the plant. For instance, in the spray booths and paint shop areas, all equipment is covered (with materials ranging from paper and plastic covers to masking tape and foil) to avoid additional use of cleaning chemicals. In other cases, reduced use of cleaning chemicals has been achieved with reductions in solid waste as well. Plant A has eliminated tacky coating on the spraybooth walls, for example. The workers had objected to the lack of visibility caused by the coating. Through discussions with supervisors, they agreed to reduce overspray by more carefully applying paint if management would agree to remove the tacky coat. The agreement has been maintained by both parties, resulting in one of the few automotive assembly plant spray booths in North America without tacky coat on the walls.

Other changes stem from worker suggestions and projects. One of the more unique worker developed projects is the use of waterborne paints in low bake repair. Spot repair areas have traditionally used solvent-based paints. When the plant switched to waterborne basecoats, they purchased solvent-based paints formulated to match the waterborne colors. The head worker in the repair area (a union worker) took the initiative to push the idea of using waterborne paints, and undertook the testing required (working with suppliers) to convince the plant of the benefits of the idea. Plant A now uses waterborne in repair areas, which has also allowed them to replace solvent-based purge and cleaners with waterborne materials in repair.

Some of the environmental innovations adopted at Plant A resulted from projects targeting other areas of improvement at the facility. An ergonomic study on the installation of windshields resulted in a new procedure that also cut solvent use dramatically. Under the old system, two separate steps were required by the workers. First, the windshield was wiped around all edges with solvent, to clean the glass. Second, a solvent-based sealer was applied to the edge of the windshield, using another rag. Workers dipped the wiping rags in buckets of solvent-based materials to accomplish the task. Under the new system, a robot is used instead of manual labor. The robot has a small "wick" of material, which it dips first in solvent, wiping around the glass, then in sealer, wiping the opposite way back around the glass. When finished, the small part of the wick used for the operation is snipped off and is disposed of as waste. Far less solvent and sealer is used in this process, and less waste is generated with the wicks (instead of wiping clothes and rags). Worker exposure to solvents was also reduced. Another project focusing on quality has led to investment in new bells that are expected to improve the transfer efficiency of the waterborne paints. Improving transfer efficiency will also save money on materials and reduce environmental impacts.

Environmental Performance

The environmental performance of Plant A as measured by changes in releases over time from the facility is described primarily through TRI data, with some additional data provided by the plant. The primary environmental problems at the plant (as with most automotive assembly plants) come from paint shop operations. Environmental performance data from the TRI was obtained for this facility from the years 1989 through 1994 (the latest available data).[a] A number of performance measures were evaluated over this time period. First, the total emissions from the plant were tracked. This data shows changes over time in the total pounds of chemicals released from the plant directly into the environment. These emissions were primarily air emissions from plant operations. Second, the transfers made from the plant to waste treatment facilities offsite were tracked. This data is important to understand whether reductions in emissions are due to shifting the waste burden to outside sources or whether they represent true reductions in waste releases. The total emissions and transfers for Plant A over the time period analyzed are shown in Figure 4.2. The disposition of this transferred waste material is shown in Figure 4.3. Third, the emissions figures are normalized to account for plant production levels. This analysis ensures that any reductions found in chemical emissions are due to true improvement measures and not a result of reduced production activity at the plant. This data is shown for Plant A in Figure 4.4. Fourth, an analysis of total and normalized emissions for specific chemicals was performed. The parent company for Plant A had agreed to significantly reduce the use of these chemicals as part of a voluntary agreement with EPA (the 33/50 toxic chemical reduction program). The results of this analysis are shown in Figures 4.5 and 4.6. Each of these figures is discussed in more detail in the paragraphs below.

[a] Data from the TRI database is available from 1987 on. However, during 1987, Plant A produced a different model vehicle, and was in transition between models (with reduced production) in 1988. This analysis thus focuses on the years 1989-1994 to ensure a more consistent base of information across plants.

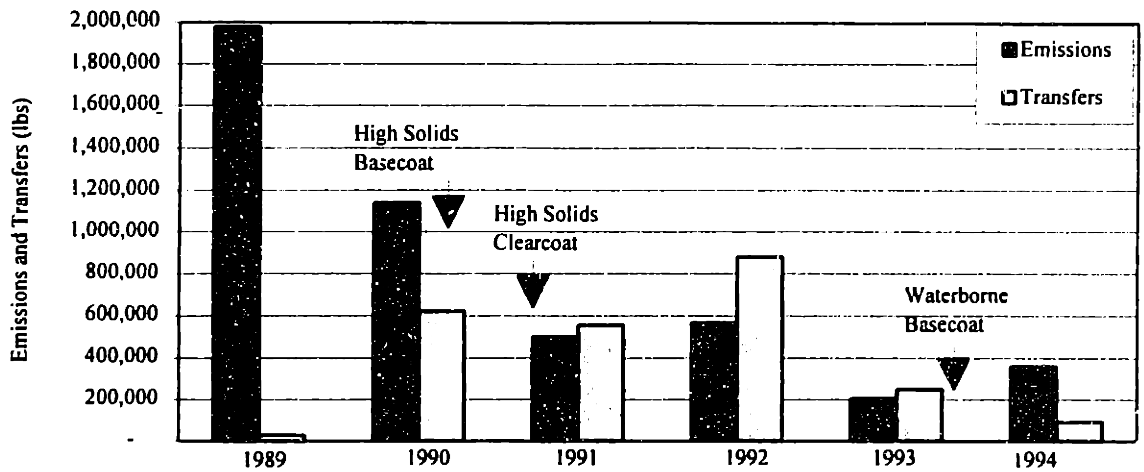

Figure 4.2. Total Emissions and Transfers for Plant A Decrease Over Time

A review of the trends in total emissions and transfers over time (Figure 4.2) suggests continuous improvement over time in reduction of chemical releases from Plant A. It also suggest a marked reduction with the implementation of the waterborne paint technology in 1993-1994. At the same time that total emissions from the plant were decreasing, however, the transfers to offsite waste handlers were increasing (during the 1990-1992 period), before declining again after the introduction of waterborne paints and other new technologies aimed at chemical and waste reduction. Data from the TRI releases and treatment data bases were reviewed to trace the shifts in waste disposal and treatment activities at Plant A. Wastes transferred offsite were sent to the local water treatment plant, to other vendors for further treatment, or to land disposal. Figure 4.3 (next page) shows the shift in waste disposal techniques over time at Plant A for those materials transferred offsite (these figures do not include the chemicals sent to local water treatment facilities). In 1989, most of the waste was released from the plant as air emissions. The transfers to offsite disposal (primarily zinc compounds) were destined for landfill. In 1990, emissions declined and, with new reporting requirements in place[a], the amount of offsite transfers showed a dramatic increase. Most of these (95%) were glycol ethers sent to the local water treatment facility (these are not shown

[a] This requirement added information to the TRI database on whether waste materials transferred offsite were recycled in some manner (either for solvent/organics recovery or for energy recovery).

on this chart). The remainder, again primarily zinc compounds, were sent to landfill. By 1991, a variety of alternative techniques were being implemented for handling wastes. Although the zinc compounds still were being sent to landfill, energy recovery techniques were used to treat the bulk of the solvents and organic wastes (such as xylene, toluene and methyl isobutyl ketone). In 1992, although energy recovery (fuel blending) was still used with many of the organic wastes, others were treated to recover the solvents for remanufacture and reuse. The amount of chemicals sent to land disposal was dramatically reduced. In 1993, Plant A implemented the new technology of waterborne paints, waterborne deadeners, and the paint sludge drying system, among other changes. Although these changes reduced the amount of solvent-based wastes, they also significantly reduced the amount of chemicals available for energy recovery or solvent remanufacture. But in terms of overall volumes of chemicals as waste, the plant had achieved major reductions.[a]

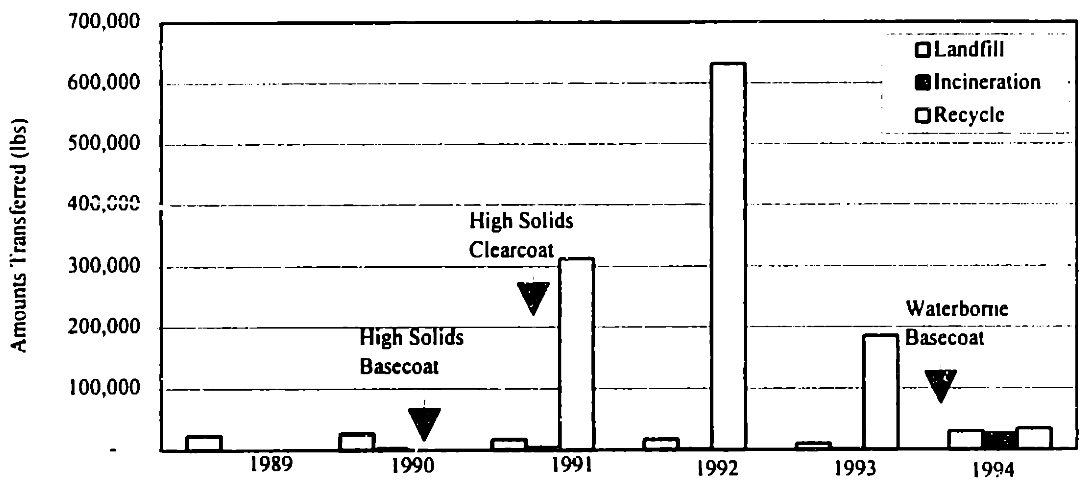

Figure 4.3. Disposition of Chemical Waste Shifts from Landfill to Recycling

Emissions data must be coupled with production data to provide a more complete picture of the environmental performance of any particular facility. Many companies achieve perceived reductions in emissions through plant closures or reduced production levels The production data for Plant A for the years 1989-1994 were used to normalize the emissions figures for

[a] Note that figures for 1993 at Plant A are for a short production year while the plant transitioned to a new model.

Plant A and provide additional insight into the changes in emissions from the plant over time. As shown in Figure 4.4, the plant continues to show decreases in emissions over time. The implementation of the new waterborne technology is evident in the 1994 data (implementation of waterborne on production vehicles occurred late in 1993 at Plant A).

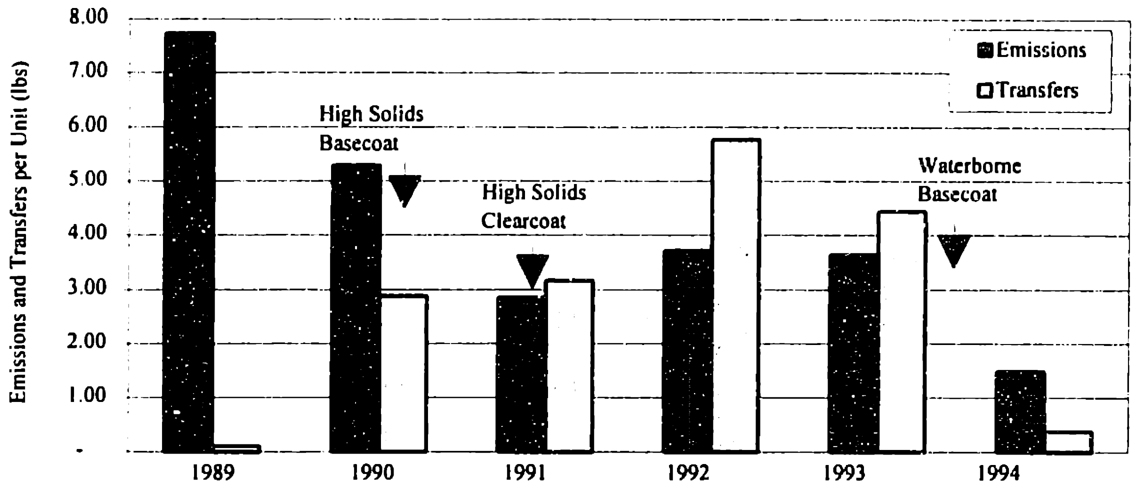

Figure 4.4. Emissions and Transfer Data for Plant A Normalized for Production

Chemicals listed in the EPA 33/50 voluntary program for reduction constitute some of the largest problem areas (in terms of emission volumes) at Plant A. The environmental strategy at the plant has been to reduce the use of these chemicals, but also to eliminate reportable chemicals from the manufacturing process and the paints and coatings products as much as possible. The TRI data for the major 33/50 chemicals at Plant A (shown in Figures 4.5 and 4.6 on the next page) show that through process modifications, chemical substitutions in material formulations (working with suppliers), and increased application of recycle and reuse techniques, the generation of wastes from chemicals on the 33/50 list has dramatically declined over time.

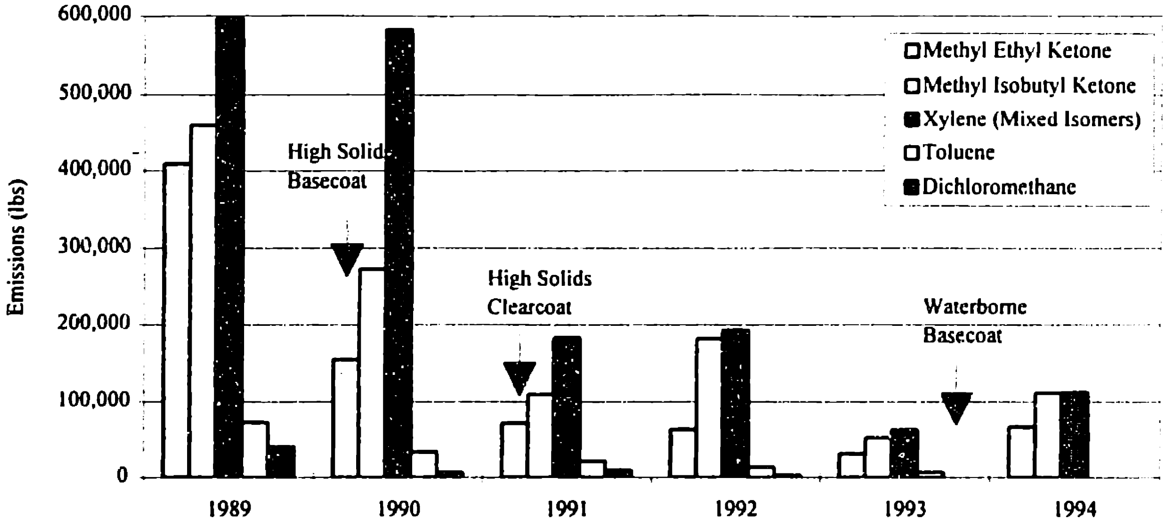

Figure 4.5. Total 33/50 Chemical Air Emissions Decline Over Time

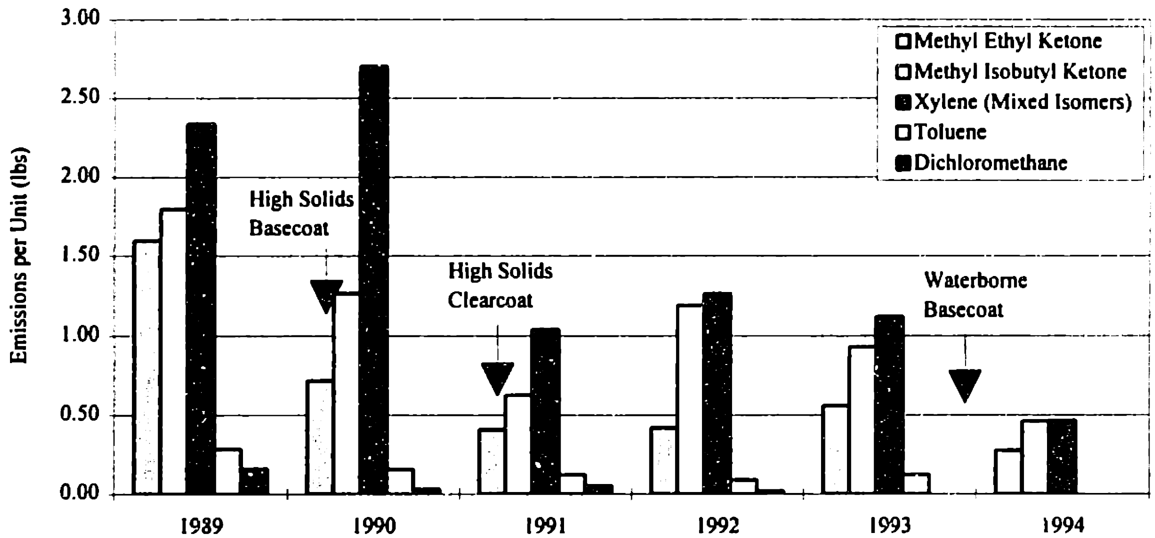

Figure 4.6. Normalized Emissions Data for 33/50 Chemicals Decline over Time

The TRI data provide insight to changes in processes at Plant A based on changes in the emissions and offsite transfers (and treatment) of specific chemicals. This data facilitates an examination of the effects of changes in technology, in procedures, and in disposal techniques on the environmental releases and transfers of specific chemicals from a facility. Plant specific data provides additional detail on the environmental effects of different steps of the paint process. To better understand the impacts of technological and process change on the environmental performance of the plant, three major areas of questioning were pursued. First, it is useful to understand the relative contributions of different parts of the painting process to the overall emissions from the plant. This information is important to understand the potential contributions of material or process innovations to improvements in environmental performance. Second, data on the reductions in VOC content of new materials and paint formulations is important in assessing the potential contributions of source reduction through materials changes to environmental performance improvements. Third, the disposal of paint sludge is a particular problem for most automotive assembly plants. Plant data is needed to understand how shifts in technology impact the sludge handling process and the role of innovative technology in supporting corporate goals of reduced waste volumes to landfill.

Relative Contributions To Overall Emissions

Air emissions (in terms of VOCs) were obtained from plant records for different elements of the paint process for the years 1992 and 1994.[a] The paint shop emissions for these years (see Table 4.3 on next page) were 80% of the total emissions from the plant. Within the paint shop, however, there are particular parts of the process that contribute the majority of the VOC emissions. The topcoat (basecoat and clearcoat) is a major source of VOC emissions, contributing almost 40% in 1990, and up to almost 60% in 1994. Even with the change to waterborne basecoat and overall reductions in total emissions, the topcoat continues to be a major contributor to VOC emissions at Plant A. The data also point out the importance of purge solvents and cleaning chemicals in VOC emissions. The contribution of these materials to paint shop emission totals averaged around 50%. Moving to waterborne basecoat paint materials can provide added environmental benefits through the ability to employ waterborne purge and lower VOC cleaning materials in the basecoat spray booth areas. Transfer efficiency is important in reducing paint waste and VOC emissions at a plant. Data from Plant A show, surprisingly, that calculated transfer efficiencies were not

[a] Data for 1993 is not included, since it does not represent a full year of production.

significantly reduced for the basecoat when they implemented waterborne paints. In 1992, using high solids, solvent-based paints, the transfer efficiency for the clearcoat was almost eighty percent. Basecoat transfer efficiency averaged 55% for all colors except black; black paints experienced a significantly higher transfer efficiency, showing the lowest waste of all colors. Data for 1994 show a transfer efficiency figure for clearcoat of about 72%. The waterborne basecoat transfer efficiency (averaged over all colors) was about 54% and had a much smaller range among colors than had been experienced with the solvent-based paints (the highest was 57% and the lowest, 47%, was represented by only one color, green).

Table 4.3. Contributions (%) of Paint Process Elements to VOC Emissions at Plant A

VOC Emissions (lbs) (after credits & abatement)	1992	1994
Total Plant	1,676,620	1,071,410
Total Paint Shop (a)	1,341,300	857,130
Ecoat	2	2
Primer-Surfacer	< 1	0
Sealer & Adhesives	6	8
Topcoat	39	47
Basecoat (w/o credits)	27	21
Clearcoat (w/o credits)	12	26
Deadener	16	0
Repair (hi & lo bake)	3	3
Cleaning & Purge Solvents	34	36

(a) Numbers calculated based on plant totals (paint shop is 80% of plant total).

New Paints and Materials Formulations

Paints and coatings materials and associated purge and cleaning chemicals are the primary source of VOC emissions in painting operations. Reducing that pollution at the source means changing the fundamental materials used for paints and coatings and the related cleaning materials and chemicals. Plant A has made a number of material changes that have contributed significantly to improvements in environmental performance at the plant, as measured by emissions and waste transfers. Changes in key materials are shown in Table 4.4 (next page), which highlights some of the differences in materials used before and after adopting waterborne paint technology. Data from 1992 and 1994 production demonstrate the differences in VOC content of some of the input materials used in the painting process.

Table 4.4. VOC Reductions from Changes in Input Materials or Use Patterns

	Input Material VOC Content (lbs/gal)		**Output of VOC Emissions (lbs/vehicle)**	
	1992	**1994**	**1992**	**1994**
Basecoat	4.35	1.41	3.41	1.06
Clearcoat	3.55	3.52	1.24	1.49
Deadener	0.22	0.0	1.70	0.0
Solvents/Cleaners	5.82 (average)	6.86 (average)	2.05	1.81

The shift to waterborne basecoat paints and waterborne deadener led to significant decreases in the VOC content of materials used at the facility and the resultant VOC emissions per vehicle. The decrease in VOC emissions with the use of the waterborne basecoat is encouraging. Even with using more material (due to decreased transfer efficiencies), there are still good results in terms of reduced VOC emissions. Alternatively, reduced use of higher VOC materials can also result in a significant decrease in emissions from the plant, as demonstrated by the data on solvents and cleaners at Plant A. In 1992, 55% (by volume used) of the solvents and cleaners used contained no VOCs; another 12% contained 0.45 VOC per gallon. The remaining materials, however, were fairly high in VOC content (from 5.95 to 7.93 pounds of VOC per gallon). In 1994, the use of low VOC cleaners was reduced, but the overall volume of solvents and cleaners used was also dramatically reduced (by about 85 percent from 1992 levels). This reduction in usage, not in input material content, led to the reductions in VOC emissions per vehicle for solvents and cleaners in 1994. These figures show that although reductions in VOC emissions can be achieved through reduced material use, which can be an important element of a VOC reduction strategy, greater reductions are achievable through reducing the VOC content of the input materials. A reduction strategy that simultaneously employs lower VOC content materials and strives to reduce material usage, particularly of higher VOC content materials, seems to be the best course of action for reducing environmental impacts (in terms of VOC emissions) for automotive assembly plants.

Handling and Disposal of Paint Sludge

Changes in technology can also affect environmental performance by shifting releases from one media to another, such as from air releases to solids that must be treated or disposed of in landfills. Table 4.5 shows the reduction over time in sludge volumes (for both industrial wastewater and paint sludge) and changes in sludge treatment at Plant A. This data is consistent with the TRI evidence, which shows greater use of recycling over time for waste materials and a reduced dependence on landfill. Paint sludge was initially considered a hazardous waste, with much higher disposal costs than industrial waste sludge. In 1994, Plant A initiated operation of a paint sludge drying system to reduce waste volumes sent to landfill and to avoid future liabilities of land disposal of industrial wastes. The new technology is extremely costly for Plant A--far more expensive than sending the paint sludge to traditional landfills--but is consistent with the corporate strategy of minimizing landfilling of waste.[a] The dried sludge is sold to an asphalt company, which uses the material as filler. Discussions are underway with local manufacturers of concrete and other building materials to find a closer market that would reduce transportation costs.[b] The dried powder is also being tested for suitability as a component of the sealers and adhesives used in the manufacturing process at Plant A. The hope is that the material can ultimately be recycled back into productive use at the plant, achieving a "closed loop" recycling of the material.

Table 4.5. Differences in Volumes, Treatment and Costs for Paint and Industrial Waste Sludge at Plant A

	1990	1992	1994	1995
Industrial Waste Sludge Landfilled (lbs/yr) [inc. phosphate sludge]	6,930,000	6,187,500	3,648,000	3,192,000
% solids by weight	40%	52%	52%	52%
Waste Sludge Disposal Costs ($/ton)	$36.65	$43.63	$65.79	$65.79
Paint Sludge Landfilled (lbs/yr)	326,000	326,000	0	0
Paint Sludge Recycled (lbs/yr)	0	0	115,000	140,000
% solids by weight	25%	25%	100%	100%
Paint Sludge Disposal Costs ($/ton)	$141.10	$171.78	(inc. in pay as painted program)	

[a] When this decision was made, it was expected that paint sludge would be classified as a hazardous waste and that disposal costs would continue to increase. Although neither of these scenarios came to pass, the company has committed to the drying of sludge as part of its longer term goal to avoid landfilling of wastes in the future.

[b] Transportation costs are a major contributor to the unfavorable economics of sludge drying. Identifying acceptable customers closer to plant locations would significantly improve the economics of the technology.

4.2. Case Study: Plant B

This facility was designed for assembling and painting large and luxury vehicles (it does not include other operations, such as stamping or engine manufacture). Plant B has been renovated a number of times since its original construction in the mid-1960s, gradually expanding the size of the facility from its original 970 thousand square feet to its current size of two million square feet. The plant was temporarily closed in the 1980s, but has otherwise operated continuously since it opened. In the late 1980s, a major capital investment ($370 million) was made to upgrade the paint shop and other areas of the plant, in preparation for a new vehicle launch, which was produced at Plant B until early in 1995. Late in 1995, a number of changes and upgrades were made to support another new product launch. Over $578 million was invested in facility upgrades, new automation, and retooling. Many of these process and product changes, such as adopting waterborne and powder paint technologies, targeted reductions in SARA reportable chemicals. These new paint technologies required large investments in infrastructure improvements and new application equipment. Piping systems were replaced with stainless steel materials; spray booths were retrofitted for air conditioning and humidity control (air conditioning was installed in the entire plant); distribution and collection systems were installed for powder applications; and traditional bells were replaced with equipment that did not rely on electrostatic application (for the waterborne basecoat). In addition to these technological changes, the plant implemented a program with its solvent supplier directed at reducing the use of regulated chemicals and VOC emissions from the plant.[a]

[a] In 1997, the plant plans to implement the "Pay as Painted" program for coating materials (see Plant A).

Plant Process Technology and Operations[a]

The plant generally runs two ten hour shifts per day, five days a week (with one shift on weekends), producing about 1600 vehicles per day. It has at times operated three shifts a day to meet increasing demand for its product. The painting process used at Plant B through 1994, compared to the baseline process described in Chapter 2, is depicted in Table 4.6.[b] The process begins with a complete cleaning of the vehicle, followed by a phosphate rinse. This is followed by electrocoating and an oven bake. After the application of sealers, a high-solvent primer-surfacer is applied to the vehicle. The topcoat is a high solids, solvent-based basecoat/clearcoat system (two coats of clearcoat are used to ensure good coverage). As with many automotive painting processes, a number of formulation changes have been made to the coating system over time, including shifts to high solids paints in 1990 (for the clearcoat) and 1992 (for the basecoat).

Table 4.6. Painting Process Steps and Technology for Plant B (through 1994)

Process Steps -- Baseline	**Process Steps -- Plant B**
Cleaning and Pretreatment	Yes
Phosphate Rinse	Yes
Electrocoating -- Dip system	Yes
Oven Bake	Yes
Sealer	Yes, hazardous material
Oven Bake	Yes
Primer-Surfacer	No
Antichip Protection	Yes, high solvent content
Tutone	Yes
Oven Bake	Yes
Basecoat (color coating)	Yes, high solids solvent-based
Oven Bake	No
Clearcoat	Yes, high solids solvent-based
Oven Bake	Yes
Repair	Full body repair (full vehicle repaint); limited spot repair

[a] The process description for this plant is focused on the timeframe prior to 1995, to allow comparison with other plants in this study and the available environmental data from TRI. Process changes after 1995 are noted in the text.

[b] The plant implemented a new painting process in 1995.

The plant uses about eleven colors, with white, teal and green the most popular. Paint is delivered as needed by the supplier in ready-to-spray form. There is no mixing of paints at this facility, other than some minor additions of solvents that may be needed to adjust paint viscosities. This is part of a larger effort at Plant B to reduce the amounts of hazardous and reportable chemicals onsite. Different products required for the paint system (E-coat, basecoat, clearcoat, sealers) are supplied by different companies.[a]

There are a number of sources of high material use for this facility. First, the plant does not utilize block painting, and thus uses high volumes of purge solvents and generates larger volumes of waste paint. The environmental staff agree that this is an issue, but say they cannot implement block painting without additional conveyors and sequencing equipment (at a cost of $1.5 million). A second source of material use stems from the repair process used at Plant B. Full body repair is performed on vehicles, for the most part, rather than spot repairs. When defects are spotted, the vehicle is sent back through the full paint process (repainting the entire vehicle). This approach uses more paint and purge solvents than otherwise necessary and generates additional waste.[b] Third, the plant employs a red tinted clearcoat on about 150 vehicles per day. This material is almost like a red paint, and creates a tough cleanup job in the booths, according to the cleaning chemicals supplier. The lines must be purged before applying a normal clearcoat to the next vehicle. Cleaning chemicals and solvents constitute a large percentage of the VOC emissions at Plant B (see Table 4.8). The plant was using up to 14,000 gallons of solvent a year for booth cleaning, until installing tacky coat in 1994.[c]

Air emissions are the primary environmental concern for Plant B. The painting operations generate about 80% of total air emissions, and 90% of the VOCs emitted from the plant. Existing environmental regulations as interpreted by state and local authorities in the operating permit for Plant B are the primary drivers for environmental activities. There is a high priority

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[a] In 1995, Plant B went to a single supplier for its paint materials.

[b] Although Table 4.8 (page 155) shows the repair process itself as only one percent of the plant VOC emissions.

[c] With the installation of tacky coating and other process changes made in 1995, annual booth cleaning chemicals use is down to about 2,000 gallons a year.

at the plant on maintaining compliance with these requirements. In many cases, these regulations are more stringent than the federal regulations, and noncompliance could result in shutdown of the plant. Some of the operations and waste streams affected by various environmental regulations are listed in Table 4.7 below.

