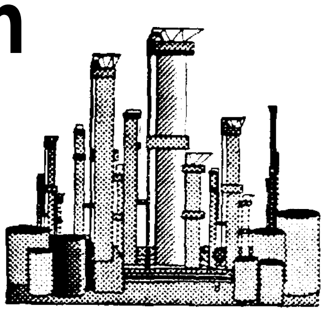
Competitive Implications of Environmental Regulation



A Study of Six Industries

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with the

U.S. Environmental Protection Agency

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EXECUTIVE SUMMARY

Competitive Implications of Environmental Regulation

The following industry studies were conducted in 1993 and 1994 to examine the role that environmental regulations play in determining competitive advantage. The six industries -- paint and coatings, pulp and paper, computers and electronic components, refrigerators, batteries, and printing inks -- have three common characteristics. They are global industries, they face significant environmental challenges, and the U.S. is a leading producer. In aggregate, these industries comprise world sales of $160 billion per year.

This project was a collaboration between the Management Institute for Environment and Business, Hochschule St. Gallen, and three offices of the U.S. Environmental Protection Agency -- the Office of Policy Planning and Evaluation, the Office of Air and Radiation, and the Office of Cooperative Environmental Management.

Main Conclusion

Environmental pressures can create opportunities for companies to gain competitive advantage in domestic and international markets.

One of the great strengths of the private sector is its ability to develop innovative solutions to both new and old problems. The challenge for environmental policy-makers is to engage the creativity of the private sector in protecting the environment. Hence, environmental policy which stimulates and rewards innovation will result in the best solutions for the environment and for the companies that develop them.

In all of the industries in this study, environmental investments created some change in the competitive structure of the industry. Often, the greatest competition occurred among the suppliers to regulated industry, as these companies generated better and better solutions to the environmental challenges of their customers. Each of the six case studies yields examples of companies gaining advantage in process efficiency and product quality through innovations spurred by environmental pressures.

These innovations include: material substitutions, change or elimination of process steps, and changes in product formulations.

They can result in: cost reductions, yield improvements, market share increases, and export expansion.

Environmental pressures in these industries emanate predominantly from regulation, but also result from consumers and professional advocacy campaigns. These pressures are focused on the release of certain substances in the production process or on the use of a wide variety of product categories. They induce companies to change in one of two general directions. Those companies that see opportunity in the environmental pressure will innovate by developing an alternative means of making the product, using different materials or adapting the production process. Those companies that do not see opportunity in the environmental pressure, for instance in strict command and control regulatory situations, will adopt a control technology to limit emissions at the end of a pipe, smokestack or waste bin. It is the subject of this study to determine why some environmental pressures stimulate innovation, and others stimulate dissemination of existing technology.

The importance of this question cannot be overemphasized. In the cases where innovation occurs, environmental pressures are catalysts of productivity, of creativity, and of positive social and economic progress. In the cases where companies do not innovate, environmental pressures are only a cost. Although these costs may be justifiable, in most cases there are ways of getting the same or better environmental result at much less cost, or even at a profit. For example:

Pulp bleaching: Due to concerns over the release of dioxin into the environment, the pulp and paper industry has sought to reduce chlorine use in the pulping process. Two Scandinavian companies, Sunds and Kamyr, dominate the market for chlorine-free pulp bleaching technology, a technology which is more and more widely adopted because of regulation and public pressure. Sales of bleaching technology are approximately one billion dollars per year.

Automotive paint - In the automotive industry, companies have been required to reduce the emissions of volatile organic compounds when painting vehicles. A great deal of innovation has occurred in the industries which supply coatings to the auto manufacturers, mostly centered on new paint formulations which contain fewer VOCs: water-based coatings, powder coatings, high solids coatings, etc. In determining how to meet the new standards, manufacturers evaluate the relative costs of new coatings -- in price as well as possible performance degradation -- against the costs of the control technology, a ventilation hood which captures VOCs for incineration. In the race to develop coatings which meet environmental standards without compromising performance at the least possible cost, two European companies have been clear winners. BASF from Germany and ICI from the U.K. have both marketed water-borne automotive coatings to the U.S. auto, industry. In the process, they have gained market share at the expense of U. S coatings manufacturers. The economic impact is significant, as the automotive coatings market had 1990 annual sales of $1.2 billion in the U.S. alone.

Solvents for cleaning electronic components - The Montreal Protocol has required countries to phase out the use of chlorofluorocarbons (CFCs). In the $300 million market for CFC-based solvents, substitutes afforded as high as 80% cost reductions and increases in product quality. The reduction of chlorinated solvents from cleaning operations reduces raw material costs of the solvents, and often improves productivity from the elimination of the cleaning process steps. These benefits were widely dispersed among large users of solvents.

Refrigerators - In the German refrigerator market, dkk Scharfenstein introduced a CFC-free butane/propane refrigerator well ahead of the market. The so-called ‘Greenfreeze’ commanded a 25% price premium and in the first year dkk could not meet demand for the product. All other German manufacturers subsequently introduced similar products, as have Whirlpool and General Electric.

Printing Inks - FFC International of Lancaster, Pennsylvania developed a lithographic printing solution with zero VOC content to replace isopropyl alcohol. Although the new solution cost 5 - 10% more than the old method, it afforded cost savings of up to 50% overall, because so much less of the product was required in the process.

Dry Cell Batteries - Varta, the leading German battery maker, gained first mover advantage by developing a mercury-free ‘green’ battery in the U.K., anticipating moves by the European Union to regulate the level of mercury and other noxious materials in dry cell batteries. Other competitors rapidly jumped onto the ‘green’ bandwagon.

Each of the six case studies also yields examples of companies, and entire industries, which have been handicapped by environmental regulation. Many regulations require companies to make large fixed investments in treatment facilities. Within a country, smaller companies suffer from such requirements, because they have less sales volume to cover the costs. Hence, their environmental expenditures will be higher as a percentage of sales than their large competitors. The most obvious example of this effect is in the printed wiring board (PWB) industry, where companies were required to build wastewater treatment systems. This requirement increased environmental capital spending in small companies to 9.6% of total capital, whereas in large companies only 5.9% of capital was devoted to the environment. The ultimate effect over the decade of the 1980s was a consolidation in the industry, from 2,000 to 900 competitors.

At a national level, the requirement for an industry to make large fixed investments can place one country’s industry at a disadvantage to another. This happened in the PWB example, as U.S. firms’ share of the world market fell from about 40% to 29 % in the same period during which the consolidation occurred. In the U.S. pulp and paper industry, firms were required to build large secondary treatment facilities in the 1970s. This provided a disincentive to invest in the recycling of process water. The major obstacle to recycling was the use of chlorine during bleaching: the chlorine in the effluent would corrode the pulping equipment if re-used. Scandinavian firms did not have the secondary treatment requirement, and made investments in non-chlorine bleaching. Hence, when the removal of chlorine was made a priority because of its role in the formation of dioxin, Scandinavian firms were the best positioned to capture the chlorine-free bleaching market.

Whether the business outcomes of environmental regulation are positive or negative can be influenced by the structure of the regulation. It is critical to understand the influencing factors which determine the outcomes. The purpose of this study is to illuminate the circumstances under which environmental regulation affords the most opportunities for gaining competitive advantage without sacrificing environmental quality. The matrix below maps types of environmental investments against the resultant opportunities for innovation.

Competitiveness Evaluation

Environmental Investment	*Opportunity for Innovation*
Control Technology	Low -- reduce relative costs
Material Substitution Change/Eliminate Steps Product Re-formulation	High -- reduce relative or absolute costs, improve quality or yield, expand market

Determinants of Competitive Impact of Regulation

The six industry studies identify four determinants of the potential for regulation to stimulate competitive advantage. When regulations are developed with these determinants in mind, they will generate the best possible economic outcomes.

1) Regulatory Structure

When companies are free to choose their method of compliance with environmental standards, they arrive at the best way of reducing emissions in their particular circumstances. Companies that innovate may achieve standards more cost-effectively than competitors, and may even exceed the standards. When a company develops a clearly superior method of compliance, it can recoup its investment by selling technology to competitors.

2) Purpose of Controlled Substance

When regulations focus on substances which have a purpose in production (such as solvents for cleaning) or are present in the final product (such as solvents in paint or CFC refrigerants). manufacturers and suppliers have a direct incentive to replace the substance. The environmental problem which results from the use of a given substance can be addressed by achieving the same production outcome through other means. This encourages competition from substitute materials suppliers and producers of equipment for alternative processes.

This scenario contrasts with situations where by-products must be isolated and disposed or when leakage must be addressed. When the regulated substance is a by-product, the incentive for change is less immediate. This situation results more often in the installation of a control technology, which is usually more expensive than innovation.

3) Industry Structure

An industry's ability to respond innovatively to regulation is partly determined by the number and size of companies in the industry, and by its rate of technological change. Generally, large companies in industries with a high rate of change have the most resources for innovation. Large computer and chip manufacturers, as well as coatings suppliers to the automotive industry, have responded innovatively to environmental regulation with process changes and new products.

Conversely, smaller companies have fewer resources to devote research investments toward environmental improvement, as was the case in the U.S. PWB industry. A similar challenge is currently confronting the architectural coatings industry.

Often, it is the supplying industries that develop new products to adapt to a changing market. Supplier firms recognize that the imposition of regulations creates a new market opportunity to assist their customers in reducing their costs of compliance. When innovation comes from suppliers, it is the nature of the supplier industry that must be considered if regulations are to be designed that spur innovation.

4) Investment Life Cycle

Most companies resist turning over productive assets before they have completed their useful life, which is determined by the product life cycle, or the depreciation schedule for production machinery. When capital assets are fully depreciated, firms then can make substantive changes. Hence, timetables for compliance should reflect the financial feasibility of making substantive change. When the timetable is restrictive, firms have little choice but to install an end-of-pipe treatment, in order to avoid write-offs of undepreciated equipment.

The effects of these four determinants are summarized in the chart below

The Potential for Competitive Advantage

Regulation that fosters innovation can:	Create Supplier Opportunities Lower Absolute Costs Lower Relative Costs
Rigid regulation can:	Increase Costs Inefficiently Increase Costs Disproportionately

Research Methodology

In each case, industry characteristics and environmental regulations are discussed for each of the major producing countries. While available economic data are used, the studies extend beyond traditional analyses of environmental spending and measures of trade. Research for the studies has included extensive discussions with industry leaders, trade groups, and environmental regulators. Additionally, suppliers and customers of the industry have been interviewed to determine how environmental regulations have affected their markets and raw materials. By combining broad economic statistics with information gathered in these interviews, larger trends are understood through the individual experiences of affected parties.

Each study begins with an examination of the industry using an approach developed by Michael Porter in his work, Competitive Strategy. This entails looking at the influence of the industry's "five forces:' buyers, suppliers, substitutes, competitors, and potential entrants.

After the industry structure has been developed, the effects of the industry on the environment are discussed. A range of potential environmental factors including resource use, production releases, product use, and product disposal are explored. The areas that were most important to strategic decisions within the industry in the late 1980s and early 1990s are highlighted in these sections.

International factors are then presented in the "Competition" section of the studies. Here, those nations which lead production, export, or foreign direct investment in the industry are examined according to a second framework developed by Porter. Using the "diamond," which was presented in The Competitive Advantage of Nations, these sections consider how factor endowments, demanding buyers, domestic related and supporting industries, and characteristics of firm strategy, structure, and rivalry have influenced the competitiveness of these nations in these industries.

After discussing the industry structure and characteristics of competition, the cases explore how responses to environmental pressures have affected competitiveness. While traditional measures of cost of compliance for regulated firms is covered, this section focuses on innovations adopted by the industry, its suppliers, and its customers. It covers where these innovations have led to market opportunities for the innovating firms and examines where these innovations have provided benefits to the industry's customers. The case studies close with discussions of the lessons that can be drawn from the experiences of the industry being studied.

COMPETITIVE IMPLICATIONS OF ENVIRONMENTAL REGULATION OF CHLORINATED ORGANIC RELEASES IN

THE PULP AND PAPER INDUSTRY

This case study was prepared by Ben Bonifant, Management Institute for Environment and Business with the assistance of Ian Ratcliffe. The research was conducted in collaboration with the U.S. Environmental Protection Agency and Hochschule St. Gallen Copyright 1994 by MEB.

THE PULP AND PAPER INDUSTRY
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EXECUTIVE SUMMARY

Paper use is an integral part of any society. In fact, the per capita consumption of paper has been found to be highly correlated with a nation's level of industrial development. This is not surprising as the primary uses of paper are in communications and in packaging. As economies develop, there is increased need for transfer of information as well as a growing market for materials to package the products being manufactured.

Paper production can have significant deleterious effects on the environment. Manufacturers must consider resource management in acquiring wood raw materials; they must address the potentially high levels of waste resulting from pulping operations; and they must respond to or participate in the substitution for virgin pulp products with those manufactured using recycled materials. The following information deals primarily with the competitive implications of regulations, litigation, and market forces which have encouraged or required paper producers to dramatically reduce the amount of wastes which result from their manufacturing operations.

Early Regulation - Addressing Conventional Pollutants

In the 1970s regulations - initially promulgated in the U.S. - required that paper manufacturers begin to take steps to reduce "conventional pollutants" released in their effluent. End-of-pipe treatment was typically employed to limit the releases of suspended solids and oxygen demanding organic materials, or to moderate fluctuations in pH. Canada, Japan, Sweden, Finland, and other major producers followed the U.S. lead with similar regulations tailored to the characteristics of the industry in those countries.

U.S. regulations required manufacturers to adopt "best available" or "best practicable" technologies. For bleached chemical pulps, this invariably led to the installation of secondary wastewater treatment facilities. Meanwhile, work was on-going to develop innovative means of production which would forestall the need for such equipment. Manufacturers found that installation of these production methods could result in environmental benefits while providing savings in energy and chemical costs. Although the economics in the absence of environmental requirements did not typically justify retrofitting of existing facilities, operating costs were lowered by adopting innovative pulping and bleaching technologies (while secondary treatment systems led to increased operating costs).

U.S. costs of environmental compliance in response to early regulations of wastewater releases (as measured as a share of capital costs) were higher than those borne by other primary suppliers in the early 1970s. However, as regulations were implemented in other countries, the cost of compliance for their manufacturers grew and in many years exceeded those of U.S. producers.

Similair to U.S. firms, many Canadian operations were required to install secondary treatment to control releases. Those that discharged into large receiving waters, however, were not as rigorously regulated because, it was felt, the assimilative ability of the large water bodies was large enough to accept the pulp and paper mill releases without harming aquatic life. In Sweden, environmental capital spending was lower in the 1970s but began to rise in the 1980s. Swedish spending was much more highly weighted toward internal operations (as opposed to secondary treatment) than was the case in the U.S. or Canada. Swedish firms installed innovative pulping and bleaching equipment that provided environmental improvement while lowering operating costs. The reductions in conventional pollutant releases were not as great as would have been achieved through secondary treatment, but because of more lenient requirements, the internal changes were adequate to meet Swedish regulations of the early 1980s. The cost savings were not, in the absence of environmental requirements, acceptable for lines which were not otherwise in need of upgrading. However, by taking in-process pollution prevention steps over a period of many years, Swedish manufacturers were well positioned for later environmental challenges.

Concerns About Dioxin Emerge

In the 1980s, dioxin was detected in rivers downstream from U.S. pulp mills. Further study revealed that small amounts of the chemical were produced in processes where chlorine was used to bleach (by removing lignin from) chemically manufactured wood pulps. Because of significant public and regulatory concern over dioxin, paper manufacturers were faced with a new and very high profile environmental problem. In Scandinavia, concerns were less specifically, focused on dioxin. There, similar concerns about bleaching in pulp mills were raised both because of the chlorinated organic releases and because of comparably higher releases of conventional pollutants

Pressures to reduce the toxicity of mill emissions came from three sources with varying amounts of influence depending on the country where the paper was manufactured. First, regulations were developed in most pulp producing countries that required changing methods of production. A second factor, one that encouraged new bleaching methods, was a growing market demand spurred by grassroots environmental organizations for paper produced in manners that reduced emissions. These markets were largest in Northern Europe. Therefore, they significantly influenced the decisions of paper manufacturers in Scandinavia who exported large shares of their production to Germany, the Netherlands, and the U.K. Finally, in the U.S., litigation was influencing the production decisions of pulp producers. Manufacturers were facing billion dollar law suits from class action groups demanding restitution and punitive damages from companies which had released dioxin over many years.

Competitive Implications

Compliance Costs

Developing new means of bleaching had required coordinated efforts among paper manufacturers, equipment suppliers, and chemical suppliers. Several innovative approaches were developed that allowed manufacturers to adopt those technologies that provided the lowest cost means of reducing emissions and were best matched to their operations. In-process technologies which were under development to reduce conventional pollutants typically had a positive effect on the emissions of chlorinated organics (including dioxin). The correlation resulted from the role of chlorine in both problems. Using chlorine in bleaching sequences increased conventional pollutant releases because corrosive chlorine compounds in the wastewater could not be returned to the recovery boiler. Instead, those effluent streams that occurred after a chlorine (or chlorine dioxide) stage had to be released. Therefore, in-process methods of pollution prevention had aimed to reduce chlorine use by replacement with other oxidizing chemicals. Without the chlorine, the streams could be cycled to the recovery boiler. The reduction in chlorine use also resulted in lowered dioxin formation. Prior to the late 198Os, if conventional pollutants were controlled through secondary treatment, chlorine typically continued to be used in bleaching sequences and dioxin was still formed. This dioxin was eventually introduced into the environment in wastewater releases, in treatment sludges, or in the paper products themselves.

Installation of some earlier forms of control affected the attractiveness of installing technologies that emerged later. For example, once mills had installed secondary treatment to address conventional pollutants, the compliance benefits of installing oxygen or ozone bleaching equipment were considered primarily to be the reduction of chlorinated organics. U.S. manufacturers maintained that the most dangerous materials could be eliminated using other less costly technologies such as chlorine dioxide bleaching. The capital costs of installing equipment needed for chlorine dioxide substitution was estimated at approximately $15 million for a typical mill. If a facility needed to reduce both conventional releases and dioxin and there was no existing secondary treatment, a more attractive alternative was to reduce the total amount of effluent by adopting other in-process modifications. Capital costs were approximately $30 million for oxygen delignification and $35 million for ozone bleaching (although facility conditions could dramatically affect the cost and practicality of these alternatives).[1] As such either one of these investments was roughly similar to the combined cost of installing chlorine dioxide bleaching equipment and the $20 to $25 million estimated for installation of secondary treatment. However, when operating costs for chemicals and fuel were considered, investments in alternative bleaching appeared much more attractive. Secondary treatment increased operating costs by $2 to $2.50 per ton, and chlorine dioxide substitution was estimated to increase costs by $9 per ton. On the other hand, both oxygen delignification and ozone bleaching were estimated to decrease operating costs by approximately $10 per ton and using both systems in a single line was anticipated by some analysts to reduce costs by $ 17 per ton.

The method chosen for addressing the releases of conventional pollutants and chlorinated organics was, of course, also affected by whether the level of control achieved by each technology met the requirements of regulations. Secondary treatment reduced the oxygen demands of the effluent by 90% .[2] Oxygen delignification, on the other hand, only reduced effluent oxygen demand by 50%. If regulations required the higher level of control, oxygen delignification alone would not be an acceptable technology.

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1. The cost of the equipment itself is well established. However, there was considerable disagreement concerning the cost of upgrading existing equipment to deal with the increase-d loads of material on the recovery system. See pages 60-63 for a discussion of these issues.