Table 4.7. Operations and Waste Streams Subject to Federal, State or Local Regulation

Operations and Waste Streams	Primary Regulatory Guidance
Water Treatment and Discharge	County Water Treatment Regulations
Sludge Disposal	County Solid Waste Disposal Regulations
Toxic Chemical Use Restrictions	SARA and State Implementation Plan
Hazardous Waste Disposal	RCRA (State and Federal Requirements)
Solid Waste Restrictions	State and Federal Requirements
Noise	County and State Restrictions
Air Emissions: Odor	County Air Pollution Control Regulations
Air Emissions: Visibility	County Air Pollution Control Regulations
Air Emissions: Urban Ozone or VOC	New Source Performance Standards (CAA)
Air Emissions: NOx	State and Federal Requirements

The environmental staff at Plant B feel they have a very cooperative relationship with the local regulatory agencies. They maintain an open relationship with the county, informing them promptly of any unique operating conditions or problems they may experience and their plans for addressing the situation. In one instance, the plant had some peak emissions for which they could have been fined. The environmental staff informed the county of the problem as soon as they were aware of it and were able to work with the county agency to solve the problem without incurring penalties. Plant B also provides the local agencies with information on planned production changes that may affect operating conditions. The relationship with the local regulatory agencies has developed through concentrated effort by the environmental staff at Plant B. It has been reinforced, however, by the environmental performance record of the facility. The plant has always succeeded in operating under their annual permit limits for air releases. The original operating permit for the plant was based on a facility constructed with a number of pollution control technologies (incinerators, filters, and other "end-of-pipe" equipment). This permit sets a limit for annual VOC emissions of 1700 tons, after taking account for credits. The renovation of the facility in 1995 created a challenge for Plant B. The extent of the changes to the paint shop and related pollution control equipment required the plant to meet more stringent environmental standards for new sources (the New Source Performance Standards). The new operating permit set an annual limit of 1291 tons of VOC emissions, with specific limits placed on each major element of the painting process. Introducing new materials in the paint process and implementing operational process changes have been important in maintaining compliance under the new permit. Without the shift to waterborne and powder technologies, Plant B would have required a major investment in pollution control equipment to achieve their new emission limits. In spite of these material and process changes, however, existing pollution abatement equipment must be maintained as a requirement of the operating permit, whether or not this equipment is needed to meet compliance limits. This lack of flexibility in the operating permit for the facility seems inconsistent with an agency willing to consider new, innovative approaches to compliance. It also continues to focus attention on compliance rather than pollution prevention as a primary goal, even as corporate directives encourage greater emphasis on prevention.

Disposal of solid wastes (from treatment of paint and industrial wastewater sludges) is another environmental concern for Plant B. Solid wastes generated at the facility include industrial and paint sludges and packaging materials, such as cardboard and plastics. The traditional method for disposing of both industrial waste and paint sludge is to incinerate and/or landfill the material. Plant B sends its sludge waste materials to a landfill for disposal.[a] Other solid wastes generated at Plant B include packaging materials (cardboard, plastics, etc.), rags and other solid wastes. The plant has implemented a returnable container program with suppliers to try to reduce packaging waste volumes. They also have a recycling program for cardboard and other paper wastes run by an outside vendor. These recycling programs have achieved mixed results to date. There have been difficulties in getting the workers on the line to collect and separate the packaging materials. The recycling program at Plant B is fairly new, however, and is continually being improved to try to achieve better performance. For rags and related solid wastes, a shift to premoistened wipes and a reuse/laundering program has helped to significantly

[a] Plant B installed a sludge dryer for paint sludge recycling, but has had difficulty getting the equipment to work properly. They continue to landfill the material (which is actually cheaper for them than drying the sludge).

reduce the volume of waste rags. The permitted limit for the plant in solvent wipes, for instance, is 310 tons per year. In 1995, the plant used only 25 tons of wipes.

There are two major future environmental challenges for Plant B: 1) incorporating the requirements of Title V of the Clean Air Act Amendments into their operation, and 2) meeting new (more stringent) limits for air emissions expected as the local area is reclassified from a moderate to severe nonattainment area. These changes will likely affect their operating limits. In addition, they will be increasingly asked to incorporate activities supporting corporate environmental goals of pollution prevention into their environmental program.

Corporate Strategy and Environmental Policies[a]

A number of corporate goals were mentioned by the environmental staff at Plant B. An important corporate goal is to have no effect on the environment from manufacturing vehicles by the year 2000. Although the environmental specialist for Plant B recognizes that the goal of zero effects is probably unattainable, projects are designed to try to move toward this goal. The strategy for achieving this goal centers on reduction of hazardous material use and reuse/recycling of materials. Achieving progress is strongly tied to material decisions made at the product design team level, at corporate. The assembly plant staff, while providing input and recommendations to the design team, are not significantly involved in that decisionmaking process. Their primary responsibility is to manufacture the vehicle with as high a quality and as cost-effectively as possible. Factors considered in making decisions on materials include: cost (per gallon or pound, and per vehicle); feasibility of recovery or reuse; effectiveness (performance); long-term liability (warranty issues or waste handling/disposal); and health and safety. Environmental factors are generally second to cost or quality issues. The decision to switch to a waterborne basecoat from a high solids formulation, for instance, was based on a combination of cost and performance factors. The rising costs of traditional pollution abatement

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[a] The corporate strategy for Plant B is driven by the same parent company as Plant A. The details of that strategy are outlined in the Plant A discussion. The focus here is on the plant perspective of those goals.

equipment were a major driver, as was the corporate strategy to reduce pollution at the source. Implementing high solids paint technology in the retrofitted facility would have cost the company over $25 million in environmental control technology to meet the new permit limits. The waterborne technology required abatement equipment only for the ovens (with waterborne, a higher percentage of solvents are carried over into the ovens, relative to solvent-based formulations) and the waterborne materials had a lower VOC content. However, without the ability to deliver a high quality finish, the environmental benefits of the technology alone would not have driven the change. Another corporate goal requires a pollution prevention plan for each facility, with specific waste reduction goals set by the plant. At Plant B, a goal of 10% improvement (that is, reduced wastes) has been set for the year 1996 (the first year of a formal pollution prevention plan at the plant level). A third corporate goal is to save $1 million per year through reduction of waste. This has created a lot of pressure at Plant B to ensure that the environmental staff and related projects can show results in dollars saved. One of the biggest areas of cost-reduction (as well as VOC reduction) has been eliminating waste in solvents--reducing the usage of paints and related purge and cleaning solvents. A number of projects focused on reductions in these materials.

Corporate goals are translated to the plant level through a number of mechanisms. Each plant has an environmental specialist onsite, as well as a corporate environmental liaison called an Environmental Coordinator that is part of a company-wide network. The Environmental Coordinator (EC) has a dual reporting responsibility, to the plant manager and to a manager at the corporate level. The EC is there to help the plant manager and environmental specialist meet environmental goals for the plant, and develop and support new projects for continuous improvement. The EC is also the primary contact point for the suppliers at the plant, and helps to ensure that environmental goals and priorities are incorporated in contractual requirements for the suppliers. Most of the goals are related specifically to permit requirements for the plant. However, there are also corporate "stretch" goals included, and suppliers are evaluated, in part, by how well they perform in helping the plant meet these goals. For instance, although the permit level for nonproductive solvent wipes in the paint shop is 300 tons per year, there is a corporate goal of 216 tons per year, to which the suppliers are pushed. The environmental coordinator at Plant B says that even with environmental goals written into the performance requirements for suppliers, "that clause never really seems to get enforced. It is all cost or quality". The problem is that a good paint finish, according to him, is not compatible with environmental issues. The paint companies want to get the best possible finish, and this makes them reluctant to reduce VOC if it could possibly endanger the product quality. Trying to get attention for environmental issues has been difficult.

The environmental performance goals for the plant are set primarily by environmental regulation (state and federal) and corporate goals and policy. Interestly enough, these goals are not incorporated into the performance requirements of the managers at Plant B. Although each department manager must meet some overall goals and the plant must stay in compliance, "it is not like they get extra credit for going beyond what must be done to keep the operations going". The quality of the car and the number of units per hour are the critical measures for the plant managers. At Plant B, emission limits set by the operating permit receive top priority. Corporate environmental goals are transmitted to all plants, but most projects and activities at Plant B are devoted first and foremost to ensuring compliance and continued operation.

Management Approach and Work Culture

Plant B is in transition from a traditional, hierarchical management to a new culture of worker involvement and partnerships with suppliers. During the 1987-1994 timeframe, they were still well entrenched in the more traditional management culture. As with most organizations in the midst of cultural change, the stated management system is not yet consonant with the actual experience in the workplace. The management at Plant B is attempting to implement a new, leaner management system, "empowering" workers on the line through greater use of teams and fewer supervisors (each supervisor now has about 70-90 people). The original organizational strategy included team leaders from the union, but the incomplete implementation of this plan has resulted in fewer front line supervisors who are tremendously overworked. One past supervisor described a day in the life of a supervisor as follows:

> "When they first get in to work, they spend the first hour or so just getting enough staff together to run the line. With our high absentee rate, that is not a trivial job! Then the next couple of hours is spent making sure they [the workers] are doing it right. Then, the supervisor gets to go to meetings for a while, before the next problem hits. It's a tough job."

The paint shop manager maintains the priority on production quotas and quality, not team building or environmental issues. Quality of the product is measured by fit of parts, finish gloss, component failure rates, paint defects and warranty data. The supervisors at the plant recognize that these elements are highly dependent on workers. According to one supervisor, "our quality is always worse on Monday, Friday and late in the day". But changing the operating culture at the plant has been difficult. Supervisors doubt that line workers value greater involvement in the job, claiming it is viewed by workers only as a source of extra work and responsibilities, with no additional reward. One supervisor in the paint shop stated that "All they care about is getting their paycheck". In reality, at this facility line workers have very little control over their jobs. For instance, there was a problem with the fluid delivery rate out of the guns creating problems with the paint and poor film builds on the vehicles. The issue was that of achieving proper pressures in the lines and guns. In defining and solving the problem, the line workers were not involved at all; it was handled solely by operating supervisors and the supplier staff. The solution to readjust pressures in the equipment was implemented by the supervisors--not the equipment operators. The team concept is not fully implemented at this facility.

The environmental staff feel that, for the most part, "environment has not been viewed as a value-added function". Environment gets attention only if a problem comes up or a particular report is needed. The inherent improvement in the plant and product design (in 1995) has resulted in significant emission reductions; the plant is in no danger of exceeding permit limits. The limited potential for fines from noncompliance has reduced the interest of plant management in investing in environmental improvements. Environmental costs are allocated at the plant level, not by department or center of operations. Environmental projects may be funded out of corporate accounts or plant level budgets, and often require fairly short payback periods (four to nine months, depending on the level of investment). Most projects are justified based on economic returns. Those that can be shown to reduce waste and inefficiency (and therefore cost) in plant operations are the most likely candidates for funding. Since many of the compliance-oriented problems are now under control, more of the funding can be applied to pollution prevention and system improvement projects, but these projects must still show cost benefits. For instance, to justify paying for four full-time people to maintain a recycling program at Plant B, they must show equivalent or greater savings from the program. To support these requirements, the recycling team gathers data to demonstrate savings in returnable packaging and recycling of paper, cardboard and plastics over several years.

The Environmental Coordinator job has traditionally been a compliance-oriented function, although the corporate directive is to shift this position to one that is more focused on integrating environmental issues into production activities. The environmental staff at Plant B, while not sure how well this will work, now view the shift as possible since the new product design and process material changes (after 1994) have eliminated many of their traditional compliance problems at the plant, with more time available to address prevention issues. An example of the benefits of integrating environmental responsibilities with operational processes comes from a problem at the plant with high solvent waste streams first identified by the EC in the sludge processing system. In tracing the cause for this problem, he discovered that line workers in the paint shop were purging lines after every vehicle, whether they had a color change or not. In addition to the environmental implications of this activity, there are tremendous costs incurred in excess use of material and increased treatment and disposal costs. Understanding the processing system and tracing the problem from that perspective allowed the EC to identify the root cause of a difficult problem, saving money and reducing VOC emissions from the plant.

The relationship with suppliers is a traditional one, with materials purchased from a number of vendors on a volume basis. The incentives for the supplier are on the amount of chemicals sold--the more the better. In 1995, the plant consolidated its purchasing to a limited number of major suppliers and now has a single supplier for paints and coatings and another for purge materials and cleaning chemicals. The new contract with suppliers includes not only the purchase of high quality materials, but also services such as technical consulting, tracking of inventory and material usage rates, and innovative ideas for reducing usage (for environmental as well as cost purposes). "Some suppliers know our needs so well, we don't even have to put them through the bidding process--they are simply given the job and we negotiate specific terms." The benefits of this kind of a relationship are trust and performance. The move to a single supplier for managing this process has allowed consolidation of chemical usage across the plant, simplifying reporting requirements and identifying areas of high usage. For instance, in the past, there may have been as many as four or five different floor cleaners being used, from different suppliers, each with different chemical compositions that required separate reporting to EPA. By standardizing products used in the facility, Plant B has been able to streamline their reporting, find ways to reduce usage of certain products, and achieve price breaks on materials that can now be ordered in larger volume. Having a single supplier then track these materials and chemicals across the plant further simplifies the job for the plant staff. And, says one manager, "we know what we are getting! With a bidding system, you don't always know who you may end up with, and whether they can perform the job satisfactorily."

A single supplier is also now used in the paint shop for the primary coating materials. Although this supplier is still paid on a materials volume basis, part of their contract requirements include tracking material inventory and usage, improving process efficiency and quality, and providing technical advice and problem-solving. The supplier has seven staff located onsite to support the paint shop (up from four in 1992). The paint shop managers originally were against this shift to a single supplier, believing that the move would result in increased costs and reduced freedom for them. However, the demonstrated benefits of the shift, including more detailed and timely operating data, consistent supplies of quality materials, and technical support for process improvements and waste reductions, have won their support. The reports and data from this new system have been critical to identifying and achieving cost and environmental emission reductions. With the single supplier, they get quick response time on chemicals and materials, and minimum shipment amounts, achieving price breaks in many cases and reducing the amount of unused inventory at the plant. The single supplier concept has helped Plant B not only in terms of compatibility of the products that must be integrated to produce a quality finish, but also in getting more and better (more accurate and timely) data and control of materials. This is a major improvement from trying to collect the information from a variety of suppliers. With the data and materials coming through a single source, it makes it much easier to trace performance and gather information. If they have a question about paint usage, they don't have to try to trace it through a system of suppliers--they ask the primary supplier to analyze and solve the problem. According to the EC at the plant, suppliers frequently provide assistance on optimizing the performance of coatings and monitoring the final quality of the coating process. Dependence on a single supplier for a particular plant is balanced by managing the supply base across all plants in the company. If there is a problem with one supplier not being able to perform or deliver as desired, there are other competent suppliers to whom the company can go.

A single supplier is also used to supply the solvents and related materials used in the painting process, including purge solvents, cleaning chemicals, and tacky coat. The supplier manufactures about 90% of what they sell, but also provides some products that they purchase from others. Chemical products are shipped to Plant B once a week. They are not really operating on a just-in-time basis, but do try to keep inventories of materials as low as possible. The problem with the just-in-time concept for chemicals is that it does not easily provide for dealing with emergency situations, or with special needs that may arise in the course of production. Although this supplier has been the primary chemicals supplier to Plant B for a number of years, they have only recently added inventory and material usage tracking services to their contract (as of 1995). These numbers are reported monthly to the environmental coordinator. The supplier also provides a great deal of technical consulting and problem-solving at the plant, working closely with the line workers. For instance, the onsite supplier works with the booth cleaners (often on graveyard shift) to determine ways to use less chemical and still achieve good performance results. Even though the supplier is paid based on volume of product sold, plant management has made it clear that a requirement for continued business is to help meet the permit requirements and reduction goals for VOC emissions from purge solvents and booth cleaning. The company supports this with a purchasing philosophy that does not always go with the low dollar bid; past performance and service by a supplier also count heavily toward winning a contract.

The supplier supports this arrangement because of a sense of trust that the automaker will support them in moving to related businesses (as the need for high solvent products declines), selling related products (such as lower VOC cleaners) or provide recommendations for them in seeking contracts with other companies. The business is very competitive, and the more the supplier is viewed as a part of the plant production team, the better their competitive advantage. Finally, the arrangement helps to build the supplier's understanding of the plant production processes and the customer's needs, which helps them in their product development and sales. The automaker staff also see benefits to the single supplier concept. In addition to the timely and accurate reporting of material and process data, they have access to supplier expertise right onsite. Plant staff openly admit that the paint supplier has a much better understanding of the coating products; however, the knowledge of the operating process is still largely held by the automotive company. This sharing of competencies "helps keep everybody honest". Although paint shop staff maintained that decisions were made as a team, interviews suggested that the supplier, not the automaker, had a large responsibility for ensuring that the paint process went well (although they do not make the operating decisions). Both the plant staff and supplier personnel stated that the suppliers have a very serious investment in the appearance of the vehicle.

The relationship between supplier and automaker at this facility is still not a full partnership. Even with the more innovative contract mechanisms with suppliers and the attempts to construct more of a partnership arrangement through single supplier systems, the relationship with suppliers (particularly during the 1987 to 1994 timeframe) retained some of the adversarial view traditionally found in the U.S. automotive industry. When problems arise in an operating system, the first response is to "go beat up on suppliers", rather than work as a technical team with the suppliers to solve the problem. Although suppliers are present full time onsite, they are clearly identified as part of another company, with different "uniforms" from automaker staff. Suppliers agree that they have no control over decisions in this plant. What the supplier offers is advice, support and followup on identified problems. The supplier has a local satellite plant for serving this customer and often will work with their primary research facilities located elsewhere to address materials problems identified during production. The supplier for cleaning chemicals echoed that the biggest obstacle to getting things done at Plant B is that the suppliers onsite do not have any real power at the plant. "Our job is to act like a consultant--it is frustrating at times not to see things followed through [by the plant management or staff]".

A number of innovative projects and technologies were implemented with the new vehicle design in 1995. The plant also continues to explore mechanisms for improving environmental performance, particularly in reducing use of solvents and improving performance in solid waste reduction and recycling. Although these design and process changes were made at Plant B after 1994 (the specific timeframe used for analysis of environmental data), they are indicative of the strength of the corporate strategy and environmental policies in this company and are included to provide additional data on the corporate strategy influencing Plant B. They also provide insight into the challenges of implementing new paint technologies at an operating facility. While most of the ideas for new projects originate with the environmental or supervisory staff at the plant, some are initiated by suppliers. Few appear to be from line workers (at least based on interviews with plant staff). Although these projects do have some benefit to the environment, most are justified on the basis of cost savings to the plant.

New Booth Coating Materials

To reduce solvent usage in the clearcoat booth, a peelcoat was developed by the supplier to substitute for the traditional tacky coating used on booth walls. The peelcoat is a latex paint that can be peeled off the wall and has inherently lower VOCs than tacky coating. It also reduces the amount of tacky coating material in the waterwash system. Tacky coating is like a gel, containing chemicals that are incompatible with the treatment process for the waterwash. Although the EC agrees that disposal of the latex sheets with peelcoat may be an issue, the expense of water treatment chemicals and the problems presented by the consistency and chemical incompatibilities of tacky coating make the project worthwhile.

Recycled Waterborne Purge

The new waterborne paint process requires a purge material which, while water-based, still contains some solvent. Under the old system of solvent-based purge, the material was collected and remanufactured by the supplier (as the clearcoat solvent-based purge still is). The waterborne purge, while containing solvent, has too little to make it attractive to the supplier for remanufacture and cannot be effectively used in fuel blending, reducing an important avenue of recycle/reuse. This has created an additional waste stream for the plant and eliminated a source of credits (for reclaim) used in reporting VOC emissions. It is possible for the material to be chemically separated and reused, but the current process technologies just add expense and more potentially hazardous or regulated chemicals to the plant inventory. The company has agreed to fund a project (run by the environmental staff at the plant) to explore the possibility of recycling waterborne purge through the use of a mechanical separation process. If successful, the purge material would be sent directly to the paint mix room and recycled within the plant.

Premoistened Wipes and Reuse of Rags

Rags are used widely throughout the plant for wiping down vehicles at various stages of the assembly or painting process, or for cleaning tools or parts throughout the facility and are a high volume waste for Plant B. Traditionally, cleaning and wiping rags were colocated with buckets of solvent, resulting not only in excess use of solvent (and high VOC emissions) but also in a hazardous solid waste (the rags) requiring disposal. By state regulation, rags with even small amounts of solvent or alcohol on them are classified as hazardous waste. However, the regulations also state that if the rags are laundered and reused by the manufacturer, they are no longer considered hazardous waste. At Plant B, reduction of waste rags followed two paths: first, reducing the use of solvent with rags; and second, eliminating the hazardous waste classification for this high volume solid waste. The paint shop switched to using premoistened wipes, and as a result, has dramatically reduced the solvent content in cleaning rags. Laundered rags are reused for applications that do not have the quality requirements of the paint shop.

Sludge Drying System

Paint sludge is generally considered a hazardous waste, with higher disposal costs than industrial waste sludge. A corporate program designed to implement more closed loop processing at automotive assembly plants identified sludge drying as an alternative to disposing of paint sludge in landfills. In this system, the paint solids are removed through the sludge dryer and the water is cleaned and returned as makeup water into the booth waterwash processing system. The dried paint sludge is in the form of a powder or pellets that is sold to asphalt or roofing companies as fillers. Drying the paint sludge creates a recyclable, reusable product, and reduces the amount of expensive landfill disposal required by the plant. However, sludge drying is still more expensive than traditional treatment and the plant must incur the costs of transporting the product, since there is insufficient volume of this kind of recycled material to serve as a regular input material for users. Sludge drying is an environmentally beneficial practice, but one that does not yet save the company money. In this case, corporate policy to avoid landfilling waste has been the major driver to continue operating the sludge dryer, even at increased expense.[a]

Environmental Performance

The environmental performance of Plant B as measured by changes in emissions over time from the facility is described through both TRI and plant data. The major environmental problems at the plant are from paint shop operations. The environmental performance data as provided in the TRI were obtained for this facility from the years 1987 through 1994 (the latest available data) and reflect the solvent-based painting process (as described in Table 4.6).[b] A number of performance measures were evaluated over this time period. First, the total emissions from the plant were tracked to show changes over time in the total pounds of chemicals released directly into the environment. Other than minor releases to water in 1987, these consisted solely of air emissions from plant operations. Second, the transfers made from the plant to waste treatment facilities offsite were tracked, to understand whether reductions in emissions stem from true reductions in waste releases or are a result of a shift in waste burden from the manufacturer to a waste handling company. The total emissions and transfers for Plant B over the time period analyzed are shown in Figure 4.7. The disposition of the transferred waste material is shown in Figure 4.8. Third, the emissions figures are normalized to account for plant production levels. This analysis ensures that reductions in emissions are due to true improvements at the plant and

[a] Note that this expense is one that must be borne by the plant budget, not corporate.

[b] The switch to waterborne paints and nonhazardous sealers, among other design changes, was made in 1995. Performance data from the plant for these later years were not available.

not simply a result of reduced production. This data is shown for Plant B in Figure 4.9. Fourth, an analysis of total and normalized emissions for specific chemicals was performed (see Figures 4.10 and 4.11). The parent company for Plant B had agreed to significantly reduce the use of these chemicals as part of a voluntary agreement with EPA (the 33/50 toxic chemical reduction program). Each of these figures is discussed in more detail below.

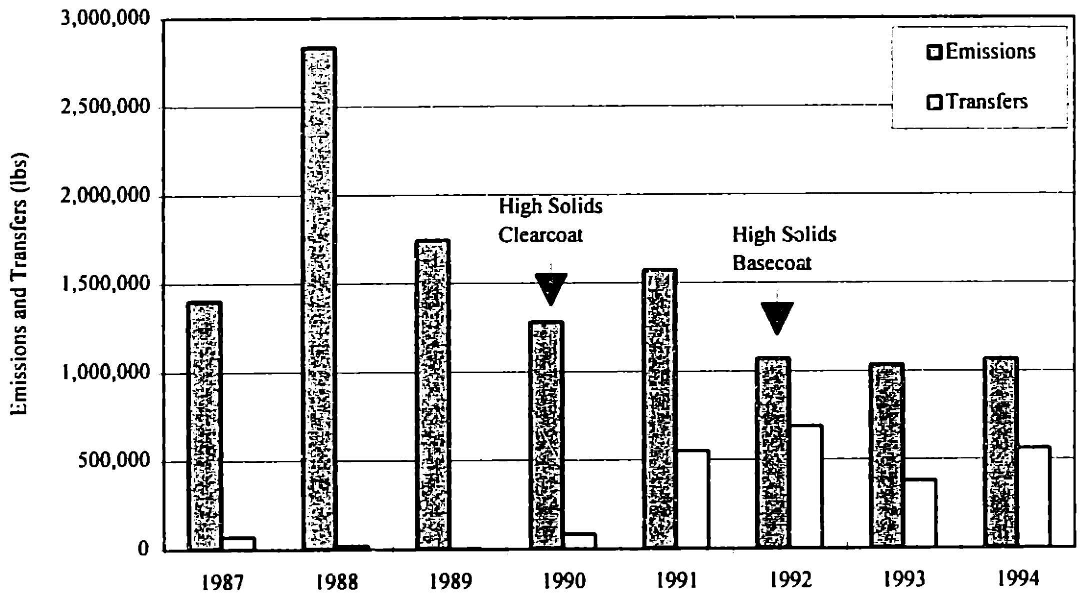

Figure 4.7. Emissions and Transfers from Plant B

A review of the trends in total emissions and transfers over time (Figure 4.7) show reductions in emissions even before implementing significant changes in materials inputs. Additional reductions were achieved with the shift to high solids paint technology, followed by a stabilization of emissions over time. The plant experienced a significant reduction in emissions in 1989, followed by the implementation of a high solids, solvent-based clearcoat formulation in 1990. In 1992, the high solids, solvent-based basecoat was introduced, yielding additional improvements in environmental performance. Since 1992 the level of total emissions has been steady at about one million pounds of TRI reportable chemicals per year. Further reductions in emissions were not achieved as of 1994. The transfers from the plant show increases in 1991 and beyond,[a] although these quickly reach a relatively stable level. Figure 4.8 shows the disposition of the chemicals contained in transferred material. Plant B continues to incinerate some chemicals, but shows an increase in the amounts sent to recycling, and a sustained decrease in the amount of chemicals sent in materials to landfill over time. The recycled chemicals are primarily those contained in purge solvents. The plant sent almost 150,000 pounds of TRI-reportable chemicals to landfill in 1991, and by 1994 was down to under 25,000 pounds.[b]

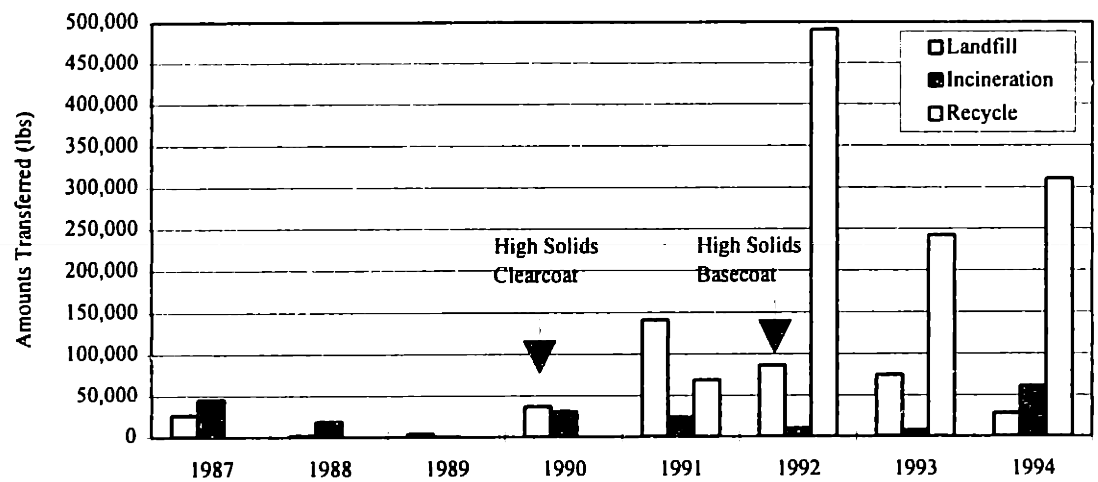

Figure 4.8. Increased Transfers of Waste over Time to Reuse and Recycling

Another perspective on plant performance is provided by coupling emissions data with production data to understand whether changes in environmental performance are related to changes in the number of vehicles produced (and painted). Figure 4.9 (next page) shows the results of an analysis that used production data for Plant B for the years 1987 to 1994 to normalize the emissions data as reported in TRI for those years. The normalized data shows a stronger trend toward reduction of emissions than was evident in the total emissions picture. Plant B has had dramatic increases in production over time, with a three shift schedule at times in the early 1990s. The data in Figure 4.9 suggest that emissions generated per unit produced have

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[a] 1991 is the first year in which plants were required to report disposition of transferred material to the TRI, based on the implementation of the Pollution Prevention Act of 1990.

[b] Note that these figures refer to the pounds of chemicals contained in the transferred material. Total volumes sent to landfill would be significantly larger.

consistently decreased over time. The implemention of the high solids basecoat in 1992 had a particularly strong effect, causing a step function reduction in emissions per unit, which was maintained over time. The level of emissions per unit basically stabilized at a level of about four pounds (of TRI reportable chemicals) per unit in 1993 and 1994.

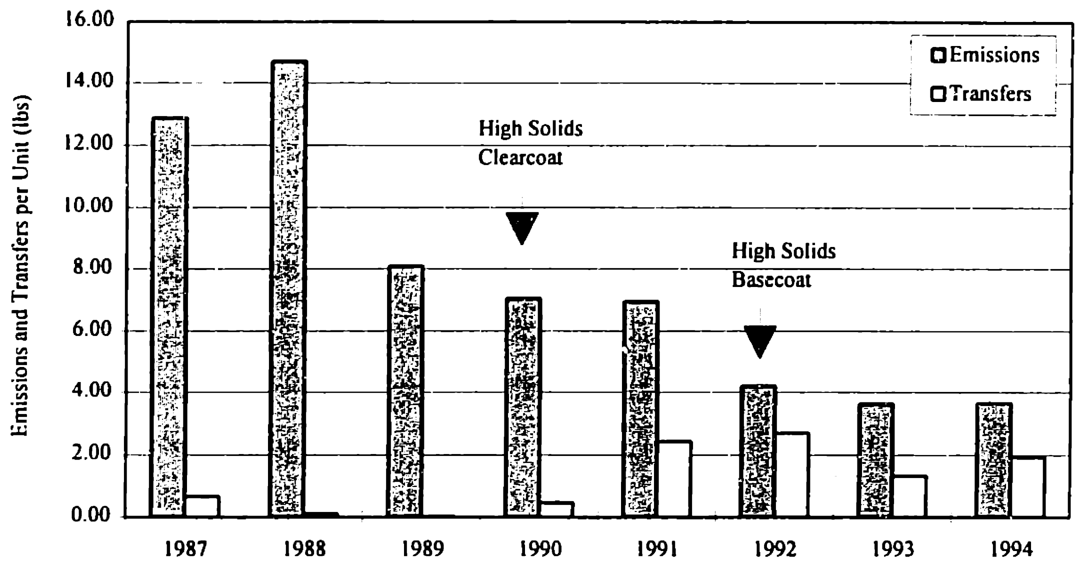

Figure 4.9. Emissions and Transfer Data for Plant B Normalized by Production

Chemicals listed on the EPA 33/50 voluntary program for reduction constitute some of the largest problem areas (in terms of emission volumes) for Plant B. The environmental strategy at the corporate level has been to not only reduce these chemicals, but also to eliminate reportable chemicals for the manufacturing process and the paint products as much as possible. The TRI data for the major 33/50 chemicals at Plant B (shown in Figures 4.10 and 4.11 on the next page) show that significant reductions in xylene, traditionally a primary element in most paint products, were achieved with the shifts to high solids paints (for both clearcoat and basecoat). Emissions of other 33/50 chemicals also show significant decreases over time.