2. Release of effluent with high oxygen demand will result in a decrease of the oxygen content in the receiving water. When oxygen level is reduced, the receiving waters are less able to support aquatic life.

Scandinavian producers had been less strictly regulated concerning conventional pollutants in the 1970s and 1980s. As a result, the levels of control offered by the early innovations in bleaching were adequate to meet regulatory requirements. Many of these facilities installed oxygen delignification and extended cooking both to reduce operating costs and to improve their environmental performance. In the late 1980s, Swedish and Finnish regulators took a much more aggressive approach to regulating releases of chlorinated organic substances in pulp mill effluent. In response, all mills had installed oxygen delignification by 1993, and all bleaching was done without elemental chlorine. For those mills that had not installed secondary treatment (about half of those in Sweden, for example), both conventional and chlorinated organic pollutants were substantially reduced with a single major capital outlay. By contrast, all U.S. manufacturers were required to install secondary treatment when conventional pollutants were regulated in the 1970s. When concerns about chlorinated organics (particularly dioxin) emerged in the late 1980s, U.S. mills were faced with a second major expenditure. The industry took a number of steps including the installation of substantial capacity for chlorine dioxide substitution. While this was the most economical approach given the previous installation of secondary treatment, taking on each problem individually proved less cost effective than had these firms been able to address both issues concurrently.

Market Opportunity

Growing public awareness of the environmental problems associated with pulp mill effluents drove the emergence of a niche market in the early 1990s. A small number of Scandinavian firms were capturing higher prices by providing totally chlorine free (TCF) papers to a market segment of customers basing their purchase decision on the environmental effects of the production process. A large part of this market had resulted from campaigns by grassroots environmental groups to encourage subscribers to demand that magazines be produced on totally chlorine free papers. No similar market had developed in North America or Japan and evidence of lost export market share was not evident by 1992. Prior to 1994, U.S. pulp suppliers had chosen not to pursue the TCF market. These producers felt that with no local demand and higher costs for production, efforts in the TCF market would not be rewarded. U.S. firms continued to track this market niche, however, as projections of growing demand for TCF in northern Europe suggested that an increasing share of the European market would become unavailable to suppliers of chlorine bleached products.

Suppliers

Scandinavian equipment suppliers benefited from increased attention to environmental issues. These firms were first to commercialize several alternative pulping and bleaching methods. Extended cooking, oxygen delignification, and ozone bleaching systems found early in Sweden and Finland and, therefore, the manufacturers supplying those markets dedicated resources to developing those technologies. In North America, manufacturers could not reach required levels in controlling conventional pollutants by these methods, and therefore, their suppliers did not focus on alternative bleaching methods, Once concerns emerged surrounding dioxin in pulp bleaching waste streams, North American manufacturers were pressured to adopt in-process methods of reducing chlorine use. Swedish and Finnish suppliers quickly responded to this market and achieved substantially improved market positions in pulp equipment sales. One U.S. firm with unique requirements to reduce conventional pollutants also entered this market attempting to commercialize its process expertise in non-chlorine bleaching processes.

Conclusions

Several lessons emerge from the competitive experiences of pulp manufacturers and their suppliers:

1. *Environmental concerns change markets at several point in the value chain.*

In some cases, this may simply be changes in the size of the markets for traditional products. This was the case in the shift of consumption of pulp manufacturers from chlorine to chlorine dioxide and non-chlorine oxidizing chemicals. In other instances, the shift in markets may result from innovations which incorporate solutions to environmental concerns in existing products. Bleaching processes that used non-chlorine chemicals displaced other types of processes. In many cases, they reduced the requirements for secondary treatment.

2. *When "best available technology" standards require the adoption of secondary treatment, innovative in-process technologies will not be adopted. Lacking markets, technologies which might provide methods of totally eliminating waste streams through further development may remain dormant.*

Innovative bleaching technologies adopted in Scandinavia did not reduce conventional pollutants to the level achievable by secondary treatments. However, later developments enhancing the initial technologies further substantially reduced the volume of the entire waste stream. Without the adoption of the first innovations, the additional environmental improvements might not have been possible.

3. There will be no competitive "fist mover" advantage achieved by regulated firms and their traditional suppliers in a nation which leads in regulation when the regulations are likely to be met by end-of-pipe treatments.

Although the U.S. led the identification and regulation of most environmental issues associated with paper manufacturing, Scandinavian firms captured the lion's share of markets resulting from innovative, environmentally responsive methods of manufacturing.

4. The costs of responding to environmental issues may be reduced when efforts are made to recapture the value of the waste.

In many of the non-chlorine methods of bleaching, operating costs were reduced for chemical and energy purchases. In many cases, this return was not high enough to justify retrofitting existing facilities, but for new facilities and those undergoing extensive renovation, these methods were the most economical means of manufacturing.

5. In-process pollution prevention programs provide insurance against unidentified environmental problems which may not be addressed by end-of-pipe controls.

In the early 1990s,U.S. manufacturers were likely to need to adopt in-process methods of pollution control to respond to dioxin issues after having already shouldered significant costs for the installation of secondary treatments for the control of conventional pollutants.

INDUSTRY STRUCTURE

Paper manufacturers faced a variety of environmental issues. Resource protection, waste disposal, and production emissions were the most significant of these. Pressures were mounting from both environmental activists and government regulators. The following paper discusses one area, the effort to reduce emissions from the pulping process, and explores how technological innovations in this area affected paper manufacturers, their suppliers and their customers.

Product

Product Description

In 1990, thousands of products were made from paper. Its versatility, availability, and disposability made it essential to all industrialized societies and a measure of their sophistication. There were a large number of different paper grades ranging from weak but highly absorbent tissues, to very strong paperboards used for packaging. Many products were not obviously paper but their common bond was that they had their origin in a pulp mill. The most common use of paper was for communication or packaging and paper production had grown to meet the constantly increasing demand for these items (world production of paper and paperboard is given in table 1 and table 2 breaks down production into subcategories for several countries).

All paper fiber came from wood pulp, wastepaper, or some other cellulose containing fiber such as cotton, flax, or bagasse. The vast majority (99%) of paper was made from the first two sources of pulp.

Wood pulp was made mechanically or by using chemicals. (See the section on production processes below for details.) This difference in production process affected its physical properties and therefore its applications. The fiber pulp was either converted directly into paper at an integrated mill or sold on the open market as a product in its own right (market pulp).[3] The majority of wood pulp was converted into paper products at its place of manufacture with only 12 % of production being shipped as market pulp.

3. If the pulp plant and paper making facility are located at a single site the mill is referred to as "integrated."

Paper products were selected according to several properties with buyers matching the characteristics which resulted from differing raw materials and processes to the specific needs of their applications. The key property of all paper was the strength of its cellulose fibers and their ability to form a sheet of considerable strength by hydrogen bonding. It was this strength which made paper such a useful packaging and writing material.

Printing and writing papers came in many grades. Newsprint was the most basic of these products, having little or no value added post-production treatment and was the cheapest printing material. More expensive printing papers had a higher brightness due to their higher level of bleaching and were usually sized by a starch solution to smooth the surface, increase water resistance and resist the pressures of printing.[4] They could either be coated (magazine printing) or uncoated (as used by printers to produce books or by office workers for communications). Fine or writing paper was predominantly uncoated free-sheet which had been sized to give a smooth writing surface and resist ink penetration.

Tissue papers were characterized by softness and the ability to absorb liquids. Softwood sulfite pulp (a chemical process described below) had been the preferred grade raw material because of its softer more flexible fibers prior to the 1950s but recycled office waste had become more popular because of the decreasing availability of sulphite pulp in the U.S. and because the recycling process shortened fiber length increasing absorbency.

Packaging or converting paper could be broken down into four groups according to their final use:

1. Corrugated and solid fiber boxes
2. Paper bags and sacks
3. Folding and setup boxes
4. Miscellaneous

The brown cardboard box was the cheapest, strongest. protective shipping container available. It was usually made from a multilayer board with liner board outer faces and a corrugated (fluted) inner layer.

4. Kline, James E. Paper and Paperboard Manufacturing and Converting Fundamentals 2nd Edition, pp. 35, 1991, San Francisco; Miller Freeman Publications Inc.

The outer layers were generally unbleached and usually used 80% virgin fiber to maintain strength properties.[5] The estimated U.S. consumption of these boxes was 125 per person annually.[6] Paper grocery bags used a high virgin fiber content to maintain strength while being thin enough to make them cheap and light. The majority of these bags were unbleached. Folding boxes and cartons were used to package food such as cereals, beverages, retail products and cosmetics. They were generally bleached and coated for milk, ice cream, and frozen foods and contained approximately 80% virgin pulp. Recycled, coated watsepaper was used for folding cartons such as cereal packets. Miscellaneous packaging included composite fiber cans for frozen juice, shipping bulk chemicals, detergents, dried foods and other products.

Substitutes

Two methods of substitution for paper products were growing in the early 1990s. Manufacturers were finding increasing methods for utilizing recycled fibers and some environmentally sensitive consumers were replacing disposable paper products with reusable materials. The substitution of recycled fiber for virgin fiber was increasing all over the globe for both environmental and financial reasons. In 1991, 30% of the fiber supply was secondary fiber, up from 23% in 1978. Legislation in several nations was requiring that some paper products (particularly newsprint and corrugated packaging) contain a specified minimum recycled content. The recycled fiber was made up of pre- and post- consumer waste and the amounts of each were often limited by the strength and brightness requirements of the product.[7] Solid waste concerns had also forced governments to adopt laws which promoted recycling and programs that lowered the amount of material used in packaging.

Environmental groups vigorously promoted less paper usage of any sort by telling consumers to use

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5. Union Camp Corp., Richard Venditti - Manager Recycled Fibers, Interview, August, 3, 1993, Franklin, Virginia,

6. Sitwell, E Joseph, R. Claire Canty, Peter W. Kopf, and Anthony M. Montrone, 1991 Packaging for the Environment: A Partnership For Progress, pp. 51, New York; American Management Association.

7. Pre-consumer waste refers to materials which have been collected prior to their distribution to consumers. Items such as tailings from printing processes are pre-consumer wastes. Post-consumer waste is collected following use by consumers. At times the definition becomes blurred. For example, magazines which are printed but not distributed are classified as pre-consumer.

canvas shopping bags, washable bathroom hand towels and diapers, reuse envelopes and frequent restaurants which provided reusable plates and utensils.

In the 1980s, plastic manufacturers had found areas of the paper market vulnerable to entry with their products. Notably, a substantial share of the paper sack market had been captured. However, in 1990, paper still accounted for 65% of the U.S. market, and this ratio appeared to have stabilized. Similarly, plastic bags had clearly replaced paper as the material of choice for household food storage. Finally, although plastic was more durable than corrugated containers it was not price competitive in the same service and no viable cost effective alternatives to construction board had been developed.[8]

The widespread assumption made in the 1970's that the arrival of electronics would lead to the "paperless office" appears to have been erroneous. The use of paper by U.S. offices rose from 850 billion to 1.4 trillion sheets between 1981 and 1984, and in Japan computerization had increased the volume of office waste.[9]

Production Processes

Wood was the primary raw material for paper production. The main components of wood were cellulose (50%), hemicellulose (15-18), lignin (30%), and extractives (2-5%). These quantities varied by a few percent dependent upon the type of wood. Hardwoods such as maple, birch and eucalyptus contained more cellulose fibers but of shorter length (0.05 inch), while softwoods, such as pine, spruce and fir contained more lignin but longer fibers (up to 0.2 inch long). Wood pulp could be produced by mechanical or chemical processes.

Mechanical Pulping: In mechanical processes, the debarked wood logs were reduced to fiber by grinding them against large rotating grindstones or serrated disks to produce groundwood pulp. If the

8. Sitwell, E Joseph, R. Claire Canty, Peter W. Kopf, and Anthony M. Montrone, 1991 Packaging for the Environment: A Partnership For Progress, pp. 51, New York; American Management Association.

9. Caimcross, F., Costing the Earth, p271, 1991, Great Britain; The Economist Books Ltd; and Sitwell E Joseph, R. Claire Canty, Peter W. Kopf, and Anthony M. Montrone, 1991 Packaging for the Environment: A Partnership For Progress, pp. 51, New York; American Management Association.

wood was softened first using heat and pressure it was termed thermomechanical pulp. If pretreated with chemicals as well, it was termed chemi-thermomechanical pulp, All these processes retained the lignin glue which bound the wood fibers together. This meant that much more of the tree ended up in the pulp but because lignin discolored when exposed to light, the resulting paper had a shorter Life. The attrition process of grinding the pulp also shortened the fiber length making the resultant paper relatively weak. The main use for this type of pulp was to make newsprint and other low strength, shortlife publications such as telephone directories and direct mail advertising.

Chemical Pulping: Cellulose fibers were the raw material needed for making paper, but before good quality, high strength paper could be made, the other three components had to be removed from the pulp. The chemical pulping process dissolved up to 95% of the lignin and hemicelluloses, liberating the relatively undamaged cellulose fibers. The resulting pulp was strong and long lasting. Unbleached it was suitable for packaging liner board and grocery sacks; if bleached and made bright it could be used for quality printing and book manufacture. See Figure 1 for a sketch of the chemical pulping process.

In the chemical process, wood chips were cooked with a mixture of chemicals under pressure in a digester. Two main chemical processes were used, both employing sulfur based chemicals - sulfite and sulfate pulping. The “kraft” (from the German word for strong) sulfate based process generally produced stronger paper and was much more common than the sulfite process.

The kraft process used an alkaline caustic soda solution made up of sodium hydroxide and sodium sulfide. Large portions of the lignin were dissolved in the pulping liquor. Then, this “black liquor” was evaporated to a high concentration and burned in the recovery boiler to reclaim energy and the inorganic chemicals. The pulping process was essentially a closed loop where 95% of the chemicals used could be reclaimed and recirculated with the next batch. In 1990, 85 5% of U.S. chemical pulp was produced using the kraft process. It was the only practical method of pulping southern pine because of the wood’s high lignin content.

In the sulfite pulping process, wood chips were boiled in a mixture of sulfur dioxide and water - sulfuric acid and alkaline oxides (of sodium, magnesium, or calcium). As with the kraft process, the cooking liquor was evaporated and burned in the recovery boiler to reclaim energy and inorganic chemicals. The resultant pulp was lighter in color, weaker and softer than kraft pulp.

The pulping process could not remove all the lignin from the wood fiber. A small part of the original lignin, 5 to 10%, remained in an insoluble form and discolored the pulp. Since many uses of paper required it to have a permanent high brightness the remaining lignin had to be removed. Further cooking damaged the cellulose fiber, however, so bleaching compounds such as chlorine, chlorine dioxide, ozone, peroxides, and hypochlorites were used to remove the lignin. Bleaching was carried out by treating a slurry of pulp in sequence with a combination of these compounds (Appendix 3 lists the symbols used to denote bleaching sequences). The most common bleaching sequence was CEDED and started with pre-bleaching using a chlorine treatment (C) followed by an alkaline extraction of the bleaching reaction

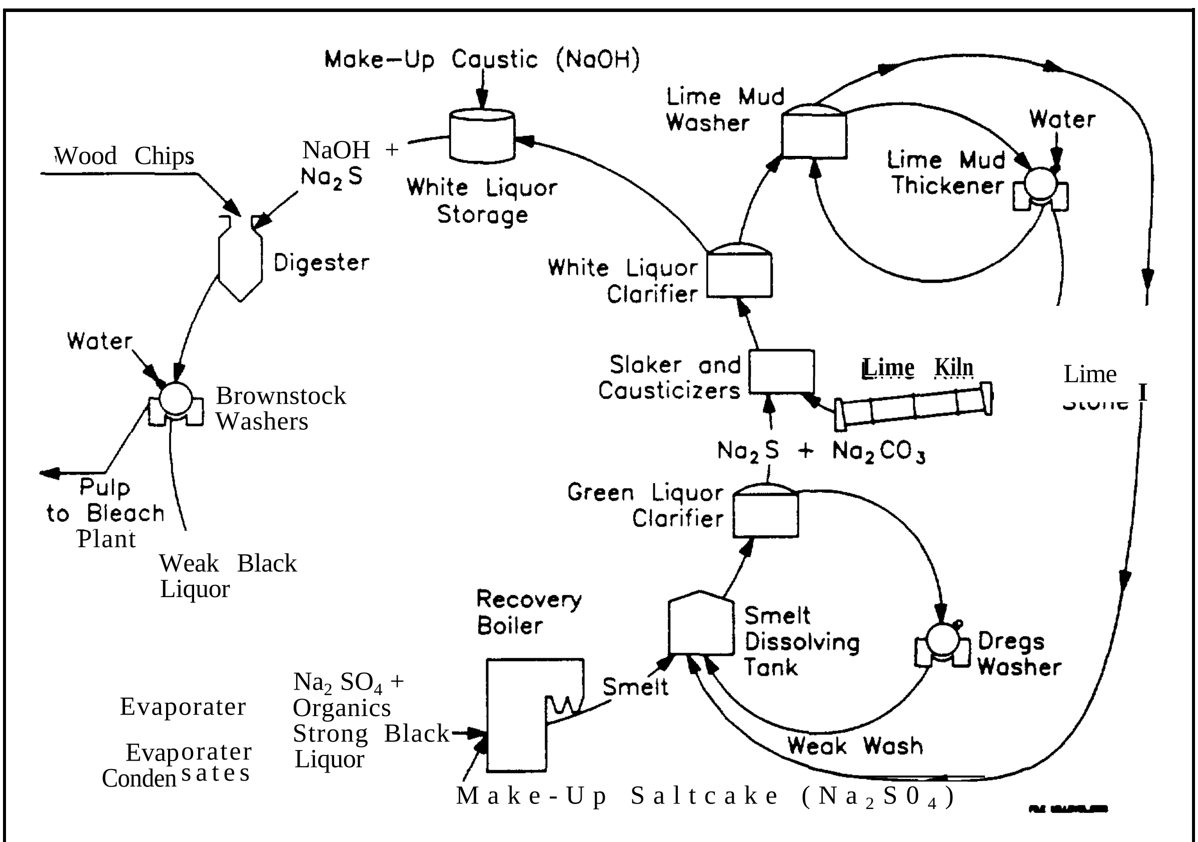

Figure 1: Source: McCubbin, "Kraft Mills in Ontario'

products using sodium hydroxide (E). This was then followed by further final bleaching using chlorine dioxide (D) and alkaline extraction and a final chlorine dioxide “polishing” step.

Between each bleaching or extraction stage, the pulp was washed with fresh or recycled water.. Because the water from the bleaching processes contained chlorine compounds, it could not be cycled through the recovery boiler. An attempt to do this would cause rapid deterioration of the equipment. Thus, the excess water discharged from the washers was released to the plant’s sewer system. It required between 19,000 and 27,000 gallons of water to bleach one ton of pulp.[10]

Paper pulp was converted into paper by making a suspension of fibers and additive: in water known as a “stock.” The stock was beaten to produce uniform fibers with the desired characteristic length, surface area, strength and density. Chemicals were added at this point to give the final paper particular characteristics: alum or synthetics to reduce ink absorbency, dyes to add color, starch to increase strength.

To produce a sheet of paper the water had to be removed from this stock. The water was removed by three methods, first gravity, then pressure and finally heating, progressing from the “wet’ to “dry” end of the plant. First the stock was deposited on the “wire” - a continuous belt of meshed material - where water drained from the fibers. Then, the relatively fragile web of paper was run through rotating roller presses which squeezed more water out. The paper passed through the rollers at 1500 to 2000 feet per minute through 400 foot long machines. The water that drained from the paper drying process was collected and reused. Finally the paper was heated on a series of large, cast iron, steam heated cylinders until dried to a residual moisture content of - 5% .[11]

Prior to winding onto a large spool (“core”), the paper was "calendared" by pressing on hardened, cast iron rollers to improve its surface texture. The paper was then ready for “converting” into finished

10. Bettis John, “Bleach Plant Modifications, Controls Help Industry Limit Dioxin Formation,” pp. 79, Pulp & Paper June 1991

11. Kline, James E, Paper and Paperboard Manufacturing and Converting Fundamentals 2nd Edition, pp. 16-23. 1991, San Francisco; Miller Freeman Publications Inc.

products. This could be done at the integrated mill or passed onto an independent converter who mechanically made bags, boxes, packaging, or envelopes. Some paper products required coating with pigment (for writing) or barrier agents (for food packaging) prior to shipment to their end user.

Economies of Scale

Facility size could significantly affect costs in the pulp and paper industry although there were few apparent advantages based on the size of the overall firm. The number of paper and board mills in the U.S. reduced from 677 in 1980 to 538 in 1990 (-21%), in the same period the number of mills in Western Europe reduced form 1654 to 1239 (-25%) and in Japan from 593 to 444 (-23%). There was also a decrease in the number of pulp mills in the same period but by a smaller amount.[12] The difference resulted to some extent because of the increasing number of integrated pulp mills.

In the U.S., the average capacity of individual pulp and paper mills also increased. From 1980 to 1990, the percentage share of annual capacity of mills producing more than 450,000 tons per year (tpy) of pulp rose from 40% to 58 % , and of paper from 23 % to 42 % . The majority of closures occurred in mills producing less than 50,000 tpy while the number of mills producing more than 500,000 tpy doubled to 39 by 1990.[13] The industry considered 365,000 tpy the minimum size for a greenfield kraft pulp mill and 110,000 tpy - 300 tpd the minimum size for a cost effective recycling facility.[14]

Entry and Exit Barriers

The paper industry was one of the most capital intensive industries in the world. In 1990, the U.S. paper industry made capital investments equivalent to more than 13 % of sales - higher than any other industry sector. Each employee in the U.S. pulp and paper industry was supported by more than $100,000 of capital equipment - over twice the average of other domestic manufacturing industries.[15]

12. Pulp and Paper International Fact and Price Book 1992, p26-27, 1991, San Francisco, Miller Freeman Inc.
13. Pulp and Paper 1992 North American Factbook, pp. 4-6, 1992 Miller Freeman, San Francisco
14. Lloyd Chambers, V-P Georgia-Pacific Corporation, Presentation to Wastepaper IV, 1992, Washington
15. American Forest & Paper Association (AFPA), Investing for Success, 1992 Washington D.C., AFPA

As both market pulp and all forms of paper products were globally traded commodities, and there was fierce competition in the merchant and retail markets, global overcapacity in the market had forced down both prices and margins in the early 1990s. However, because the equipment was so specialized the paper maker's large investments represented a formidable exit barrier, as the equipment had no other use.

When demand again approached capacity, the surviving manufacturers could anticipate significant profits. Large entry barriers existed in the paper business shielding the industry from new entrants using traditional technologies. The control of expensive and complex equipment and intimate knowledge of paper making were prerequisites for any new facility. Another significant barrier to entry in the U.S., was the difficulty in getting an operating permit to open a new facility.[16] Established companies had the industry expertise and also existing production facilities with operating permits, thus new entrants into the industry were more likely to enter by acquisition than as a new start-up company.

Competing in the large commodity grades of pulp (market pulp) and paper (kraft liner board and newsprint) required the economies of scale described above. There was, however, room for smaller niche players. Especially in Europe, the more specialized small market segments such as coated board for graphics use, totally chlorine free (TCF) paper, writing and printing papers with a high recycled content and specially coated grades of printing paper for high quality magazine manufacture represented areas potentially open to new entrants or to smaller current industry participants.

Buyers

Buyer Description

Customers wanted a number of different attributes from their paper or paperboard products. The demands of the buyer depended upon where they were in the distribution chain and the attributes which they most valued. The difference in product performance and appearance varied widely, but could be summarized as shown in figure 2.

16. Union Camp Technology Corporation, Wells Nutt - President, Interview, August 3, 1993. Franklin,, Virginia; and Georgia-Pacific Corporation, George Kincaid, Interview, July 7, 1993, Charlottesville, Virginia

Distribution Channels

Different grades of pulp and paper were distributed differently due to the type of product and the end user requirements.

Customer Segment	Primary Properties Desired
Newsprint	Priniting Quality, Machine Runability
Magazine and Printing Papers	Printing Quality, Machine Runability, Brightness, Smoothness, Gloss
Office Paper	Brightness, Gloss, Runability on Office Equipment
Tissue	Absorbency, Softness
Packaging and Converting Board	Strength, Regulatory Compliance
Packaging and Grocery Sacks	Strength

Figure 2

Commodity Trading: Market pulp was internationally traded between companies on the commodity markets, according to its intrinsic qualities (such as production process, strength, and brightness). Large volumes of pulp moved duty-free between the net producing regions and the net-consuming regions.

Industrial Sales: Newsprint and liner board products were critical inputs to the operations of the companies which used them. They could not allow interruptions in deliveries or significant changes in properties, Further, the majority of these products were sold in large quantity lots. As a result, paper manufacturers typically dealt directly with the buyers of these products and provided shipments directly to their operations.

The largest printing companies such as RR Donnelly (sales of $4 billion) and Banta also bought direct from mills. However, smaller printing companies such as Balmar (sales of $40 million) bought through their local brokers who in turn bought from the local area trade representatives of the manufacturing companies.

Sales Through Intermediaries: Printing and writing grades were often sold by paper companies through merchants and brokers to the ultimate customers. It was not considered economical by most paper companies to sell directly to customers because of the range of products they required and the stock carrying, order taking, and distribution costs associated with direct sales. Paper was transported to brokers warehouses which were closer to the demand centers. In practice this chain was very difficult to jump because of the economies of scale associated with each link. As the brokers dealt with many manufacturers they were able to offer a range of paper product qualities to their clients (such as various quanitities of pre- and post-consumer waste content paper, different weights, and levels of brightness) to meet the end users particular needs.

Bargaining Power and Switching Costs

With dramatically changing capacity and demand balances, bargaining power lurched over time. In the early 1990s, the power in the paper market was with the buyers as all segments of the pulp and paper markets were depressed by overcapacity. This resulted in fierce competition between companies in the traditional markets. Many Canadian and Scandinavian producers chose to adopt a strategy of taking downtime to reduce inventories rather than drop prices. There had also been increasing competition from low cost producers using fast growing eucalyptus pulp such as Brazil, Spain, Portugal, and Korea.

The increasing liberalization of trade achieved by the General Agreement on Tariffs and Trade (GATT) had a gradual but marked effect on the industry and its markets. By 1990 it was possible for all grades of paper, technology and capital investment to flow with limited interference resulting from tariffs and permits. Although the predominant flow across the Atlantic was still West to East, there was a growing flow of certain high added-value European grades such as coated magazine and wood-free papers into the North American market.[17]

Since paper was an internationally traded commodity with many producers making almost identical products in very similar ways, the cost of switching between suppliers was low and this decision was almost always driven by economics. However, for certain grades of "environmentallydriven" (ED) products such as TCF or high post-consumer recycled content printing and writing papers, there could be costs due to the limited number of suppliers and consequent choices. This was especially the case in the U.S. where environmentally conscious organizations such as Greenpeace and Conservation

17. Paper and Packaging Analyst, The West European Paper Industry in 1992, pp. 34-35, No. 9, May 1992. The Economist Economic Intelligence Unit (EIU), 1992, London

International had found difficulties in getting paper grades to their specifications for the printing of annual reports.[18]

Suppliers

There were three types of primary suppliers to the pulp and paper industry:

* Fiber materials wood/ wood chippings/ market pulp
* Equipment and technology
* Chemicals for treatment, bleaching, filler, coating, and wastewater treatment

<u>Fiber Material</u>: The largest paper companies in the U.S. were vertically integrated. They planted and cut their own trees or leased the harvesting rights for forest areas. Many had forest products companies with cut lumber operations who made particle board (PB) and orientated strand board (OSB) as well, and used the leftover shavings and unusable branches and debris as a supplemental source for wood chips.

The paper companies demand for recycled furnish coupled with increased cost of landfill operations and local and federal legislation had resulted in the start up of many recycling collection companies. The paper companies entered into contracts or joint-ventures with the haulers to collect and grade waste paper to their specifications and deliver it to their facilities. This had earlier been a well established practice in the old newspaper (ONP) and old corrugated container (OCC) grades but was a relatively new activity for office waste paper. In addition to growing environmental demand, the increasing recycling opportunities had been made possible by advances in de-inking technology which allowed the production of better quality fiber from lower quality sources at lower costs.19 Old magazines (OMG) had not yet become a regular part of wastepaper recycling because the variable grades, coatings, fillers, inks, and glues introduced contaminants that reduced the pulp yield below that of other recycled pulps. The waste OCC and ONP was either bought directly from a waste hauler such as Browning-Ferris Industries and Waste Management of North America Inc, from grocery store chains, or from brokers.

18. Greenpeace, Mark Floegel, Campaigner, Interview, June 25, 1993, Washington

19. American Papermaker Staff Report, "Some Novel Approaches to Deinking Operations In the United States," pp.36-38, American Papermaker, Septmember 1992

Increasing recycling of paper in Europe was reducing the growth rate of virgin pulp usage. Much of the pulp for German paper production came from Sweden and Finland, and was made to exacting German specifications regarding the recycled paper content and type of bleaching method used. The rest of the EC had less rigorous specifications. Many large Swedish and Finnish companies were vertically integrated like their U.S. competitors and thus used their own forests and tree plantations to produce fiber for paper production. Although Scandinavian countries had been recycling paper for many years, their relatively small populations meant that even with high per capita paper use, the recovered paper volume was relatively low in comparison to virgin pulp availability. In Sweden utilization outgrew the supply in the late 1980's. This resulted in significant waste paper imports of OCC and ONP to satisfy recycled content demands of their European customers.[20]

Equipment and Technology: In 1990, the U.S. pulp and paper industry bought more than $15 billion of capital equipment each year; during the 1980's the industry average investment was equivalent to 10.7 cents of each sales dollar. This level of investment was typical of that required throughout the world to remain in a competitive low cost position and comply with new more stringent environmental regulations. Paper machinery can be broadly broken down into the following categories:

* Wood Preparation: Machinery used from the receipt of rough wood at the mill yard to delivery of the prepared wood chips to the pulp mill such as debarkers, washers, chippers and screens.

* Pulp Manufacturing: All equipment required for processing wood or other raw fiber (including secondary fiber processing and deinking) into pulp for delivery to stock preparation, including chemical recovery equipment such as digesters, blow tanks, evaporators, recovery boilers, causticizers, and liquor storage tanks.

* Pulp Refining: Equipment used to process pulp for delivery to the paper machine(s) including bleach plant equipment washers, mixing boxes and refiners.

* Paper and Paperboard Manufacturing: Machinery used from the head-box through to the machine winder including fourdrinier, presses, dryers, and calendars.

20. Cockram R.. Capps C., NLK-Celpap Consultants Ltd and The Pierce and Pierce Group, "Impact of Environmental Legislation on the Pulp and Paper Industry in the 1990's," pp. 170, August 1991, NLK-Celpap Consultants Ltd , Chertsey, England

- Finishing: Equipment used to prepare paper for use such as supercalenders, winders, sheeters and sheet and rollwrapping.

- Converting: Equipment used to convert paper stock to products such as boxes, cores, bags, and envelopes; including coaters, laminators, embossers, saturators, corrugators and fabricating equipment.

Air emissions control and water treatment plants were also purchased by paper companies to comply with environmental requirements set by the company or the government.

Although a few suppliers such as Beloit provided equipment to several areas of the paper making process, many specialized in limited markets. Sunds Defibrator and Kamyr had unique skills in pulping equipment and had achieved very strong market positions, for example. Similarly, Voith and Valmet had achieved significant world market share by focusing on equipment used downstream of the pulping operation.[21] All the major equipment suppliers had international operations and sold their products all over the world either directly, through licensed agents or by some form of joint venture arrangement. Some of the largest equipment suppliers and their headquarters country are listed in figure 3.

The U.S. had the largest market for pulp and paper equipment, and U.S. shipments of equipment were four tunes that of the nearest rivals Canada, Germany, and Finland. In the U.S. Beloit (bought by Harnischfeger in 1986), Black-Clawson, Manchester, Bird, C-E Sprout Bauers, Impco (Division of Ingersoll-Rand), and Combustion Engineering (bought by ABBG in 1990) participated in the industry. Beloit alone had manufactured 45% of the new papermachines started up in the U.S. between 1983 and 1992. However, U.S. companies penetration into the export market had been limited and the country suffered a negative trade balance in all years after 1981.

Pulping and bleaching processes were responsible for a substantial share of emissions in paper production. These suppliers are, then, of particular interest for this study. Three firms supplied almost all of the pulping equipment installed throughout the world:

21. U.S. Department of Commerce, “A Competitive Assessment of the U.S. Paper Machinery Industry,” International Trade Administration, March 1989

- Impco

In the 1960s, Impco, a division of Ingersol Rand was the dominant supplier of chemical pulping and bleaching equipment in the U.S. The company had a marketing agreement with Sunds Defibrator of Sweden. Impco marketed Sunds equipment in the U.S., and Sunds marketed Impco technology in the rest of the world.

- Kamyr (Kamyr Inc. and Kamyr AB)

Kamyr had been founded in the 1930s as a combination of Finnish, Norwegian, and Swedish manufacturers supplying the pulp and paper industry. Throughout the 1950s, the company worked on technologies for a continuous cooking process. In 1962, this technology was successful leading Kamyr to aggressively enter international markets. Already, the firm had entered the U.S. having incorporated in Delaware in 1957. In 1989, one of the three founding partners sold out his interest in the business to the other two. This arrangement led to a split in the companies with Kamyr AB remaining based in Karlstad, Sweden and Kamyr Inc. being owned by the Finnish company Ahlstrom and establishing U.S. headquarters in Glens Falls, New York. Prior to this time, technology had been traded freely between the Scandinavian and U.S. operations. After the 1989 split, the organizations endured a bitter legal conflict over allowable marketing areas. In October of 1993, this conflict was resolved by a Swedish court ruling allowing both Kamyr Inc. and Kamyr AB (renamed Kvaener Pulping) to compete worldwide.

Headquarters country	Paper Equipment Suppliers
Germany	Harnischfeger, Voith, Hnekel
Finland	Valmet, Ahlstrom, Tampella
Sweden	KMW, Asea brown Boveri Group (ABBG), Sunds (owned by Rauma Repola), Kamyr AB (owned by Ahlstrom), Rauma-Repola
Switzerland	Sulzer Escher Wyss
France	Lamort
U.K.	Siebe, Appleton
U.S.	Beloit, Black-Clawson, Manchester, C-E Sprout Bauers, Impco, Combustion Engineering, Kamyr Inc.

Figure 3

- Sunds Defibrator

Sunds Defibrator was also experiencing ownership changes in the 1980s. As was stated earlier, the company had a long standing marketing arrangement with Impco. In 1985, the two companies announced their intention to merge. However, the arrangement was not allowed because of antitrust concerns. With the expectations of ultimately joining firms eliminated, the companies ended their other agreements at that time. Sunds had developed particular expertise in oxygen delignification systems and used this technology to support its entry into the U.S. market.[22]

Chemicals:

The U.S. pulp and paper industry bought more than $2 billion in chemicals per year to make pulp and another $1 billion to make this pulp into paper. This made chemical costs over 2% of sales. Worldwide this varied significantly by country, location of the mill, size of the mill (annual purchase of chemicals), mineral and energy costs for the country and domestic capacity for particular chemicals.

The use of chemicals by the pulp and paper industry could be broadly grouped into three categories

Pulping Chemicals: sodium hydroxide (caustic soda), sodium sulfate, soda ash, sulfur dioxide, sodium sulfide

Bleaching Chemicals: chlorine, sodium chlorate and methanol (for conversion into chlorine dioxide), sodium hydroxide (for extraction), hydrogen peroxide, oxygen, ozone, sodium hypochlorite, and a number of organic chemicals for new processes

Papermaking Chemicals: aluminum sulfate, titanium dioxide, Kaolin (china clay), starches, sodium silicate, calcium carbonate and a number of polyamides and acrylics.

The choice of pulping chemical used depended on the initial pulping process, alkaline pulping (the kraft process) used mainly sodium hydroxide and sodium sulfate to break down the wood chips while acid pulping (the sulfite process) used sulfur dioxide.

The choice of bleaching chemicals used and the sequence in which they were used depended on the mill's installed equipment and the brightness of the product required. Traditionally, U.S. kraft mills used a combination of chlorine and chlorine dioxide for bleaching processes. In the late 1980s, the proportion of chlorine dioxide used in "substitution" for chlorine increased steadily reaching almost 40% in 1992.

22. Sunds Defibrator, Mark Hallenbeck, Vice President Chemical Operations, Interview, October 13, 1993

Less chlorine was used in Europe and Scandanavia. In Scandinavia, for example, a large installed base of oxygen delignification equipment drove greater oxygen use. The lower lignin content of the pulp emerging from the oxygen delignification process allowed higher substitution of chlorine dioxide and hydrogen peroxide for chlorine

The choice of papermaking chemicals was very wide and totally dependent upon the qualities desired for the product. in general, European paper companies tended to use more coatings and treatments in their paper production than in the U.S. In 1991, even though European manufacturers only produced 70% of the amount of paper and paperboard as was produced in North America, they used 6.1 million tons of papermaking chemicals (60 % Kaolin and 30 % calcium carbonate) while North American manufacturers used only 4.3 million tons (80% Kaolin).[23]

1993 Major Pulping and Bleaching Chemicals Used by U.S. Pulp and Paper Manufacturers

	Tons (000))
Elemental Chlorine	1,004
Sodium Chlorate	915
Hydrogen Peroxide	132
Oxygen	375
Caustic Soda	2,525
Soda Ash	200
Others	530

Source: American Forest and Paper Association

Figure 4

Chemicals were supplied to the industry by many large chemical manufacturers, such as Dow Chemicals, DuPont, FMC, Air Products, Akzo Chemical, Hercules, American Cyanamid, Eka Nobel Occidental, Tenneco, TexasGulf, Olin, Georgia Gulf, ICI America, Kerr-McGee and many others.[24] There was a spot market for many of the bulk chemicals used, but transportation costs had a significant impact on supplier competitiveness in any one region.

23. Paper and Packaging Analyst, "The West European Paper industry in 1992," pp. 28, No. 9, May 1992, The Economist Economic Intelligence Unit (EIU), 1992, London

24. Chemicalweek, "New Challenges in Pulp and Paper," pp36-38, May 8, 1991

Environmental Regulation

Environmental Risk Analysis

In the early 1990s, the pulp and paper industries in many countries were addressing emissions of chlorinated organic materials resulting from their pulping and bleaching operations. While these issues commanded a tremendous amount of industry attention at the time, they were by no means the only environmental concerns these manufacturers faced. The activities surrounding every step of the paper products life cycle, from raw material collection through manufacturing operations to final disposal of the product, could significantly affect the environment.