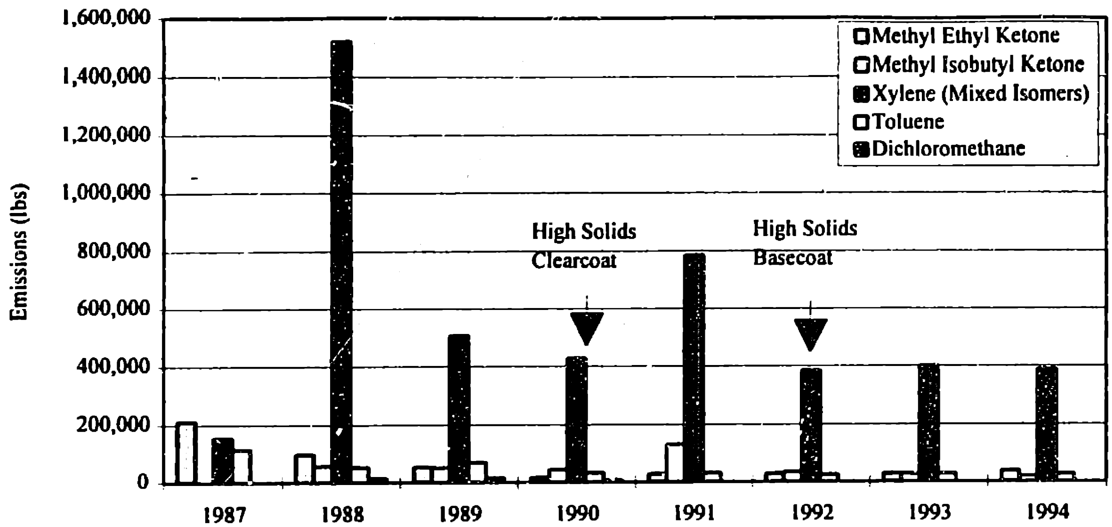

Figure 4.10. Total 33/50 Chemical Emissions at Plant B

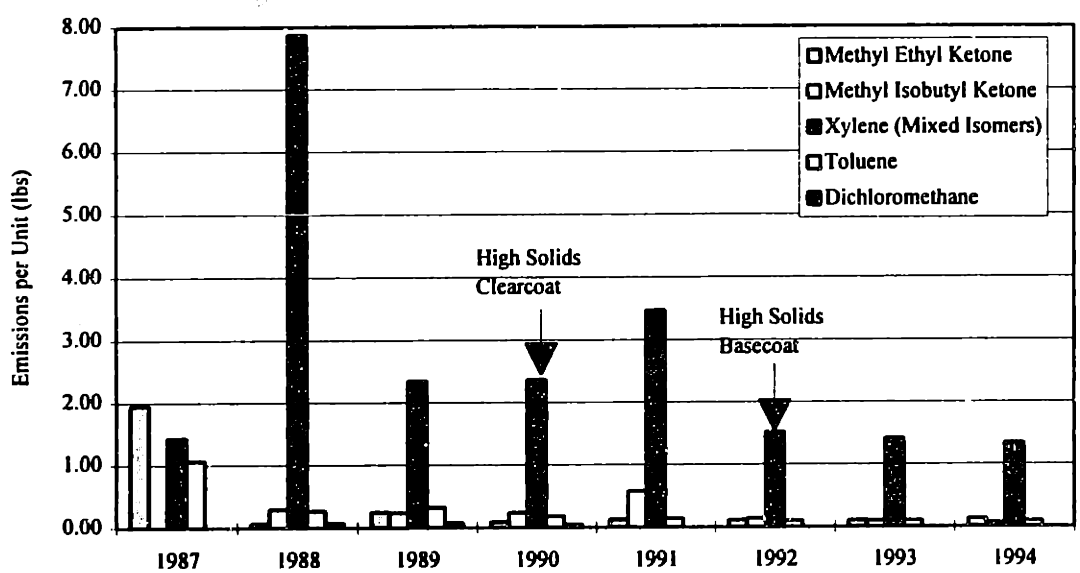

Figure 4.11. Normalized Emissions Data for 33/50 Chemicals at Plant B

The TRI data is one important source of information about the performance of the plant. However, the data is limited to those chemicals reportable under the SARA legislation. It does not include the full range of materials and chemicals used at Plant B. Data on materials treated or disposed of offsite is by amount of specific chemical included, not total volume of waste. A more complete understanding of the environmental performance of the plant is provided by plant data. First, the relative contributions of different elements of the paint process to the total emissions from the plant were evaluated. This data provides a basis for understanding where changes in materials can lead to significant benefits in emissions profiles for the plant. Second, data on the paint formulation and VOC content in related materials was obtained, to understand the potential effects of changes in formulation on plant emissions. Third, because paint sludge is such a problem for automotive assembly plants, data was obtained on solid waste disposal for Plant B. Although the primary basis of comparison among plants is limited to the years 1987 through 1994, some data from Plant B based on the new technologies adopted in 1995 are included to shed light on the challenges of shifting technologies in a production facility.

Relative Contributions to Overall Emissions

While Plant B must meet a variety of air emissions requirements, emissions of VOCs are one of the most closely tracked and largest source of environmental releases. They are also one of the more difficult and expensive of emissions to control. Almost all VOC emissions at an automotive assembly plant stem from the painting operation. Not all elements of the painting and assembly process, however, contribute equally to the overall emissions from the plant. Understanding the relative contribution of different parts of the process to emissions is important to develop effective strategies for emissions reduction. Table 4.8 (next page) highlights the major contributors to VOC emissions at Plant B for the years 1992 through 1994. These figures reflect VOC levels after accounting for waste disposal credits and abatement. Without abatement, these figures would be significantly higher. This table shows that the topcoat and the cleaning and purge solvents (which include materials used outside of the paint shop) are the major contributors to the VOC emissions from Plant B. Solvent wipes and body cleaners also contribute significantly to VOC emissions.

New materials can make a significant contribution to reducing VOCs, particularly in areas of the process that are not easily controlled by traditional pollution abatement technology or where additional efficiencies are technologically limited or cost-prohibitive. A dramatic reduction in the contribution of sealers and adhesives to total VOCs was achieved at Plant B with a substitution of materials containing less than two-tenths of a pound of VOC per gallon, replacing materials that contained over six pounds of VOC per gallon. Additional reductions were achieved from traditional pollution control equipment (almost half of the VOCs from sealers in the paint shop are captured and destroyed by the incinerators in the bake ovens). Changing materials, however, is not the only way to affect these numbers. Process changes can also reduce VOC emissions by improving transfer efficiencies in the spray booth or by implementing block painting. The transfer efficiencies (using solvent-based paints) at Plant B are already relatively high (about 65 percent for basecoat and 76 percent for clearcoat). Additional benefits in this area are technologically limited. Block painting, however, could reduce both the use of paint materials and cleaning and purge solvents (thus also reducing VOCs).

Table 4.8. Contributions (%) of Paint Process Elements to VOC Emissions at Plant B

VOC Emissions (lbs) (after credits & abatement)	**1992**	**1993**	**1994**
Total Plant	2,829,970	2,543,180	2,773,510
Total Paint Shop (a)	2,546,970	2,288,860	2,496,160
Ecoat	3	4	(b) 6
Primer-Surfacer	0.01	1	0.06
Sealer & Adhesives	5	(c) 2	1
Topcoat	46	46	47
Basecoat	31	31	32
Clearcoat	15	15	15
Deadener	4	5	5
Repair (hi & low bake)	1	1	1
Cleaning & Purge Solvents	40	40	35

(a) Calculated (paint shop is 90% of plant total).
(b) Problem with incinerator (efficiency of 70% instead of usual 90%)
(c) Change to lower VOC content materials

New Paints and Materials Formulations

The timeframe for which environmental data is available from the TRI (1987-1994) is one in which Plant B used solvent-based coating materials. The VOC content of these materials is highlighted in Table 4.9 (next page). In 1995, the plant shifted to new coating materials, utilizing both waterborne basecoats and full-body powder antichip on the vehicle. The new waterborne basecoat has a VOC content of 1.48 pounds per gallon, a significant reduction in the VOC input to the painting process at Plant B. The average solvent content of purge materials for the basecoat area decreased to some extent as well. Even with the reduced transfer efficiency experienced with waterborne paints (about 45 percent as opposed to 65 percent with solvent paints), the overall reduction in the VOC content of materials input resulted in a measurable improvement in overall plant performance. Although the EPA environmental release data for 1995 is not available to fully evaluate the effect of this process change, data on VOC emission levels from Plant B in 1994 and 1995 give some indication of the magnitude of the change. In 1995, the plant had actual VOC emissions (after allowances for waste credits) of about 900 tons, compared to 1394 tons in 1994 (although some of this may be due to reduced production levels in 1995, about fifteen percent lower than in 1994). Even considering the differences in production levels, this still yields a result of 7.3 pounds VOC per vehicle in 1995 as opposed to 9.6 pounds VOC per vehicle in 1994.

Table 4.9. VOC Content (lbs per gallon) of Selected Coating Materials at Plant B

	1992-1994	Transfer Efficiency	**1995-1996**	Transfer Efficiency
Uniprime	0.63	1.00	0.63	1.00
Basecoat	4.26	0.65	1.48	0.45
Clearcoat	3.49	0.76	3.49	0.76
Underbody Deadeners	1.95	NA	NA	NA
Solvents & Cleaners	6.87	NA	NA	NA

While shifting to waterborne paint technology has improved the environmental performance of the plant, it has also provided a number of operating challenges. The paint shop staff feel that the switch to waterborne has resulted in a need for greater control of key operating parameters in the paint process. In addition to the effects of outdoor temperature and humidity, they have to be careful to flash just the right amount of water out of the basecoat before applying clearcoat. If the basecoat is left too wet, it can absorb too much of the clearcoat material when applied, resulting in a hazy finish. The water also has to be evaporated at the correct rate--if evaporated too fast, it creates popping defects in the finish. There have been problems with waterborne paint drying in the lines and the guns (trying to minimize the use of waterborne purge), leading to increased material requirements for waterborne purge. In spite of the operating challenges, Plant B is committed to using waterborne paints, and not only because of the environmental benefits.

They believe that the waterborne basecoat with a solvent-based clearcoat finish has a much better appearance. There is a tradeoff between environmental limits and functional performance when making material substitutions in a high volume production process. Finding new, more environmentally beneficial solvents that yield the performance of the older solvents is important to ensure that the plant does not have to use more material to achieve the same results.

Handling and Disposal of Paint Sludge

Paint sludge, although not the only solid waste generated at Plant B, is one of the more difficult to handle. Table 4.10 provides data on the total volumes of industrial waste and paint sludge generated by the plant in selected years throughout the early 1990s. Volumes of sludge for disposal have increased significantly at the plant. While costs for disposing of industrial sludge have been decreasing (on a per ton basis), costs for paint sludge disposal have been increasing. In addition, the shift to new technologies (waterborne and powder) at Plant B in 1995 have resulted in additional volumes of sludge.

Table 4.10. Differences in Volumes, Treatment and Costs for Paint and Industrial Waste Sludge at Plant B

	1990	1992	1993	1995
Industrial Waste Sludge Landfilled (lbs) [inc. phosphate sludge]	510,000	480,000	2,352,040	2,130,030
% solids by weight	46	40	30	30
Waste Sludge Disposal Costs ($/ton)	$275	$270	$56	$55
Paint Sludge Landfilled (lbs)	1,310,000	84,000	398,010	1,476,020
Paint Sludge Recycled (lbs)	0	330,000	330,000	369,030
% solids by weight	22	22	20	20
Paint Sludge Disposal Costs ($/ton)	$157	$400	na	$868

For Plant B, the shift to waterborne and powder coating technologies in 1995 resulted in increased sludge volumes. Waterborne paint has lower transfer efficiencies and has required more paint to get the proper film builds on the vehicles. In addition, the booth waterwash and paint sludge handling systems, which were not redesigned in the shift to waterborne basecoats, are of insufficient capacity to handle the current mixed solvent-based and waterborne waste streams. The waterborne purge, which contains some solvent, makes up about half of the sludge waste volume. This material must be treated before being sent to the local wastewater treatment facility. The chemical treatment necessary for separating the paint solids from the water is incompatible with that necessary for treating waterborne resins. The need to treat two very different kinds of materials in the wastewater has led to additional expense in new chemicals and processing in the sludge treatment system. The use of both waterborne and powder coatings has also been problematic. The effect of local weather conditions on both technologies creates inconsistency in operations from day to day. On high humidity, high temperature days, "the paint can just slide off the car". The powder sticks more, and loses its static charge, in spite of internal temperature and humidity control in the facility. Powder materials clearly reduce the VOC emissions from the paint process, however. The powder generates far fewer VOC emissions in the baking process than previous materials (about 0.25 pounds per vehicle, compared to 1.5 to 3 pounds of VOC per vehicle). But the use of powder coating has increased the volume of solid wastes at the plant. While theoretically waste powder can be reused in the production process, at Plant B the recycled powder can only be used on the lower part of the vehicle. Virgin powder is used on the top and sides. The powder process has ended up generating an additional 2000-3000 pounds of waste per month. The company is hoping to find a user for the material, but it is currently in drums at the facility awaiting disposition.

4.3. Case Study: Plant C

Plant C was built in the late 1980s for large production volumes, unlike other assembly plants which were expanded over time to accomodate increases in production demands. The facility, which is fully air-conditioned, includes a stamping plant, engine and transmission production, an injection molding operation, painting and final assembly and trim. The plant was designed to meet all existing and developing environmental, safety and health regulations, and minimize environmental impacts to the surrounding communities. Ecological issues were an important consideration in all aspects of the manufacturing operation, from siting the plant to designing the vehicle to be produced in Plant C. Environment was also a major consideration in selecting the materials and processes to be utilized in the assembly plant. This plant was one of the early users in the U.S. of waterborne paints and in-mold color.[a] The vehicle was designed with lighter weight materials for greater fuel efficiency, adding to the challenges of using waterborne paints, since there were few experiences in the industry with applying waterborne basecoats to multisubstrate vehicles.

The influence of the parent company philosophy on quality and environment are reflected in the operations at Plant C. There is a strong belief within the company that quality control is more effectively obtained by producing major components and parts for the vehicle in-house. Many of the primary vehicle components, including engines, transmissions, exterior body panels and interior parts and panels, are produced onsite at Plant C.[b] The focus on quality is also evident in the organizational construct used at the plant. A team management approach has been implemented, rather than the traditional hierarchical system used in many automotive assembly plants, with distributed responsibility and a high level of worker involvement in problem-solving and quality improvements. Corporate environmental

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[a] The in-mold color is primarily used for interior parts.

[b] Some parts, of course, are produced outside the plant. For items shipped to the plant from outside suppliers, (such as seats or critical production materials such as paints and coatings), supplier representatives must be present onsite to inspect the incoming items.

priorities on recycling and minimizing solid wastes from the plant are reflected in many innovative projects throughout the facility. Projects at Plant C are directed at creating more closed loop systems, where instead of sending recycled materials to outside users, material is recycled within the plant and used to manufacture other vehicle parts. For instance, scrap material from polymer panels is recycled for use in rocker supports and wheel covers. One of the design engineers at corporate estimates that thirty-five percent of each vehicle at Plant C is comprised of recycled materials, including recycled steel, aluminum and plastics. The design of the plant also stresses energy efficiency; plant managers believe that the facility uses up to forty percent less energy than their competitors to produce similar sized cars.

Plant Process Technology and Operations

The plant runs two shifts, six days a week, producing about 1000-1100 vehicles a day. The plant produces almost all of the major parts needed for the vehicle, including all body panels, fascias, transmissions and engines. The painting process used at Plant C, compared to the baseline process described in Chapter 2, is depicted in Table 4.11 (next page). The steel panels and frame are cleaned and then put through a phosphate process, followed by electrocoating (using the standard dip process). All body panels are robotically coated with one coat of solvent-based primer, two coats of waterborne basecoat, and two coats of a high solids, two component (2K) solvent-based clearcoat. A separate paint area is set up for the fascias, which are painted with a waterborne basecoat, followed by a solvent-based clearcoat (a two-component solvent-based clearcoat). The plant also produced a small number of tutone vehicles in the first two years of production. Vehicles are assembled from painted panels in the final assembly area. The luster and durability of the final finish is very important to the quality assessment. An injection molding process is used not only for specific body parts and panels, but also for interior parts. Achieving an acceptable surface finish on the external body parts has been a difficult challenge. Some sanding and finishing of the parts is required. Some of these parts are painted, some are constructed using in-mold color, and some have vinyl coverings which are thermobonded to the part.

Table 4.11. Painting Process Steps and Technology for Plant C

Process Steps -- Baseline	Process Steps -- Plant C
Cleaning and Pretreatment	Yes
Phosphate Rinse	Yes (Steel panels & frame)
Electrocoating -- Dip System	Yes (Steel panels & frame)
Oven Bake	Yes
Primer-Surfacer	Yes (solvent-based)
Antichip Protection	Yes (Powder)
Sealer	Yes (after painting & assembly)
Oven Bake	Yes
Basecoat (color coating)	Yes (Two coats, waterborne)
Oven Bake	Yes, to flash-off water
Clearcoat	Yes (Two coats, solvent-based)
Oven Bake	Yes
Repair	Spot repair of panels as needed

The painting process utilizes waterborne paints and a powder blackout coating (since 1993), both for the performance characteristics delivered by these materials and to reduce VOC emissions from the manufacturing process. At Plant C, body panels and parts are painted before the vehicle is fully assembled.[a] This approach to painting was adopted to try to reduce the amount of rework required, minimizing additional material requirements, labor and environmental emissions that can be generated from high levels of paint repair. There are tradeoffs, from both a cost and an environmental standpoint, in using this approach. Painting separate body parts and panels results in reduced transfer efficiencies (and increases in paint-related emissions) for any one piece.[b] This results in greater usage of paint, which is very expensive, and increases in VOC emissions. However, painting parts rather than the entire vehicle has dramatically reduced the amount of rework at Plant C. In the event of paint defects, only that particular part needs to be replaced rather than repainting the entire vehicle.

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[a] At other plants, painting generally occurs after the body-in-white is fully constructed.

[b] The amount of overspray, or wasted paint, is higher for smaller pieces than for larger ones. See discussion in R. Joseph et al., "Transfer Efficiency Training at Hill and Edwards AFB--Results in Significant Pollution and Cost Reductions", in Proceedings of the Air and Waste Management Association 89th Annual Meeting and Exhibition, Nashville, TN, June 1996.

The plant also uses block painting extensively to balance to some extent the waste (in paint overspray) from painting separate parts. Block sizes vary depending on the orders sent from general assembly.[a]

This facility had the advantage of selecting a construction site in the post-Superfund era, and as a consequence, has not experienced some of the historical hazardous waste and remediation problems found at other automotive assembly plants. One of the plant environmental engineers emphasizes the importance of being able to learn from the experiences of other plants. From a manufacturing standpoint, many of the environmental issues at Plant C are similar to those experienced at other automotive manufacturing facilities. In spite of the presence of the stamping plant and injection molding facility and the additional chemicals and hazardous materials required in building engines and transmissions, the paint shop is the major source of environmental impacts. The facility also contends with solid and hazardous wastes, including some heavy metals.[b] Solid wastes from the facility include paint sludges, scrap metals (including aluminum, brass, and nickel) and a variety of packaging wastes, cardboard, paper and plastics. Waste streams and related manufacturing activities at Plant C are regulated by federal, state, and in some cases, local agencies. Some of the specific operations subject to these environmental regulations are listed in Table 4.12.

Table 4.12. Operations and Waste Streams Subject to Federal, State or Local Regulation

Operations and Waste Streams	Primary Regulatory Guidance
Wastewater Pretreatment and Discharge	Local Wastewater Pretreatment Rules
Sludge Disposal	State Solid Waste Disposal Regulations
Toxic Chemical Use Restrictions	SARA, State Regulations
Hazardous Waste Disposal	RCRA, State Regulations
Solid Waste Restrictions or Reduction	Pollution Prevention Act of 1990
Air Emissions: Visibility	State Regulations
Air Emissions: Urban Ozone or VOC NOx	CAA: BACT (Best Available Control Technology) and LAER (Lowest Achievable Emission Rate) New Source Performance Standards (CAA)

[a] Block sizes at the plant generally run from seven to ten vehicles.

[b] All the heavy metals, in particular, are recycled by the plant, generally sold to the original material supplier.

The operating permit for Plant C was developed by setting separate standards of performance for each of the major process areas within the plant. The lack of significant experience at the time in painting with waterborne, particularly on plastics, made it necessary to initially estimate the production levels of VOC emissions that might be experienced at the plant. The final negotiated permit limits the total VOC emissions from the plant to about 2900 tons per year, based on a full capacity production level of about 360,000 vehicles per year, or 1500 vehicles per day. In 1995, with production levels of 302,000 vehicles, plant data indicates that actual VOC emissions (after abatement) were about 900 tons (or six pounds per vehicle).

From a systems perspective, the reduction of emissions from repair and rework has been important to the overall environmental performance of the plant. The waterborne basecoat paint, while containing only about one-third the VOCs of solvent-based paint, has a much lower transfer efficiency. Electrostatic application techniques cannot be effectively used with waterborne, and only half as much paint as with solvent-based systems adheres to the vehicle. Painting individual vehicle panels rather than the entire vehicle added to the challenge of increasing system transfer efficiencies. Initial experiences with waterborne at Plant C generated greater than anticipated VOC emissions from the plant. There were also unexpectedly high contributions to VOC emissions from the solvent-based processes and purge material used at the plant.[a] Production engineers initially overestimated the amount of material reclaim available from solvent-based purge. Rather than full recovery of purge solvents, only about seventy percent of the solvent was reclaimed. This led to the facility being out of compliance with their permit limits in 1991.

In 1993, a one million cfm carbon adsorption system was installed at the paint shop to remedy the emissions problem. This was a major investment ($21 million) in an advanced pollution control technology, made based on a company assessment of the direction of future environmental regulations, particularly related to the Clean Air Act Amendments of 1990. The carbon adsorption system was installed on the roof of the paint shop. It consists of five

[a] The waterborne paint process initially used a 1% solvent purge, but now uses a 100% hot water purge.

carbon beds through which all emissions are passed. It is not generally operated at full capacity. If the carbon adsorption unit were operated at maximum capacity, and the plant took full advantage of recycle opportunities for the solvent-based materials, they could achieve 300 tons per year VOC emissions, a dramatic reduction. But this would set a challenging standard not only for other facilities belonging to the parent company, but also across the entire automotive industry. The potential of setting new standards for the industry creates a strong disincentive for plants to push their environmental technology to maximum performance.[a] The plant has also experienced some problems with the carbon system. It has been more expensive than anticipated. After three years of operation, the carbon beds, which are very expensive, had already been changed out twice. The process of stripping the old carbon and replacing with new is extremely expensive and time consuming. The location of the system on the paint shop roof requires using a helicopter for reloading the carbon beds (an additional expense). It does, however, provide the plant with future operational flexibility. While plant staff say that with this technology they could shift back to solvent-based paints and still meet environmental requirements, there are no current plans to abandon waterborne at Plant C.

Although major technological shifts are not planned at Plant C, there are continuing efforts to identify process and material changes that could lead to reductions in cost or improvements in quality. Ideas for innovative projects come from a number of sources, including plant environmental engineers, suppliers, and line workers. Many of the ideas for improvements have developed through focusing on cost, quality or safety improvements. The installation of the carbon adsorption unit was somewhat unique in that it focused primarily on environmental performance improvements and required a major investment by the plant. Other process changes have focused on reductions in or reuse of materials. For instance, an examination of the use of rags in the paint mix room and resultant process changes achieved a 50 percent cost reduction (from $150,000 annually to $75,000). Another example concerns the use of

[a] Although this plant might have a competitive advantage in the market, it would create a competitive disadvantage for other plants owned by the parent company. Competition in the industry is among companies, not specific plants.

solvents in painting. Plant C initiated production using all virgin solvents in its painting processes. Although the solvent was reclaimed, it was used in fuel blending rather than remanufacturing solvent. The increasing cost for solvent led a task force comprised of workers, suppliers and team leaders to evaluate this practice. The team identified the potential for and benefits of solvent remanufacturing and reuse, which was then implemented at the plant, reducing average solvent costs by 25 percent.

Technology decisions made with attention to environmental issues have resulted in a plant designed to achieve strong environmental performance. The challenge of integrating these various technologies to achieve that performance was difficult the first few years of operation, particularly as production increased rapidly to meet market demand. Recent data suggests that the combination of technological advances, new materials and attention to operational processes are continuing to reduce the environmental impact of manufacturing at Plant C. Continued monitoring of the performance of this plant in the next few years as production climbs will provide additional evidence of the benefits of product and process design that consider environmental issues.

Corporate Strategy and Environmental Policies

The environmental strategy for the parent company of Plant C is built on a set of principles that encourage pollution prevention, waste reduction, recycling, conservation of resources, and promoting strong partnerships with local communities and governmental agencies in achieving environmental performance improvements. Pollution prevention is a top corporate priority for Plant C. The vehicle design, while driven from the corporate platform team, incorporated a number of features and materials directed at making the vehicle lighter (therefore more fuel efficient) and more easily recyclable at end of use.[a] Scrap plastics from injection molding processes are recycled within the plant to provide raw material for fascias and fenderliners. Environmental criteria were considered using life cycle approaches to help

[a] Environmental engineers were included on the vehicle design and development team.

the design team choose among different material and design options. Plant operations were also designed to support a more flexible work environment, one that utilized teams rather than the traditional directive management style of most automotive assembly plants. Although a number of different suppliers are used to provide various materials, chemicals and parts, the company attempted to involve those suppliers earlier in the product design to get more input from and a stronger working relationship with suppliers.

The corporate environmental organization serves as a central resource for the plants on environmental issues, including updates on regulations and legislative trends, waste minimization projects at various company facilities, and new technologies for reducing and/or treating waste streams. The information is primarily transmitted through the network of plant environmental engineers. Outreach to local communities is an important part of the corporate environmental philosophy, and all plants have some program in place to work with community groups on selected environmental issues.

In 1990, the company initiated an internal program for reducing waste and cost in all facilities as part of their total quality program. Projects specifically focus on those that reduce the use of raw materials, reduce the generation of waste, or benefit the environment in some other way. The company has also developed an innovative contract mechanism to encourage chemical suppliers to reduce the overall volumes of chemicals used onsite. The chemical supplier is paid on a fee basis to manage and track chemical use at a plant. Financial incentives encourage reductions in chemical usage at the plant level for both the automaker and the supplier. Beginning in 1994, the corporation also included the environmental performance of operating units as one of the criteria to be considered in performance reviews and promotional opportunities for plant managers.

Management Approach and Plant Culture

While overall environmental policy is developed at the corporate level, the specific operating goals and performance measures for environmental issues are determined and managed at the plant level. Plant C shares the overall company commitment to environment through its own operating philosophy. The environmental manager states this philosophy as "not only complying with what [regulations] exist, but also anticipating where future regulations will be going". Working with the local community to understand and respond to its needs has been a major priority for plant management. The investment made in the carbon adsorption unit demonstrates the importance that management places on minimizing the environmental impact to the local community of the manufacturing operation. While air emissions constitute the majority of environmental releases at Plant C, solid wastes are also a challenge, as for many assembly plants. Scrap metal wastes and plastics constitute a large portion of the solid waste volume at Plant C. However, most of these materials are recycled, either within or outside the plant, and bring revenue to the facility. Plant C also has a strong recycling program for packaging and cardboard wastes, with almost 90% of these solid wastes recycled. Suppliers are an important part of achieving these results, implementing with the automaker a returnable packaging program, where pallets and other containers are returned for reuse. Agreements with suppliers have been developed to work toward reducing the volume of packaging used and to make the packaging materials that are used more recyclable. Staff at Plant C have also implemented a program to reduce the amount of hazardous wastes generated at the plant, reducing amounts by about 10% over the last few years.

The organizational structure at Plant C is built around business units that are comprised of teams dedicated to specific tasks, such as installing the engine block, or applying basecoat paint to plastic body parts. The intent of structuring around teams was to move decision making down to the worker level. An environmental manager coordinates information among business units at the plant and provides the primary link to community activities and communications. Environmental engineers and chemical safety coordinators report to the environmental manager on a dotted line basis, but are assigned to specific business units, each of which comprise a number of work unit teams. The environmental staff at Plant C is larger than that observed at many other automotive assembly plants. These people are responsible not only for the regulatory compliance activities at Plant C, but also for working on waste reduction projects and serving as a resource on environmental issues to workers. They also have a role in decisions on new materials and chemicals. All chemical purchases are evaluated by the hazardous material coordinator to identify potential hazards and long-term disposal costs.

One important element of the success at Plant C in waste reduction is moving the costs of waste from the plant level overheads to the specific team level. That is, any group generating hazardous waste out of their operation is charged for that at the team level. This has created greater attention at various management levels to the cost of waste, and heightened worker awareness in looking for ways to reduce waste volumes. Although many investment decisions are based on standard cost-benefit criteria, some are now based on life-cycle costs for materials. For instance, the environmental manager at Plant C describes a decision to switch from solvent-based to waterborne adhesives for attaching vinyl coverings to interior surfaces of the vehicle. One 55-gallon drum of the solvent-based adhesive is $245, as opposed to $500 for the waterborne material. The performance of the materials is essentially the same. However, with the waterborne material, the plant can avoid record-keeping and handling costs associated with reportable solvents and a $975 per drum liability for waste disposal. Using this perspective results in a cost advantage for the waterborne materials. This life-cycle perspective, however, is still relatively rare among automotive assembly plants and in corporate purchasing groups.