The goal of making paper was to extract the valuable cellulosic materials from trees and transform them into usable forms. Therefore, the environment was affected both by how material was removed - in the form of trees, and by how material was introduced - in the form of production effluents and product disposals. The issues can be grouped into three primary areas: Forest Resource Collection; Manufacturing by-products, emissions, and effluents; and Product Disposal.

* Forest Resource Collection

The vast majority of paper products were manufactured from woodpulp.[25] The industry had attracted considerable attention for the use of wood and had been questioned concerning its impact on deforestation rates in both developing and developed nations. In the United States in 1990, 27% of all timber consumption was used for pulpwood, much of this in the form of byproducts from sawmill operations.[26] This share compares closely with measures reported by the Japanese Paper Association with pulpwood share of timber harvest in all industrialized countries of 25 % . Emphasizing that paper feedstock use represented efficient utilization of forest resources, the trade group further reported that only 46% of virgin domestic wood pulp and 50% of imported virgin wood pulp was taken from roundwood. This roundwood was reported to be of low grade and unsuitable for lumber. Other sources of raw material included sawmill residues, logging residues, and damaged wood.[27] [28]

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25. A very small portion of papers manufactured in developed nations are made from stock different than wood Cotton is used for example in high quality writing papers and currency. In developing countries, the situation can be different. In some regions, for example, various raw materials including bamboo may be used.

26. American Paper Institute, Inc., “Paper: Linking People and Nature”

27. Japan Paper Association, “In Harmony with Nature,” 1992

Pulpwood represented a far lower portion of timber consumption in developing countries. In 1989, pulpwood made up less than 2% of wood use. By far the greatest issue in these countries remained the destruction of forest areas for fuelwood and for conversion into faming and grazing lands. Recent information on wood consumption in Brazil reinforces this point. In 1989, the country consumed 267 million m^3 of wood. A full 50% of this material was used for fuelwood, and an additional 35 % was used in the production of charcoal.[29]

Although the above information suggests that deforestation for pulp production was not a critical global issue, local practices could significantly affect regional environments. Therefore, plans to site pulp facilities - particularly near fragile rain forest environments in Latin America or Southeast Asia - met stem resistance from local and international environmental organizations. For example, the poorly conceived Celgusa mill which was built in Guatemala with $275 million in foreign investment never began operation because of concerns over available wood sources.

* Manufacturing By-Products, Emissions, and Effluents

The goal of the production process was to extract the fibrous cellulose material from naturally complex wood raw materials. Mechanical pulping methods did this by tearing and separating the components of the wood while chemical processes selectively removed lignin leaving behind a less damaged cellulose product. In mechanical pulping approximately 10% of the original wood feedstock was removed and in chemical processes, more than 50% became part of the final paper product. The remaining material was either used for fuel or discarded.

Chemical pulping processes posed particularly difficult environmental challenges because the methods being used in the 1980s required manufacturers to release between 1% and 15% of the removed material to the sewer. As has been described, in kraft production the first stage of lignin removal occurred in the

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28. In Sweden, a substantial share of forest removals were used for pulp production. According to the Swedish Pulp and Paper Association, 64% of forest removals are used in the pulp industry.

29. Cockram R., Capps C., NLK-Celpap Consultants Ltd and The Pierce and Pierce Group, “Impact of Environmental Legislation on the Pulp and Paper Indust? in the 1990’s”, August 1991, NLK- Celpap Consultants Ltd , Chertsey , England

digester where sodium sulfide and sodium hydroxide were used to remove gross quantities of the lignin. The cooking chemicals, after having reacted with the lignin, made up a material called black liquor. This material was transported to the recovery boiler where the organic materials were burned off (producing steam for other areas), leaving inorganic materials to be prepared for reuse.

After the black liquor was removed, additional bleaching steps were necessary to whiten the brown stock pulp. Traditionally, the first of these had used chlorine to react with the remaining lignin. The reacted materials were extracted using sodium hydroxide. Unfortunately, because chlorine compounds were present in the extracted effluent, the material could not be cycled to the recovery boiler. Attempts to bum the effluent would have resulted in rapid deterioration of the recovery boiler equipment through corrosion. As a result, the material was disposed as a waste.

Prior to the adoption of control technologies, the release of the bleaching effluent had a dramatic effect on the receiving waters surrounding a pulp plant. High levels of organic material released in the effluent provided nutrition for micro-organisms in the water. These organisms also removed oxygen. Through this process, the receipt of pulp plant effluents diminished the oxygen content of the receiving waters. When oxygen levels fell far enough, fish and other life were adversely affected. The concern with oxygen removal was greatest in low volume receiving waters where smaller changes in oxygen levels made a larger percentage difference in the waters.

A measure of the impact of pulp effluents on receiving waters was the BOD_5, (biological oxygen demand) test, which represented the amount of oxygen taken up by the effluent in a five day period.[30] During the 1970s most major pulp producing countries put limits on the acceptable amount of effluent BOD. Figure 5 summarizes these measures and they are further discussed in following sections on each country. Limits in the range of 3 to 20 kg/ton were typical. Dramatic reductions in BOD emissions had occurred

30. Reportedly, the decision to test five day oxygen demand results from the early development of the test in the U.K. where the major industrial centers are all within five days river flow to a major receiving body of water.

in the industry. One manufacturer reported that emissions of BOD for their operations had dropped from 20 kg/ton in 1975 to a level of less than 2 kg/ton in 1993.[31]

In most countries, pulp manufacturers reduced BOD through the installation of secondary water treatments systems. These systems encouraged oxygen reactions prior to release of the effluent into receiving waters. Reductions in total suspended solids (TSS), an additional area of regulation, were also achieved through installation of secondary treatment.

plants which released effluent into large receiving waters found little benefit in reducing BOD. Canadian mills releasing to the Great Lakes and Swedish mills releasing to the Baltic and North Seas typically did not install secondary treatment. The conclusion of these manufacturers and the agencies regulating them was that the additional oxygen uptake of the mill effluents was insignificant relative to the oxygen capacity of the large receiving waters.

Air emissions were also a concern for pulp and paper manufacturers. Three types of emissions attracted the attention of regulatory bodies, and therefore manufacturers. The familiar rotten egg odor surrounding a kraft pulp mill was caused by reduced sulfur compounds including hydrogen sulfide, methyl mercaptan, and dimethyl sulfide. These compounds were not released in quantities which posed a threat to the health of the surrounding population. However, the odors were considered a nuisance and led to the unpopularity of pulp manufacturing in populated areas. Installation of low-odor recovery boilers had significantly reduced the intensity of the unpleasant odors. Similarly, the vast majority of pulp plants had installed particulate collectors and sulfur dioxide scrubbers which greatly reduced concerns in these areas

In the early 1990s, attention had begun to be focused on the very high emissions of chloroform in pulp bleaching operations. The Toxics Release Inventory[32] reported that 75% of chloroform releases came

31. Weyerhaeuser Co, Jerry Bollan, Director of Environmental Affairs, Telephone Interview, October 22, 1993

32. The Toxics Release Inventory (TRI) published annually by the U.S. EPA, summarizes industrial releases of approximately 300 chemicals. The requirement of industrial sources to release information on emissions was ppart of the Superfund Amendments and Reauthorization Act of 1986

from pulp and paper processes.[33] More than 90% of the releases occurred in hypochlorite bleaching making it the primary source of chloroform.[34] Approximately 125 mills produced chloroform in this way. These releases as well as releases of methanol occurring in the recovery boiler began to be regulated in the U.S. under Title III of the Clean Air Act Amendments of 1990.

Milestones and National Initiatives Concerning Pulp and Paper Mill Effluent

United States	
Federal Water Pollution Control Act	1972
Clean Water Act	1977
New Source Performance Standards are Promulgated	November 1982
National Dioxin Study indicates high levels of dioxin downstream from pulp and paper mills	August 1987
Proposed Effluent Guidelines [for AOX]	December 1993
Canada	
Effluent regulations established for new mills under the Fisheries Act	1971
Effluent regulations established for existing mills under the Fisheries Act	May 1992
Rules under Canadian Environmental Protection Act require process changes to prevent formation of TCDD and TCDF by January 1994	May 1992
Japan	
Environmental Protection Act establishes permitting system	1969
Water Pollution Control Act	1970
Japanese Paper Association establishes voluntary guidelines for AOX	1991
Sweden	
Sweden (and Finland and other five Baltic States) sign Convention on Protection of the Marine Environment of the Baltic Sea Area	March 1974
National Swedish Environmental Protection Board establishes target for reduced chlorine compounds in pulp effluent	May 1987

Figure 5

In the mid-1980s, a new area of environmental impact emerged. At that time, researchers in Scandinavia and North America became concerned with the effect of pulp mill effluents on fish downstream of the discharge. They found that disturbing amounts of chlorinated organic materials could be detected in the bleaching effluents of most chemical pulping processes. Further, researchers found that measurable amounts of dioxins and furans could be found in the effluent.

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33. U.S. EPA, September 1991, "Toxics in the Community, National and Local Perspectives: The 1989 Toxics Release Inventory National Report."

34. Luken, Ralph A., 1990, "Efficiency in Environmental Regulation: A Benefit-Cost Analysis of Alternative Approaches," p. 266

Early studies of dioxin suggested frightening outcomes resulting from very short exposures to very low quantities of the material. Death, carcinogenicity, teratogenicity, and immunotoxicity had been associated with dioxin exposures in animal studies.[35] In humans, the EPA had classified 2,3,7,8-tetrachlorodibenzo-p-dioxin as "a probable carcinogen."

The chemical structure of dioxins and furans made them extremely stable suggesting that continued slow release would yield increasing levels of the substance with little control through naturally occurring destructive processes. Over time, some of the initial fear of dioxin's extreme carcinogenicity had been challenged and in the early 1990s a comprehensive dioxin reexamination was underway. Preliminary conclusions of the reassessment suggested that harm to fetal development and detrimental effects on the immune system were the most important effects of human exposure to dioxin.[36]

The connection between dioxin releases and pulp bleaching was initially unexpected. In fact, in the U.S. EPA's National Dioxin Study, the high levels of dioxin occurring downstream of pulp and paper plants was only discovered in a national survey of fish and streams which was intended to demonstrate background levels of the substance. In analyzing test results, researchers were surprised to find significant levels of dioxin in fish samples taken downstream of pulp plants in Minnesota, Wisconsin and Maine. [37]

In October of 1987 the U.S. EPA released results of a follow-up study of five mills which confirmed that dioxins and furans were formed in the bleaching processes of pulp mills. In what became known as the "Five Mill Study," 2378-TCDD was found in 60% of water effluents tested, in more than 75% of pulps, and in 100% of wastewater treatment sludges.[38] The results of the Five Mill Study led the EPA and the

35. US EPA, "National Dioxin Study, August 1987

36. Schneider, Keith, "Fetal Harm, Not Cancer, Is Called the Primary Threat From Dioxin," New York Times, May 11, 1994

37. US EPA, "National Dioxin Study, August 1987

38. US EPA, July 1990, "USEPA/Paper Industry Cooperative Dioxin Study: The 104 Mill Study."

U.S. paper industry to undertake a study of the pulp, effluent, and sludge of all 104 mills which produced chlorine bleached, chemically produced pulps.

The 104 Mill Study provided a comprehensive analysis of how much dioxin was produced during pulp manufacturing and in what forms it was released to the environment. The study found that significantly more dioxin was produced in kraft mills than in those using sulfite processes. Further, it found that the dioxin which was produced was released to the environment in the pulp itself, in the water effluent, and in the sludge of the secondary treatment plants. While individual plants varied dramatically in the media to which the dioxin was released, the industry overall released the substance in fairly equal parts among pulp, effluent, and sludge. The total annual production of dioxin for the industry estimated in the 1988 study was 1.46 pounds of 2378-TCDD, and 11.7 pounds of 2378-TCDF.[39] The pulp and paper industry responded to the emerging concerns about dioxin over the next several years with a series of process modifications, and by 1993, releases of TCDD and TCDF had been reduced to less than one pound.[40] Environmental groups continued to call for further reductions.

Severity and Impact of Regulation

Environmental regulations aimed at reducing emissions from the pulp and paper manufacturers required that firms install a variety of control equipment. Large costs were incurred to build primary and secondary water treatments systems to reduce BOD and TSS, and similarly large expenditures were made for air control equipment such as particulate collectors and boiler scrubbers. The National Council of the Paper Industry for Air & Stream Improvement (NCASI) began tracking environmental capital expenditures for the pulp and paper industry in 1970. That year, U.S. firms spent $181 million for control of air, water, and solid waste. In 1992, the organization reported expenditures of $1,048 million.[41]

39. US EPA, July 1990, "USEPA/Paper Industry Cooperative Dioxin Study: The 104 Mill Study."

40. Federal Register, 40 CFR Parts 63 and 430, Effluent Limitations Guidelines, Pretreatment Standards, and New Source Performance Standards: Pulp, Paper, and Paperboard Category; National Emission Standards for Hazardous Air Pollutants for Source Category: Pulp and Paper Production; Proposed Rule, December 17, 1993

41. National Council of the Paper Industry for Air and Stream Improvement, "A Survey of Pulp and Paper Industry Environemental Expenditures- 1992: Special Report No. 93-10," August 1993

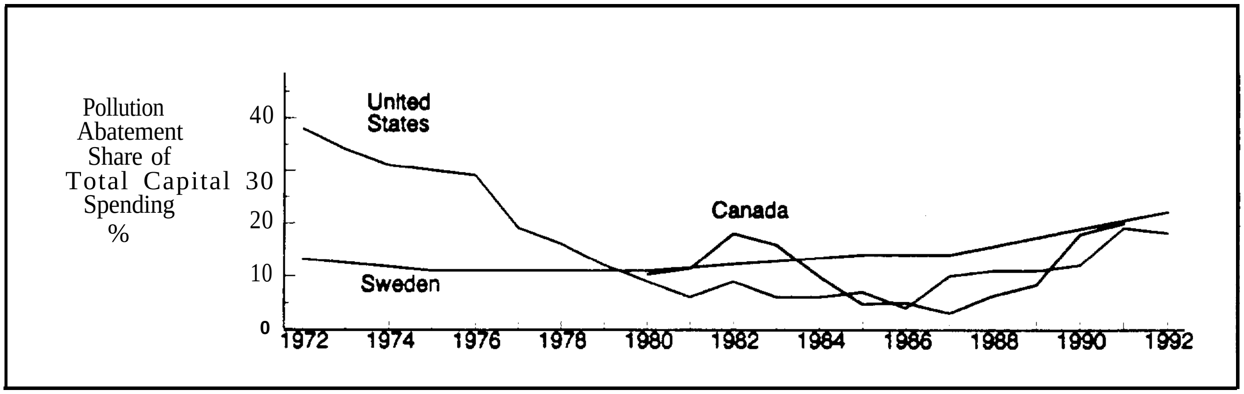

Figure 6: Pollution Abatement Capital Spending Share of Total Capital Spending for Pulp and Paper Manufacturers in the United States. Canada, and Sweden

Between the years 1973 and 1990, NCASI estimates indicate that 47% of environmental capital expenditures was aimed at air control while 42% was incurred for water treatment. The remaining 11% was associated with solid waste issues. Because these dealt primarily with disposal of water treatment sludge, those costs might also be included as part of water control costs.

Environmental capital expenditures made up a significant portion of the total capital outlays of pulp and paper firms. In the early 1970s, environmental expenditures made up more than 30% of total capital spending. This share declined rapidly in the late 1970s and 1980s as installation of the necessary and long-lived equipment was completed. In that period, environmental capital spending consistently made up a modest 4 to 9% of the total. By 1987, increased concern over dioxin releases as well as increased costs associated with solid waste disposal pushed the share of capital spent on environmental control above 10%. Environmental costs share of capital began growing again at this point, reaching 18% in 1992.

In comparing to total capital expenditures it should be noted that the paper industry was the most capital intensive industry in the U.S. In 1991, capital expenditures were 7% of sales (down from 8 % in 1990).[42] Further, the industry reported that between 1989 and 1991, capital expenditures significantly outstripped

42. U.S. Department of Commerce, "1991 Annual Survey of Manufactures"

cash flow. Therefore, additional funds, primarily in the form of debt, were being used to finance capital needs.[43]

The operating costs for pollution abatement and control in the U.S. pulp and paper industry was $1.43 billion in 1990 (including current depreciation of $33 1 million). These costs consumed 1.1% of the value of the industry's shipments and 2.3% of the value added by manufacturers in the industry. On a measure of percentage of value added, the pollution abatement costs in the pulp and paper industry ranked behind only petroleum and coal producers (9.8%) and primary metal producers (3.7%).[44]

Canadian, Swedish, and Finnish expenditures for environmental controls had lagged those in the U.S. in the 1970s, but were often higher in the 1980s (as measured by share of capital). In the early 1990s all of the major pulp producing regions were experiencing pollution control spending of roughly 1/5 of total capital expenditures. Information from the Canadian Pulp and Paper Association and Statistics Canada indicated that Canadian environmental expenditures exceeded 20 % of total investment in the early 198Os, but trailed off to below 10% by the middle of the decade. In the early 1990s, environmental costs were again ramping up (as total capital expenditures were being lowered). In Sweden, environmental capital spending hovered between 10% and 15 % between 1971 and 1985, but had reached more than 22 % in 1992.[45] The Finnish Forest Industries Federation (Metsateollisuus) similarly estimated 10 - 15% of investment went toward environmental projects between 1985 and 1991.[46]

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43. At the same time, a massive financial restructuring of the industry had occurred. Between 1984 and 1990, the debt to net worth ratio of the industry had grown from 49% to 89%. A large part of this movement had been the result of leveraged buy outs including a $3.96 billion transaction for Fort Howard Paper as well as debt taken on by manufacturers to finance acquisitions. With this high debt load, the industry was poorly positioned to support additional demands for capital expenditures.

44. U.S. Department of Commerce, "Current Industrial Reports. Pollution Abatement Costs and Expenditures, 1990."

45. Skogsindustrierna (Swedish Pulp and Paper Association), Information provided by Agneta Lindstedt, International Public Relations

46. Matsateollisuus (Finnish Forest Industries Federation), "The Cost of Environmental Protection in Pulp and Paper Industry," in Environment Report 1992

Comparisons among these values should be made cautiously however, because like the information reported for the U.S., the represent only estimates made by industry personnel. In many cases there were limited guidelines on what should be included as an environmental expenditure and what was included could vary from survey to survey. Additionally, few of the surveys factor in benefits resulting from these expenditures. Thus, for example, the costs of installing oxygen delignification equipment were included, but the benefits of reduced chemical consumption were not.

COMPETITION

United States

Competitiveness Overview

The United States produced 57,214 thousand tons of pulp in 1990 more than doubling the production of the second leading producer, Canada. U.S. capacity for pulp was estimated at 59,425 thousand tons making up 32% of the world total (tab. 1). Similar dominance existed in the production and capacity for paper and paperboard products. Here, the 1990 production was 71,519 thousand tons representing 94% utilization of a capacity of 76,241 tons. The U.S. held 29% of the world paper and paperboard capacity in 1990.

Although a large share of U.S. production was absorbed by internal consumption, international trade in pulp and paper products was very important to the health of the industry. The U.S. was the second leading exporter of market pulp in 1990 with 23.8 % of total world trade in the commodity at $4.1 billion. Of exported pulp, 60% was sulphate and 97% of that was bleached (tables 4 through 18).

The U.S was a comparatively less important trader in paper products ranking fifth with 7.8 % of world trade. Although exports increased at an average annual of 17% between 1985 and 1990, growing overall trade in the commodity resulted in the U.S. share remaining in a fairly constant range of 7-8 % U.S. exports of paper represented a 3.9 billion market. The largest category of U.S. exports in 1990, was kraft paper and paperboard in 1990 making up 36 % of the nation's total paper exports. The U.S. share of world exports of paper was 24.8% in 1990 and was exceeded only by Sweden's 26.2% share.

Leading Firms[47]

In 1990, seven of the world's ten largest paper companies were headquartered in the U.S. The largest of these, International Paper, had sales in excess of $10 billion from pulp and paper operations.

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47. General information on company revenue from pulp and paper operations is taken from the Pulp and Paper International 1992 International Fact and Price Book

International Paper like other large paper firms including Georgia Pacific, James River, Champion International and Weyerhaeuser participated in several segments of the industry. Each of these firms supplied market pulp, printing and writing papers, corrugated containers, and paper based packaging products such as paper bags, milk cartons, or cereal boxes. An example of the range of products produced by these types of manufacturers is found in table 19 which details production capacities reported for Georgia Pacific and Champion International for a variety of products.

Kimberly Clark and Scott Paper, ranked as the fourth and seventh largest paper manufacturers in the world, had achieved sales of $6.2 billion and $5.4 billion with a more focused strategy. Tissue products and personal care items drove 79% of Scott Paper's 1992 revenues and 81 %of Kimberly Clark's. The market for these products was more than $11 billion in the U.S., and was made up of several segments (see figure 7). The majority of these products were branded consumer items. As a result, marketing sales and administration costs were in the range of 15-20% of revenue for these companies while similar costs were consistently below 10% for such large companies as Georgia Pacific and International Paper.

International - for Home and Sanita
($ million)

	Canada	Germany		United States
Diapers	$356			$3,990
Facial Tissue	$150	$38	$152	$1,012
Household Towels	$143	$140	$113	$1,870
Bathroom Tissue	$355	$631	$615	$2,500
Feminine Pads	$127	$291	$118	$1,097
Tampons		$126	$90	$668

Source: Kimberly Clark, 1992 Annual Report

Figure 7

Distinctive Environmental Regulation in U.S.

Regulation:

The first comprehensive regulation of the U.S. pulp and paper industry's water discharges came under the requirements of the Federal Water Pollution Control Act Amendments of 1972 and the later amendments under the Clean Water Act of 1977. The legislation required that the EPA "revise and promulgate effluent limitations and standards for all industrial point sources of water pollution."[48] The regulations established limits on five-day biological oxygen demand (BOD_5), total suspended solids (TSS), pH, zinc, chloroform, trichlorophenol, and pentachlorophenol. Simple substitution of some biocides and slimicides were the only requirement for control of trichlorophenol and pentachlorophenol. Requirements for zinc and chloroform control were incorporated in the steps required for control of the conventional pollutants: BOD_5, TSS, and pH.

The regulations on conventional pollutants set effluent limits that effectively required all facilities to improve some in-plant control technologies as well as install end-of-pipe treatment. In plant modifications included improvements in pulp washing and taking steps to avoid spills. The end-of pipe requirements included preliminary screening, primary sedimentation a mechanical clarifier, and secondary treatments, aerated stabilization basins or activated sludge treatment systems. The secondary wastewater treatment systems requires. the greatcapital expenditures by industry to reach compliance. In 1980, the EPA estimated that compliance with the regulation would require $1.4 billion in capital expenditures and $430 million annually operating costs.[49] In retrospective work, one author concluded that the actual costs of compliance with the regulations has been lower than was anticipated by industry. In fact, the cost of compliance was estimated at $4 to $5.50 per ton compared to industry estimates of $16.40 per ton (all in 1984 dollars).[50]

48. US EPA "Economic Impact Analysis of Proposed Effluent Limitations Guidelines, New Source Performance Standard and Pretreatment Standards for the Pulp, Paper and Paperboard Mills: Point Source Category Volume I," December 1980

49. US EPA "Economic Impact Analysis of Proposed Effluent Limitations Guidelines, New Source Performance Standard and Pretreatment Standards for the Pulp, Paper and Paperboard Mills: Point Source Category Volume I," December 1980

50. McCubbin, N. "Kraft Mill Effluents in Ontario," March 29, 1988, p. 12-208

As has been noted, a second round of environmental concerns hit the pulp and paper industry with the discovery of chlorinated organics including dioxin in the effluent stream. The industry had experienced a series of environmental challenges, but none prior to these concerns had centered on a toxic pollutant Although all U.S. operations produced only about 13 pounds of TCDD and TCDF, the public sensitivity to these pollutants led manufacturers to take actions to limit their release.

U.S. manufacturers searched for the most cost effective means of reducing releases of the specific compounds, TCDD and TCDF, that had been identified as toxics. Many manufacturers adopted substitution of chlorine dioxide in the bleaching process where chlorine had previously been used.[51] Chlorine dioxide bleached pulp primarily through oxidation (rather than substitution or addition) which led to a substantial reduction in the formation of chlorinated organics[52] The rapid adoption of chlorine dioxide substitution was evident in the large increase in sales of sodium chlorate (a precursor in the formation of chlorine dioxide and used almost exclusively by the pulp and paper industry). Between 1990 and 1993 sodium chlorate sales increased 40% from 650,000 tons to 915,000 tons.[53]

By 1993, chlorine dioxide substitution other measures had allowed the pulp and paper industry to reduce releases of TCDD and TCDF more than 90% to less than annually.[54] Industry claimed these efforts had pushed annual environmental control spending $billion.[55] At this point, however, environmental groups were not satisfied. First, many of maintained that detection levels for dioxin were inadequate. They said that even minute am the material, at concentrations which could not be measured, should be considered harmful. Therefore these groups suggested, the

51. See for example, Georgia Pacific, "Wrapping Up the Chlorine Controversy in the Pulp and Paper Industry," Company Publication, August 1992

52. U.S. EPA, Pollution Prevention Technologies for the Bleached Kraft Segment of the U.S. Pulp and Paper Industry, August, 1993

53. Data provided by American Forest and Paper Association

54. Federal Register, 40 CFR Parts 63 and 430, Effluent Limitations Guidelines, Pretreatment Standards, and New Source Performance Standards: Pulp, Paper, and Paperboard Category; National Emission Standards for Hazardous Air Pollutants for Source Category: Pulp and Paper Production; Proposed Rule, December 17, 1993

55. Cavaney, Red, "Environmental Regulation - New Consensus for an Old Problem," Paper Age, March, 1994

elimination of dioxin should be assured by removing all chlorine containing chemicals from the bleaching process.[56] Secondly, while chlorine dioxide substitution substantially lowered TCDD and TCDF releases, it was less effective at lowering the total volume of chlorinated organics generated in the bleaching process. Environmental groups advocated that others among these compounds might similarly pose adverse health effects, but were less well understood than TCDD and TCDF. They called for limits on all chlorinated organics in the waste stream. One test, adsorbable organic halides (AOX, which was substantially lower costs than testing for individual compounds) provided a broad measure of the organically bound chlorine in the mills' wastewaters. Using chlorine dioxide, AOX could be lowered by approximately 50% (but it did not lower BOD releases, the chlorine in the chlorine dioxide continued to preclude recycling of the waste streams).[57] Pressure remained on pulp mills to demonstrate further reduction in organochlorine releases (as measured by AOX), with many environmental groups again calling for the complete elimination of all chlorine containing materials from the bleaching process. This, they claimed, was the only way to assure no formation of harmful chlorinated organics other than dioxin and furans. Industry had countered the suggestion that all chlorinated organics should be removed by pointing out the variety of characteristics of organchlorine compounds.. These compounds ranged from the toxic compounds driving regulations to beneficial substances such as drugs and food additives.[58]

Environmental Advocate Groups

In preparing a response to chlorinated organics issues, pulp and paper manufacturers were faced with a new dimension to environmental matters the growing role of advocacy groups. With the initial findings of dioxin in mill effluents, the industry began working very closely with the EPA to gather more information on the levels of chlorinated organics. Industry agreed to pay for a substantial share of the

56. See Environmental Defense Fund, "Petition to Prohibit the discharge of 2,3,7,8 Tetrachlorodibenzo-P-dioxin by Pulp and Paper Mills," September, 1993

57. McCubbin, Neil, "Costs and Benefits of Various Pollution Prevention Technologies in the Kraft Pulp Industry," in Proceedings of the International Symposium on Pollution Prevention in the Manufacture of Pulp and Paper: Opportunities & Barriers, August 18-20, 1992. Washington, D.C.

58. Fleming, B.J., "The Organic Spectrum: Mills, Public Must Discern Toxic, Nontoxic," Pulp and Paper, April, 1992.

cost of testing and further assisted in the identification of facilities for sampling. However, the industry wanted to maintain some control over the release of results.

Greenpeace, an international grassroots environmental advocacy group with more than 3 million members, learned of the study and the cooperation between EPA and industry. Members of the organization were concerned that the high level of cooperation might compromise the integrity of the study and shade results toward interpretations sympathetic to pulp and paper company concerns. In 1987, Greenpeace released "No Margin of Safety: A Preliminary Report on Dioxin Pollution and the Need for Emergency Action in the Pulp and Paper Industry." The report laid out Greenpeace's position on dioxin, including a critical assessment of the National Dioxin Study, and an expose of the cooperative study undertaken by the paper industry and EPA. The cloak and dagger tone of the document was enhanced by a description of the method in which the organization learned of the study:

> In December, 1986, an unmarked envelope arrived in a Greenpeace office. It contained leaked EPA documents, revealing that a major secret research program on pulp and paper mill dioxin sources was underway. belying government and industry claims that no serious problem is posed by dioxin pollution from the industry.[59]

The EPA documents themselves were included No Margin of Safety. They suggest a relationship that was perhaps somewhat less cunning then depicted by Greenpeace ve industry and the EPA had, in fact, entered into an agreement to do a pilot study of five : !ar agreement had not been subjected to public comment Although there was no legal requirement publiccomment, Greenpeace was able to use the appearance of impropriety to demand greater. by the industry concerning production and emission information.

Using the newly available effluent information along with readily available data on processes from the traditionally very open industry, Greenpeace and other environmental groups became highly informed on the differing technologies used to manufacture paper. Representatives of the organizations began

59. Van Strum, Carol and Merrell, Paul, "No Margin of Safety A Preliminary Report on Dioxin Pollution and the Need for Emergency Action in the Pulp and Paper Industry.' Greenpeace, USA, 1987

participating in industry conferences and providing articles to trade publications.[60] While these groups commented in public regulatory development meetings, they also attempted to sway industry opinion by convincing paper buyers to demand chlorine free papers. To educate consumers about the possible linkage between chlorine bleaching, dioxin formation, and adverse health effects, Greenpeace prepared explanatory documents such as "The Greenpeace Guide to Paper." Perhaps more importantly, these documents were prepared on paper manufactured in a manner Greenpeace would recommend. In doing so, the organization demonstrated the performance of papers produced in this way allowing their members to judge for themselves the impact of adopting the alternative production methods (of course, this did not allow a comparison of the cost to achieve this performance).[61]

One final impact of the participation of environmental organizations was the increased globalization of the discussion of environmental issues in the pulp and paper industry. Pulp and paper technology had traditionally been transferred quite rapidly around the world. However, environmental concerns had often been discussed on a local or national level particularly when concerns had to do with stream and river water quality. By demonstrating and publicizing advancements in one region, Greenpeace pressured companies in other areas to make similar changes. For example in the introduction to "The Greenpeace Guide to Paper," Renate Kroesa comments:

> "This booklet is printed on chlorine-free paper, made of clay-coated wood-containing pulp, and was obtained by Greenpeace from a Swedish manufacturer. Unfortunately, such paper is not yet commercially available in North America, Australia, or New Zealand. By using this paper and setting an example, Greenpeace is taking a step towards demonstrating to North American and Australian paper producers that high quality chlorine-free paper can be made, that the market demand is growing, and that they should set about supplying the market accordingly. "[62]

60. See for example, "Chlorine: An Environmentalist Perspective," by Mark Floegel in Pulp and Paper, February 1992

61. Greenpeace representatives point out that the organization will not recommend or endorse any individual product. However, they will endorse a process. They feel this will encourage manufacturers to talk about the process which they use and thus further educate their buyers.

62. Kroesa, Renate, Greenpeace International, "The Greenpeace Guide to Paper," January, 1990

Litigation:

One final area of pressure was dramatically influencing the pulp and paper industry in the early 1990s. At that time, several large law suits had been brought against paper companies for compensatory and punitive damages stemming from releases of dioxin. Examples of legal actions reported in company financial documents include the following:

> * Georgia Pacific lost two suits brought against Leaf River Forest Products which G-P had acquired. The suit charged harm inflicted by exposure to the company's dioxin releases. Compensatory damages of $241,000 and punitive damages of $4 million were awarded. The company was appealing the judgement. In 1992, Georgia Pacific was involved in "approximately 211 suits involving 8,815 plaintiffs."
>
> ● International Paper was named in a series of law suits in Mississippi where it was alleged that the company had polluted the Pascagoula, Leaf, and Escatawpa Rivers by releasing dioxin and other chemicals. The plaintiffs sought $1.02 billion in compensatory damages and $7.98 billion in punitive damages.
>
> ● Weyerhaeuser faced a complaint seeking $1 billion in damages from a class of riparian property owners.
>
> * Champion International was sued by "a class consisting of persons who own land along Perdido Bay in Florida and Alabama this suit sought more then $0.5 billion in damages.

Such enormous litigation liabilities further encouraged pulp and paper manufacturers to install equipment which would eliminate dioxin emissions. However, it may have also affected the companies' ability to promote elemental or totally chlorine free papers as less environmentally damaging. No executive could tout the environmental benefits of their new technology on the one hand while on the other claiming in court that historical emissions had caused no harm.

Litigation and the entry of environmental groups in the discussion dramatically changed the setting for pulp and paper manufacturers. The question of rigorous scientific analysis of dioxin's effects on health was no longer of primary importance. Instead, companies focused on new constituencies. The emotional response of a small jury to the claims of harm made by sympathetic plaintiffs against large deep-pocketed industrial entities was now of critical concern. On the other hand, new markets were emerging in some regions for customers who, with the urging of Greenpeace, might feel better about purchasing products made in a particular way (these markets are discussed below in the section on "Effects of Regulation on Competitive Advantage").

Sources of Competitive Advantage in U.S. Firms

* Factor Conditions

Pulp production required access to raw wood products. While some countries were able to develop a strong position in paper production through imported pulp, the strongest pulp producers relied on domestic supplies for the majority of their raw materials. The U.S., for example possessed one billion square miles of forested land area (see table 20). While this ready supply was important to the development of the pulp and paper industry, it does not provide the full explanation of how the industry became so important. In fact, much larger forested areas existed in the former Soviet Union as well as in South America. The U.S. share of world forest area was only approximately five percent.

The industry was surpported by several universities which had specialized departments in paper science. Several strong programs had developed in regions of the U.S. where paper making was an important employer. North Carolina State University, Auburn University, the University of Maine, the University of Wisconsin at Stevens Point, and the University of Washington all were supported by pulp and paper companies with research grants and scholarships and all graduated engineers who moved directly into the industry. The North Carolina State program, for example, awarded degrees to 20 to 40 undergraduate students each year as well as 5 to 10 graduate students. Undergraduates in this program often graduated with a dual degree which included chemical engineering. With this expertise, 30% of these students worked for chemical suppliers to the pulp and paper industry.

The Institute for Paper Science and Technology(IPST), located in Atlanta, Georgia, was a fully accredited program focused exclusively on graduate study in the technical aspects of the pulp and paper industry. Primarily funded by industry, the Institute provided full scholarships to all of its approximately 15 doctoral and 20 masters students. In 1993, these students were also receiving stipends of $12,000 to $15,000 during the academic year.[63]

For many companies, the association with IPST represented the firms primary efforts at more basic areas of research. According to the National Science Foundation, $736 million was spent on research and development by the pulp and paper industry in 1990. These expenditures represented approximately only 0.8% of total sales.[64] Even at this level, much of this funding was dedicated to customer support and product development. In 1993, only five companies, Union Camp, International Paper, Westvaco, Weyerhaeuser, and Champion International continued to maintain dedicated research or technology centers.

* Domestic Demand Conditions

U.S. per capita consumption of paper was by far the highest in the world. In 1990, the average U.S. citizen used 686 pounds of paper per year.[65] Residents in other large pulp and paper producing countries also had high rates of usage, but none came close to the U.S. total. Finns used 615 pounds per year, Swede used 508, and Canadians use 174 pounds per year. Similarly, other nations with high per capita incomes used large amounts of paper, but their usage was again modest when compared to the U.S. Germans used 510 pounds of paper per year and Japanese citizens used 503.[66] The high U.S. demand for paper when coupled with its large population made the country's domestic market the largest in the world. High demand alone does not, however, necessarily provide an advantage. U.S. firms were spurred to continually improve

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63. Institute of Paper Science and Technology, Richard Ellis, Vice President - Research and Academic Affairs, Interview October 13, 1993

64. National Science Foundation, "Selected Data on Research and Development in Industry: 1990," June 1992

65. All values of per capita paper usage are from the OECD publication, "The Pulp and Paper Industry, 1990' 1993

66. Japan had the highest growth rate of per capita paper usage between 1985 and 1990 of any industrial nation. Japanese growth in this area averaged 6.4% annually during this period while that in the U.S. was 1.9% and that in Sweden was -0.7%.

their products by a highly informed and sophisticated market. In particular, in the newsprint, writing papers, packaging, and tissue markets, the industry's close cooperation with its customers provided continual feedback on product developments.

- Related and Supporting Industries

The U.S. had long been the largest producer of paper making machinery. The Department of Commerce estimated that this industry had shipments of $1.3 billion in 1987 and was four times the size of the industry in Sweden, West Germany, or Canada. However, the U.S. had developed a sizable trade deficit in paper making equipment during the early 1980s losing what had previously been a very strong international trading position. By 1987, the negative balance of trade had reached more than $200 million. Paper companies had begun to rely primarily on Scandinavian sources for pulping and bleaching technology, and they were increasingly depending on German and Swiss imports for equipment used in the later stages of paper making.[67] Imports from Germany alone were $184 million in 1987 (as compared to exports of $15 million).

Despite the deteriorating trade position, U.S. firms supplying the domestic market continued to make new developments in paper making. Firms such as Beloit, Black Clawson, and Sandy Hill had been founded in the 1800s and continued to focus the primary paper making lines. Other firms such as Combustion Engineering (CE) and Thermo-Electron had begun supplying paper makers as extension f existing expertise in such areas as power generation or process control.

- Strategy, Structure, and Rivalry

Possessing local markets as well as large raw material reserves, encouraged U.S. suppliers to become integrated. Thus, the needs of the final customers could be

Figure 8: Ratio of Paper Capacity to Pulp Capacity for Leading Suppliers

	Sweden	U.S.	Japan	Germany
Paper Capacity 000ton	9.075	77.104	30.728	13.042
Pulp Capacity 000ton	11,000	58,218	13,484	2.503
Ratio Paper Pulp Capacity	0.83	1.32	2.28	5.21

67. U.S. Department of Commerce, "A Competitive Assessment of the U.S. Paper Machinery Industry," International Trade Administration, March 1989

communicated within a single organization. This contrasted with European manufacturers. There. large raw material sources were in countries with smaller markets. Non-integrated paper makers emerged in areas with large demand. They purchased market pulp from other non-integrated suppliers who were located near raw material sources. The contrast can be seen in figure 8.