The management of the operation through teams focuses on cost, quality and productivity issues. At Plant C, it is the link between environment, safety and cost which has most served to support improvements in environmental performance. For instance, reduction in scrap rates (which is a high priority at the team level) also leads to a reduction in waste. Problems with hazardous chemicals may be more often addressed from a worker safety standpoint, yet still lead to overall reductions in chemical use. Although the plant environmental engineers say they have good support from leadership on environmental issues, the importance of financial measures at the plant often result in cost reduction as a primary motivation for undertaking environmentally-oriented activities. The prevalence of payback criteria as an evaluation mechanism for discretionary investments can also discourage some engineers from proposing new projects that may yield only long term benefits.[a] The lack of environmental performance reports at the team level (which is where costs are reported and measured) can make it difficult for workers to determine how their job affects environmental goals. As put by one environmental engineer, "the real challenge now is getting people on the line to think about how to reduce pollution at the source".

There are a number of reward systems in place at Plant C that help ensure effective training and productivity of all employees. A small portion of each worker's salary is set aside, and can only be received if the worker achieves an agreed upon annual training goal (usually about 5% of the annual work schedule, or over two weeks). This training includes operational as well as environmental issues. There are also bonuses tied specifically to quality and productivity goals at the plant. Unlike other facilities, many of these goals are developed at the team level. The cross-functional teams help to integrate environmental considerations with productivity goals. At the corporate level, plant engineers feel there is still progress that needs to be made in integrating environment into the design process. One environmental engineer says "they may do the right thing, but not because of the environment". The desire is to build more of an awareness in both plant workers and corporate designers about the environmental impacts of certain material and/or design choices.

Suppliers are an important factor in the environmental performance of the plant. The plant has an open relationship with suppliers, and tries to involve them in process decisions that relate to their products, but they have a large number of suppliers with whom they are working. Plant management has been trying to reduce the number of major suppliers, but in

[a] While a life cycle approach to cost analysis is supported, it has not been fully integrated into all decisions made at the facility.

the paint shop, for instance, different suppliers are responsible for providing each of the following materials: phosphate, electrocoat, basecoat paint, adhesives, sealant, clearcoat, purge chemicals and cleaning chemicals. The team concept developed for the automaker staff is extended to suppliers in an attempt to build closer working relationships. Suppliers are given more information and responsibility for production that at many other assembly plants, and are expected to work together to achieve the levels of quality demanded by the plant management. The company attempts to reinforce this team approach through uniforms and name tags for suppliers that are the same as those for the automaker employees. The program seems to be working. Some of the supplier staff interviewed stated that they would not make a decision that would help them but not help the automaker.

In addition to the suppliers providing materials and products for the paint process, outside vendors are utilized for tracking and disposing of solid waste. These companies are responsible for identifying and implementing waste-related cost reductions at the plant. The company responsible for the solid waste program has seven staff onsite who manage and run that activity. Staff from an outside environmental consulting firm are also employed to help with environmental issues plantwide. The plant attributes many of their waste reduction ideas and successes to the support of suppliers. Plant environmental engineers reinforced the role of suppliers in identifying and implementing environmental improvements, and said "they are doing a good job at that". There is a major focus on reducing VOC emissions from solvents, and a management program has been implemented with the primary supplier. The supplier is responsible for all solvents brought into the paint shop, and works with the automaker staff to find ways to reduce the VOC content of and emissions from materials used in cleaning and purge. For instance, modifications to equipment and procedures recommended by the supplier in one project at the plant resulted in a savings of almost $18,000, as well as reductions in the use of and emissions from a regulated chemical.

Environmental Performance

A combination of measures and data sources is used to evaluate the environmental performance of Plant C over time. As noted earlier, the many factors that influence the environmental outcomes at a manufacturing facility make this a complicated task. Product design decisions on input materials can have a major effect on environmental performance. Corporate investments in innovative environmental projects are also important. The TRI database maintained by the EPA is used to analyze changes over time in chemical releases and transfers from Plant C. This data is enhanced by information obtained from Plant C. Environmental performance data as provided in the TRI was obtained for the years 1990 through 1994 (the latest available data). The information for 1990 is from early in the plant production history, and less representative of full-scale operation than the later years. The 1990 data has not been used for normalized figures, since production in that year was extremely small. The data has been included for evaluation of total emissions, however, partially for completeness, and also to allow more effective comparisons with other plants which also experienced new product launches during the timeframe under investigation.

A number of performance measures were evaluated over this time period. First, the total emissions from the plant were tracked, to show changes over time in the total pounds of chemicals released from the plant directly into the environment. The total emissions and transfers from Plant C over time are shown in Figure 4.12. These emissions consisted solely of air emissions from plant operations. The transfers show amounts of chemicals sent in various waste streams from the plant to waste treatment or recycling facilities offsite. The disposition of this transferred waste material is shown in Figure 4.13. This information is important to understand whether reductions in emissions are due to true reductions in waste or to shifting the waste burden to outside sources. Third, the emissions figures are normalized to account for changes in plant production levels. This data is shown for emissions and transfers from Plant C in Figure 4.14. Fourth, an analysis of total and normalized emissions for specific chemicals was performed. The parent company for Plant C had agreed to significantly reduce the use of these chemicals as part of a voluntary agreement with EPA (the

33/50 toxic chemical reduction program). The results of this analysis are shown in Figures 4.15 and 4.16. Each of these figures is discussed in more detail below.

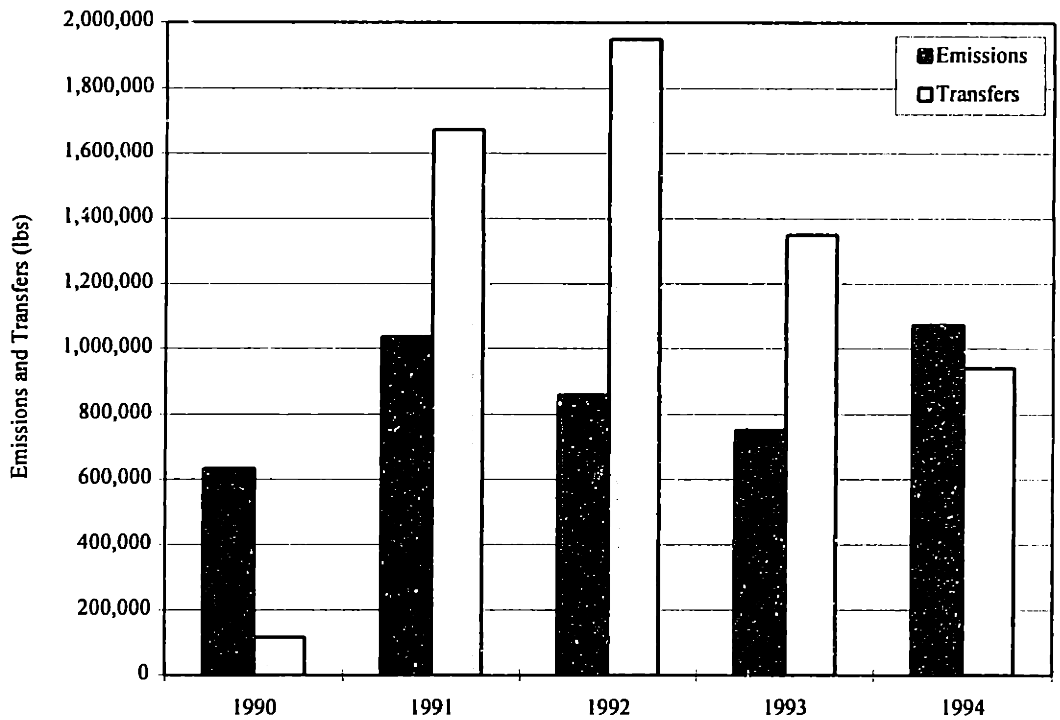

Figure 4.12. Total Emissions from Plant C are Generally Stable over Time

Air emissions from Plant C generally decrease through 1993, with a significant increase observed in 1994 as production levels at the plant increase toward full capacity. However, even with the increase in 1994, the total emissions are less than those experienced at other plants in this study. An examination of the transfers from Plant C to offsite waste handlers yields additional insight into the operation of the plant. This data is important to understand whether changes in total emissions represent real reductions in waste at the plant or are simply a shifting of the waste burden from one media to another. The data show a significant increase in chemical transfers over time, through 1992, before they begin to decline. Further analysis of the disposition of these transfers (see Figure 4.13, next page) shows that over ninety percent of these chemicals are metals (copper, manganese, nickel and zinc compounds) which were sent to metal recycling facilities. Although there continue to be relatively large volumes of metals transferred offsite in subsequent years, the 1992 transfers were clearly a peak. The remaining chemicals transferred are principally acetone and glycol ethers. These chemicals were sent to offsite waste handlers for energy recovery through fuel blending or treated at local POTWs. There was also an increase in solvent reclaim and remanufacture in 1992 as a result of the task force activities to reduce solvent use and disposal costs. A small percentage of chemicals were disposed of in landfill, including those contained in paint and industrial wastewater sludges.

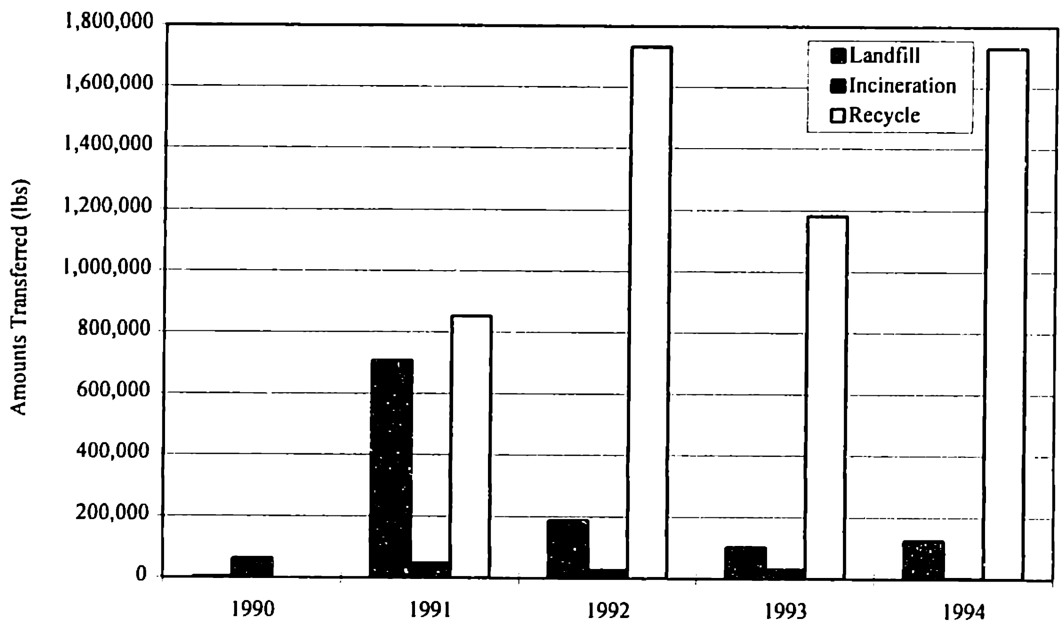

Figure 4.13. Bulk of Transfers over Time to Recycle/Recovery Uses

The total emissions from a plant are an important part of understanding its environmental impact on the local community. However, from a manufacturing process standpoint, understanding the amount of emissions per unit production is also important. In Figure 4.14 (next page), the emissions per unit produced for Plant C are depicted. As production increases over time, the emissions per unit generally decrease. Tracking normalized data for emissions and transfers over time for Plant C shows a similar trend. The reduction in emissions as well as transfers suggests that the waste reduction programs in place at Plant C after 1992 are beginning to show results. Metals transferred to offsite handlers for recycling still constitute a large percentage of offsite transfers (thirty percent in 1993 and over forty percent in 1994). Solvents such as toluene, xylene and methyl isobutyl ketone continue to be used at Plant C, but are increasingly collected for shipment to offsite handlers for remanufacture or energy recovery.

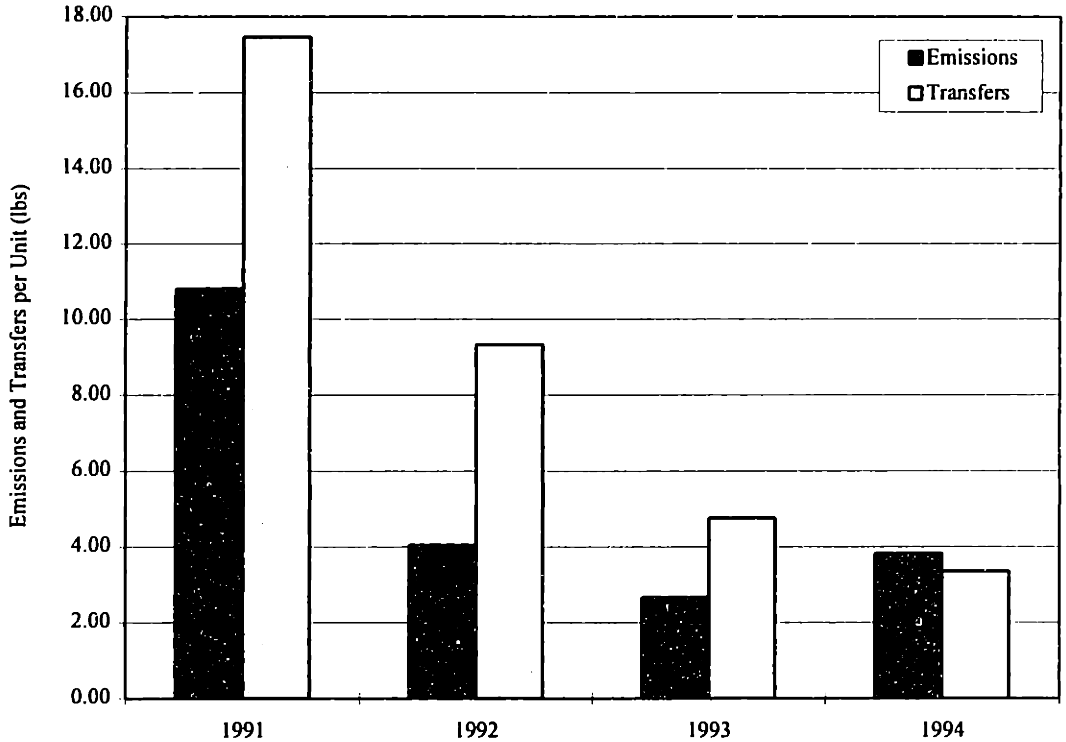

Figure 4.14. Normalized Emissions from Plant C Decrease over Time

The parent company of Plant C has made a commitment to participate in the EPA 33/50 program, a voluntary program designed to reduce the emissions of specific chemicals from manufacturing facilities. The performance of Plant C in reducing key chemicals on this list was evaluated, both in terms of total emissions and reductions, and on a normalized basis. These data (shown in Figures 4.15 and 4.16, next pages) suggest that although the emissions of certain chemicals declined, such as methyl ethyl ketone and methyl isobutyl ketone, key constituents of many paint materials, emissions of other important elements such as xylene (a constituent in many solvent-based cleaners and paints) and toluene remained stable or increased. Adjusting these emissions figures for production levels shows a more encouraging picture, with all emissions per unit either declining or generally stable.

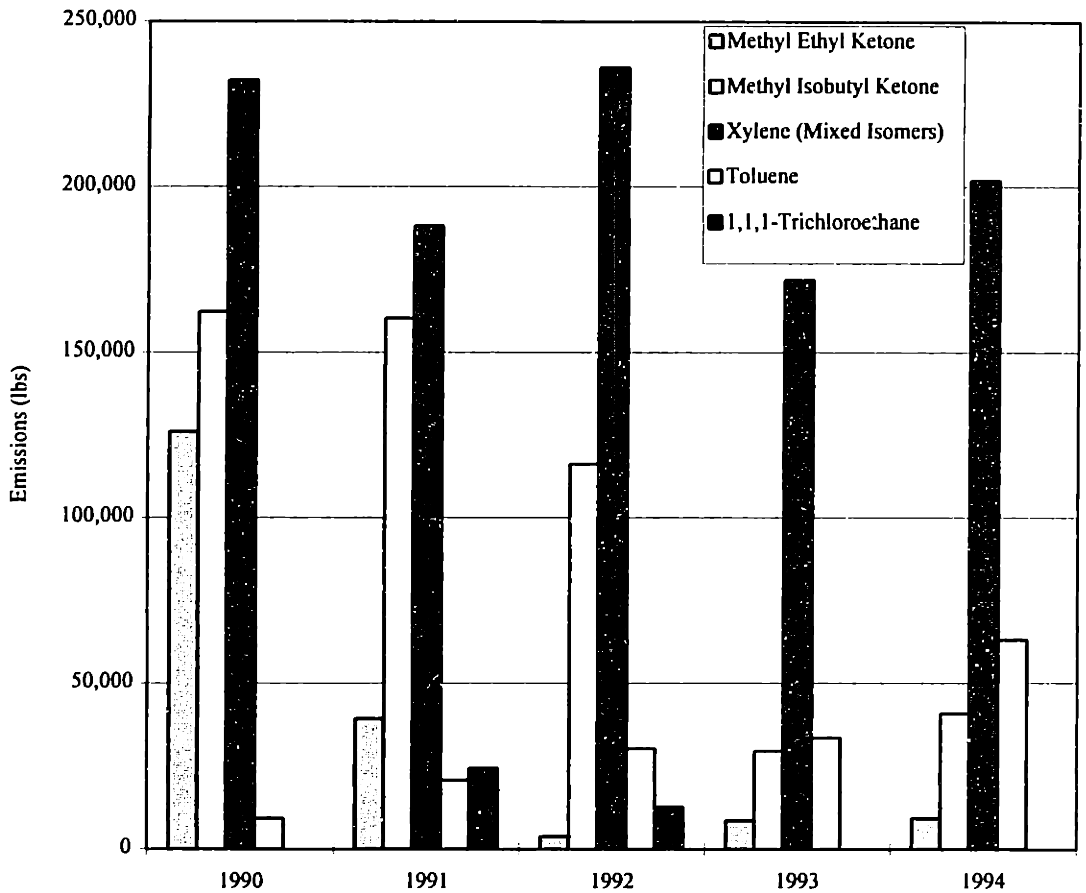

Figure 4.15. Mixed Results in Reductions of 33/50 Chemical Emissions over Time

The TRI data provide insight to the performance of Plant C based on changes in emissions and offsite transfer (and treatment) of specific chemicals. Plant data on key elements of the paint process provide more detailed understanding of the impacts of using powder and waterborne paint technologies on emissions profiles. Plant C, while implementing minor changes to paint formulations over time as operational adjustments were needed, for the most part retained its original paint technology. Material usage and VOC emissions data from the plant show the contribution of different elements of the paint process to the overall emissions profile.

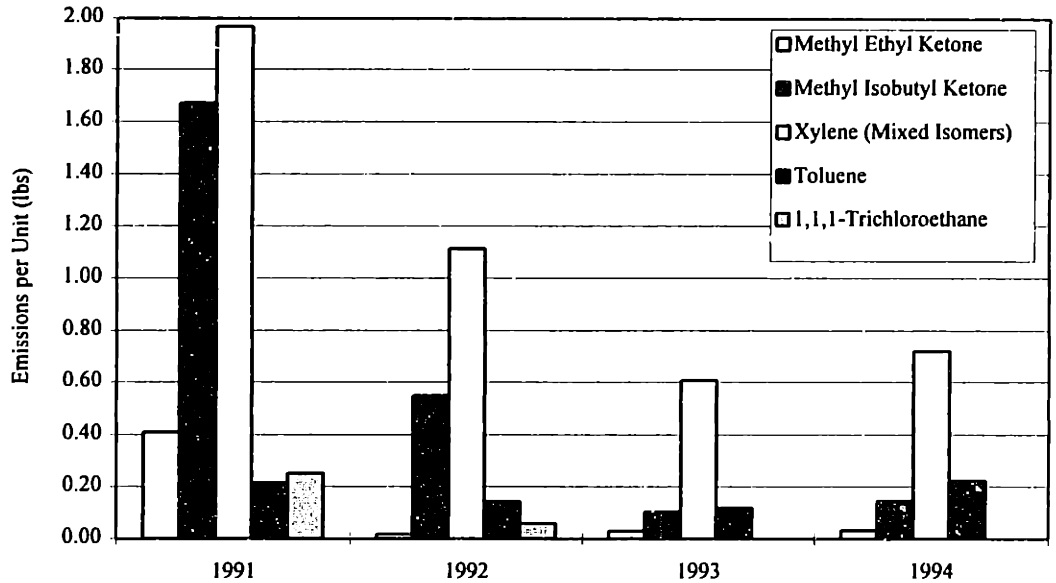

Figure 4.16. Normalized Emissions Data for 33/50 Chemicals Decline over Time

Relative Contributions to Overall Emissions

Air emissions (in terms of VOCs) were obtained from plant records for different elements of the paint process for the years 1991 through 1995.[a] The paint shop emissions are about ninety percent of the total emissions from the plant, even with the presence of the stamping and machining facilities at Plant C. Within the paint shop, however, there are particular parts of the process that contribute the majority of the VOC emissions (see Table 4.13, next page). The topcoat (basecoat and clearcoat) is a major source of VOC emissions, contributing about thirty percent from 1992 through 1995. Cleaning and purge solvents are another major contributor, with about twenty percent over the time period analyzed. In 1991, cleaning chemicals and purge solvents contributed almost fifty percent of the VOC emissions from the plant. In 1992, the plant initiated a solvent reclaim program with its solvent supplier, and succeeded in reducing emissions to the current low level of twenty percent based on credits

[a] This data is based on mass balance calculations for VOC emissions, and do not reflect actual emissions from the plant, which would be significantly lower after accounting for the effect of pollution abatement equipment.

obtained from capturing and remanufacturing a high percentage of their solvents.[a] The benefits in reclaiming solvent-based material are evident from the change in emissions from this category between 1991 and 1992.

Table 4.13. Contributions (%) of Paint Process Elements to VOC Emissions at Plant C

VOC Emissions (lbs) (before abatement)	1991	1992	1993	1994	1995
Total Plant (a)	1,975,727	2,392,879	2,803,241	2,808,189	3,129,353
Total Paint Shop	1,778,154	2,153,591	2,522,917	2,527,370	2,816,418
Ecoat	3	3	4	3	4
Primer-Surfacer	14	15	18	16	14
Sealers & Adhesives	na	6	8	6	6
Topcoat (body panels)	17	27	36	32	30
Fascia Topcoat	6	8	10	7	8
Underbody Deadener	na	4	3	3	3
Tutone & Repair	4	2	2	3	2
Cleaning & Purge Solvents (minus reclaim, except 1991)	46	25	20	20	22

(a) Numbers calculated based on paint shop totals (paint shop is about 90% of plant total)

New Paints and Materials Formulations

Production at Plant C was initiated with materials chosen for their environmental (as well as their performance) properties. Major changes to materials have been limited since initiating production. Any substitution of materials must be approved by corporate and is considered based on a hierarchy of materials (lower VOC materials are preferable to those with higher VOC content, for instance) provided to all plant engineers. This list also includes those materials specifically prohibited from use. Changes in materials are made only if they can be shown to yield lower environmental impact. In addressing problems from the initial experience with the waterborne paints, for instance, with the higher than expected emissions, attention was focused on improving the application process (particularly the transfer efficiency) rather than shifting materials. The inability to use electrostatics limited the

[a] The TRI data confirm the initiation of a large recycling/reclamation program for solvents in 1992. About half of the cleaning solvents are acetone, which in 1994 was delisted as a regulated VOC. Although Plant C continues to calculate and track emissions including this chemical, reporting after 1995 will likely reflect reductions from acetone delisting.

changes that could be made in paint application; ultimately the formulation was adjusted to increase the efficiency of the application process. The plant adopted a high solids waterborne formulation that achieved higher transfer efficiencies (and therefore lower emissions).

Major formulation changes to the primary materials used in the painting process are not anticipated in the near future, although minor improvements and adjustments in materials continue to be made. The supplier-run solvent reduction program regularly introduces new cleaning chemicals and purge materials in an attempt to reduce VOC emissions. The plant also introduced a powder blackout in 1993 (used around the doors and under the body), eliminating VOC emissions from underbody coatings (from 0.09 pounds per vehicle to zero) despite early implementation problems due to the high temperatures required for curing.

Handling and Disposal of Paint Sludge

One of the major environmental concerns at automotive assembly plants is the disposal of paint sludge. At Plant C, paint solvents are collected separately from the paint sludge to maintain a nonhazardous waste classification for the sludge, which remains, however, a major waste category for the facility. Sludge volumes from two paint shop sources are shown in Table 4.14, along with disposal costs. The paint sludge, thirty to forty percent solids by weight, is sent to landfill. Some paint solids are incinerated, an extremely expensive process (over $1400 per ton of contaminated materials in 1992 and 1993)[a]. In addition, over $500 per ton was spent on disposal of E-coat filters and debris, of which the plant had about twenty tons per year in 1992 through 1994. Ongoing projects are directed at reducing solid paint wastes.

Table 4.14. Volumes and Costs for Disposal of Paint-Related Sludges at Plant C

	1992	1993	1994
Sealer/Phosphate Sludge Landfilled (lbs/yr)	588,000	562,000	640,000
Disposal Costs ($/ton)	$128.23	$72.82	$147.31
Paint Sludge Landfilled (lbs/yr)	3,920,000	3,804,000	3,462,000
Disposal Costs ($/ton)	$359.29	$74.20	$121.25

[a] Plant C had about 100 tons per year of this material in 1992 and 1993.

The paint sludge generated at the plant is collected and sent out of state for landfill disposal. At current production levels (production volume in 1995 was 302,000 vehicles), they generate about 1700 tons per year of paint sludge, consisting of 30 to 40% solids by weight. In addition, the rags, coveralls, and booties used in the paint shop are disposed of as solid wastes. An environmental engineer at the plant says that "next to paint sludge, this is our biggest waste stream [for body systems], costing us up to $100,000 a year for disposal". Most of this material is disposed by fuel blending; the rags and booties are disposed of by incineration. The environmental manager of the plant says that they have explored the possibilities of drying the paint sludge to a powder for recycling (as is done at some other plants), but do not see that as a realistic option at this time for Plant C.[a] The lack of a sure market for the material and the prohibitive cost of the drying equipment are two of the factors prohibiting use of this option. Rather than focus on alternative methods of disposal, the environmental manager at Plant C says "we are spending our efforts on getting more paint on the vehicle".

[a] The plant is initiating an experimental program with a major supplier in 1997, however, to explore the feasibility of employing sludge drying in the future.

4.4. Case Study: Plant D

Plant D was built in the late 1970's and initiated production of large-size, luxury vehicles in the early 1980's.[a] The plant is focused on vehicle assembly and does not include a stamping plant or injection molding facility. Vehicle parts are shipped in as needed from other plants or suppliers. The painting process at Plant D was initiated with traditional low solids, high solvent-based paints. In 1990, new materials were introduced to the painting process, primarily to try to lower the VOC emissions from the plant. A low solids, waterborne basecoat was introduced in 1990, as well as a high solids, solvent-based primer-surfacer (which had lower organic content than the previous low solids formulation). A high solids, solvent-based clearcoat was adopted in 1991, as well as a modified waterborne basecoat formulation with higher solids content than the initial material used in 1990. The parent company of Plant D is focused on quality and production, and has a proactive, written policy on environmental performance. The implementation of these policies at the plant (during the period prior to 1994) focused on the quality and production elements; environmental issues at the plant are primarily considered relative to compliance with the operating permit for the facility [b] As with other automotive assembly plants, the paint shop is the source of most of the environmental concerns at the facility. Air emissions are the primary focus of attention, regulated by the operating permit for the facility. Solid wastes, including paint sludges, are regulated under hazardous waste legislation and are also of importance from a cost and future liability standpoint.

The renovation of the paint shop (as well as the rest of the assembly plant) after 1993 in preparation for the launch of a new vehicle brought a number of technological changes to Plant D. A large number of robots were introduced to the plant, not only for welding and general assembly activities, but also for painting processes. Fascia painting was eliminated at the plant

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[a] This same vehicle was produced at Plant D until the end of 1993, at which time the plant was shut down to prepare for the launch of a new vehicle.

[b] After the facility modifications in 1994, there was a greater focus at the plant on pollution prevention. For the time period of 1987-1993 for which the performance of this facility was analyzed, however, the primary focus was on compliance, as it was for many automotive assembly plants at that time.

in 1989, with prepainted bumpers shipped in from outside. A stamping plant will be completed in 1997, to cut shipping costs on major body parts and to get better control of the quality on input materials and parts. Having control of parts and major processes is consistent with the corporate philosophy of building quality through tight process control.

Plant Process Technology and Operations

The plant runs two shifts, five days a week, producing about 1000-1050 vehicles a day for the time period analyzed in this research.[a] The painting process used at Plant D, compared to the baseline process described in Chapter 2, is shown in Table 4.15 (next page). The process begins with cleaning the vehicle with a water and surfactant rinse, followed by phosphate etching to prepare the unit for electrocoating (E-coat). Liquids and solids from the closed loop E-coat system are filtered through an ultrafiltration process and reused. After E-coat application and curing, sealers are applied, using both robotic and manual means, followed by a curing cycle. After inspection, a primer-surfacer is applied, using a high solids, solvent-based coating, and then cured. A moist sanding process is used to sand down any defects after the cure is complete. The topcoat is then applied, with two separate production lines operational for paint application. During the late 1980's, a low solids, solvent-based paint was used for the basecoat. In 1990, the plant shifted to a low solids waterborne basecoat, which was still relatively new to the assembly plants in the U.S. Solvent-based purge materials were retained in the process for clearcoat only. The plant was successful in implementing a non-solvent water purge for the waterborne basecoat (a unique accomplishment) and lower solvent content cleaning chemicals were substituted for high solvent cleaners in the paint shop. The new material presented a number of challenges; according to an engineer who worked in the paint shop at the time, "the first year was hell" in terms of trying to learn how to properly apply the new material and getting all the process parameters right. The following year, the paint formulation was adjusted to a higher solids content waterborne, which seemed to work better with the plant application equipment; the plant also adopted a high solids clearcoat at that time. The process as implemented in the early 1990's

[a] The current production rate at the plant is about 700 to 800 vehicles per day.

included two coats of a waterborne basecoat, followed by flashoff of the water in an infrared oven. Then two coats of a high solids, two-component clearcoat are applied, after which the vehicle enters the final curing oven. Fascia painting, performed at the plant until 1989, utilized the same general process outlined above, adding to the overall emissions from the plant for those early years.[a]

Table 4.15. Painting Process Steps and Technology for Plant D

Process Steps -- Baseline	**Process Steps -- Plant D**
Cleaning and Pretreatment	Yes
Phosphate Rinse	Yes
Electrocoating -- Dip System	Yes
Oven Bake	Yes
Primer-Surfacer	Yes, solvent-based (high solids after 1990)
Antichip Protection	Yes
Sealer	Yes
Oven Bake	Yes
Basecoat (color coating)	Yes, waterborne after 1990; tutone used for some models
Oven Bake	Yes, to flash-off water
Clearcoat	Yes, solvent-based (high solids after 1991)
Oven Bake	Yes
Repair	Spot repair

Luxury vehicles demand a particularly high level of quality in the finished paint product. This plant has achieved several awards for the quality of the coatings on the vehicles, and had a first time through capability of between 85 and 95% (which is fairly high, on an industry average basis). Many of the elements important to a high quality paint job are also helpful for environmental performance. Block painting is used at this facility to reduce waste of materials, with block sizes of ten vehicles on the average. This limits purging of lines and application

[a] Fascia were painted with solvent-based paints.

equipment to every ten vehicles, reducing the material waste and VOC emissions found with most assembly plants, which change colors every one to three vehicles.