Competition in the U.S. paper industry was based significantly on price. Of course, product performance and marketing played some role in a customers selection of paper products. The industry had a series of analytic test which characterized the performance of the product. Important distinctions were made in specific markets over particular areas of performance. For example, the strength of the product was very important in sales of corrugated boxed but not as critical in writing papers. Brightness was a critical concern for buyers of printing papers but not for those purchasing newsprint. Typically, a minimum performance based on testing was required beyond which price again became the key purchase criteria.

Marketing and product image were more important as sales came closer to consumers. As has been noted, tissue and personal care items were aggressively marketed. Writing papers and some office paper sales may also have been influenced by buyers brand awareness. However, even these areas and certainly in industrial uses, paper producers competed predominantly on price.

Canada

Competitiveness Overview

In 1990, Canada was the world's second leading producer of pulp with production of 22,835,OOO tons. Paper production ranked third behind the U.S. and Japan at 16,466,OOO tons (table 1). The country was the leading producer of mechanical pulp and newsprint. These products made up more than half the country's pulp production and paper production respectively.

Canada was the world leader in export of market pulp with a 30.9% share of world exports. The nation had held a relatively consistent share beginning in 1985 following a drop from 35.8%

share in 1980. Canada also led in paper and paperboard with 15.2% of world exports in 1990. However, there had been a steady decline from 22.2% in 1985.

Sulphate production made up 82 % of the value of Canada's exported pulp and 98 % of that was bleached. The country held a commanding 37.1% share of world exports in this area with $4.3 billion in shipments.

In paper exports, 67 % of the value of Canada's shipments came from newsprint. The Canadians provided 56.7% of world exports of this commodity in 1990. Canada thoroughly dominated this trade although even higher shares, above 65 % had occurred in the mid-1980s. Share was lost primarily to Sweden. Additionally, new entrants to the world market also played some role in eroding Canada's overall position by moving from virtually no participation to modest shares of l-3% (such countries as New Zealand, the Netherlands, and the U.K.). In other areas such as printing and writing papers, paper containers, and kraft paper, Canada ranked no higher than fifth in share of world exports.

Leading Firms

Although Canada a eloped a commanding position in some areas of pulp and paper exports, there were no Canadian companies among the world's largest pulp and paper producers. In 1990, Noranda Forest, headquartered in Toronto, had the largest sales from pulp and paper with $2.2 billion. Other large suppliers were Canadian Pacific Forest Products, MacMillan Bloedel, and Abitibi-Price.

As would be expected from the above discussion, Canadian pulp and paper firms relied heavily on the export market for market pulp and newsprint. Profitability was, then, significantly affected by exchange rate fluctuations as well as capacity utilization and operational efficiency. The industry was put at risk when, as in the early 1990s. low capacity utilization was coupled with unfavorable exchange rate positions. A survey of 17 Canadian pulp and paper companies found that the unfortunate combination of events had caused these manufacturers to lose C$439 million in the first half of 1991.[68]

Distinctive Environmental Regulation in Canada

Regulations on Canadian pulp and paper operations were promulgated at both the provincial and the national level. The country had, of course, always struggled with the appropriate balance between federal and provincial power, and this relationship was being sorely tried in the early 1990s. From a pragmatic standpoint, pulp and paper manufacturers focused primarily on emission limits set by the provinces. Thus, manufacturers in Ontario were expected to reach AOX levels of 1.5 kg/ADT by 1993 while those in British Columbia were not expected to reach this level until 1996.

Regulations of traditional pollutants (TSS, BOD, pH) in Canada were not felt to have achieved as great a reduction in emissions as had been achieved in other major pulp producing countries.[69] Strict limits on BOD which would have required such equipment were felt to be unnecessary in many areas because of the large receiving waters (such as Lake Superior and the Pacific Ocean) where the plants discharged. As a result, many manufacturers remained compliant with Canadian regulations without installing secondary treatment. In 1991, 23 of Canada's 47 bleached pulp mills had secondary treatment. Of those mills located near the coasts, only 3 of 13 mills had such equipment.[70] Despite lacking this equipment, Canadian manufacturers reported similar shares of capital expenditures going toward environmental needs as found in the U.S. These costs were associated with dry debarking, steam stripping, effluent neutralization and other types of control equipment.

In May 1992, under rules in the Canadian Environmental Protection Act, the federal government announced a requirement that all manufacturers implement process changes by January 1994 to

68. Pulp and Paper 1992 North American Factbook, pp. 4-6, 1992 Miller Freeman, San Francisco

69. McCubbin. N. "Kraft Mill Effluents in Ontario," March 29, 1988, p. 6-123

70. Environment Canada, "Effluents from Pulp Mills Using Bleaching," Ottawa, 1991

Province	AOX Discharge Limit (kg/ton)	Target Date
Ontario	2.5	1991
Quebec (existing softwood)	2.5	1993
(existing hardwood)	1.5	1993
(new softwood)	1.5	1993
(new hardwood)	1.0	1993
Alberta	1.5	1990
British Columbia	2.5	1991

Figure 9

prevent the formation of dioxins and furans. The government anticipated the regulation would cost approximately $560 million to implement.[71] The Canadian regulators assessed AOX and decided that, at the levels of releases under consideration, it was not a useful measure of toxicity. Instead, once the regulations took effect, any measurable level of dioxin or furan constituted a violation. By contrast, several of the provinces had set limits for their facilities in their regions. These varied in stringency, but set targets which were roughly in line with those taking effect in Scandinavian countries (see figure 9).[72] As in the U.S., public pressure may have been a more compelling force than strict regulation. In 1990, dioxin could not be measured in the effluent of 60% of the bleach mills in Canada.[73]

71. Recognizing the dismal performance of the industry in 1990 and facing strong resistance from British Columbia, the government later extended the deadline for implementation to 1996.

72. Environment Canada, “Effluents From Pulp Mills Using Bleaching,’ Ottawa, 1991

73. Environment Canada, “Media Backgrounder: Regulatory Package for the Canadian Pulp and Paper Industry.” 1991

Sources of Competitive Advantage

Canada possessed 1.4 billion square miles. of forested land, an area 40% greater than that available to the U.S. Forests made up 44% of the nation. Technical developments were supported by the nations leading research group for pulp and paper the Pulp & Paper Research Institute of Canada (Paprican). Not surprisingly, this group focused on process improvement and application development in mechanical pulping and methods of reducing emissions of organochlorines in the bleaching process.

Export markets were critically important to Canadian pulp and paper producers. Thus, an additional advantage for the industry was the easy access to the U.S. market. The same demanding buyers who had forced innovation and development by U.S. manufacturers encouraged growth in Canadian technology.

Japan

Competitiveness Overview

Perhaps surprisingly., Japan ranked in 1990 as the third largest producer of pulp with 10.3 million tons. However, Japan was almost non-existent in the export market for pulp. In 1990, the country imported more than $2.0 billion of pulp and exported only $13 million. However, Japan had a modest trade surplus of $500 million in paper and paperboard. There was no single market segment where Japan maintained a significantly large export position.

Leading Firms

There were several large paper firms in Japan in 1990 with nine achieving revenue in excess of $1 billion. The two largest of these, Oji Paper and Jujo Paper ranked as the twelfth and thirteenth largest paper producers in the world. The Japanese industry was somewhat slower to consolidate than those in the North America or Scandinavia and several single mill operations continued to operate in the early 1990s. This had begun to change in 1992, however, as both Jujo Paper and Oji Paper undertook significant acquisitions.

Distinctive Environmental Regulation in Japan

Japanese manufacturers were required to meet both national and local limits on effluent levels with the local regulations often being significantly more strict than those coming from the national Environmental Agency. For example, a national limit of 160 ppm for BOD was modified to 10 ppm in the most strict local agreements. These regulations forced most Japanese facilities to adopt some form of secondary treatment. In a survey conducted by the Japanese Paper Association in 1992, 53 of 60 kraft mills reported having some form of secondary treatment and the remaining seven had primary treatment .[74] The most common type of secondary treatment was aerated biological treatrnent.[75]

In 1991, the Japanese pulp and paper industry undertook a voluntary initiative to respond to concerns about dioxin. The issue had been brought to the attention of the industry when Professor Wakimoto of the Ehime (National) University reported having found elevated dioxin levels in fresh water fish caught near pulp mills. The Japanese Paper Association quickly responded with a set of guidelines targeting an AOX level of 1.5 kg per metric ton by the end of 1993. The guidelines included recommendations for adopting oxygen delignification equipment and chlorine dioxide substitution (see Attachment 1 for the guidelines set by the Japanese Paper Association).

By May of 1993, 93 % of bleached kraft pulp was produced using oxygen delignification.[76] Part of the reason for the rapid adoption of this technology was the comparatively low price of oxygen in Japan. Despite these developments, no Japanese manufacturers were supplying totally chlorine free pulp in 1993, and very few supplied elemental chlorine free pulp.

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74. In 1992, Japan had 35 bleached kraft mills and 15 kraft mills which employed no bleaching.

75. Industrial Pollution Control Association of Japan, “Sectoral Overview of Industrial Pollution Control Efforts in Japan - History and Pollution Combating Technologies,” Tokyo, Japan, 1993

76. Japanese Paper Association, Keiji Ikuta, Interview November 11, 1993

Sources of Competitive Advantage

Because Japan had very limited sources of wood, Japanese manufacturers were very innovative in finding alternative sources of raw materials. In 1990, 52% of the fiber used in Japanese paper production was from recycled paper stock. Further, 9% came from saw mills and other secondary sources. This familiarity with alternative sources is perhaps partially responsible for the introduction in 1993 of a paper made from sugar cane fibers by the Tokai Paper Company.

The vast majority of pulping equipment used in Japan was either imported or produced by transplanted manufacturers such as Kamyr or Sunds. Thus the country tended not to lead in adoption of innovative pulping methods. However, it could be an early follower as occurred with the introduction of oxygen delignification equipment. By 1992, more than 16,000 tons per day of capacity for bleached kraft, oxygen delignified pulp had been installed.

Sweden

Competitiveness Overview

Pulp and paper production was an important part of the Swedish economy, In 1989, this segment contributed 9.5% of the value of all industrial shipments for the country and employed 6.8% of those individuals employed in industrial sectors (as compared to the U.S. where pulp and paper industry contributed 4.5 % of shipments and employed 3.7% of industrial workers).[77] However, because of the smaller population of the country, the industry did not rank as high as larger more populous nations on measures of total production. Sweden was the fifth largest producer of pulp and the eighth largest manufacturer of paper with 1990 production of 9,914,000 tons and 8,426,000 tons respectively.

For Sweden, trade in pulp and paper was a major part of the country's exports making up 14.5% of the nation's total. Of $2.0 billion of pulp exported in 1990, 78% was produced by the sulphate process and 94% of this was bleached. More than 80% of Sweden's pulp exports were

77. Yearbook of Nordic Statistics, 1992 (U.S. information from U.S. Department of Commerce, Annual Survey of Manufacturers)

shipped to other parts of Europe with Germany alone accounting for 34% of the value of shipments. Sweden led the world with 26.2% of exports of kraft paper and paperboard and was the second leading supplier of newsprint at 13.1% (although it was well behind Canada in this last area).

Leading Firms

Two of the world's 20 largest pulp and paper companies were headquartered in Sweden. Svenska Cellulosa was the nation's largest in 1990 with $4.3 billion in pulp and paper revenue and Modo was the second largest with $3.1 billion. In the area of environmental technology, the much smaller Sodra Skogsagama was particularly progressive in the early 1990s. Although this firm ranked as the only the sixth largest in Sweden and (83rd largest in the world), it had positioned itself as a leader in adopting innovative bleaching technology.

Distinctive Environmental Regulation in Sweden

Sweden is a relatively small country and many of its most important environmental initiatives developed as a result of international agreements. In 1972, Sweden hosted a conference which ushered in a period of international cooperation toward shared environmental goals. At the UN Environmental conference in Stockholm, a primary recommendation was made for coordinated protection of the seas. Sweden, Finland, and the other five Baltic states followed up on the initiative ultimately signing the Convention on the Protection of the Marine Environment of the Baltic Sea Area on March 22, 1974. Known as the Helsinki Convention, this agreement covered pollution from land sources as well as ships.[78] Several initiatives have aimed at improving the environmental quality of the North Sea. The Oslo Convention, signed in 1972 put limits on dumping in the sea while the Paris Convention addressed land-based sources.

Sweden was similar to other European countries in addressing environmental performance of industrial facilities through a permitting system. However, unlike legislation in most other

78. Tillander, Staffan, "Sweden and International Environmental Cooperation" Swedish Ministry for Foreign Affairs Information, Stockholm, 1991

countries, the Environmental Protection Act of 1969 addressed more than a single media. Putting limits on emissions to both air and water, the act "carried the same weight as a court ruling. Violations were punishable by fines and imprisonment. [79]

Sweden was less restrictive on allowable BOD releases than the U.S. or Canada because the largest pulp and paper mills released into large receiving waters. Here, it was felt that low limits on BOD releases were not necessary because of the large dilution capabilities. In an industry publication, Nils Jirvall spoke for the Swedish Pulp and Paper Association on this philosophy:

> "We are convinced that it is the right approach to aim for all emissions to be brought down to non-injurious levels. This means that society will be obliged to tolerate very modest emissions, which are within the bounds of what Nature can withstand and satisfactorily deal with, but nothing beyond this threshold."[80]

BOD requirements in Sweden ranged from 8-17 kg/ton (as compared to 4-8 kg/ton in the U.S.). As a result, Swedish pulp manufacturers were able to take a variety of steps to achieve acceptable performance. Better washing, improved screening, and modified cooking procedures yielded substantial reduction in BOD releases. Additionally, many mills in Sweden adopted oxygen delignification stages in the mid to late 1980s. In several cases, these steps were adequate to meet permit requirements. In some others, secondary biological treatment systems were installed. McCubbin reported in 1988 that 9 [of 18] Swedish kraft mills had installed oxygen stages.[81] Given the option of adopting internal controls, Swedish firms are assumed to have optimized the system selected to the particular mills.

Growing concerns of the effects of oxygen demands in Scandinavia later coupled with the significant fears about toxicity of effluent led Swedish manufacturers to realize that additional

79. Person, Goran, "Developing an Environmental Policy: The Swedish Experience," Swedish Environmental Protection Agency," Stockholm, 1991

80. Skogsindustriera (Swedish Pulp and Paper Association), "Plain Facts on the Swedish Forests and Their Products, " Stockholm, 1992

81. McCubbin, N. "Kraft Mill Effluents in Ontario," March 29, 1988

steps were needed. Sweden took a more aggressive stance in regulating toxic materials. The country's schedule for implementing limits on AOX were among the most aggressive of the major pulp producers in the early 1990s. The regulations were targeting between 1.5 and 2.3 kg/ADT in 1990, with anticipated reductions to 0.75 in 1995 and 0.5 by 2000. Between 1988 and 1992, Swedish producers installed oxygen delignification capacity of almost 10,000 tons per day, more than doubling the previous capacity in this technology.[82]

Information provided by Skogsindustriena (the Swedish Pulp and Paper Association) indicates that between 1985 and 1988, the industry spent 2.7 billion krona on capital equipment for environmental improvements. 59% of this was spent on internal measures to improve water emission levels.[83] Manufacturers who had responded to BOD limits by installing oxygen delignification were in an advantageous position when later required to meet strict AOX regulations Using oxygen delignification lowered the lignin content of the pulp prior to the bleaching process. With less lignin to remove manufacturers had a variety of options in the later stages of the bleaching process which would further lower AOX and BOD. This contrasted sharply with the position of U.S. manufacturers who's investment in secondary treatment (as required by regulations) to lower BOD provided little benefit in reducing AOX.

Demands for Swedish producers to take further steps to lower their release of organochlorines came not from regulators but from their customers. Greenpeace was very strong in Europe in the late 198Os, particularly in Germany, the Netherlands, and the U.K. In 1989, the organization began a campaign in Germany to discourage the use of chlorine bleached papers. Using well developed grassroots methods, Greenpeace expanded awareness and built support for its position that no chlorine (or chlorine containing chemicals) should be used in bleaching kraft pulp. Then, in March of 1991, the organization made a stunningly effective move that dramatically changed the market for bleached kraft paper in Europe. Using chlorine-free paper supplied by the

82. Johnson, Tony "Worldwide Survey of Oxygen Bleach Plants - Examples and Case Studies," from Proceedings of the Non Chlorine Bleaching Conference, Hilton Head, South Carolina March 2-5, 1992

83. Skogsindustriena, information provided by Agneta Lindstedt, International Public Relations, October 1, 1993

Swedish company Munksjo, Greenpeace issued a magazine titled Das Plagiat (the Plagiarist) which had the structure and look of the popular German magazine Der Spiegel (Attachment 2).[84]

Greenpeace encouraged the readers of Der Spiegel and other magazines to demand that the publishers switch to paper made using TCF processes. Der Spiegel promised to switch "as soon as the product was available." Manufacturers then had a promised market which provided the rationale for making the needed production changes. By December 1992, Der Spiegel was being published on TCF papers. Stem and other popular periodicals soon followed.[85] Similarly in 1992, the IKEA catalog was printed on chlorine-free paper. This one catalog represented a market shift of 40,000 metric tons.[86]

Responding to this market, manufacturers replaced chlorine and chlorine dioxide bleaching sequences with ozone and hydrogen peroxide steps. Again, these changes benefited from earlier in-process changes which had been made.

Sources of Competitive Advantage in Sweden

Sweden held 108,000 square miles of forests making up 62% of the nation's land area. Starting with this endowment, Sweden built a strong pulp and paper industry through continued development of its industry. Large companies in the industry competed fiercely among themselves and against other Scandinavian suppliers for domestic and export markets. Despite this competition, the industry was fairly open with one explanation for this being the ties to academic institutions developed by many of the industry's decision makers. Strong programs

84. Clarke, David, "Non-chlorine Pulp and Paper Markers From a European Perspective," Confederation of European Paper Industries, from Proceedings of the Non-Chlorine Bleaching Conference, Hilton Head, South Carolina, March 14, 1993

85. Rainey Consulting, Margaret Rainey, telephone interview. September 21, 1993

86. Clarke, David, "Non-chlorine Pulp and Paper Markets From a European Perspective," Confederation of European Paper Industries, from Proceedings of the Non-Chlorine Bleaching Conference, Hilton Head, South Carolina, March 14, 1993

existed in pulp and paper at the Royal Institute of Technology in Stockholm and at Chalmers University in Gothenberg.

The world's leading suppliers of technology for pulping processes were headquartered in Sweden. The strongest of these were Kamyr AB and Sunds Defibrator. Although both of these firms experienced changes in ownership in the 1980s. both continued to rely on technology developed in Sweden into the beginning of the 1990s. While these firms provided support in pulping and bleaching operations, demanding customers - primarily in nearby export markets - insured that Swedish pulp and paper suppliers continually upgraded their products. Germany in particular had leading industries in paper products and in printing. Given the importance of this export market, Swedish market pulp and paper suppliers maintained close ties with these demanding buyers.

EFFECTS OF REGULATION ON COMPETITIVE ADVANTAGE

When pulp and paper firms took measures to reduce their releases, it affected the products they supplied, the materials they used, and the capital equipment which they purchased. As a result, environmental regulation (and other environmental pressures) on the industry did not merely affect manufacturers of pulp and paper. The industry's customers were affected by the types of products they could purchase and suppliers were affected by the changing demand for their products. A summary of the major effects on these groups is provided in figure 10, and discussed further in the following section.

Summary of Effects of Environmental Regulations

	Chemical Suppliers	Equipment Suppliers	Pulp and Paper Companies	Paper Purchasers
Costs of Regulation	Substantial loss in markets for chlorine		Requirement to invest in equipment (yielding less than acceptable financial returns - limiting capital availability for alternatives)	Additional costs for some paper products
Positive Effects of Regulation	Improved markets for sodium chlorate, oxygen and hydrogen peroxide	New markets for innovative pulping and bleaching equipment	Reduced operating costs through lower chemical and energy use	Opportunity to purchase products felt to provide environmental benefits
			Premium priced markets for some products	
			New markets for process technology transfer	

Figure 10

Direct Effects on the Product

Product Attributes

How a manufacturer responded to environmental issues was not apparent in the paper product. However, some customers were beginning to question whether manufacturers used chlorine or chlorine containing materials in their processes. Estimates in 1993 expected the TCF share of the northern European market to increase to 50% by 1996. In the rest of the world, the share was anticipated to remain below 10%.[87] Other sources expounded that approximately 45 % of the northern European market of TCF pulp was manufactured using the sulfite process. TCF was anticipated to make up approximately 25% of the bleached kraft market in northern Europe.[88] Changes in demand in the German and British markets were critically important to Swedish suppliers of bleach kraft paper and bleached sulphate pulp. In 1990, Germany imported 12% of Swedish sulphate pulp production and 19% of its non-newsprint printing and writing papers. Similarly, the U.K. imported 19% of the Swedish production of non-newsprint printing and writing papers.[89]

North American manufacturers claimed that the demand for totally chlorine free (TCF) or elemental chlorine free (ECF) papers was very low in their domestic markets. Growing home demand coupled with export opportunities led Swedish and Finnish suppliers to quickly respond to the changing market. However, U.S. and Canadian suppliers' change in production methods had not been as rapid despite the fact that Canada exported even more market pulp to Germany than did Sweden, and the U.S. exported more than Finland. As of 1993, there was little movement toward TCF by major North American suppliers of market pulp.

In 1992, despite the trends toward TCF in German speaking countries, U.S. manufacturers had increased their share of the European market for chemical pulp reaching 19.4% from a 1990 level of 16.4% (Sweden had similarly increased its share from 15.9% to 17.4%).[90] U.S. suppliers had held a 14% share of the German market for chemical pulp in 1990 and the bleached portion of these sales made up 30% of U.S. exports to Europe. Since U.S. firms did not produce TCF pulp, the gain in European share must have resulted from growth in the 75% of the German

87. Clarke, David, "Non-chlorine Pulp and Paper Markets From a European Perspective," Confederation of European Paper Industries, from Proceedings of the Non-Chlorine Bleaching Conference, Hilton Head, South Carolina, March 14, 1993

88. Data supplied by the American Forest and Paper Association

89. OECD, "The Pulp and Paper Industry in the OECD Member Countries," Paris, 1993

90. Data supplied by the American Forest and Paper Association

market which, in 1992, was made up of ECF and chlorine bleached pulp and from countries in the rest of Europe where TCF pulp made up only 1% of the market. Market analysts expected the TCF share of European market for free sheet paper to increase to 21% from a 1992 level of 8%.[91] U.S. firms targeting further gains in export share were forced to consider strategies for either supplying TCF or significantly improving their position in the remaining 79% of the market.

Sodra Skogsgama was Europe's largest market pulp supplier when the market began to change. After trying to satisfy European demand by supplying elemental chlorine free paper, the company realized that a market niche existed for totally chlorine free (TCF) products. Despite extremely poor financial results in 1991, the company dedicated the necessary resources to modify its Monsteros mill to TCF during 1992. While carefully claiming that "Greenpeace has not won this environmental battle," the company was targeting exactly the market motivated by Greenpeace. For its efforts, in a small part of the overall market, the firm initially commanded 25 % premiums for its product (as compared to other bleached kraft papers).[92] By 1993, the TCF market had become more competitive and the premium prices were being lowered. Sodra maintained additional capacity, however, that could be shifted to TCF production as market conditions required.

Direct Effects on Production Processes

Production Method

There had been a gradual but steady movement away from the use of elemental chlorine as a bleaching agent since the early 1970's. The general trend in production process redesign to introduce more effective process chemicals and to reduce the amount of pollution contributed by pulp mills, could be summarized as follows:

91. NLK Consultants, "Totally Chlorine-Free Pulp and Paper: European Supply and Demand Trends," January, 1993

92. Pulp and Paper International Magazine, "Sodra Sees Bright Future in TCF Pulp," May 1992

* to extend the delignification process ahead of pulp bleaching, i.e. to keep the kappa number (the measure of residual lignin content) down as low as possible, while taking into account pulp quality and yield requirements

- to eliminate the use of elemental chlorine from the bleaching process

- to reduce process water consumption and effluent water volumes

There was considerable argument over the expected costs of making these changes. The adoption of processes which removed lignin prior to bleaching increased the amount of material which could be recycled to the recovery boiler. It could result in increased energy efficiency and decreased use of bleaching chemicals. In greenfield plants where there were limits on BOD released, systems such as oxygen delignification and ozone bleaching were the most economic alternatives. However, if there was an installed base and secondary water treatments were already in place as in the U.S. mills, installation of these systems could not be justified purely on economic grounds.

Within the industry, respected and knowledgeable analyst disagreed on the average costs of achieving reduced chlorinated organic emissions. As figure 11 shows, two authors who attended the same conference in 1992, provided models of similar plants and the costs expected to adopt modifications which would reduce the release of chlorinated organic compounds.[93 94] The estimates of the cost of modifications differed substantially in some cases.

93. McCubbin, Neil, "Costs and Benefits of Various Pollution Prevention Technologies in the Kraft Pulp Industry," and Lancaster, Lindsay, et. al., "The Effects of Alternative Pulping and Bleaching Processes on Product Performance - Economic and Environmental Concerns." Both in Proceedings of the International Symposium on Pollution Prevention in the Manufacture of Pulp and Paper: Opportunities & Barriers, August 18-20, 1992, Washington, D.C.

94. The plants modelled by McCubbin and Lancaster did differ slightly. McCubbin describes his mill as "a 1,000 air-dried ton per day, single line mill using typical 1970s technology. This technology includes wet debarking, traditional batch digester cooking, a brown stock washing system operating with 20 kilograms per ton of salt cake loss, and a bleach plant with 10 percent chlorine dioxide substitution." Lancaster suggests a mill "producing 1,320 air-dried tons per day of bleached pulp. It is a two-species mill, making 660 tons per day hardwood and 660 tons per day softwood, each on a separate fiber production line. The bleaching sequence to achieve 86 percent brightness for each line was assumed to have been recently modified to reduce the formation of dioxin, using the bleaching sequence: D50cd+pD for softwood and D50CDEOo+pD for hardwood, each with 50 percent substitution of chlorine dioxide for chlorine in the first bleaching stage."

The differences in these estimates resulted from assumptions the authors made concerning existing

Capital Costs

	100% Substitution	Extended Delignification	Oxygen Dclignification w/ 100% Substitution
Lancaster	$18.8 million	$4.9 million	$104.1 million
McCubbm	$13.6 million	$4.6 million	$34.7 million

Operating Costs

Source	100% Substitution	Extended Delignification	Oxygen Dclignification w/100% Substitution
Lancaster	$9.23/ADT	($6.19/ADT)	$2.73/ADT
McCubbin	$9.14/ADT	($10.57/ADT)	($5.71/ADT)

Figure 11

mills ability to absorb new technologies. The cost of adopting systems such as extended cooking or oxygen delignification depended substantially on the existing operations of the facility. As has been noted, these systems provided the opportunity to cycle additional effluent to the recovery boiler to reclaim energy and chemicals. If it was assumed that the recovery boiler was operating at capacity, then the process modifications would require adding capacity to the boiler. If, instead, idle capacity for the - 5 % greater load was available, the capital cost estimates would be substantially lower. Differences in assumptions regarding boiler capacity explain a substantial portion of the variation in the two estimates above (to a great extent, Lancaster assumed operations under existing conditions while McCubbin assumed greater adoption of innovative technologies which would offer greater throughput in the existing equipment).

Assumptions concerning the type of digester used in the pulping operations could also drive substantially differing conclusions about the cost of achieving reductions in chlorinated organics. Digesters could be either batch or continuous and each of these could be modified for extended cooking. Assumptions concerning base case of a mill had to be made in order to reach a conclusion about the cost of installing extended cooking equipment. In the information presented above, the authors made similar assumptions concerning the ability of the mill to be modified for extended cooking.

Finally, assumptions about the cost of reducing emissions varied as a result of simple differences in engineering decisions. Using higher "design factors" or "factors of safety" increased the anticipated cost of the project.

Even as regulations approached implementation, the gap between cost estimates could be huge. When the EPA announced new effluent guidelines in 1993 for the pulp and paper industry, the agency estimated the cost to the industry of complying with the combined air and water rule would be $4 billion. Industry estimated that the rules would lead to expenditures of more than $10 billion.[95]

Many analysts expected the adoption of pollution control technologies to provide a reduction in operating costs for many facilities. In fact, McCubbin estimated that steps taken by Swedish mills had reduced operating costs for those producers by approximately $20 per ton.[96] Since many of these steps were the economic choice of new facilities in areas such as Brazil and Portugal, new regulations in the U.S. might be viewed as having their greatest impact by making several types of equipment obsolete. Outdated pulping equipment was required to be replaced - whether fully depreciated or not. However, once done, the facilities would perform at an operating cost level equivalent to the newest mills in the industry.

95. "EPA Seeks Strict Paper-Industry Rules Aimed at Cutting Dioxin. Air Pollution," The Wall Street Journal. November 2, 1993

96. McCubbin, Neil, personal communication, September 21, 1993

Process Technology as a Product

One U.S. company had taken a lead in developing innovative production methods aimed at reducing emissions from the kraft bleaching process. Union Camp, the 23rd largest pulp producer in the world (eighth largest in the U.S.) operated four paper and paperboard mills in 1990. The largest of these, located in Franklin, Virginia, produced 2,000 tons per day of pulp making it among the largest mills in the world. The large facility relied on the small Blackwater River for its water supply and for disposal of its effluent. During several months of the year, the flow of the river was far too low to absorb the large amounts of waste created by the mill. Permits had required Union Camp to store effluent in an eleven billion gallon pond during seven months of the year and release material only during the five months of highest water flow.[97]

Initially, Union Camp's efforts to reduce effluent loads were driven by the need to reduce BOD and TSS at the Franklin mill. The company was among the first in the U.S. to see the opportunities to reduce waste production by the introduction of an oxygen delignification stage. In 1981, an oxygen stage was introduced in a new hardwood line of the Franklin mill, followed in 1984 by the use of oxygen for bleaching of hardwood and softwood at Union Camp's new mill in Eastover, South Carolina. Union Camp had been spurred to this technology because the low flow of the Blackwater River precluded simply adopting secondary treatments (the control option chosen by most U.S. firms).

Even with an oxygen stage, the low flow of the Blackwater River threatened to require more costly effluent treatment. Spurred by this expectation, Union Camp continued research on alternative methods of removing lignin in a manner which would allow recirculation of the effluent. In 1987, the company felt it had an acceptable system of ozone bleaching which could be used after an oxygen stage.[98] Following further refinement in a pilot facility, the technology

97. Ferguson, Kelly H., "Union Camp Begins Ozone Era with New Kraft Bleaching Line at Franklin, VA." Pulp and Paper, November 1992

98. Ozone was an expensive bleaching agent, therefore, an oxygen stage was required to lower the kappa number (lignin content) prior to the ozone stage. Similarly, extended delignification was often used to lower the lignin content prior to an oxygen stage. It is interesting to note that at Union Camp, the oxygen stage occurred

was installed in the Franklin plant and began operating in August of 1992. Chlorine dioxide was used in the final stage rather than hydrogen peroxide. As had initially been the case, the company was focused on lowering conventional pollutants through these technologies. The benefits of reducing dioxin emissions became evident only later.[99]

If the technology had merely reduced conventional pollutants, it would have been only of long term interest to Union Camp's competitors. Clearly there were benefits to others facing restrictions on effluent levels, and the technology had economic merit to newly installed facilities. However, the number of these types of mills was small. For most North American facilities with large installed base of wastewater treatment and chlorine dioxide substitution, the Union Camp technology was not applicable because of the high capital expense and modest operating cost savings (from reduced chemical usage and increased energy recovery). Wells Nutt, the president of Union Camp Technology, conceded this point in an editorial in Paper Age magazine (Nutt refers to C-Free-, the trademarked name used to describe pulp made using the Union Camp process) : [100]

> "Frankly, the bleaching cost saving alone for C-Free" probably wouldn't produce a good return on the required capital. However, C-Free" is a clear choice for greenfield mills and existing mills that either require environmental improvement or new bleaching capacity"

Larger opportunities emerged for Union Camp because the technology had application beyond the narrow original goals foreseen by the company. Because the technology reduced the total amount of effluent (by using non-chlorine bleaching agents), it not only lowered BOD and TSS,

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following standard batch digesters. The company suggested that extended delignification might later be added but in 1992, it was not required because of the characteristics of the oxygen system being used.

99. Information provided by Wells Nun, president Union Camp Technology, August 3, 1993

100. Nutt, Wells E., "C-Free Pulp Bleaching: A Look Into the Future," Paper Age, May 1993, p.3

but dramatically reduced chlorinated organics and chloroform releases:[101]

BOD	Reduced by 70% - 90%
Total Chlorinated Organics	Reduced by 70% - 99 %
Chloroform	Reduced by 98% - 99%

With the rising awareness of the problem of chlorinated organics (including dioxin) other manufacturers were keenly interested in what Union Camp had achieved. The technology was clearly unique combining insights on equipment (a decision to pursue high consistency methods of ozone bleaching rather than medium consistency as some manufacturers had expected) and on processes (optimization of the dozens of variables involved in the bleaching process). Further, the company had carefully patented all relevant areas. Thus, the company quickly recognized the commercial opportunity for extending the technology to other manufacturers.

In 1990, Union Camp Technology was formed as a wholly owned subsidiary of Union Camp Corporation to license the technology - now trademarked under the name C-Free”. The company teamed with Sunds Detibrator AB to provide bleaching equipment and with a small number of engineering firms to provide engineering work to licensees. Early results for the commercial venture were encouraging with approximately 20 proposals under consideration in the organization’s first year of operation. As had been expected, the earliest opportunities were found in new mill development and in upgrades of full bleach lines.

The pollution prevention option pursued by Union Camp had been forced by the unacceptability of end-of-pipe treatments at its primary facility. However, the experiences of the company yield lessons for manufacturers who may be less restricted in their methods of responding to environmental challenges. By reducing all emissions, Union Camp not only responded to the then current environmental issue, but was also well prepared when a new, unforeseen concern

101. Union Camp, “New Union Camp Pulp Bleach Plant is First toReplace Chlorine with Ozone,” Company Press Release, October 8, 1992

emerged. Further, by taking the lead in developing the technology, the company found itself in a new marketplace extending that technology to other manufacturers.[102]

Equipment Suppliers

As has been discussed, two major innovations had occurred in the pulping process which aided in the reduction of chlorinated organic compound emissions. Extended cooking and oxygen delignification were being adopted by manufacturers throughout the world to improve environmental performance. Both of these technologies were developed by Scandinavian firms, and as the equipment was incorporated these firms strengthened their international market positions.

The environmental concerns of the pulp and paper manufacturers affected the equipment suppliers by significantly increasing the market for extended cooking and oxygen delignification systems. Much of the early demand for this equipment developed in Scandinavian countries and, not surprisingly, manufacturers supplying those areas achieved an early lead in developing technologies. By 1992, the two Kamyr companies were the primary suppliers of extended delignification systems and Sunds had at that point supplied almost 50% of the oxygen delignification systems installed around the world. The entire U.S. market for pulp mill equipment was $1.4 billion in 1991 and was expected to grow to $1.7 billion by 1996.[103] Leadership in emerging technologies such as extended cooking and oxygen delignification provided a significant advantage to serving this market. In addition to revenue from the initial sale, companies supplying this equipment benefited later as the equipment was serviced and upgraded.

102. In other industries, this role has typically been taken by a traditional supplier to the industry. However, because pulp equipment suppliers are so much smaller than paper manufacturers, Union Camp was in a better position to dedicate resources to developments in this area than their suppliers. This only occurred because of the unique restrictions on the firm (making the benefits of the technology particularly large for Union Camp).

103. American Paper-maker, “U.S. Mills Will Buy More Equipment; Most of it Will Come From Europe,” November 1991

Kamyr had developed its Modified Continuous Cook (MCC*) and Extended Modified Continuous Cook (EMCC*) processes as natural extensions of its expertise in continuous cooking. Early installations of this equipment occurred in Finland at the Enso Gutzeit mill in Varkaus in 1983 and in the Metsa-Bonia mill in Aanekoski in 1985. Large scale introduction in the U.S. began to occur in 1988. Kamyr (in its form either as a single company or later as Kamyr Inc. and Kamyr AB) had become the only company to supply continuous cooking equipment to the industry. Innovations in extended cooking were initially targeted at providing a means to lower bleaching chemical costs by delivering a material with reduced lignin content at the end of the pulping stage.[104]

The MCC* and EMCC* technology was only appropriate for greenfield installations or retrofits of existing Kamyr continuous digesters. Thus, only Kamyr supplied this technology. By 1992, the company had installed systems in mills supplying 20 % of world capacity and 25 % of U.S. capacity.[105] Based on industry reports of the economic incentives for installing extended delignification, rapid adoption of the technology was anticipated regardless of the requirements of environmental regulations (see figure 11).[106]

The introduction of oxygen delignification as a means of bleaching pulp was the result of long years of research. Early investigative efforts supported the expected performance of oxygen as a strong bleaching agent on wood pulps. However, the reactions were too aggressive on the cellulose and yielded pulps with unacceptable strength. In the late 1960s, researchers discovered that the introduction of magnesium compounds during the bleaching process protected the cellulose while allowing the reaction of oxygen with the lignin.

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104. Kamyr Inc., Eric Wiley, Vice President Sales, Interview, October 1, 1993

105. Macleod, Martin, “Extended Cooking in the Mills,” Proceedings, Nonchlorine Bleaching Conference, Hilton Head, SC, March 1992 as cited in EPA, Pollution Prevention Technologies for the Bleached Kraft Segment of the U.S. Pulp and Paper Industry, August, 1993 p. 4-16

106. Phillips, Richard, Jean Renard, and Lindsay Lancaster, “The Economic Impact of Implementing Chlorine-Free and Chlorine Compound-Free Bleaching Processes,” Proceedings, Nonchlorine Bleaching Conference, Hilton Head, SC, March 1992

Two groups, both with strong Scandinavian representation, moved to begin commercialization of the technology. Kamyr AB teamed with Sappi (one of the two South African Paper companies), and L'Air Liquide (a French oxygen supplier) developing a 220 tons per day system which began operation in the Sappi Enstra Mill in 1970. Similar types of firms were represented in the second group with Sunds (working with Irnpco), MoDo (a Swedish paper company), and Canadian Industries Limited (a chemical supplier) participating. The system developed by this group was installed at the West Point, Virginia facility of the Chesapeake company in 1972 and at the Munksojo Aspabruk, Sweden mill in 1973. Ramp up in installations was modest at first with just over 30,000 tons per day capacity installed by 1988. With growing concerns about emissions, however, capacity of oxygen deliginification worldwide reached almost 100,000 tons per day in 1992.[107]

Swedish pulp manufacturers had responded to earlier BOD and TSS requirements by modifying internal operations to reduce the amount of material which might be released. Oxygen delignification provided one of the primary means of achieving reduced emissions. By 1987, Sweden had installed capacity for 7,730 tons per day of oxygen delignification capacity. As has been noted, the primary means of reducing BOD in the U.S. had been the installation of secondary treatment systems because the "best" technology was required in all facilities. In Sweden, many facilities released effluent to large receiving waters. Regulators set BOD limits that were higher and could be met using oxygen delignification. By 1987, U.S. manufacturers with more than five times the overall capacity of Sweden had installed only 5,100 tons per day of oxygen delignification capacity. 56% of this was put in by two manufacturers, Union Camp and Champion Intenational.[108]

The ability to use a pollution prevention method rather than a secondary treatment had later advantages for several parts of Swedish industry. When, in the late 1980s. chlorinated organics

107. Johnson, Tony, "Worldwide Survey of Oxygen Bleach Plants - Examples and Case Studies," Proceedings, Nonchlorine Bleaching Conference, Hilton Head, SC, March 1992

108. Johnson, Tony, "Worldwide Survey of Oxygen Bleach Plants - Examples and Case Studies," Proceedings. Nonchlorine Bleaching Conference, Hilton Head, SC, March 1992

became a concern for pulp mills, many Swedish manufacturers required smaller additional changes in their operations. Secondly, the equipment manufacturers, strengthened by strong home markets had become the leading suppliers of alternative pulping equipment.