Cleaning is an important part of the process, both to keep dirt down and to ensure a quality finish. Booth walls and grates are cleaned at least once a day. Application equipment is cleaned on an hourly basis, outside of the normal purges done between colors. Other equipment (ovens, vehicle carriers, and air filters) is cleaned every other week. Cleaning chemicals and purge materials constitute a large portion of the VOC emissions from the plant, particularly after the switch to waterborne basecoats eliminated a prior source of VOCs. Shifting to waterborne further eliminated purge solvents from the color coating operation since this plant has been able to use deionized water with no solvent added as a purge material for the waterborne. The clearcoat continues to use a solvent-based purge, which is collected from the booths and sent to a tank farm. Most of the purge material is captured and transferred offsite for fuel blending purposes (90%); the remaining 10% is incinerated. The booth wash water is sent to the plant sludge system for treatment. Disposal of paint sludge is a challenge for Plant D, as for most automotive assembly plants. The sludge has a high water content, which makes it more difficult (and expensive) to dispose in landfill. The material is transported by rail for disposal.

Environment is not a central function at this plant. The plant has two environmental engineers on staff, both of whom report to the manager for Central Engineering. Each of these engineers are responsible for conducting general facility engineering projects along with their environmental duties. In an interview with the environmental engineers at the plant, they said at least 25% of their time was spent on other than environmentally-related responsibilities. From an environmental perspective, they are responsible for all the hazardous waste at the plant, for permits and regulatory compliance documents, including all regular reporting to the regulatory agencies, and for air and water pollution control. They handle all the hazardous waste and environmental training requirements for plant workers. The environmental engineers provide monthly reports on VOC emissions from the paint shop, with data provided for the most part by the paint suppliers. Information on any additives to materials in the paint mix room is gathered by the plant environmental engineers. Although they are involved in discussions about changes to materials or paint formulations at Plant D, the final decisions are made by corporate staff. The environmental staff have little involvement in application equipment decisions, even though equipment choices can have a major impact on the performance of a paint (and the generation of waste from overspray or additional cleaning needs).

Although the environmental staff at Plant D feel they have a cooperative relationship with the local and state regulatory agencies, they do not necessarily see these agencies as supportive in considering new approaches for reducing emissions, particularly those that might involve extensions to permit timelines. The facility took a conservative approach in their permit negotiations, relying to a large extent on pollution control technology at the time of the permit. Some of the specific operations at the facility regulated by federal, state or local agencies are listed in Table 4.16 (next page). The plant permit includes thirty six incinerators which must be maintained and kept operational to ensure compliance. The permitted limit of VOC emissions for the plant is based on the Lowest Achievable Emissions Rate (LAER) limit, which allows consideration of cost in the decision on appropriate technology. The operating limit for the plant is 1738 tons VOC per year (total from all sources); most emissions are from the paint shop. During the time period analyzed in this research, this VOC limit translated to a production capacity of 330,000 cars per year.[a] The plant is located geographically in a moderate nonattainment area, although there is some concern about upcoming reclassifications and the potential of moving to a serious nonattainment classification.[b] In addition to the possibility of having to meet new, more stringent release standards, the Title V requirements of the Clean Air Act Amendments of 1990 are considered by the environmental staff at Plant D to be a major issue. The documentation requirements for these regulations are extensive, adding responsibilities to staff who have other jobs and few resources.

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[a] The limit negotiated with the plant modifications for the new vehicle production (starting 1996) is 225,000 vehicles, in a rolling twelve month period.

[b] See discussion of Clean Air Act Amendments in Chapter 2.

Table 4.16. Operations and Waste Streams Subject to Federal, State or Local Regulation

Operations and Waste Streams	Primary Regulatory Guidance
Water Treatment and Discharge	Local Water Treatment Rules
Sludge Disposal	State Solid Waste Disposal Regulations
Toxic Chemical Use Restrictions	TSCA, SARA
Hazardous Waste Disposal	State Hazardous Waste Disposal Regulations
Solid Waste Restrictions or Reduction	State Solid Waste Regulations
Air Emissions: Odor Control	State Air Pollution Regulations
Air Emissions: Visibility	State Air Pollution Regulations
Air Emissions: NOx, SO_2	State Air Pollution Regulations and CAA
Air Emissions: Urban Ozone or VOC	State Air Pollution Regulations and CAA

Corporate Strategy and Environmental Policies

The corporate parent for Plant D has a written environmental policy that describes a proactive approach to environmental issues, including a strong pollution prevention program. The automaker is participating in a number of voluntary environmental programs, with government agencies and with nonprofit entities, and has an annual environmental report which is made available to the public. One of the corporate goals is zero landfill for packaging wastes, focusing attention at the plants on recycling of waste materials, reduction of waste volumes (through compaction of solid wastes, for instance) and reuse of packaging, but not necessarily on prevention of wastes by considering reduction at the source. Another goal is to try to get more consistency among plants as the Title V process is initiated. Currently each facility has different requirements and priorities driven by the specific agreements in their operating permits. The corporate position is to try to gain more similarities rather than differences among plants in terms of their requirements and acceptable compliance mechanisms. The state and county laws are currently more stringent than many of the federal regulations, however, and are likely to remain the primary guidance for negotiations on operating permits.[a]

[a] This could potentially change with the upcoming negotiations on new operating rules for automotive and light truck assembly plants, to be developed under the Clean Air Act Amendments by the year 2000.

Corporate staff are a major source of information for plant personnel on monitoring regulatory requirements and upcoming changes in the law, particularly important for the environmental engineers who have limited time and resources for dealing with anything beyond compliance issues. The corporate staff also provide technical assistance on specific environmental issues, and have a major role in setting the waste reduction goals for the plant. Internal environmental audits are conducted by corporate staff once every two or three years. Environmental staff at Plant D also conduct internal environmental performance reviews on major portions of the plant on a monthly basis. The parent corporation for Plant D utilizes the results of these audits (as well as production and quality figures) to compare performance among all the plants in the company. Plants producing similar vehicles, in particular, are compared both on quality metrics and on environmental performance (as measured by emissions, pollution prevention and recycling activities, among other parameters). Because of these activities, the environmental performance of the plant does get the attention of the plant managers. These numbers are monitored and tracked at that level, which helps give priority and attention to environmental concerns. Environmental parameters are tracked and measured separately from quality measures.

There are few mechanisms, however, to ensure that individual plants adopt and implement the corporate policies and goals. Some goals at the plant level do stem from broader commitments made at the corporate level. However, from the plant perspective, many of these programs just create more paperwork and burden for the environmental engineers, who have too little time as it is. As one environmental engineer stated, "it's not like we can get the consultants that these folks at headquarters have. They come up with all these great ideas recommended by these high paid consultants, and we get to do the extra work of writing up the reports. Why don't they send these consultants down to us to help us put the reports together!" While the need to provide additional reports is onerous for plant personnel, identifying and reporting on key parameters of environmental performance, including any violations, all emissions, and other factors, does get the attention of plant managers. In particular, the annual reports that go to corporate headquarters receive the attention of the plant managers.

Although corporate environmental goals and policies provide some input to the priorities set at the plant level, particularly in driving a focus on recycling of packaging and reduction of solid wastes, the plant primarily measures its progress against key compliance-oriented goals, such as reductions in VOC emissions. Interviews with environmental engineers at the plant suggested that pollution prevention programs directed at the source of wastes were not a high priority for the plant. Environment was very important--but was defined more by reducing the waste streams from the plant at the end-of-the-pipe. A difference from some of the other plants is the limited involvement of the environmental engineers with the ongoing production process. Their focus was much more on preparing compliance-oriented reports and ensuring that permit requirements were met. The environmental engineers are involved in all process changes that affect compliance with permits. They are also directly involved with changes to paint materials and any new chemicals coming into the plant. The primary focus, however, is on compliance and reporting issues.

The approach to environment used in the plant is being refined to try to to move beyond compliance limits to reducing emissions as much as possible.[a] The environmental staff, working with the paint department manager, have made reductions in solvent usage a top priority for Plant D in 1996. In addition to teams specifically focused on identifying high usage areas and determining potential solutions, they are specifically exploring modified tacky coatings for the booth walls and no VOC booth cleaners. Prior to the plant change, these items had a lower priority than the management focus on production quotas and quality of finished vehicles. An improved program for managing chemicals used at the plant was also implemented in 1996, providing better and more timely data for tracking chemicals used in all parts of plant operations. The environmental staff at Plant D view this program as a major resource for improving environmental performance at the facility.

[a] Interviews with environmental staff suggested that this might well be a preemptive move based on fears of more stringent regulations for their operations in the next few years.

Management Approach and Plant Culture

The plant management approach is relatively traditional, with hierarchical reporting arrangements, and managers and supervisors clearly identified by their white shirts and ties. Management priorities are on specific production goals and quality measures, which were posted throughout the facility. However, the plant manager has a strong focus on environmental issues, defined in part by reduction of waste (and thus also reduction of production cost). The facilities manager (to whom the environmental engineers report) also understands the importance of compliance with environmental regulations and supports the environmental staff in dealing with particular issues. The strength of management support is seen as a key factor by these staff in accomplishing their responsibilities. The environmental engineers at the plant spend about one-third of their time on the floor. They feel that interacting with workers on the line gives them a better perspective on issues facing the plant, and more support for implementing new projects when needed. The environmental staff conduct weekly walkthroughs of the plant in conjunction with the safety staff.

Computerized tracking systems and data management systems are used extensively at the plant to monitor all chemicals (both productive and nonproductive). Although key managers and supervisors have access to this system, the two environmental engineers and the industrial safety staff are the primary users. Data in this system includes amounts and types of chemicals purchased, used and disposed at the plant, health and environmental risks of particular chemicals, and the costs of chemical use and disposal. The system also provides assistance in regulatory reporting and cross-reference to relevant environmental regulations. At Plant D, all the Material Safety Data Sheets are translated to more "friendly" and understandable safety instruction sheets to ensure that all line workers better understand what the hazards of various chemicals are and how to properly handle the materials. Of particular interest in the tracking process are the booth coatings and supplies, purge and related solvents, water house treatment chemicals, boiler chemicals and deionized water, and the central sludge system chemicals. Tracing the use of these chemicals is important not only from an environmental reporting and cost perspective, but also because changes in use patterns can provide important indications of process problems.

One of the biggest opportunities identified for reducing solvent use is linked to use of purge solvents. Purge solvent is necessary for cleaning application equipment lines, guns and bells, but is also often used for general booth cleaning because of its effectiveness. At Plant D, booth cleaners often resort to simply taking a hose of purge thinner (solvent) and hosing down the walls, rather than using other methods which might take more time or effort. This results in high costs from solvent use as well as increased VOC emissions. In 1996, a priority was placed on reducing VOC use and emissions from the plant, with one current project focused on finding a cleaner that is lower in VOC content, but can deliver the performance of solvent cleaners. In an attempt to reduce VOCs from the plant, a group has been chartered to track use and emissions data and find ways to further reduce cleaning solvents.[a]

There are reward programs in place to try to elicit worker opinions and ideas, primarily those leading to reductions in production costs (which also often identify areas for waste reduction). According to one of the environmental engineers, however, many of the ideas submitted by workers have to do with paper or cardboard recycling (and less with the details of the painting process) and have already been implemented at the plant. Most workers (90%) receive training on the corporate environmental policy and goals and in material recycling and conservation. All workers are also trained in the proper handling of hazardous materials, as required by law. This training, combined with a plant suggestion program and rewards and recognition for money-saving ideas, has led to an increased worker awareness of the importance of environmental issues. However, many workers seem to have a limited understanding of the link between their activities and resultant environmental impacts.[b]

The relationship with suppliers has shifted over time at Plant D, with changes to the supplier team made by the corporate decisionmakers if there are questions about performance or if lower costs can be obtained by letting a new contract. Decisions on suppliers are made at the corporate

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[a] The project has already achieved results. By the end of 1996, the use of solvent-based cleaners and/or purge solvents in booth cleaning operations had been eliminated.

[b] In 1996, this was improving to some extent. A number of team activities involving line workers have contributed in the last few years to improved environmental performance in reducing solid and hazardous wastes and solvent use.

level (both purchasing and technical groups are involved), but with input and significant influence from plant management. Environmental staff have little influence on these decisions. There are currently three or more suppliers serving the needs of the paint shop, with about ten supplier staff located onsite to help in troubleshooting application equipment and checking the quality of the materials in the paint shop. The automaker staff in the paint shop, however, run the process and make all process related decisions. The paint shop staff would prefer to have a single supplier, since it makes it a lot easier for them to trace and solve performance problems. The suppliers are called upon for dealing with process issues and paint defects, but at a much more arms-length relationship than that observed at some other facilities. Yet interviews with the automaker staff in the paint shop and the environmental engineers suggested that these workers place an extremely high importance on supplier expertise for help in optimizing their processes, monitoring the final quality of the coating process, solving production problems, and planning for future paint solvent requirements and material needs. They also rely on the paint suppliers for all information related to paint toxicity and emerging regulatory requirements on solvent content. The suppliers do not, however, have any role in directing the work of paint shop employees or changing the paint process. Supplier recommendations for changes to the process, equipment, or paint formulation must be worked out carefully with the automaker staff.

The decision to move away from a single supplier in the paint shop was based in part on process problems experienced in a key element of the paint process, according to one environmental engineer. Process problems often generated arguments between supplier and automaker staff, with the switch to waterborne basecoat particularly troublesome. Getting the equipment and the paint to work well in a high volume production system and produce a high quality finish was a challenge. The company decided to shift to a mix of suppliers in the paint shop, bringing in a new supplier for major process elements. The view of the paint shop staff is that having several suppliers in paint creates problems. The inbred competition and finger pointing makes it tough on the operations in paint.[a] A single supplier was selected for the topcoat (basecoat and clearcoat), but a number of other suppliers provide the phosphate, E-coat and the various sealers

[a] With the introduction of a new vehicle and process to the plant, new contracts were established with suppliers.

and cleaners used in the paint shop. The suppliers are reimbursed based on volume of material provided--their problem-solving services are simply a part of doing business with this customer. The competitive nature of the industry ensures that they pay attention to these details--their competitor is eager to come in and do it if they don't. The plant management did mention that there are financial incentives written into supplier contracts to reduce the amounts of paint, purge solvents and cleaning materials used in the process as part of a corporate program.[a]

In 1990, the plant initiated an innovative approach to working with suppliers of water treatment chemicals for the powerhouse (industrial sludge) and the paint sludge system. This contract arrangement is modeled to some extent on the "Pay as Painted" system, where suppliers of these chemicals are paid based on the number of units produced at the plant, rather than on the volume of material sold to the plant. Under the new contract system, the contractor is paid per vehicle, not by volume of chemicals sold. Therefore, if they can find a way to reduce chemical use, they save money. This provides strong financial incentives to reduce chemical use. To support longer-term projects and provide some sense of an investment rationale for the contractor, the contracts are set up on a three year basis, with renewal options. Although these contracts can certainly be cancelled at any time, this arrangement tries to give the supplier some long-term assurance of business.[b] There is also a shared savings provision in the contract for new ideas that the contractor finds that can save the automaker money. Even if not directly related to materials sold by the supplier, there are still benefits from finding ways to reduce plant costs. The contract also requires suppliers to provide key data on usage and savings. This has worked well in tracking and consolidating materials used at the plant and reducing chemical usage. For example, several different versions of floor cleaners were being used in different parts of the plant, leading to more chemicals that required reporting, tracking, etc. These have been consolidated, with reductions in the variety of chemicals used for similar purposes. The scope

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[a] An outside supplier is used to handle all the solid waste and recycling from the plant.

[b] Interviews with suppliers reveal they are aware of the short-term nature of the relationship and the fact it can be cancelled at any time. These contracts may ultimately lose their effectiveness from that standpoint.

of the contract was initially limited to water treatment chemicals.[a] It has been updated to include responsibility for all the nonproductive chemicals and materials at the plant. The supplier now has three people located onsite as part of the contract.

As the contract was extended (after 1995) to cover all nonproductive chemicals,[b] the company experienced a large savings in chemicals usage, dollars and reduction of waste. Initially, no changes in materials were made. The company had the supplier work with the different departments at Plant D to identify duplications, waste, performance requirements and narrow the inventory of products and materials based on that analysis. By the fall of 1996, the plant had implemented a program that requires suppliers to provide detailed information on the VOC and HAP content for each material under their contracts that is used at the plant. They will also continue to provide information on material usage, dollars saved, etc. The supplier is also managing experiments on new products, including the use of new tacky coatings. The supplier has been the one identifying alternative materials, getting samples from other vendors, and testing these materials out at the plant. Monthly meetings are held to discuss progress and issues.

Environmental Performance

A combination of measures and data sources is used to evaluate the environmental performance of Plant D over time. The TRI database maintained by the EPA is the primary source of data on environmental releases and transfers from the plant over time, and changes in those trends as new paint technology was adopted at the plant. This data is enhanced by information obtained from site visits and interviews at Plant D. The primary environmental releases from the plant are from the paint shop, which makes the TRI data particularly useful, as many of these chemicals are contained in paints and related materials. The plant initiated production with low solids,

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[a] In 1996, with the initiation of the new vehicle launch, Plant D has extended this contract to cover all nonproductive chemicals, including the purge solvents (but not thinning solvents).

[b] Nonproductive chemicals are those that do not go out with the vehicle. Paints and coatings, sealers and adhesives, gasoline, windshield washer fluid, transmission fluids and oils, for instance, are not included in this contract arrangement, and there is currently no move to do so.

solvent-based paints, changing over the timeframe analyzed (1987 to 1993) to a waterborne basecoat. Substitutions in clearcoat and primer-surfacer materials were also made, going from low solids to high solids formulations (although both were still solvent-based). A number of performance measures were evaluated at the plant. First, the total emissions and transfers from Plant D over time are shown in Figure 4.17. These emissions consisted entirely of air emissions of regulated, reportable chemicals from the plant operations. Transfers show the amounts of chemicals sent in various waste streams from the plant to offsite waste treatment or recycling facilities. Second, the disposition of this transferred material is shown in more detail in Figure 4.18. This data is important to evaluate whether reductions in chemical emissions are due to waste reductions or to shifts in waste burdens to outside sources. Third, the effect of production volumes on emissions and transfers are analyzed by normalizing the data to account for changes at the plant. This data is shown in Figure 4.19. Fourth, total and normalized emissions and transfers trends were evaluated for specific chemicals. The parent company for Plant D had agreed to participate in the EPA 33/50 program, designed to significantly reduce the use of selected chemicals and heavy metals. The results of this evaluation are shown in Figures 4.20 and 4.21. Each of these figures are discussed in more detail below.

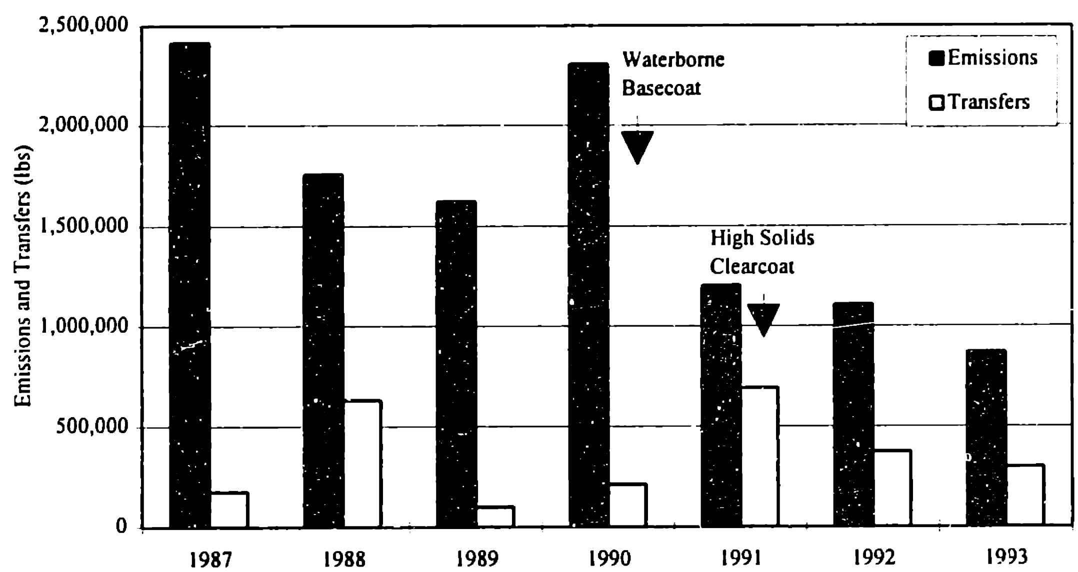

Figure 4.17. Emissions and Transfers from Plant D Decrease over Time

Air emissions from Plant D generally decrease over time, with a significant departure from that trend noted in 1990, with the problematic implementation of the low solids waterborne basecoat formulation. Reductions in 1988 may be the result of significantly lower production volumes at the plant, but the plant retained the lower emissions profiles even with a twenty-two percent increase in production between 1988 and 1989. The implementation of the waterborne formulation (once the process was stabilized in 1991) resulted in a dramatic decrease in emissions at the plant. Xylene and toluene, in particular, two of the 33/50 program chemicals, showed significant decreases (see Appendix B). The adoption of higher solids formulations of solvent-based paints did not seem to have as significant an effect on emissions profiles, although emissions continued a downward trend through 1993. Adoption of the waterborne paints resulted in an increase in the amount of chemicals sent offsite for treatment or disposal. A review of the data on transfers from the plant (see Figure 4.18) show that most of the increase is from solvents collected by suppliers for use in fuel blending.[a] Chemicals sent to landfill continued to decrease over time. This data suggests that the waterborne formulation did not significantly result in an increase of chemicals sent to landfill (although the volumes of total material, which is not measured by these data, may well have increased).

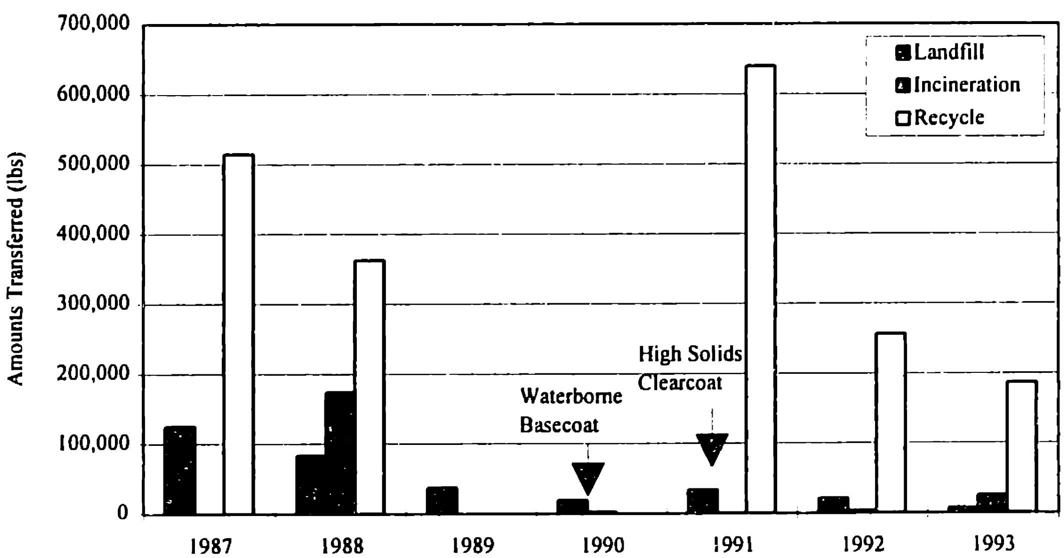

Figure 4.18. Disposition of Offsite Transfers at Plant D Varies over Time

[a] In this analysis, reuse of the material, even for fuel blending, was included with recycling/remanufacturing figures.

The total emissions from a plant yield a perspective on the impact it has on the local community and are certainly important for compliance with operating permits. However, the amount of emissions generated per unit of production are also important. Emissions and transfer data for Plant D, normalized for annual production, are shown in Figure 4.19. Outside of the year 1990, with the implementation of the initial waterborne formulation, the plant demonstrates continued reductions in emissions over time, despite changes in production volumes. Increases in amounts of chemicals transferred after 1991 are partially the result of the reclamation program implemented with the supplier, where solvent waste streams were sent offsite for fuel blending.

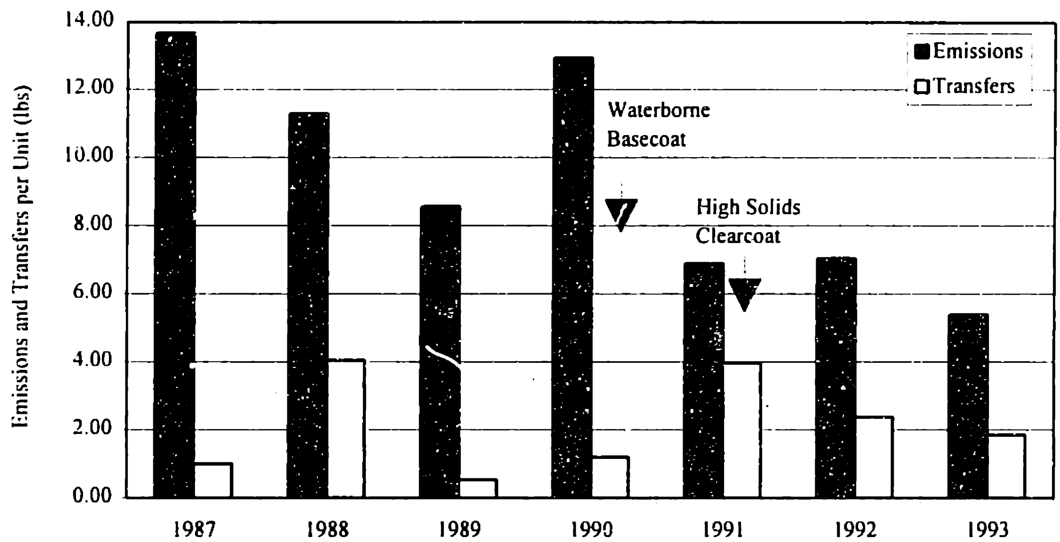

Figure 4.19. Normalized Emissions and Transfers for Plant D Decrease over Time

A detailed analysis of the data show that the majority of the reductions in emissions are from changes in reported amounts of 33/50 chemicals, many of which are primary constituents of most paint products. The implementation of waterborne basecoat at Plant D resulted in a fifty percent reduction in reported emissions of methyl isobutyl ketone, and a sixty percent reduction in xylene. Xylene is a major source of emissions for the plant, constituting about forty percent of total chemical emissions (reported in TRI) for the years 1987 to 1989, and thirty percent from 1990 to 1993. The adoption of high solids, solvent-based formulations did not seem to result in additional reductions in these major chemical categories. The data for the major 33/50 chemicals reported as emissions from Plant D are shown in Figures 4.20 and 4.21.

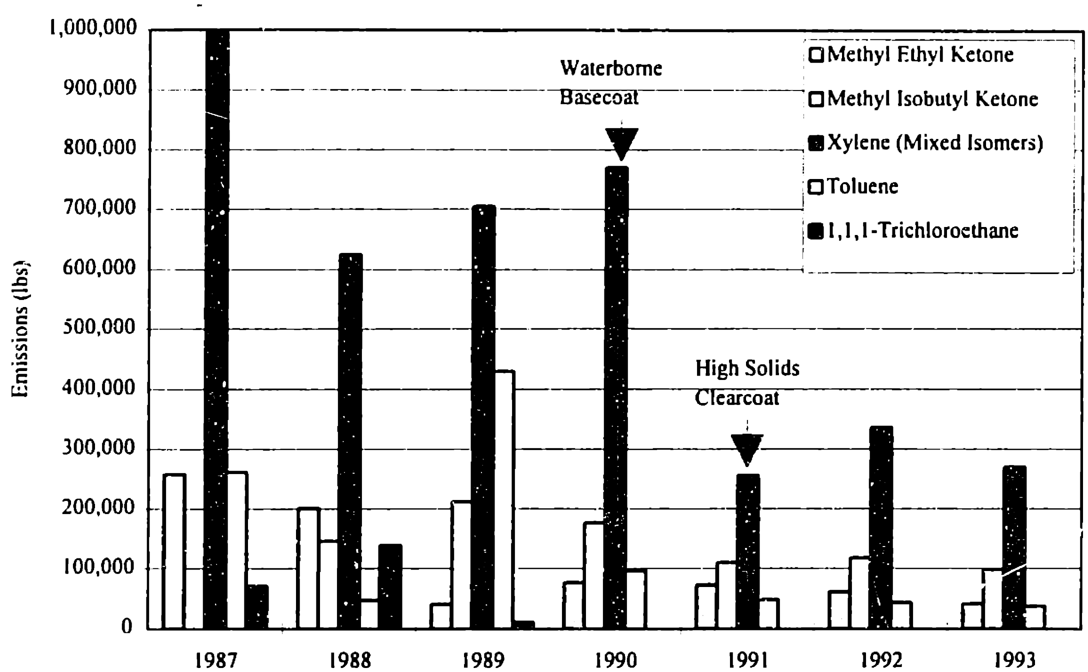

Figure 4.20. Emissions of 33/50 Chemicals Decrease over Time

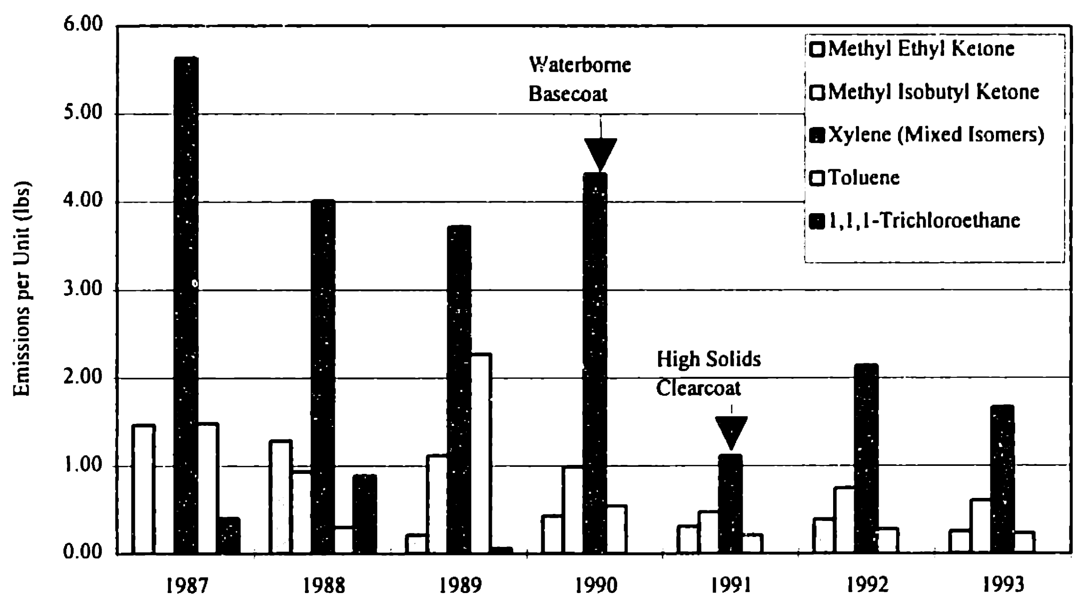

Figure 4.21. Normalized Emissions Decline over Time for Key 33/50 Chemicals

Data from the EPA's TRI database provides insight into the effects of process and materials changes at Plant D on the emissions and offsite transfers of specific chemicals. Primary data from site visits to Plant D provide additional detail on the environmental effects of specific elements of the paint process. Three major areas were pursued to better understand the impacts of technological and process change on the environmental performance of the plant. First, it is important to understand the relative contributions of different parts of the painting process to the overall emissions of the plant. This information is necessary in targeting potential areas of improvement. Second, the introduction of new materials into the painting process raises the question of the extent of environmental benefit achieved by reducing regulated chemicals at the source. Third, the disposal of paint sludge is a challenge for most automotive assembly plants. Plant-specific data is needed to understand how shifts in paint technology impact the sludge handling process. Data on the effects of new paint and coating formulations on resultant emissions and solid waste volumes at Plant D is important in evaluating the contributions of new technologies to improvements in environmental performance.

Relative Contributions to Overall Emissions

The operating permit for Plant D specifies particular levels of allowable VOC emissions, generally calculated based on production levels. Emissions of VOCs were provided from plant records for 1992 and 1993.[a] The percentage contributions of various elements of the paint process are shown in Table 4.17 (next page). Industry-wide, paint shop emissions average 80% of total plant emissions. For Plant D, in 1992 paint shop emissions were 95% of total plant VOC emissions. However, by 1993, primarily due to a shift to lower VOC input materials in the E-coat process and in sealers and adhesives, paint shop emissions were down to 78% of total plant VOC emissions. Within the paint shop itself, the major contributors to VOC emissions are the topcoat materials and the purge and cleaning solvents. The topcoat, consisting of the basecoat and clearcoat, contributed 34% of paint shop VOC emissions in 1992 and 37% in 1993. Reductions in VOC emissions from other parts of the paint process simply accentuate the importance of the topcoat in contributing to VOC emissions at Plant D. The plant data also

[a] Data were not available for prior years.

highlight the role of purge and cleaning solvents in contributing to total VOC emissions. In 1992, these materials contributed 43% of the total VOC emissions from the paint shop; in 1993, that number was up to 47%. Reducing VOC emissions in purge solvents and cleaners through lower VOC materials and reduced volumes is an important avenue to pursue in continuing to reduce VOC emissions from automotive paint shops.

Table 4.17. Contributions (%) of Paint Process Elements to VOC Emissions at Plant D

VOC Emissions (lbs)	1992	1993
Total Plant	2,500,000	1,900,000
Total Paint Shop	2,371,800	1,478,000
E-coat	7	3
Primer	9	8
Sealer/Adhesives	6	2
Topcoat	32	28
Purge Solvent	31	24
Cleaning Solvent	10	12

New Paints and Materials Formulations

Even with the changes in 1990 to waterborne, the plant continued to experiment with new materials to try to reduce its VOC emissions.[a] Between 1992 and 1993, a 25% reduction in VOC emissions was achieved plant-wide; however, the reduction in the paint shop emissions was almost 38%. Much of this reduction was achieved through the use of new materials in selected elements of the paint process. Total material usage for parts of the paint process are shown in Table 4.18 (next page), along with the changes from 1992 to 1993 in pounds of VOC emissions generated per pound of material used. Shifts to lower VOC materials in E-coat, sealers, adhesives, and purge solvents resulted in major reductions in paint shop VOC emissions. This is particularly important given that plant production from 1992 to 1993 increased by three percent.

[a] Data prior to 1992 were not available from this plant.

Table 4.18. Reduced VOC Emissions from Use of Lower VOC Materials

	Total Usage (lbs)		VOC Emissions (lbs per lb used)	
Process Element	**1992**	**1993**	**1992**	**1993**
E-coat	2,600,000	2,200,000	0.066	0.029
Sealers/Adhesives	1,500,000	2,300,000	0.107	0.014
Basecoat	2,100,000	1,400,000	0.181	0.179
Clearcoat	980,000	670,000	0.429	0.433
Purge Solvent	850,000	790,000	0.906	0.582
Cleaning Solvent	270,000	250,000	0.704	0.800

Handling and Disposal of Paint Sludge

Paint sludge is a major waste stream from automotive assembly plants, although air emissions (being the primary regulatory constraint in facility operating permits) are often viewed as more important. A concern in moving to new materials is often that of shifting the environmental burden from one media to another, in this case from air emissions avoided to increased solid wastes. Solid wastes from painting processes constitute a significant waste volume for Plant D. The waste volumes and costs of disposal from several paint shop sources are shown in Table 4.19. The paint sludge is 30 percent volume by weight, as opposed to industrial sludge at 60 percent volume. All these solid wastes are disposed of in landfill; none are recycled. There are some solid wastes (in addition to those represented in this table) that are incinerated, such as sealer and waterborne paint wastes. Rags and filters used in the paint shop are also incinerated.

Table 4.19. Volumes and Disposal Costs of Selected Paint-Related Sludges at Plant D

	1992	**1993**
Sealers Sludges (lbs/yr)	81,000	72,000
Disposal Costs ($/ton)	$412.84	$411.67
Paint & Phosphate Sludges (lbs/yr)	1,645,000	1,584,000
Disposal Costs ($/ton)	$85.00	$90.00
Wastewater Treatment Sludge (lbs/yr)	1,470,000	1,440,000
Disposal Costs ($/ton)	$85.00	$90.00

Chapter 5. Findings and Policy Implications

This chapter synthesizes the results of the individual case studies (Chapter 4) and presents the major findings of this research (results of the industry survey and the patent analysis were summarized in Chapter 3). The relevance of these findings to corporate and government environmental policies is also discussed in the latter part of this chapter. The two principal questions addressed in this research are the role of suppliers as sources of innovation in environmental technologies, and the benefits and challenges of integrating new materials or environmentally improved products into technologically complex manufacturing systems.

The findings of this research show conclusively that, for automotive painting, the suppliers are a primary source of innovation in environmentally beneficial materials and products and can have a major influence on the environmental performance of an assembly plant. This is an important finding, because much of the research in environmental strategy to date is focused on the manufacturer as the primary change agent, rather than key members of the integrated technology supply chain. Yet, recommendations for material changes in product design or production processes emerging from analytical approaches such as life cycle analysis can only be implemented with the support and input of major suppliers. Solutions to environmental problems that strive to reduce pollution at the source must extend beyond the materials and chemicals involved to include the companies that manufacture and supply those inputs. Suppliers can play an initiating role in identifying innovative approaches to environmental performance improvement if given those responsibilities by the manufacturer. This research demonstrates that not only do suppliers have new ideas to add, but that by utilizing suppliers in partnership with the manufacturer in the implementation of new technologies, dramatic improvements in environmental performance can be achieved.

Accomplishing the goals of industrial ecology, which include greater use of recycling and reduced inputs of hazardous materials to production systems, is both a technical and a managerial challenge. Innovative technology is required to find new materials and processing techniques that can be effectively integrated into complex manufacturing systems. Innovative management approaches that provide the encouragement, flexibility and opportunity to experiment with new ideas are also necessary. The expertise of major suppliers is an important source of technical input in improving environmental and product performance and is most readily accessed when suppliers are able to work in a partnership mode with automotive companies. It is in long-term relationships of trust that the ability to experiment flourishes and new solutions can be found.

The results of this work demonstrate that while innovative technologies can provide significant improvements in environmental performance, the implementation of corporate environmental policies at the plant level and a management approach that is supportive of innovation are also important. The role of suppliers in improving environmental performance by supporting implementation of new technologies and by providing a broader range of technical support and material management services was important to the success achieved by the automotive assembly plants evaluated in this research. Plant A, which utilized a combination of innovative paint technology, flexible and open management approaches, and a strong partnership with suppliers in improving both product quality and environmental performance, made the most dramatic improvements in environmental performance over time. Companies that build strong relationships with their suppliers benefit from the environmental expertise and product innovations developed through research investments by suppliers that are directed to serving the needs of an international market. Government environmental policies and related regulations that provide technological flexibility and allow companies to make tradeoffs among elements of the production system in an operating facility are important to encourage broader implementation of innovative environmental technologies in manufacturing facilities.

5.1. Comparative Analysis of Plant Performance

The primary focus of the case studies was to evaluate the impact of new materials and paint technologies on the environmental performance of automotive assembly plants. The case studies also provided data on the benefits and challenges of adopting new materials and technologies in manufacturing operations. Environmental performance was measured primarily by TRI emissions data for the years 1987 through 1994, supported by detailed data from plant personnel as available. This data provides a relatively consistent basis for comparing trends in plant emissions over time, based on key variables of paint technology, plant management approach, and the role of suppliers at the facility.[a] These variables are summarized for the four automotive assembly plants selected for this study in Figure 5.1.

Plant A	Plant B
Paint Technology: Shift to waterborne and powder **Management Approach:** Open, flexible Proactive environmental policy **Role of Suppliers:** Suppliers as partners	**Paint Technology:** Solvent-based **Management Approach:** Hierarchical, structured Compliant environmental policy **Role of Suppliers:** Supplier role limited
Plant C	**Plant D**
Paint Technology: Waterborne **Management Approach:** Open, flexible Proactive environmental policy **Role of Suppliers:** Suppliers as partners	**Paint Technology:** Shift to waterborne **Management Approach:** Hierarchical, structured Compliant environmental policy **Role of Suppliers:** Supplier role limited

Figure 5.1. Matrix of Plants in Comparative Case Studies

[a] Data from site visits was used to verify the validity of using TRI data for comparative analysis. Total VOC emissions data for each plant show the same patterns and trends in increases or reductions in total emissions and emissions per unit as shown by the TRI data. While TRI data cannot be used as an absolute measure of performance, it does provide a good indicator of changes in plant emissions from year to year.

The outcome of environmental performance was measured using a number of parameters, listed in Table 5.1. Air emissions (both total and normalized by production) are a major environmental release for automotive assembly plants and directly related to the materials used in the paint process. Air emissions are measured by pounds of chemicals released, supplemented by plant data on VOC emissions. Emissions of 33/50 chemicals are highlighted in the analysis because they constitute a large percentage of the releases from assembly plants, and are major components of paints and related products. Reductions over time in these chemical categories are also of interest to evaluate the responses of different companies and plants to voluntary government programs. Solid wastes are another important waste stream from automotive painting. Of particular interest is whether airborne emissions are reduced at the expense of increases in solid wastes from a plant. While the data on solid wastes are somewhat limited, data on recent plant performance suggests potential impacts and tradeoffs of technological shifts from solvent-based to waterborne paints. Finally, some plants stated a specific strategy for reducing the number of reportable TRI chemicals from their production processes. Changes in numbers of chemicals reported (adjusted for changes to regulatory reporting requirements where necessary) were tracked for each plant.

Table 5.1. Parameters Used to Evaluate Environmental Performance

Air Emissions	**33/50 Chemical Emissions (lbs)**
TRI Chemicals (lbs)	Methyl Ethyl Ketone
TRI Chemicals (lbs/unit)	Methyl Isobutyl Ketone
VOC Emissions (lbs)	Xylene
VOC Emissions (lbs/unit)	Toluene
Solid Wastes	**Reportable TRI Chemicals**
Paint Sludge Landfilled (tons)	Changes in Totals over Time
Paint Sludge Recycled (tons)	

All four plants selected for this study shared two important characteristics: a clearly stated corporate environmental strategy and a corporate commitment to technological innovation. The similarities among corporate strategies was somewhat unexpected, neutralizing the effect of corporate strategy differences as a variable of importance in explaining performance differences among plants.[a] Each plant has a parent company with a written, proactive environmental strategy that states a commitment to move beyond compliance with the regulations to integrate environmental considerations into their business decisions. Each of these policies includes a statement about the importance of recycling, both of the product itself (the car, at end-of-life) and of solid wastes from the manufacturing process (such as paper, cardboard packaging and plastics). Pollution prevention is a major theme in these policy statements, with particular emphasis on the life cycle of materials, reaching upstream in the supply chain for possible waste reductions and downstream to think about impacts of product and material decisions outside of the plant. Another stated element of both company environmental strategies is to pursue new technologies for minimizing the environmental impact of automobiles during use, end-of-life, and in the manufacturing process. These plants were all relatively early adopters of new paint materials and technologies.[b] Plants C and D were among the first automotive assembly plants in the U.S. to adopt waterborne basecoat technologies with the revival of waterborne as an option as the two stage basecoat/clearcoat processing technology evolved, followed shortly thereafter by Plant A. Plant B, while not using waterborne during the years for which environmental data was available in this study, did adopt waterborne basecoat in 1995. The willingness of these companies to adopt a new, relatively untried paint technology on important product lines suggests a commitment to innovation and corporate level support for trying new approaches.

There are also important differences among the plants in paint technology, plant management approaches, and relationships with suppliers in the paint shop that shed light on the influence of these parameters on environmental performance. These differences among primary variables allow an effective pairwise comparison of case study results. Specific plant pairs (see Table 5.2 on the next page) were chosen to examine in more detail the primary variables of technology, management approach and the role of suppliers in achieving improvements in

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[a] This variable is thus not included in Figure 5.1.

[b] Many U.S. automotive assembly plants, as of 1997, have not adopted nor plan to adopt waterborne paints, although suppliers believe that by the year 2000, all automotive assembly plants will be using this technology.

environmental performance. These analyses put the results of individual plants into perspective by comparing like facilities to determine whether they achieve similar results. The first set of comparisons is between plants utilizing comparable technologies, management approaches and supplier arrangements. Solvent-based technology, traditional management structures and supplier relationships are represented by Plants B (1987-1994) and D (1987-1990). Innovative paint technology (waterborne), open, flexible management styles and partnership arrangements with suppliers are explored through a comparison of Plants A (1994) and C (1991-1994). Each of these plant pairs produced vehicles of similar size.

Table 5.2. Primary Categories of Pairwise Comparisons of Case Study Results

Comparable Technology and Management Approach	
Solvent-based paint technology Hierarchical, structured management Supplier role limited	Plant B (1987-1994) and Plant D (1987-1990)
Waterborne paint technology Open, flexible management Suppliers as partners	Plant A (1994) and Plant C (1991-1994)
Comparable Technology and Contrasting Management Approach	
Solvent-based paint technology Open, flexible vs. hierarchical, structured management Suppliers as partners vs. limited supplier role	Plant A (1989-1992) and Plant D (1987-1990) Plant A (1989-1992) and Plant B (1987-1992)
Waterborne paint technology Open, flexible vs. hierarchical, structured management Suppliers as partners vs. limited supplier role	Plant C (1991-1994) and Plant D (1991-1993)
Contrasting Technology and Management Approach	
Waterborne vs. solvent-based paint technology Open, flexible vs. hierarchical, structured management Suppliers as partners vs. limited supplier role	Plant A (1990-1992) and Plant D (1991-1993)

The second set of comparisons evaluates differences in environmental performance among plants using comparable technologies (as in the first set of comparisons) but with contrasting approaches to plant management and supplier relationships.[a] Plants A (1989-1992), B (1987-1992) and D (1987-1990) are compared for solvent-based paint technology, and Plants C (1991-1994) and D (1991-1993) provide a comparison for waterborne paints. The third comparison is between plants using different paint technologies, management approaches and supplier relationships, in this case Plant A (while using solvent-based technology) and Plant D (after its transition to waterborne technology).

A summary of baseline performance of the three plants in operation in 1989[b] (see Table 5.3) shows few differences in total emissions among plants, despite a relatively innovative management approach at Plant A. However, Plant A also had the highest production rate in those years (about 256,600), while Plants B and D had significantly lower rates (216,100 for Plant B and 189,500 for Plant D). The normalized emissions results from Plant A are about ten to fifteen percent lower than those from Plants B and D. All plants at that time used solvent-based paint technologies and none of them were directly utilizing the suppliers to support improvements in the environmental performance of the operating facility. While a single year comparison can provide a useful baseline, it is also important to evaluate the progress of each plant over time, with particular attention to facilities investing in major technology shifts. The pairwise comparisons among plants producing similar vehicles provide a more complete evaluation of performance.

Table 5.3. Baseline Plant Performance (1989) Shows Few Differences Among Plants

	Plant A	Plant B	Plant D
Total TRI Emissions (lbs)	1,979,274	1,747,107	1,623,300
Normalized TRI Emissions (lbs/vehicle)	7.74	8.08	8.57
Paint Technology	Solvent-based	Solvent-based	Solvent-based
Management Approach	Open, flexible	Traditional	Traditional
Supplier Responsible for Environmental Performance	No	No	No

[a] While some of these comparisons involve vehicles of slightly different surface area and different model categories, they provide a longer timeframe for evaluating the effect of different management strategies and supplier relationships in two plants that have the same corporate parent.

[b] Plant C did not initiate production until 1990.

Comparable Technology and Management Approach

The first plant comparison evaluates the performance of automotive assembly plants using solvent-based paint technology and traditional management and supplier approaches. Plants B and D exhibit relatively similar performance profiles over the years 1987 to 1990 (at which time Plant D shifted to waterborne technology). The average total TRI emissions from these plants in the first three years evaluated is about 1.9 million pounds (see Figures 4.7 and 4.17). On a normalized basis, both plants reduced emissions, from an initial high of about 13 pounds per vehicle in 1987 to about eight pounds per vehicle in 1989 (see Figures 4.9 and 4.19). In 1990, emissions for Plant D increased by almost forty percent as it attempted to implement waterborne technology (as stated in the case study in Chapter 4, there were a number of problems experienced in the first year of adoption). In 1991, however, after adjusting to the new materials and technology, Plant D achieved a step function reduction in total and normalized TRI emissions (28 percent and 40 percent respectively, to 1.2 million pounds and five pounds per vehicle). It also continued to reduce emissions over time, reaching a level of less than 900,000 pounds total TRI emissions in 1993. Plant B, meanwhile, achieved steady but less dramatic reductions in emissions over the same time period (ten percent reduction in total TRI emissions and fourteen percent reduction in normalized TRI emissions), until reaching a relatively stable level of about one million pounds per year in 1992 through 1994. A comparison of these two plants demonstrates that incremental reductions in environmental releases can be attained without radical technological change, and under traditional management approaches and supplier arrangements. At some point, however, the limit to performance improvements from procedural changes or minor adjustments to material formulations is reached and investments in new technology are required to achieve further reductions in emissions.

A comparison of Plants A and C, however, demonstrates that when adopting radically new materials or technology, even plants with similar technologies and management approaches can experience dramatically different results in terms of environmental performance. Both total and normalized TRI emissions at Plant A in 1994 are almost fifty percent less than any of the years at Plant C (see Figures 4.2, 4.4, 4.12, and 4.14) and solid wastes are significantly less at Plant A (Figures 4.3 and 4.13, and Tables 4.5 and 4.14).[a] Toluene and acetone were completely eliminated from the production process at Plant A in 1994. While Plant C made significant reductions in the emissions of some important chemicals (such as methyl ethyl ketone and methyl isobutyl ketone), emissions of xylene remained relatively stable over the years and toluene emissions increased. Plants A and C are both using waterborne paints (for the years compared) and have proactive environmental strategies and flexible, open management cultures. They both rely on suppliers to provide them with high quality materials and ideas, but the ways in which they work with suppliers vary significantly. Plant A has committed to a single supplier for providing their paint shop materials and related chemical needs. A specific incentive program has been established that gives the supplier responsibility for product quality and for environmental performance improvements at the plant and allows them to share in any monetary savings from the application of new products or innovative ideas. The supplier can take a systems view of the plant, balancing needs and chemical use across elements of the paint process. Plant C also involves suppliers in reducing the use of chemicals at the plant (nonproduction chemicals, not paints or purge materials), but has a number of suppliers involved in various parts of the paint shop operation. No one supplier has responsibility or cognizance for materials used in the entire operation; that job is retained by the automaker. While supplier involvement appears to be an important factor for both Plants A and C in achieving successful implementation of new technologies and continued improvements in environmental performance, the experience of Plant A, at a minimum, suggests that allowing suppliers a role from a systems perspective in plant operations can achieve significantly greater emissions reductions. This comparison also demonstrates that implementing new environmental technologies in a complex production system often requires additional procedural and management changes to achieve maximum benefits. The technology alone is unlikely to provide expected performance improvements.

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[a] There is only one year of comparative data for Plant A, but it offers an interesting perspective relative to the performance at Plant C. Note that Plant C data on total VOC emissions is prior to abatement; actual VOC emissions would be significantly lower. The plants did produce similar sized vehicles during this time period.

Comparable Technology and Contrasting Management Approach

The second set of plant comparisons further explores the influence of supplier responsibilities and management approach on the successful application of new environmental technologies by evaluating plants that use the same paint technology but have differences in management style and arrangements with suppliers. Comparisons of Plant A to Plants D and B, and Plant C to Plant D (after it switched to waterborne paints) demonstrate that even with similar technologies, plants with more open management approaches and/or partnership arrangements with suppliers outperform (from an environmental perspective) those with more traditional relationships. Summary data in Table 5.3 shows that Plant A in 1989 had 12 percent higher total TRI emissions than Plant B, and 20 percent greater than Plant D. In 1990, however, it had lower total emissions than either of the other plants and by 1992 Plant A had total TRI emissions fifty percent lower than Plant B (see Figures 4.2, 4.7 and 4.17).[a] In all years, the normalized TRI emissions figures were lower for Plant A than either of the other plants. While plant data on solid waste volumes were not available for these early years of production, the TRI data on transfers suggests a similar profile, with Plant A having the highest level of chemicals disposed of in landfill in 1989, but in subsequent years having the lowest amounts of total transfers of chemicals to landfill among the three plants (see Figures 4.3, 4.8 and 4.18). While all three plants showed improvements in environmental performance over time, as measured both by air emissions and transfers of chemicals to landfill, the greatest improvements were seen in Plant A. A similar evaluation between Plants C and D, using the waterborne paint technology, shows that Plant C had lower total TRI emissions than Plant D in every year of the comparison (1991 through 1993) and lower normalized TRI emissions in every year except startup (1991).[b] However, Plant C has a significantly higher level of offsite transfers of chemicals, including those destined for landfill disposal (see Figures 4.3 and 4.13), almost five times the amounts of Plant D.

[a] Plant D switched to waterborne paints in 1990, and after a difficult transition year, experienced a major reduction in emissions in 1991 through use of this technology.

[b] Note that Plant D also experienced initial increases in emissions during startup of waterborne technology.

A summary table of the performance of all four plants in 1992 (Table 5.4) shows that all plants have achieved some level of reduction in total and normalized TRI emissions relative to the baseline performance of 1989, even without changes in technology or supplier relationships. However, differences among plants are beginning to emerge. Each facility has a unique process and set of input materials, and different operating requirements and VOC emission limits set by their environmental permit. Plants A and C have lower total TRI emissions than Plants B and D, although on a normalized basis (accounting for production levels) Plant B appears to be closer to Plants A and C. Plant B, at this time, has begun to involve suppliers in programs to try to reduce environmental emissions from the plant. Plant D, even with the waterborne technology, has higher TRI emissions per unit produced, a figure which is echoed by an evaluation of plant data. Plant D at this time utilizes suppliers in supporting environmental performance improvements only for wastewater treatment chemicals, not for the paint materials or paint shop cleaning chemicals, which have been shown to constitute a majority of the emissions from an assembly plant. These comparisons demonstrate that new materials and technology are important in achieving environmental performance improvements in individual facilities. They also show that additional reductions in environmental emissions can be accomplished through a management approach that supports innovation and take broader advantage of supplier expertise.

Table 5.4. Performance Differences among Plants Emerge (1992)

	Plant A	Plant B	Plant C	Plant D
Total TRI Emissions (lbs)	567,497	1,072,129	859,676	1,108,205
Normalized TRI Emissions (lbs/vehicle)	3.72	4.21	4.05	7.04
Total Plant VOC Emissions (lbs)	1,676,619	2,829,970	(a) 2,392,879	2,500,000
Normalized Plant VOC Emissions (lbs/vehicle)	11.0	11.1	(a) 11.3	15.9
Paint Sludge Landfilled (tons)	163	42	1960	823
Paint Sludge Recycled (tons)	0	165	0	0
Paint Technology	Solvent-based	Solvent-based	Waterborne	Waterborne
Management Approach	Open, flexible	Traditional	Open, flexible	Traditional
Supplier Responsible for Environmental Performance	Yes	Yes, limited	Yes, limited	No

(a) These data are emissions prior to abatement; emissions after abatement (as with Plants A and B) would be significantly lower.

Contrasting Technology and Management Approach

Finally, comparing Plants A and D provides insight into the effects of adopting new paint technologies under different management approaches. Plant A in 1990, using solvent-based technology, had somewhat lower total TRI emissions than Plant D using a waterborne basecoat, but higher emissions per vehicle produced (5.30 for Plant A compared to 5.09 for Plant D). Over the next two years, Plant A succeeded in reducing its total and normalized emissions by fifty percent and thirty percent, respectively, without moving to waterborne technology (see Figures 4.2 and 4.4). Plant D, at the same time, experienced a reduction of only twenty-five percent in total emissions and a slight increase in normalized TRI emissions from 1991 to 1993 (see Figures 4.17 and 4.19). There were dramatic declines in emissions of key regulated chemicals, however, including xylene, toluene and methyl isobutyl ketone with the shift to waterborne basecoat paints. Xylene was reduced seventy percent over 1989 levels, toluene over ninety percent and methyl isobutyl ketone almost sixty percent. These three chemicals alone constituted over eighty percent of all TRI emissions from Plant D in 1989, and only thirty-five percent in 1991. While overall Plant A reduced emissions, before shifting to waterborne coating technology, the chemicals xylene, toluene and methyl isobutyl ketone, for example, still constituted a signficant percentage of their total emissions with little change over time (57 percent in 1989, 62 percent in 1991 and 68 percent in 1992).

The effects on plant performance of shifting from solvent-based to waterborne paint technologies are highlighted in Table 5.5 (next page). For Plant A, the new paints resulted in significant reductions of methyl isobutyl ketone and xylene, while methyl ethyl ketone, a key chemical used in formulating waterborne paints, remained essentially stable. The reductions in key chemicals for Plant D were discussed above. The comparison of Plants A and D suggest that although there are a number of methods that facilities can successfully employ to improve their environmental performance, reducing specific chemicals of concern depends more on radical reformulation of material inputs to the plant. Both plants made dramatic improvements in total emissions profiles by implementing waterborne coating materials and also significantly reduced emissions of key chemicals. These data demonstrate that while significant improvements in environmental performance can be obtained through technology modifications rather than radical innovations in technology, reductions in specific toxic chemicals may best be accomplished through such radical shifts in materials. Selecting the materials of concern and finding substitute chemicals that will yield the same or enhanced performance in a production setting, however, is an extremely difficult task, and one that currently resides primarily with the paint suppliers.[a]

Table 5.5. Significant Performance Improvements Achieved Using New Technology

	Plant A		Plant D	
	1992	1994	1989	1991
Total TRI Emissions (lbs)	567,497	361,426	1,623,300	1,169,300
Normalized TRI Emissions (lbs/unit)	3.72	1.49	8.57	5.09
Emissions of selected chemicals (lbs)				
Methyl Ethyl Ketone	64,000	67,420	41,000	73,000
Methyl Isobutyl Ketone	182,000	112,000	212,000	110,250
Toluene	13,600	0	430,000	48,800
Xylene	193,000	113,000	705,000	257,000
Vehicle Production	254,651	291,337	189,426	229,872
Paint Technology	Solvent-based	Waterborne	Solvent-based	Waterborne
Supplier Responsible for Environmental Performance	Yes	Yes	No	No

Key Factors in Environmental Performance

The comparative analysis of the experiences of four automotive assembly plants over time demonstrates that while technological change is required to reduce the emissions of particular chemicals and is also needed to make dramatic improvements in environmental performance, it is not the only factor influencing the environmental performance of these facilities. Environmental performance is linked not only to the paints and coatings materials entering the facility, but also to the cleaning chemicals and operating procedures used at the plants. Each plant has a different set of paints and coatings used in their process, and chemical needs

[a] Although some automakers have specifically targeted key chemicals for reduction, based on current or expected regulation.

related, in part, to these processes. The in-depth discussion of the challenges faced by individual plants (Chapter 4) reinforces the importance of understanding the unique technological and management systems of a facility in thinking about how to approach environmental improvements. Modified formulations (such as high solids, solvent-based paints) and improved process technology provide reductions in emissions profiles for automotive assembly plants. Changes to operating procedures, including block painting and changes in cleaning schedules or practices, can also have a major impact on the materials used and resultant emissions. Plants that utilize a combination of innovative technology and management strategies with attention to environmental priorities may perform as well as or better than facilities specifically designed to achieve improved environmental performance. Plants that fully utilize the expertise of their suppliers by giving them explicit responsibilities for environmental performance improvements and the flexibility to bring innovative products and approaches to the plant can significantly improve their environmental performance.

Yet, while technology alone does not provide the solution, neither do corporate strategies or management approach. All plants evaluated for this study had parent corporations with proactive, clearly written and widely disseminated environmental strategies and policies. However, each plant had different approaches for implementing these policies and for linking with corporate directives. There were also differences among the plants in terms of resources available (personnel and funding) for implementing these projects and the priorities placed on pollution prevention as opposed to compliance-oriented projects by plant management. Plants A, B and C had specific mechanisms in place for ensuring implementation of corporate environmental priorities at the plant level (see Figure 5.2, next page). The model of the environmental coordinator (Plants A and B), a corporate staff person assigned to a specific plant, provided an individual onsite that had a systems view of the entire facility. They also were the primary point of contact for paints and chemicals suppliers, and worked directly with the environmental specialists at the plant. This model creates a strong link between corporate and plant priorities and an incentive for suppliers to support environmental priorities at the plant (since those are the primary focus of the individual to whom they report). The linking mechanism at Plant C was somewhat different. While environmental specialists are assigned to each operating department of the plant, the supplier connection is stronger at the plant management and corporate levels. Suppliers do have involvement at the department level in their particular element of the paint operation, but less involvement across departments and with projects that take a broader systems perspective of the plant as a whole.

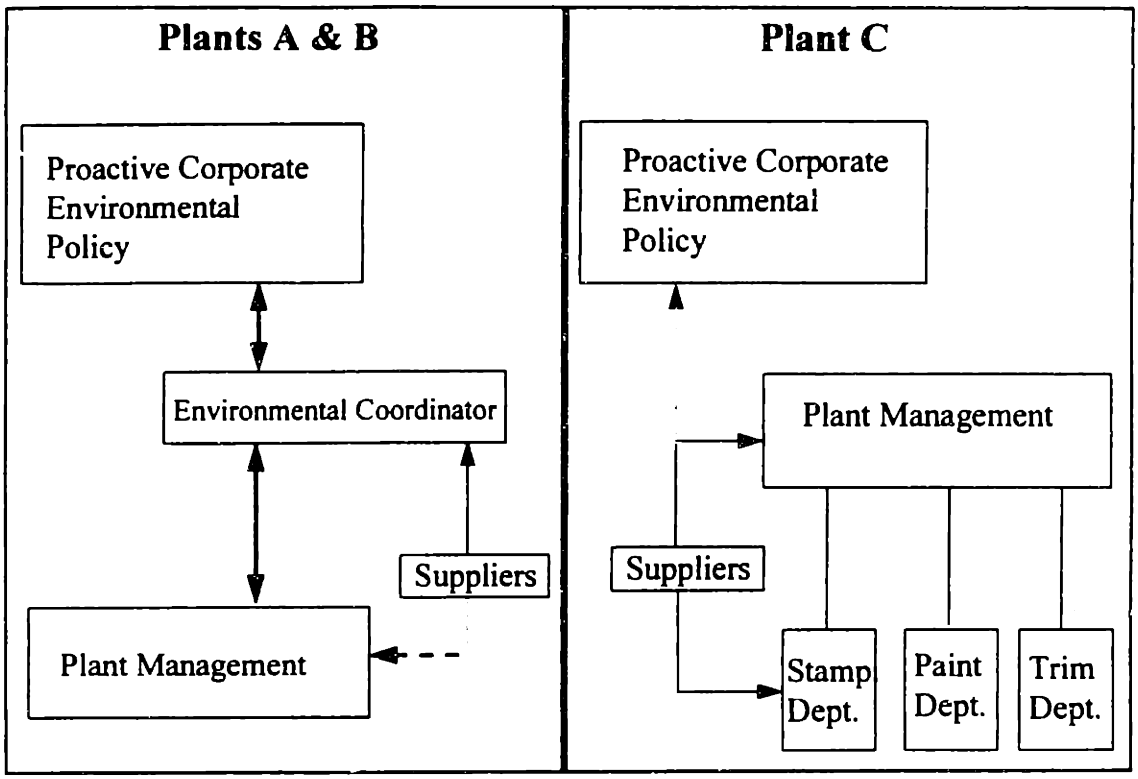

Figure 5.2. Linkages Among Corporate, Plant and Departmental Units

Data reported to the TRI from 1991 on (summarized in Table 5.6, next page) include the different approaches plants have taken to reduce emissions of specific chemicals. Plant A most often employed changes in materials and participative teams to accomplish reductions in emissions. Interviews with Plant A personnel revealed that they include suppliers as part of their team and many of these changes were made with the direct participation of, or, in the case of material changes, the recommendations of the suppliers. Plant B relied more on internal audits to point out needed changes, implementing a large number of equipment modifications to achieve emissions reductions. Plant C focused on changes to the application process or basic operations, with strong supplier support. This makes sense, since Plant C initiated production with waterborne and lower solvent materials. Their challenge was in making these new materials work effectively with their process. While at individual process element levels they relied heavily on suppliers in making environmental improvements, they did not have a mechanism for using suppliers at an integrated systems level in reducing emissions from the total paint process. Plant D reported primarily material changes, principally the shift to waterborne technology and related adjustments to process materials.

Table 5.6. Plant Strategies for Reducing Chemical Emissions Vary[a]

Improvements Attributed To	**Plant A**	**Plant B**	**Plant C**	**Plant D**
Material Substitution	11	6	5	9
Improved Application/Operation			53	
Modified Equipment Layout	6	23		
Improved Maintenance		3		
Accomplished Through				
Internal Audits		31	3	1
Participative Team Management	(a) 17		5	3
Supplier Assistance		1	56	3

(a) Suppliers included as team members

The role of suppliers appears to be important for several of these facilities (Plants A and C in particular) in implementing technological change (whether in materials substitution or in application processes) in their facilities and sustaining improvements over time. An evaluation of all four plants demonstrates that while each of them successfully reduced emissions to some extent, the greatest improvements (by 1994) were at Plant A. At Plant A, investments in new, waterborne coating technologies were coupled with plant level management approaches that encouraged innovation (open, flexible management styles), reinforced the importance of pollution prevention as an environmental priority (through the environmental coordinator position) and relied on a single, system-level supplier to help improve the environmental performance of the plant. The differences among plants in performance in 1994 are shown in Table 5.7 (next page).

[a] These data reflect the number of actions reported to TRI from 1991 through 1994 (for Plant D, through 1993).

Table 5.7. Plant A (1994) Shows Greatest Improvements in Environmental Performance

	Plant A	**Plant B**	**Plant C**	**Plant D** (a)
Total TRI Emissions (lbs)	361,426	1,066,540	1,072,482	871,844
Normalized TRI Emissions (lbs/vehicle)	1.49	3.66	3.83	5.39
Total Plant VOC Emissions (lbs)	1,071,413	2,773,513	(b) 2,808,189	1,900,000
Normalized Plant VOC Emissions (lbs/vehicle)	4.41	9.52	(b) 10.03	11.75
Paint Sludge Landfilled (tons)	0	200 (a)	1730	792
Paint Sludge Recycled (tons)	56	165 (a)	0	0
TRI Chemicals Eliminated (1989-1994)	7 (from 17 to 10)	0 (17)	1 (from 20 to 19)	2 (from 22 to 20)
Paint Technology	Waterborne	Solvent-based	Waterborne	Waterborne
Management Approach	Open, flexible	Traditional	Open, flexible	Traditional
Supplier Responsible for Environmental Performance	Yes	Yes, limited	Yes, limited	No

(a) 1993 data.
(b) VOC emissions before abatement; emissions after abatement (to be comparable with other plants) would be significantly lower.

While each plant has a different strategy for improving their environmental performance, they also have different regulatory limits dictated by their operating permits. All plants were measured on their performance in VOC emissions, and were, for most years, within compliance limits. But some plants placed a high priority on continuing to reduce emissions well below compliance limits, achieving these results through reductions in pollution at the source (such as Plant A).[a] Some concentrated on recycling and reducing solid wastes. Others focused on reducing the number of reportable chemicals in their manufacturing processes (an explicit goal for Plant A). Plant priorities dictate the level of resources available for new projects and the amount of management and plant attention paid to successful efforts. A focus on recycling supplier-generated packaging waste resulted in the implementation of returnable packaging programs, for instance. Priorities on reducing VOC emissions resulted in innovative new programs and the adoption of lower VOC content products.

[a] Plant D did not state this as an explicit plant priority until 1996.

5.2. Summary of Research Findings

The objective of this research was to determine the role of suppliers in developing and implementing innovations in paint and coating materials that make a difference in the environmental performance of automotive assembly plants. The major hypotheses tested are:

H1: Innovation in environmental technology is being driven by paint suppliers to the auto industry. The technical competence required for fundamental changes in materials inputs to the manufacturing process is expected to reside with the suppliers of automotive paints. This is important from the perspective of obtaining innovative technologies and materials for improving environmental performance. If the suppliers are the locus for innovation in materials and chemicals critical to reducing pollution at the source, then they must be included in the development of strategies for reducing environmental impacts of key products and processes.

H2: Environmental performance in a manufacturing operation is improved through the use of new cleaner technologies and supplier expertise. Significant improvement in environmental performance is expected by using innovations in paint materials and technology to reduce environmental impact in automotive painting operations. This hypothesis directly explores the potential for new technology and materials to reduce the environmental impact of complex manufacturing operations, and whether other factors are required to maximize the success of innovation in environmental technologies.

These hypotheses were explored using the research approaches shown in Figure 5.3 (next page), tracing innovation in automotive paints and coatings by first exploring the primary source of invention and then determining the factors important in the adoption of new technologies. The results of the technology survey and the patent analysis demonstrate that the technical expertise and, increasingly, the product understanding necessary for formulating new, innovative paints and coatings to meet emerging environmental and technical performance needs resides with suppliers. Paint manufacturers are focusing on improving materials characteristics to meet the demands of the international marketplace, while automakers focus their attention on developing process improvements for cost efficiencies and waste minimization. Results of the survey indicate that paint manufacturers are continually investing in the research and testing necessary to develop new products. Although not all U.S. customers are willing to pay for environmental improvements, most of the major paint suppliers also serve European markets, where these innovative products have added value.

Figure 5.3. Research Approach for Tracing Innovation in Automotive Paints and Coatings

While the performance of the paint system continues to be the primary criteria in choosing to adopt these innovations, some U.S. automakers now see environmental performance as a critical parameter as well and are willing to pay the additional costs per gallon to adopt new technologies that they believe will position them advantageously for the future. The specific technology strategy and environmental policies of each company are major determinants of decisions to adopt new paint and coatings technologies. The case studies demonstrated that plants where strong partnerships exist among suppliers and automakers see better overall results in terms of environmental performance. The more successful partnerships use contracting mechanisms that support greater supplier responsibility and incentives for both parties to use their complementary technical competencies and share key process information.

In addition to growing market demands, environmental regulations are an important driver for innovation in automotive paints and coatings, creating additional complexities for the painting process and placing new costs on automakers. While paint suppliers were developing and improving innovative materials and technologies, most automakers (when the early generation of products proved incompatible with high performance demands and existing facility designs) maintained compliance with regulations by investing in pollution control equipment to improve the environmental performance of their paint shops. Increasing costs of compliance over time with more stringent environmental regulations[a] and improvements in the performance of new paints and coatings has led to higher rates of adoption of the new materials among automakers. Figure 5.4 shows the evolution in regulatory standards for allowable VOC emissions per vehicle produced and related changes in the adoption of new paint technology. Although investments in improved pollution abatement equipment continued, automakers became more willing to explore other options for improving environmental performance at lower costs, including changes in operations, investment in more efficient application equipment, and the use of new paints and related products with lower VOC content. By the 1990s, the industry had for the most part shifted to high solids, solvent-based paint technology. Early adopters were beginning the transition to waterborne and powder technologies, in pursuit of environmental and quality performance improvements.

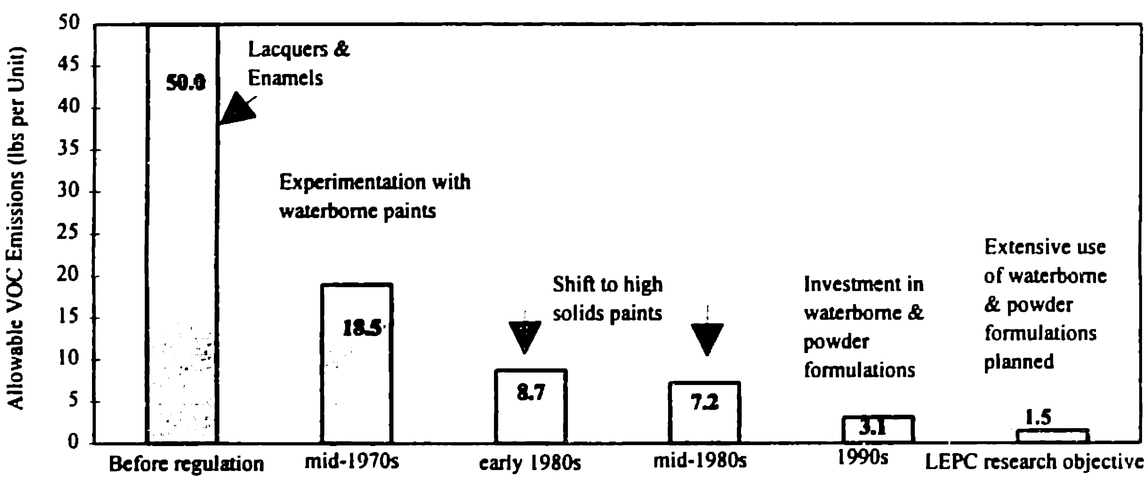

Figure 5.4. Increasing Stringency in Emissions Standards for Assembly Plants[1]

[a] The overall cost to the U.S. auto industry of achieving compliance with the new Clean Air Act (1990) requirements is estimated by the American Automobile Manufacturing Association to be about $3 billion by the year 2000, with almost all of that investment focused on paint shops (J. King, "Auto Industry Cleans up its Act", Ward's Auto World, February 1994, pp. 28-29).

The industry survey and the case studies both highlighted the difficulties in implementing new paint technologies in existing facilities. Paint products must be designed for the particular vehicle being produced, the facility layout and available application equipment at a plant. Upgrades to plants are made on a specific timetable, based on regulatory requirements, corporate investment strategies and particular model needs. Paint suppliers and plant managers influence these decisions and can be champions of technological change. The survey showed a wide range of levels of involvement of suppliers at assembly plants, however, from those integrally involved in material tracking, process improvement, and even environmental performance, to those relegated to more traditional sales and service roles. Suppliers in partnership roles were more willing to provide their latest innovations to their automotive partners and, with more knowledge of their customer's needs, better able to provide technologies suited to particular facilities. The case studies also showed that environmental performance improvements are achievable through a variety of alternatives. All plants evaluated showed reductions in air emissions over time. Lower VOC products are only one option among many (including additional pollution control equipment) that companies can use to keep their plants operating at or below permitted limits. New materials, however, are necessary to reduce emissions of specific chemicals and to make dramatic improvements in environmental performance. The choice depends on the specific technology and environmental strategies of a company, since decisions on material changes are made at the corporate level.

The results of this work demonstrate that material substitution in complex manufacturing systems is not a simple process. Each plant faces a unique situation in terms of technological possibilities, regulatory constraints and management approaches. Corporate policies focused on pollution prevention and recycling have to be implemented at the plant level. Successful implementation of new technologies within the plant must have not only the support of corporate management (and related resources and priorities) but must also be consistent with the needs and directions of the plant management. Plant managers of the four plants evaluated in this study all had a focus on environment, although some defined environment more from a perspective of compliance with permit requirements than of reducing waste at the source. Plants A and C took the most systemic view of environmental issues, attempting to integrate reduction of waste at the source into their business practices and material purchase decisions. These plants also had the strongest involvement of suppliers in their environmental management and pollution prevention activities. Plant A used a single supplier, with clear responsibilities for plant level environmental performance as well as material quality and had the best results in terms of environmental performance (as defined for this study).

This research leads to an important framework (represented in Figure 5.5) for innovation in environmental technologies and improvements in environmental performance. An integrated approach that includes innovative technology, supportive management approaches and partnership arrangements with primary suppliers is most likely to result in dramatic improvements in environmental performance. Technology is one important element of change. Technological change and reducing toxic materials at the source can result in

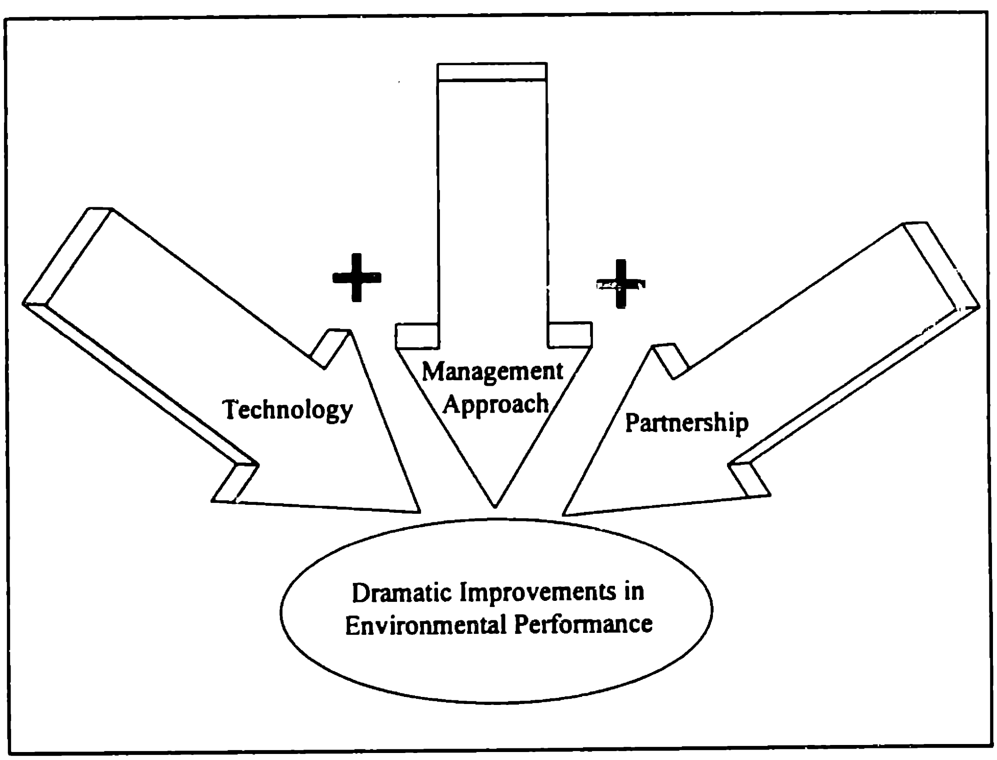

Figure 5.5. A Framework for Achieving Dramatic Improvements in Environmental Performance

significant reductions in pollution from production processes. Changing materials in technologically complex products and/or manufacturing systems is a difficult challenge, however. The manufacturer may not have the technical knowledge to define the necessary changes in the supply chain, or to implement process changes in the manufacturing plant. This work has demonstrated that the source of innovative ideas for change (based on technical knowledge) may reside instead with the supplier.

Management is another important element of change. Successful adoption of innovative environmental technologies also requires a proactive management approach at the plant level that reflects corporate environmental priorities. Mechanisms for implementing proactive corporate environmental policies at the plant level are critical to achieving environmental performance goals in the production process. In addition to the importance of an integrated technology and management perspective in achieving improvements in environmental performance, this research has identified a third important factor--that of partnerships between the manufacturer and key suppliers. The most significant improvements in environmental performance are achieved when new technology and management priorities are coupled with supplier expertise. The most effective partnerships are based on new contractual arrangements with suppliers built on trust to encourage broader sharing of innovative products and ideas across more elements of the production system. Given the complexity of automotive painting and the challenges in adopting new materials or process technologies at a production plant, strong partnerships among paint suppliers and automakers, supported by appropriate incentive systems, were an important element of success for innovative environmental technologies. This framework of integrating technological advances with innovative management approaches and strong partnerships with key suppliers leads to new thinking on how companies and governmental agencies might approach the development and implementation of policies for environmental performance improvements.

5.3. Implications for Corporate and Government Environmental Policy

Many plants can achieve good environmental performance results (and certainly perform well below compliance levels) with incremental technology changes. Minor adjustments to paint formulations and operating procedures can improve environmental performance to some extent. The large percentage of emissions due to cleaning chemicals shows that use of lower VOC cleaning products and implementing block painting, for example, can have a major effect on the emissions profile of a facility. Once these actions have been implemented, however, additional improvements in performance require changes to the input materials at the plant. All the plants in this study showed improvement when shifting from low solids solvent-based paints to high solids. The use of waterborne materials in the topcoat system and other elements of the paint process that contributed significantly to plant emissions (such as the underbody coatings) resulted in more dramatic performance improvements. The greatest improvements were seen when the plants implemented these new technologies with the onsite technical support and assistance of suppliers.

Relevance to Corporate Strategy

From a corporate perspective, these results suggest three important areas for developing and implementing effective environmental improvement strategies. First, material substitution is NOT a simple process. A broad mandate for bringing in new materials to the plant must recognize that during the initial adoption process, technologies designed to reduce emissions may actually result in an increase as the plant adjusts to the new technology. New materials affect the broader manufacturing process and can create unanticipated problems in other parts of the system. Both Plants C and D experienced increases in emissions when adopting waterborne technology, as they worked to adjust related processes in the plant to the new materials. Plant B, when implementing waterborne in 1995, experienced difficulties in controlling key process parameters (the effects of temperature and humidity on the waterborne paint was greater than originally anticipated) and dramatic increases in paint sludge volumes.[a] Adoption of powder technology for antichip coating at Plants A and B, while essentially eliminating VOC emissions for that part of the process, increased solid waste volumes. These plants are attempting to find other uses for the waste material, while continuing to make process changes to reduce waste volumes.

Second, companies need to rethink the ways in which they utilize supplier expertise. The automotive industry is currently moving toward new partnership arrangements with suppliers, attempting to shift the traditional, adversarial approach to one that uses fewer suppliers but with stronger connections. This is particularly important when making use of new, innovative technologies. The Low Emission Paint Consortium (LEPC), a research partnership of the automotive companies and their material and equipment suppliers, is an excellent example of the benefits to be gained from partnerships in environmentally related technologies. However, these partnership arrangements are also important during the implementation stage of new technologies at the plant level. The industry survey and patent analysis demonstrated the shift over time to suppliers of formulation expertise and suggest an increasing trend toward process knowledge as well. Automakers currently are the primary source of expertise in paint processes, but need to work with suppliers more closely to get the new ideas they need once the "low-hanging fruit" of environmental improvements has been harvested.

The interviews with suppliers suggest that long-term partnerships that build relationships of trust are more important than the automakers might believe. Recent studies on the automotive industry show an increase in the type of partnerships that have been observed over time between the paint manufacturers and the automakers[2] and suggest that the industry is likely to face a greater degree of change in the next eight to ten years than it has faced in the last

[a] The experience of Plant A, however, shows that shifting to waterborne technology does not necessarily increase solid waste volumes. Additional research on the system effects of technology shifts is needed.

hundred.[3] The new trend in partnerships resembles the much-studied Japanese supplier-manufacturer relationship, characterized by a tiered structure of suppliers, where the first tier suppliers take on larger responsibilities for design and quality, performing as systems integrators for the second and third tier suppliers.[4] Capabilities in systems integration and a global presence are expected to be more important than short-term price in the future to automakers in choosing suppliers. Similarly, the level of investment made by an automaker in developing and managing relationships will be more important in the future to suppliers in choosing their customer base.[5] Partnership models that view the roles, responsibilities and relationships of suppliers as an extension of the company are expected to become the preferred industry model, particularly for first tier suppliers.[6]

In the automotive coatings sector, the technical competencies in formulation for new paint products have shifted to the formulators and their suppliers. As automakers have continued to cut their budgets for basic R&D in paint and coatings chemistry, investments in new technologies by the suppliers have gained greater importance. In addition to increased technical competency, suppliers have gained a stronger role in conceptual design of new products. In some cases, suppliers are performing roles similar to those of the advanced engineering groups of the automaker. "It is no longer unusual to find an automaker's engineers at a supplier house, or vice-versa, as supplier and OEM [Original Equipment Manufacturer] brainstorm ideas and participate together throughout a project's development".[7] Suppliers will often initiate projects based on an increasingly competent level of understanding of automaker needs, beyond the general level of knowledge suggested by federal or state legislation.

Each automaker has a different strategy in working with suppliers. The automotive paints and coatings industry, as with many automotive suppliers, is extremely competitive. It is also one where margins for suppliers have been shrinking as the cost for their raw materials increase, while their customers, the automakers, continue to resist price increases. Suppliers want to find ways to provide more and better services to the automakers by expanding their product line and bringing their environmental expertise to the table. They are less likely, however, to provide experimental innovations and cutting edge products to customers with whom they have tentative or limited contractual arrangements. Interviews with suppliers show that there is a difference in how they operate among their customer base. Customers with whom they have closer, more trusting relationships are likely to gain the most from suppliers who are increasingly developing a broad base of expertise. Presented with a more extensive systems role in the plant, suppliers are more likely to bring their best innovations to that customer, with less concern about other suppliers taking unfair advantage of proprietary disclosures.

Finally, environment is sometimes viewed by corporations as something that must be treated differently than other business issues, such as quality improvements or productivity enhancements. This research suggests that great gains can be made when environment is treated as any other major business objective. Achieving business results requires assigning a clear priority to an area, specifying challenging, but achievable goals, and dedicating resources and senior staff who are accountable for performance results and have opportunities to develop and implement new projects. Plants A, B and C all share these characteristics. Plant A, in addition, specifically draws on the technical expertise of suppliers in the area of environment to achieve some truly dramatic results. The ability to move well beyond compliance in a production environment also provides Plant A with operational flexibility as environmental regulations and national (as well as international) priorities continue to evolve.

Relevance to Government Environmental Programs

From a government perspective, these results suggest that the current trends toward more innovative approaches to environmental regulation, including industry sector approaches (as represented, for instance, by the Common Sense Initiative) are useful in encouraging the broader development and application of environmentally-beneficial technologies in manufacturing processes. However, providing the flexibility in regulatory approaches to incorporate benefits from the technology supply chain is also important. The upcoming development of new regulations for automotive assembly plants (in the year 2000) mandated by the 1990 Clean Air Act Amendments provides an opportunity to incorporate the lessons of this research into a new framework for regulation. Rather than continuing to regulate automotive painting by setting limits for each major element of the painting process, developing regulatory goals from a systems perspective would allow more tradeoffs to be made among elements of the process contributing the most significant environmental impacts. Involving the paint suppliers in incorporating innovative opportunities for environmental improvements in setting new regulations is an important part of the negotiation process. While regulations are clearly needed to encourage action by manufacturers (all the plants in this study understood the importance of regulatory pressure--without that pressure, some would not implement the newer technologies), a more flexible regulatory approach would allow plants to approach the painting process from a systems perspective, trading off improvements in underbody coatings or repair relative to the adoption of radical innovations in topcoat materials.

Another important policy issue is allowing companies flexibility in implementing radically new technologies in a production setting. Implementing technological shifts in a manufacturing operation is a difficult and costly process. Radical shifts in materials (to full-body powder coatings and waterborne basecoats, for example) that significantly reduce or eliminate VOC emissions at the source, for instance, should be coupled with the flexibility for the plant to negotiate with regulators on other permit parameters, such as pollution control equipment that may no longer be needed. There should also be a recognition that plants implementing innovative technologies may initially experience increases in emissions as they adjust to the needs of the new technology, and need to be given a timeframe of "experimentation" for that adjustment. Both Plants C and D, for instance, experienced increases in emissions in the first year of adopting waterborne paints. Plant C emission levels were well above permitted compliance limits. However, the local regulatory authorities were informed of the problem and worked with the plant over time to find a solution that would support the new technology, which ultimately lowered VOC emissions dramatically.

Regulations are needed to drive new technology and to keep the attention on the environment. The results of the industry survey and the case studies demonstrate the importance of environmental regulation in driving the development of new, innovative technology and encouraging the adoption of these technologies by automotive companies. Voluntary programs such as the 33/50 program are primarily useful for those companies that overcomply anyway, or can readily target those reductions. Plant C, while having environment as a major corporate and plant focus, did not achieve reductions in all 33/50 chemicals. Levels of xylene remained fairly stable over time, while emissions of other chemicals were reduced. Voluntary programs alone are insufficient to achieve results.

Finally, the solution for one plant may not be the solution for all. The flaw in using a best practices, technology-based approach to setting the MACT standard for the year 2000 is that what may be easy to implement in one plant, due to the baseline technology at that facility, its management approach, or support from suppliers, may not be as readily implemented at another. While Plant A experienced reductions in VOC emissions and solid wastes when implementing waterborne basecoats, Plant B, while reducing VOC emissions with waterborne, experienced a dramatic increase in solid wastes. The attention on air emissions and VOCs (and now HAPS) while important, neglects the overall environmental effects of potential shifts among media. Alternatively, the "best" technology identified today limits the thinking about the possibilities for technological improvements in the future and incentives for continued improvement (if such incentives are not integral to the company practices themselves). A flexible regulatory approach combined with the five year continuous reevaluation of permits[a] may provide a way to encourage continuous innovation and improvement in operating facilities as technology advances. The framework developed in this research demonstrates that technology alone is not the answer to reducing pollution at the source. Environmental problems represent a complex interaction of technology and management, requiring a systems approach and multiple perspectives from various partners to provide innovative solutions that can be sustained over time.

[a] Mandated by Title V of the Clean Air Act Amendments of 1990.

5.4. Directions for Future Work

This research has focused on the role of suppliers in developing and implementing innovative environmental technologies in manufacturing plants for environmental performance improvements. In evaluating the performance of four automotive assembly plants over time, the findings of this work point to the importance of technological change and evolution, and innovative management approaches in formulating long term solutions to environmental problems. Incorporating new materials into product and process design requires that a number of companies work together to ensure successful implementation. This research illuminates a new direction for exploring solutions to environmental problems that provide a foundation for fundamental change in products and processes. In addition to these findings, the results of this work suggest new directions for future research.

First, the case study approach, while facilitating in-depth evaluation of a few plants, would be strengthened by an industry-wide assessment. While it is well documented that the major environmental challenges in automotive assembly stem from the painting process, there is no current assessment of the environmental performance of the U.S. population of automotive assembly plants. These plants should be evaluated relative to the key factors identified in this work (technology, management approach, and supplier role) to understand the transferability of the results of this work to the broader industry. The rate at which automotive companies are adopting new paint technologies and new management approaches (at the plant level) is not well documented and is important in understanding emerging industry trends. For instance, do other plants utilizing contracts with suppliers that include broad plant-level responsibilities experience the same levels of environmental performance improvements observed in this research? Of particular interest is the way in which the transplants (both the Western European and Japanese companies) have chosen to operate under the U.S. regulatory regime.

In addition to broadening the case study research to the total U.S. plant population, a related research effort should be conducted on the differences in the key variables of importance identified here between the U.S.-based automotive assembly plants, those located in Western Europe and Japan, under different regulatory regimes, and those being established now in developing countries. This spectrum of facilities provides a rich source of data for exploring the extent to which companies adapt their environmental and technology strategies to their plant location, as opposed to the strength with which they adhere to corporate environmental policies. The influx of U.S. automotive companies into developing countries is of particular interest, in terms of the environmental technologies and supplier relationships they choose to form. Local suppliers may or may not have the technological competencies in environmental technologies necessary to provide strong leadership roles in product or process design.

Beyond the additional work recommended within the automotive industry, the transferability of these concepts to other industries must be explored. The chemicals industry, for instance, supplies a number of other major manufacturing industries. Does the importance of suppliers and innovative technology apply within the chemicals industry itself, or to other industries for which the primary sources of environmental impact are the material inputs to the manufacturing process? Companies that have given more responsibility to major suppliers at their facilities find that they get better and more timely data on their operations and their environmental performance, and faster identification and resolution of process problems. This research has focused on the first level suppliers to the automotive company. The extent to which this model applies in other industries is expected to depend on the environmental competencies developed in the supplier companies and the influence of the material and product inputs of the suppliers on the overall environmental performance of the manufacturer's production process.

Second, this work raises an important issue about the implementation of corporate environmental policies at the plant level. Most large companies now have proactive, written environmental policies. The extent to which these policies are being implemented at any one plant, however, is unclear. Corporate environmental reports mask the performance of manufacturing plants at the individual plant level. Those plants performing well under compliance levels and implementing innovative technology and management approaches may be motivated to underreport their performance from the industry perspective (based on the approach taken in developing environmental regulations based on the top industry performers). Understanding the factors that support effective transfer of corporate policies to plant levels and how to transfer these priorities in a systematic way among distributed business units would benefit a broad set of industries searching for more effective, less costly environmental strategies. Research on the mechanisms used to transfer corporate directives and priorities to plant levels and what makes for successful implementation is important for taking the environmental commitment made at corporate levels to the plant floor.

Finally, the role of innovative government programs and regulations in encouraging technological innovation should be further explored. How do the current and emerging set of government environmental policies and programs serve to encourage innovation and new approaches to product development and what barriers must still be overcome? A thorough evaluation of the EPA 33/50 program for reducing key chemicals in manufacturing industries should be performed to determine the role of voluntary programs in emerging national policies.[a] The magnitude of the reductions achieved by various industries and different companies within industry segments, and the mechanisms by which those reductions in emissions were achieved would shed additional light on the role of innovative technologies, management approaches and partnerships in achieving improvements in environmental performance. Other programs are still in the early stages of development. An evaluation of the progress to date of other innovative regulatory approaches, including the Common Sense Initiative, should be performed to illuminate the extent to which these programs are likely to encourage innovative environmental technologies that reduce pollution at the source or form closed-loop systems. Government environmental policies must also begin to incorporate the lessons learned from beyond our borders, as the effects from and the solutions to environmental problems become increasingly international in scope.

[a] The program was designed to end in 1995, allowing a research effort to measure progress over time for those companies involved in the program.

5.5. Conclusions

Material substitution in the design and manufacturing of a product is one of the most important mechanisms for reducing the environmental impact of products and processes. Changing materials at the early stages of product design is also one of the most cost-effective methods for achieving product change. Incorporating new materials into technologically complex systems is, however, a major challenge. Major investments in research and development are required to successfully formulate new materials that meet the performance requirements of the old at a cost that users are willing to pay. The burden of these investments are most often borne by suppliers, who, in the case of cleaner materials and technologies are targeting an uncertain market, at least in the U.S. Integrating substitute materials into a complex manufacturing system may require major changes to existing production equipment, operating procedures and supply chains.

While traditional views of supplier involvement suggest that the manufacturer is the primary source of design specifications, changes that involve fundamental shifts in materials or major environmental innovations may be difficult for a manufacturer to identify on their own. This is especially the case when environmental improvements involve new technologies and materials with which the manufacturer does not have much experience. Achieving improved environmental performance in technological systems where inputs and processes cut across organizational boundaries requires that these companies share technical information and expertise, develop mutual goals, and create supportive incentive systems.

This research demonstrates the importance of suppliers in developing and implementing innovative environmental technologies through an in-depth examination of technology innovation in paints and coatings and the application of these technologies at four U.S. automotive assembly plants. Technology is only one important element of successful change. An integrated technology and management perspective is crucial in identifying and successfully implementing improvements in environmental performance. The most significant improvements are achieved when new, innovative technology and management priorities at the plant level are coupled with supplier expertise. This framework of integrating technological advances with innovative management approaches and strong partnerships with key suppliers leads to new thinking on how companies and governmental agencies need to approach the development and implementation of policies for environmental performance improvements.

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[1] Adapted from E. Praschan, "What the Clean Air Act Means to the Auto Industry", Automotive Body Painting, Proceedings of the International Body Engineering Conference, IBEC '94, IBEC, Ltd. Publications, Warren, MI (1994): 78-81.

[2] S. Helper and M. Sako, "Supplier Relations in Japan and the United States: Are They Converging?', Sloan Management Review (Spring 1995): 77-84.

[3] M. Flynn et al., The 21st Century Supply Chain: The Changing Roles, Responsibilities and Relationships in the Automotive Industry, A.T. Kearney, Inc., Chicago, IL, 1996.

[4] M. Sorge, Automotive Industries (January 1996): 71.

[5] M. Flynn, 1996.

[6] M. Sorge, 1996.

[7] K. Buchholz, "Automotive Tech Centers--Where do they fit in?", Automotive Engineering (September 1995): 110-112.

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Appendix A: Industry Technology Survey Instrument

Technological Innovation and Change

What have been the primary incentives leading to technological advances and change in paints and coatings (over the last decade or so)?

When were the various technologies first applied commercially? What were the barriers to implementation in automotive applications?

What are some of the key challenges that must be overcome to get broader use of the newer technologies (ie, powder, radiation cure, in-mold color)? How do the technical performance parameters of these technologies compare? What are critical factors for improving performance?

How has the network of relevant firms (paint manufacturers, basic and intermediate chemical manufacturers, and automakers) worked together in formulating new products? What are the roles of each of these firms? Are equipment manufacturers involved? If so, to what extent?

How has your investment in R&D shifted over the last 10-20 years, relative to prior years or to that of your suppliers? More, less, about the same? New partners or approaches, if any? New focus areas and specialties, if any (ie, environmental specialists)? How has the interaction between the automakers and paint manufacturers changed over time?

Selection and Implementation of New Technologies

How are decisions about implementing new paints and coatings technologies made, particularly since automakers have options to reduce VOC emissions through other mechanisms?

-Does this differ from plant to plant (assembly plant level)?
-What role do paint manufacturers play in those decisions? What about environmental staff?

How and when are decisions about paint and coating products made for new or production models? How and when is the decision on color made? By whom? Again, what role do paint manufacturers play in those decisions?

What are the key criteria and tradeoffs considered in selecting new paint formulations and technologies? What are the most important to you? To your customers? To your suppliers?

Are corporate level, industry or government voluntary programs (such as company environmental policies, the Responsible Care program, or the EPA 33/50 program) impacting product decisions? If so, how? Have they affected your suppliers; your customers; your competitiveness?

Expanded Product Scope and Technical Services from Suppliers

What are the benefits of paint manufacturers running the paint shops at an assembly plant? The challenges? What special incentives are provided, if any, to support these programs?

Appendix B: Environmental Data for Case Study Plants

This appendix provides an overview of the challenges in measuring environmental performance, the use of the Toxic Release Inventory (TRI) data, and the specific data used in this research. Environmental performance is an increasingly important strategic concern for companies today. Public expectations, reinforced by government regulation, include performance on such broadly defined issues as industrial safety, environmental protection, natural resource conservation, protection of public health, and management of technological risks.[1] Society expects companies to comply not only with the existing legacy of environment, safety and health regulation, but to take the lead in developing new models of environmental performance. There is as yet, however, no concensus on what elements of environmental performance should have priority (for instance, biodiversity or toxic waste), or how to measure across multiple dimensions of environmental performance. Most large companies today have environmental policies that encourage minimization of hazardous waste, promote recycling, and support stronger relationships with local communities, but use measures related to compliance with federal, state and local environmental regulations to gauge performance.[2] While there is a need to continue to refine measures of environmental performance, the TRI database provides an important source of data for evaluating the environmental performance of U.S. companies.

The Toxic Release Inventory

The TRI is a publicly available database containing chemical releases and transfers for a number of manufacturing facilities throughout the U.S. The database was established as part of the Emergency Planning and Community Right-to-Know Act (EPCRA) of 1986, also known as Title III of the Superfund Amendments and Reauthorization Act (SARA). Congress passed this legislation to promote planning at the community level for chemical emergencies and to provide better information to communities about the presence and releases of toxic and hazardous chemicals. Section 313 of SARA requires manufacturing facilities that have ten or more employees and use 10,000 pounds of a particular listed chemical annually, or 25,000 pounds of that chemical in manufacturing and processing operations, to report annually to EPA. These facilities provide data on the use of listed chemicals, the maximum amount onsite during the year, the amounts released to air, water and land media, and amounts transferred offsite for treatment and/or disposal. For chemicals sent offsite, facilities must specify the destination of those transfers and the waste treatment or disposal method used by waste handlers. The Pollution Prevention Act of 1990 added reporting requirements for waste management and pollution prevention activities.

While the TRI provides an extensive national data base, it does have some limitations that must be fully considered when using the data to measure environmental performance. Primary among these are limits on reporting, accuracy of the data, and consideration of chemical risk. There are limits both on which facilities are required to report to TRI and on the chemicals that must be included in that reporting. Reporting of data to the TRI is limited to manufacturing companies defined by the Department of Commerce's Standard Industrial Classification (SIC) codes 20-39, in addition to the volume and personnel limitations stated in the paragraph above. Although capturing many large manufacturing firms, this leaves out nonmanufacturing facilities, such as dry cleaners, power plants, and gas stations, which have large releases of some toxic chemicals, and also excludes many small businesses.[3] In addition, federal facilities have been traditionally excluded from reporting requirements.[a] There are also limits on the chemicals that are reported to the TRI (only those specifically listed by EPA). Through the reporting year 1994, that list included 370 chemicals and chemical categories. Yet, there are more than 72,000 chemicals in commerce in the U.S., excluding food, drugs, cosmetics and pesticides. Each year, EPA receives hundreds of proposals for the manufacture of new chemicals.[4] The TRI data, while useful for evaluating releases and transfers of certain chemicals, cannot be viewed as a total inventory of releases, even for those companies reporting.[b] For evaluations that focus on key chemicals of interest,

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[a] On August 3, 1993, President Clinton signed Executive Order 12856, which requires all federal facilities to report annually all information required by the TRI. The first reports under this order were due July 1, 1995, for the calendar year 1994.

[b] The list of required chemicals for reporting was expanded in 1995 by 286 chemicals. These will be included in the 1995 calendar reports, scheduled to be received by EPA July 1, 1996.

however, such as specific listed volatile organic compounds, hazardous air pollutants and heavy metals, the database provides a good source of information on releases, treatment methods and disposal amounts.

The accuracy of the data is another frequently mentioned limitation of TRI. The TRI data is self-reported by facilities and often based on estimations rather than direct measurement of discharges. Companies differ in the methods used for estimating discharges, which must be taken into account in any comparison among facilities. Amounts released or transferred may also be entered in terms of ranges. The EPA Form R, used for submitting TRI information, specifies three range options: 1) from 1 to10 pounds; 2) from 11 to 499 pounds; and 3) from 500 to 999 pounds. Different approaches to the use of estimation and ranges in TRI data can result in large differences across facilities or reporting years. A study by EPA on the accuracy of the data submitted, however, showed most release estimates were within 20 percent of the actual amounts released where facilities conducted periodic monitoring and sampling.[5] Also, TRI data does not adequately account for changes in production volumes from year to year, making it difficult to determine whether changes in emissions are the result of production volume shifts or waste prevention programs. Although a production ratio was required starting with the 1991 reporting year to account for this, each company calculates this number in a different way and it does not always reflect actual production at the facility.[6] Production data from the facility itself or a reliable industry source is necessary if comparisons in emissions are to be made over time. Use of the TRI data must be coupled with an understanding of the processes and materials being used at the facilities of interest and additional primary data from the plant itself to ensure an accurate understanding of the environmental emissions profile.

The third major limitation of the TRI for some analyses relates to assessments of health risk. Chemicals on the list are not differentiated based on their potential impact to public health. A smaller reported release of a more toxic substance may be of greater concern than larger releases of other materials. For instance, hydrochlorofluourocarbons, which damage the ozone layer, and benzene, which is a known carcinogen, receive equal ranking and treatment on TRI listings. The attention to TRI numbers has focused companies on reducing emissions; their chief motivations are compliance and reducing the volume of wastes reported in the TRI.[7] Reducing the volume of TRI emissions, however, may not result in the highest reduction of human health risk.[a] Critics of TRI suggest that it focuses management on short-term, compliance-oriented activities rather than pollution prevention opportunities by continuing to use emissions as the measure of performance. Some companies, however, have stated that until they began to collect the data for the TRI, they had no idea how much material waste their processes generated. Understanding their emissions profile helped to initiate environmental audits and pollution prevention programs, resulting in reductions of waste and production costs.[8]

The limitations of the TRI data can be effectively managed if coupled with first-hand knowledge of the specific facilities being investigated. This research focuses on an analysis of changes over time in emissions of specific chemicals at four facilities. The TRI data analysis is coupled with extensive site visits and contacts to ensure a thorough understanding of the facility and its equipment, materials and processes. This knowledge puts the TRI data in context and identifies any reporting anomalies. Production data for each plant was obtained from an extensive review of industry data, including Automotive News and Automotive Market Data Books. Tables B.1 through B.8 list the emissions data and disposition of transferred materials for each plant, and the production data used as the basis for normalizing the TRI data.

[a] Recent work by researchers at Carnegie-Mellon demonstrates the impact of adding a toxicity weighting factor to analyses of TRI release and transfer data (see A. Horvath et al., "Toxic Emissions Indices for Green Design and Inventory", in Environmental Science and Technology, 29, no. 2 (1995): 86A-90A).

Table B.1. Air Emissions (lbs) of Specific Chemicals from Plant A (from TRI Reports)

CHEMICAL NAME	VOC	HAP	33/50	1989	1990	1991	1992	1993	1994
ACETONE	X			71000	28000	23200	28220	18660	Delisted
BARIUM COMPOUNDS					42				
BENZENE	X	X	X	1430	561	383	906	330	1059
CHROMIUM COMPOUNDS		X	X						62
COPPER COMPOUNDS						15	15	7	
CYCLOHEXANE	X			1770					
DICHLORODIFLUOROMETHANE	X				Added	1800	1900	630	
DICHLOROMETHANE	X		X	40900	6740	9340	3000		
ETHYLBENZENE	X	X		8480					
ETHYLENE GLYCOL	X	X		252	32	43	35	13	2140
FORMALDEHYDE	X	X				9540	13500		8790
FREON 113				48022					
GLYCOL ETHERS		X		170000	25700	31800	20200	19600	52500
HYDROCHLORIC ACID		X					10150		
METHANOL	X	X		96000	35000	39000	36400	11700	4429
METHYL ETHYL KETONE	X	X	X	409000	155000	72000	64000	31700	67420
METHYL ISOBUTYL KETONE	X	X	X	460000	273000	110000	182000	52700	112000
METHYL TERT-BUTYL ETHER	X	X		2420					
N-BUTYL ALCOHOL									
NAPHTHALENE	X	X							
PHOSPHORIC ACID				0	533	270	540	260	
SULFURIC ACID				0	37	22	31		26
TOLUENE	X	X	X	73000	34000	21400	13600	6900	
XYLENE (MIXED ISOMERS)	X	X	X	597000	583000	183000	193000	63500	113000
ZINC COMPOUNDS				0	0	0	0	0	0
TOTAL AIR EMISSIONS (Same as total plant emissions)				**1,979,274**	**1,141,645**	**501,813**	**567,497**	**206,000**	**361,426**

Table B.2. Emissions, Transfers and Disposition of Chemical Wastes (lbs) from Plant A (from TRI Data)

	1989	1990	1991	1992	1993	1994
Total Emissions	1,979,274	1,141,645	502,173	567,497	206,000	361,426
Total Transfers	28,320	623,301	556,375	881,557	251,463	92,853
POTW Transfers	4,510	593,500	221,020	230,652	54,165	3,091
Offsite Transfers	23,810	29,801	335,355	650,905	197,298	89,762
Production	255,633	215,569	175,622	152,649	56,601	242,822
Emissions/Vehicle	7.74	5.30	2.86	3.72	3.64	1.49
Transfers/Vehicle	0.11	2.89	3.17	5.78	4.44	0.38
Offsite Transfers/Disposal Techniques						
Landfill						
Disposal--Landfill	23,810	26,980	18,000	17,852	10,070	30,160
Disposal--Other			4			
Treatment/Incineration						
Treatment--Solidification/Stabilization						1,589
Treatment--Incineration		2,820	248	300	1,134	22,285
Wastewater Treatment (not POTW)						
Treatment--Other			4,103	864	139	1,305
Treatment--Transfer to Waste Broker					34	
Recycle/Recovery						
Recycling--Solvent/Organics Recovery				144,015	48,798	4,075
Recycling--Metals Recovery						
Recycling--Other Reuse or Recovery						6,233
Transfer to Waste Broker--Recycling					35	
Energy Recovery			313,000		56	24,111
Transfer to Waste Broker--Energy Recovery				487,629	136,940	
TOTAL	**23,810**	**29,800**	**335,355**	**588,222**	**197,206**	**89,758**

Table B.3. Air Emissions (lbs) of Specific Chemicals From Plant B (from TRI Reports)

CHEMICAL NAME	VOC	HAP	33/50	1987	1988	1989	1990	1991	1992	1993	1994
1,2,4-TRIMETHYLBENZENE	X						21100	29900	39900	77600	89900
2-METHOXYETHANOL							2450	3980			
ACETONE	X			143000	32250	35250	36360	20400	42000	16700	Delisted
BARIUM COMPOUNDS				0	0	0	590	1200	550	371	
BENZENE	X	X	X	2600	2600	820	55	106	70	120	160
BUTYL ACRYLATE						500	10200				
BUTYL BENZYL PHTHALATE						1250	0				
COPPER					0	0	0	0	40	42	3980
CYCLOHEXANE	X			2600		1240					
DICHLORODIFLUOROMETHANE	X						Added	2700	1700		
DICHLOROMETHANE	X		X		14250	16250	8300				
DIMETHYL PHTHALATE		X					9700				
EPICHLOROHYDRIN	X	X		250							
ETHYLBENZENE	X	X		2600		3520	100000	66500	74300	76600	75500
ETHYLENE GLYCOL		X		500	2	252	23	35	250	361	232
FORMALDEHYDE	X	X					10300	13300	20000	33400	18900
GLYCOL ETHERS		X		68000	56750	17750	52800	57300	58500	49000	129500
HYDROCHLORIC ACID		X			250	500	7	1	27500		311
LEAD		X	X	3	5	5	5	7	7	2	23
METHANOL	X	X		10250	294000	384000	160000	76500	64000	49000	39000
METHYL ETHYL KETONE	X	X	X	213000	99000	54200	16500	29800	29700	30000	39000
METHYL ISOBUTYL KETONE	X	X	X			52750	44000	132000	35600	27900	18900
METHYL TERT-BUTYL ETHER	X	X		5200	58250	1860					
N-BUTYL ALCOHOL	X			190750	708000	598000	347000	321000	266000	243000	233000
NAPHTHALENE	X	X		490000							
NICKEL COMPOUNDS		X	X				11	1	4		
NITRIC ACID					250	250				110	244
PHOSPHORIC ACID					250	250	1200	900	912	644	1890
SULFURIC ACID				500	276	290	43	69	96	60	
TOLUENE	X	X	X	116000	53020	70170	33000	32000	25000	28000	27000
XYLENE (MIXED ISOMERS)	X	X	X	155400	1518000	508000	429000	786000	386000	401000	389000
TOTAL AIR EMISSIONS (same as total plant emissions)				**1,400,653**	**2,837,153**	**1,747,107**	**1,282,644**	**1,573,699**	**1,072,129**	**1,033,910**	**1,066,540**

Table B.4. Emissions, Transfers and Disposition of Chemical Wastes (lbs) from Plant B (from TRI Data)

	1987	1988	1989	1990	1991	1992	1993	1994
Total Emissions	1,401,903	2,837,403	1,747,707	1,282,64 4	1,573,69 9	1,072,129	1,033,910	1,066,540
Total Transfers	72,550	21,147	4,264	85,666	549,884	686,591	378,456	561,362
POTW Transfers	250	0	0	18,265	315,584	98,310	52,761	161,283
Offsite Transfers	72,300	21,147	4,264	67,401	234,300	588,281	325,695	400,079
Production	108,817	192,699	216,104	181,954	226,273	254,651	283,753	291,337
Emissions/Vehicle	12.88	14.72	8.09	7.05	6.95	4.21	3.64	3.66
Transfers/Vehicle	0.67	0.11	0.02	0.47	2.43	2.70	1.33	1.93
Offsite Transfers/Disposal Techniques								
Landfill								
Disposal--Landfill	25,550	1,997	4,014	37,030	135,888	70,654	74,910	28,000
Disposal--Other	1,250				5650	15816		
Treatment/Incineration								
Treatment--Solidification/Stabilization	750							
Treatment--Incineration	13,750	19,150	250	30,371	23,892	2,804	2,806	9,911
Wastewater Treatment (not POTW)								
Treatment--Other						830	4,381	51,175
Treatment--Transfer to Waste Broker	31,000					6,320	300	
Recycle/Recovery								
Recycling--Solvent/Organics Recovery					46,270	418,598	164,978	281,621
Recycling--Metals Recovery							16,000	3,000
Recycling--Other Reuse or Recovery						450		
Transfer to Waste Broker--Recycling								
Energy Recovery					22,600	53,492	3,082	3,106
Transfer to Waste Broker--Energy Recovery						19,258	58,151	23,245
TOTAL	**72,300**	**21,147**	**4,264**	**67,401**	**23,4300**	**588,222**	**324,608**	**400,058**

Table B.5. Air Emissions (lbs) of Specific Chemicals from Plant C (from TRI Reports)

CHEMICAL NAME	VOC	HAP	33/50	1990	1991	1992	1993	1994
1,1,1-TRICHLOROETHANE	X	X	X		24239	12717	4422	
1,2,4-TRIMETHYLBENZENE	X	X			21467			14490
ACETONE	X			2764	210359	99000	51690	Delisted
BENZENE	X	X	X	1741	1021	500	1586	51000
COPPER		X		255	255	250	5	0
CYCLOHEXANE	X						255	15
DICHLORODIFLUOROMETHANE	X			Added			750	
DIETHANOLAMINE		X		255	250			
ETHYLBENZENE	X	X			12787	39889	28428	29100
ETHYLENE GLYCOL		X		5	5	250	255	61
GLYCOL ETHERS		X		57313	275364	240221	297067	401000
LEAD COMPOUNDS		X	X	0	5	0	0	0
MANGANESE		X		2082	8692	2196	5	1
METHANOL		X		255	9869	59070	90251	42700
METHYL ETHYL KETONE	X	X	X	126050	39369	3882	8670	9300
METHYL ISOBUTYL KETONE		X	X	162212	160177	116201	29544	40900
METHYL METHACRYLATE		X						49000
METHYL TERT-BUTYL ETHER		X					250	11
N-BUTYL ALCOHOL					11838	15490	19229	16000
NICKEL COMPOUNDS		X	X		5	5	0	0
NITRIC ACID							5	0
PHOSPHORIC ACID				0	0	750	1271	900
STYRENE	X	X		8806	16090	1704	14667	153000
SULFURIC ACID				0	0	0	0	
TOLUENE	X	X	X	9162	20661	30389	33329	63000
XYLENE (MIXED ISOMERS)	X	X	X	232184	188424	236162	171636	202000
ZINC COMPOUNDS				29441	35522	1000	500	3
TOTAL AIR EMISSIONS (Same as total plant emissions)				**632,525**	**1,036,399**	**859,676**	**753,815**	**1,072,482**

Table B.6. Emissions, Transfers and Disposition of Chemical Wastes (lbs) from Plant C (from TRI Data)

	1990	1991	1992	1993	1994
Total Emissions	632,525	1,036,399	859,676	753,815	1,072,482
Total Transfers	116,794	1,674,294	1,979,741	1,350,059	941,002
POTW Transfers	47,567	63,680	29,984	31,497	9,680
Offsite Transfers	69,227	1,610,614	1,949,757	1,318,562	931,322
Production	4,245	95,821	212,112	282,657	280,002
Emissions/Vehicle	149.00	10.82	4.05	2.67	3.83
Transfers/Vehicle	27.51	17.47	9.33	4.78	3.36
Offsite Transfers/Disposal Techniques					
Landfill					
Disposal--Landfill	4,394	708,628	189,554	104,166	126,131
Disposal--Other					
Treatment/Incineration					
Treatment--Solidification/Stabilization	750	47,771	23,874	29,756	
Treatment--Incineration	63,833	2,010	4,134	1,770	1,333
Wastewater Treatment (not POTW)	250				
Treatment--Other					
Treatment--Transfer to Waste Broker					390
Recycle/Recovery					
Recycling--Solvent/Organics Recovery			1,003,065	790,260	461,903
Recycling--Metals Recovery		49,091			
Recycling--Other Reuse or Recovery				15,941	72
Transfer to Waste Broker--Recycling		1,000	684,000	350,494	336,102
Energy Recovery		802,114	12,871	26,175	2,891
Transfer to Waste Broker--Energy Recovery			32,259		
TOTAL	69,227	1,610,614	1,949,757	1,318,562	928,822

Table B.7. Air Emissions of Specific Chemicals (lbs) from Plant D (from TRI Reports)

CHEMICAL NAME	VOC	HAP	33/50	1987	1988	1989	1990	1991	1992	1993
1,1,1-TRICHLOROETHANE	X	X	X	71000	139250	11200		12250		
1,2,4-TRIMETHYLBENZENE	X								48300	19790
2-ETHOXYETHANOL					13640					
ACETONE	X			13000	199000	11000	430000	200250	195000	175875
ALUMINUM (FUME OR DUST)				1000						
BARIUM COMPOUNDS				500	1350	0	250	0	250	
BENZENE	X	X	X	500	2920	1300	2150	4950	2950	500
BUTYL ACRYLATE				11500						
CHLORINE		X		21000		15000	16000	34000	0	5
CHROMIUM COMPOUNDS		X	X	500						
COBALT COMPOUNDS		X		500						
COPPER COMPOUNDS					1450		2705			
DICHLORODIFLUOROMETHANE	X						Added	750	750	222
DICHLOROMETHANE	X		X					7900		
ETHYLBENZENE	X	X			94000	34500	195000	83800	77400	54608
ETHYLENE GLYCOL	X	X		500	500	750	133000	8000	750	633
GLYCOL ETHERS	X	X		314450	500	30750	34000	33300	22250	12570
HYDROCHLORIC ACID		X		250	91000	250	85250	92000	100000	85154
LEAD		X	X	500	500	0	0	0	5	5
MANGANESE COMPOUNDS		X						250	500	10
METHANOL	X	X		15000	1500	2600	108000	161100	28400	25535
METHYL ETHYL KETONE	X	X	X	259000	201000	41000	77000	73000	62000	41519
METHYL ISOBUTYL KETONE	X	X	X		146000	212000	177000	110250	118000	98254
N-BUTYL ALCOHOL	X			447000	189000	122000	170000	38000	67400	46913
NITRIC ACID				500	500	4700	10000			
PHOSPHORIC ACID				500	500	250	5	1000	250	250
SULFURIC ACID				250	500	250	2505	2700	3000	2689
TOLUENE	X	X	X	262000	48000	430000	97000	48800	44000	37304
XYLENE (MIXED ISOMERS)	X	X	X	995000	625000	705000	770000	257000	337000	270003
ZINC COMPOUNDS				1000	1780	750	5	0	0	5
TOTAL RELEASES TO AIR (Same as total plant emissions)				**2,415,450**	**1,757,890**	**1,623,300**	**2,309,870**	**1,169,300**	**1,108,205**	**871,844**

Table B.8. Emissions, Transfers and Disposition of Chemical Wastes (lbs) from Plant D (from TRI Data)

	1987	1988	1989	1990	1991	1992	1993
Total Emissions	2,415,700	1,758,390	1,623,300	2,309,870	1,202,670	1,108,205	871,844
Total Transfers	176,900	631,190	99,200	212,465	692,660	374,920	298,500
POTW Transfers	88,450	10,580	61,500	191,040	18,170	94,345	78,920
Offsite Transfers	640,500	620,610	37,700	21,425	674,490	280,575	219,580
Production	176,604	155,806	189,426	178,358	174,283	157,335	161,669
Emissions/Vehicle	13.68	11.29	8.57	12.95	6.90	7.04	5.39
Transfers/Vehicle	1.00	4.05	0.52	1.19	3.97	2.38	1.85
Offsite Transfers/Disposal Techniques							
Landfill							
Disposal--Landfill	125,300	83,600	37,700	19,225	33,780	20,965	7,194
Disposal--Other							
Treatment/Incineration							
Treatment--Solidification/Stabilization							
Treatment--Incineration				2,200	255	3,505	25,445
Wastewater Treatment (not POTW)							
Treatment--Other		173,950					
Treatment--Transfer to Waste Broker							
Recycle/Recovery							
Recycling--Solvent/Organics Recovery	515,200	363,060			156,550	71,900	72,540
Recycling--Metals Recovery							
Recycling--Other Reuse or Recovery					14,000		
Transfer to Waste Broker--Recycling							
Energy Recovery					469,900	184,700	114,401
Transfer to Waste Broker--Energy Recovery							
TOTAL	**640,500**	**620,610**	**37,700**	**21,425**	**674,485**	**281,070**	**219,580**

[1] P. Shrivastava, "The Greening of Business", in Business and the Environment: Implications of the New Environmentalism, D. Smith, ed., St. Martin's Press, New York, N.Y, 1993, 27-39.

[2] T. Lent and R. Wells, "Corporate Environmental Management Survey Shows Shift from Compliance to Strategy" in Environmental TQM, Second Edition, J.Willig, ed., Executive Enterprises Publications Co., Inc., New York, NY, 1994, 7-32.

[3] J. B. Courteau and N. Lilienthal, Toward a More Informed Public: Recommendations for Improving the Toxics Release Inventory, INFORM, Inc., New York, NY, 1991.

[4] C. L. Bastion, ed., Toxics Watch 1995, INFORM, Inc., New York, NY, 1995.

[5] U.S. E.P.A., 1994 Toxics Release Inventory: Public Data Release, Office of Pollution Prevention and Toxics, EPA 745-R-96-002, Washington, D.C., June 1996.

[6] Ibid.

[7] K. Heller, "Clean Air Act, TRI Drive Emission Reduction", Chemical Week, June 22, 1994, 31-33.

[8] Courteau and Lilienthal, 1991.