As of 1992, after a tremendous surge in worldwide purchases of oxygen delignification equipment, Sunds had supplied 48% of the systems and Kamyr (through either Kamyr Inc. or Kamyr AB) had supplied 35%. Impco, the primary U.S. supplier, had installed only 12%.[109] Impco continued to pursue the market and was regaining some lost ground in 1992 and 1993. During this time, the company supplied systems to U.S. manufacturers such as Glatfelter and Pope and Talbot as well as products to manufacturers outside of the U.S. including Ence of Spain and Laykam of Austria.[110] The challenge remained, however, for the company to reestablish its strong position relative to its Scandinavian competitors.

Chemical Suppliers

The major changes in bleaching technology which took place in the paper industry reduced the quantity of chlorine used by paper manufacturers by more than 25% between 1990 and 1995.[111] Industry data show that the use of chlorine decreased as manufacturers substituted sodium chlorate, oxygen and hydrogen peroxide. The choice of a paper manufacturer to use a certain bleaching chemical could have a major impact on their upstream chemical suppliers. Since the selection of one chemical necessarily replaced rather than supplemented another, one chemical supplier's gain was a competitor's loss. As an example, if a paper company decided to replace some of its conventional chlorine bleach plant capacity with upstream oxygen delignification, the company's chlorine supplier would experience reduced demand while the oxygen supplier would have a new consumer.

109. Johnson, Tony, "Worldwide Survey of Oxygen Bleach Plants - Examples and Case Studies," Proceedings, Nonchlorine Bleaching Conference, Hilton Head, SC, March 1992

110. Ingersol Rand Co. - Impco, Lew Shackelford - Manager Products and Technology, Telephone Interview. October 20, 1993

111. Data provided by the American Forest and Paper Association

Historically, caustic and chlorine were sold in balance because the chloralkali process derived a ton of chlorine from salt while yielding approximately a ton of caustic. Because of the nature of this reaction, the cost of an electro-chemical unit (ECU) of chlorine and caustic was below the combined spot market prices of the two chemicals. Estimates for the worldwide increase in chlorine consumption were 0.85 %/year in 199 1 while those for caustic were approximately 1.5 % annually. This suggested that there would be a shortage of 1.4 million tons of caustic by 1994 if nothing were to rebalance the supply.[112] Chemical companies anticipated this imbalance and acted accordingly. FMC, Tenneco, and Texas Gulf had installed causticization plants to convert Wyoming Trona (a naturally occurring sodium carbonate ore) into caustic soda without making any chlorine.[113] Further, several companies, Albright & Wilson, Lugil Gmbh, and MoDo-chemetics had developed new processes to convert chlorine into chlorine dioxide. However, the technology was complex and expensive ($19 million for a 1000 tpd kraft mill) in comparison to the sodium chlorate conversion process, and the chlorine dioxide generated was contaminated with up to 15 % chlorine. Additionally, the increase in plastics production, the industry segment which used the majority of U.S. chlorine (in polyvinyl chloride) was taking up most of the slack chlorine production which the chloralkali producers were manufacturing. In 1991, there was still a differential price between co-purchased ECU caustic at $215/ton and spot market caustic at $340/ton (after 1991, caustic became plentiful and was available from either process at below $2OO/ton).[114]

The suppliers of sodium chlorate saw demand rise by 14%/year in the late 1980s and early 1990s. ICI, Kerr-McGee, and Atochem had all increased capacity accordingly. Similarly, the oxygen supply companies, Liquid Air, Air Products, and Praxair had exploited the opportunity that oxygen delignificaiton systems offered them to supply the paper industry. Not only had they

112. Fleming, Bruce, “Environmental Pressures Produce Chlorine and Caustic Imbalance,” American Papermaker, February 1991, p. 48

113. Yound, J. “Pulping and Bleaching Chemicals Accelerate Enviro-Driven Shift,” Pulp and Paper, November 1991, p. 62

114. Nutt, W., Griggs, B., Eachus, S., Pikulin, M., “Developing an Ozone Process,” Presented TAPPI 1992 Pulping Conference

supplied liquid oxygen from their own off-site production facilities, but they had also set up "over-the-fence" supply systems directly adjacent to the mill which they designed, built, and operated on behalf of the paper companies.

CONCLUSIONS

Using chemical methods to make pulp was essentially an extraction process. Manufacturers performed a series of operations aimed at isolating and removing cellulose from wood sources. In these operations, only approximately 50% of the initial raw material became part of the final product. The rest of the wood was either burned for fuel or disposed as waste. The large volume of this waste and its effect on the surrounding environment led governments to regulate pulp mills.

In the U. S., regulations demanded that manufacturers adopt the "best available technology" for control of releases from pulp and paper operations. All mills installed secondary treatment during the mid to late 1970s. This led to reductions in conventional pollutants by as much as 95 %, but required substantial capital and operating expenditures.

in Canada and Sweden, many pulp mills discharged into large bodies of water (as opposed to rivers in the U. S .) which had high assimilative capacity for the conventional pollutants of the pulp mills. As a result, only about half of pulp manufacturers were required to install secondary treatment and these requirements came later than those in the U.S. Swedish regulations put requirements on measures such as biological oxygen demand (BOD) which were less restrictive than those in the U . S. These requirements could be met through adoption of in-process, pollution prevention methods. Extended delignification and oxygen delignification emerged as technologies which could substantially reduce pollution while providing offsets to manufacturers. Instead of offering means of treating wastes, these methods made it possible to use the waste for fuel, thereby lowering operating costs. The financial benefits of extended delignification were clear (in mills where it could be adopted) and this technology would likely have emerged whether or not regulations had required waste reduction. It is less clear whether oxygen delignification provided benefits sufftcient to offset capital costs. The environmental benefits of this technology contributed to manufacturers' decisions to pursue oxygen delignification particularly in Scandinavia where these benefits were adequate in many cases to meet existing regulatory requirements.

Environmental Effect of Pulp and Paper Technologies

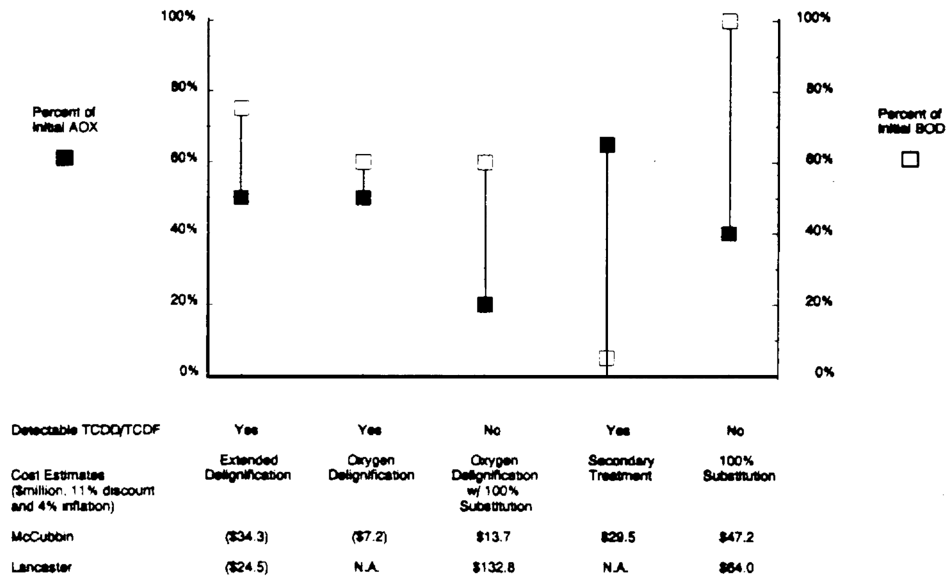


Figure 12: Environmental Effect of Pulp and Paper Technologies: The cost data are discounted at 11% and assumed to grow at a 4% rate of inflation

Using data from McCubbin,[115] figure 12 demonstrates an additional benefit of adopting in-process technologies: with the entire waste load reduced, unrecognized problem materials were reduced along with targeted pollutants. Oxygen delignification lowered BOD releases by more than 35 %, and because total bleaching effluent was reduced, AOX was reduced by more than 50%. Additionally, internal processes could be additive. Oxygen delignification could be combined

115. McCubbin, Neil, "Costs and Benefits of Various Pollution Prevention Technologies in the Kraft Pulp Industry," in Proceedings of the International Symposium on Pollution Prevention in the Manufacture of Pulp and Paper: Opportunities & Barriers, August 18-20. 1992, Washington, D.C.

with ozone bleaching to reach BOD levels which were 5% of that in mills using traditional processes (while AOX was reduced to 1 %).[116]

The nature of early U.S. regulations in many ways worked against the development of these innovative technologies. In the late 197Os, when conventional pollutants were targeted for reduction, U.S. regulations required all manufacturers to adopt the "best available technology" for the targeted pollutants (with no requirements on total waste stream). Not surprisingly, secondary treatments designed to achieve pollutant reductions resulted in the lowest emissions. The emergence of a second type of concern, reducing release of organochlorines, led to a second round of technology identification and manufacturer regulation. Ultimately, this led manufacturers to incur new expenses typically involving pollution prevention process changes. The earlier installation of secondary treatment had minimized BOD but only reduced AOX by 35 %. More importantly, there was never any reason to believe that secondary treatment would lead to reductions in the total volume of waste in the mill. So long as large volumes of material were being released, the potential remained that residual components of the treatment process would be identified as environmental hazards. This is, of course, what occurred in the case of dioxin in pulp mill effluent.

There is great uncertainty in projecting how a technology will develop and in determining what environmental challenges lay in the future. However, regulating under a system using "best available technology" tends to freeze the development of alternative technologies once a method of environmental control has been identified. When secondary treatment is chosen, innovative in-process technologies may never emerge.

When one nation adopts regulations which require a specified technology while others encourage m-process changes, the effect on upstream suppliers can be dramatic. Although the U.S. led the regulation of the pulp and paper industry, little advantage appears to have been achieved by the

116. Union Camp, "New Union Camp Pulp Bleach Plant is First to Replace Chlorine with Ozone," Company Press Release, October 8, 1992

domestic suppliers to the industry. U.S. regulations on pulp manufacturers in the 1970s could only be met through the addition of secondary treatment. Internal measures which provided reduced operating costs and environmental improvements were not implemented because they did not achieve effluent levels equivalent to those reached using secondary treatment. Once secondary treatment was installed, little experimentation was undertaken by U.S. equipment suppliers. Scandinavian equipment manufacturers, already leaders in the industry, reinforced their strong market position as they developed the innovative technologies that their customers were implementing.

The second factor which worked against the industry's suppliers was the long time lag between concept and reality in this industry. Methods such as oxygen delignification and ozone bleaching took more than a decade to bring to commercialization. Because U.S. manufacturers were required to rapidly respond to their permit requirements, they had to adopt the best technology then available to them. Meanwhile, Swedish producers, anticipating increasingly strict regulations on their operations, were more likely to incorporate improved environmental performance into the normal cycles of capacity replacement and expansion. Suppliers found a willing market for innovations which provided in-process pollution prevention. U.S. firms, later targeting further lowering of emissions, were beginning to adopt these technologies - making a significant amount of available wastewater treatment capacity unnecessary.

APPENDIX 1
POLLUTION PREVENTION METHODS USED TO REDUCE CHLORINATED ORGANIC EMISSIONS

The following summary of pulping and bleaching processes, briefly highlights the main features - advantages and disadvantages, cost impact, environmental benefits, limitations, installed base and primary equipment suppliers of each process. This is not intended to be a thorough technical review of the processes, but rather an overview which highlights the impact that these processes have had on the environment, paper companies, and their equipment and chemical suppliers. Several very comprehensive reviews of the available technologies have been carried out by U.S. and Canadian government agencies:

- The U.S. Office of Technology Assessment, Washington D.C. "Technologies for Reducing Dioxin in the Manufacture of Bleached Wood Pulp. Background Paper," May 1989

- The U.S. Environmental Protection Agency, Office of Water Regulations and Standards, Washington D.C. "Summary of the Technologies for the Control and Reduction of Chlorinated Organics from the Bleached Chemical Pulping Subcategories of the Pulp and Paper Industry," April 27, 1990

- The U.S. Environmental Protection Agency, Office of Pollution Prevention and Toxics/ Pollution Prevention Division, Washington D.C. "Pollution Prevention Technologies for the Bleached Kraft Segment of the U.S. Pulp and Paper Industry," July 1993

- The Ontario Ministry of Environment, "Best Available Technology for the Ontario Pulp and Paper Industry," February 1992

Pulping Processes

Extended Delignification

Process: Extended delignification methods achieved greater removal of lignin in the digester by lengthening the kraft cooking process. As a result, the quantity of bleaching chemicals required could be reduced. Detrimental effects on the quality and yield of the pulp were minimized by careful control of process conditions and by introducing the cooking chemicals at several points during the cycle.

The extended cooking process was initially developed by the Swedish Forest Products Institute (STFI) in the late 1970's. Commercial applications for continuous digesters, the Modified Continuous Cook (MCC) and Extended Modified Continuous Cook (EMCC) were developed by Karnyr of Sweden. The U.S.firm, Beloit, developed an extended batch process called Rapid Displacement Heating, while Sunds Defibrator of Sweden used similar principles in commercializing the SuperBatch process which used similar principles.

Installed Base: In 1992, 20% (11 million tpy) of the world's bleached kraft capacity used extended cooking pulping processes. Of the 62 extended delignification systems installed worldwide between 1983 and 1992, (40 in N. America), 48 were applied to continuous cooking digesters and thus supplied by Kamyr.[117]

Cost impact: For a new, average size (1,200 air dried short tons (ADST) per day) facility Kamyr estimated a cost of approximately $16 million for the equipment. This would suggest an installed cost of $35-45 million. Extended cooking could be retrofitted to most continuous digester systems. Dependent upon the existing installed technology the retrofit cost could vary from $1-30 million with several industry estimates averaging around $5 million. Because they tended to be older equipment, retrofitting batch systems was less attractive. In those cases where retrofitting was more attractive than replacement, conversion cost suggested by Beloit was approximately $600,00 per digester.

Installation of extended cooking equipment yielded operating cost savings, steam use savings, lower evaporation costs (due to higher solids concentration in the liquor), and reduced chemical costs of up to 50%. Beloit estimated an 18 month payback for a retrofit. However, because

117. Eastern Research Group, Inc., Pollution Prevention Technologies in the Bleached Kraft Segment of the U.S. Pulp & Paper Industry, Draft Final Report - March 1993. pp. 4-17-19, prepared for Office of Pollution Prevention and Toxics/Pollution Prevention Division, U.S. Environmental Protection Agency 1993

extended delignification increases the amount of lignin and organic solids removed in the pulping process by 5-10%, the process resulted in an increase in the recovery boiler load. Many manufacturers claimed to be boiler capacity limited suggesting they would require rebuilds and retrofits to maintain plant capacity. However, there were many ways by which to increase boiler capacity and the costs could vary from $100,000 to reduce boiler feed water temperature to $100 million for a replacement boiler; the requirement was mill specific.

It was difficult to distinguish the true capacity limitations of the mills. Manufacturers often cited recovery boiler costs as a primary reason to limit the demands on the industry for effluent pollutant reductions. Other sources, including environmental activists, claimed the capacity either existed or could be attained at a very modest cost.

Pollution Prevention: Extended delignification could reduce the kappa number of the pulp leaving the pulping stage by 50%) from approximately 30 to approximately 15. This resulted in a reduction of chlorinated organics, measured by AOX, and color from the bleach plant of 30%. Increased recovery boiler loads increased the quantity of solid waste as ash, dregs and grit by 5%, which usually went to a landfill. Air emissions were controlled by sophisticated control equipment to comply with regulations and were relatively unaffected by the increased load.

Advantages

1. Achieved additional lignin removal with recoverable pulping chemicals rather than through the use of conventional bleaching chemicals which had to be disposed
2. Reduced chemical consumption in the bleaching plant
3. 10-15 % reduction in pulping cycle time
4. Up to 65% reduction in steam consumption
5. Up to 10% increase in pulp strength
6. Significant energy savings per ton of pulp (- 800 kW/ ton of pulp).
7. Reduced chemicals consumption.

Disadvantages

1. Possible impact of increased recovery boiler loads
2. High capital cost of equipment and installation in older facilities
3. Significant amount of space requiring additional equipment, especially for batch digesters

Oxvgen Delignification

Process : In reality, there was no clear distinction between pulping and bleaching operations, both simply separated lignin from cellulose. Oxygen delignification used oxygen to remove lignin and either replaced or reduced the role of the primary chlorine bleaching stage. However, because it provided bulk delignification, it could as easily be considered and extension of the pulping process as it could the first step in a bleaching sequence.

The process added an oxygen reaction tower between the pulping and bleaching plants. After leaving the digester, the brownstock pulp was washed and treated with sodium hydroxide and oxygen prior to entering a pressurized reactor. In the reactor the oxygen removed additional lignin from the pulp in an alkaline environment. After reacting the pulp was washed and the filtrate recirculated.

The process was originally developed as a high consistency (25-28% solids) process, however, with the development of high shear mixers medium consistency (lo-12%) became feasible. The selection of consistency used is based on capital cost chemical and power cost and consumption and the degree of delignification required. Generally high consistency systems can achieve greater delignification, but require more power to operate. Oxygen delignification can be integrated with extended delignification to give very low kappa numbers.

Installed Base: Oxygen delignification technology was first developed in 1952, but the first commercial units came onstream in the early 1970's. The discovery in France that addition of magnesium salts inhibited the degradation of cellulose, which had been a problem with the early systems, led to widespread adoption in Sweden and Japan in the late 1970's and 1980's. Scandinavian companies, Kamyr and Sunds Defibrator developed and manufactured much of the technology, and sold it throughout the world. All kraft mills in Sweden had installed oxygen delignification systems by 1992. Many of these mills were initially permitted to operate without biological treatment systems (often because they discharged into the sea rather than rivers). In Japan, oxygen was relatively cheap in comparison to chlorine, and this encouraged the installation of oxygen delignification systems and activated sludge treatment systems. In North America where biological treatment systems were required to meet the more rigorous BOD standards, the additional BOD reductions achieved by the use of oxygen delignification equipment were not pursued.

In 1993 there were 155 mills worldwide fitted with oxygen delignification systems, representing 26 million tons of capacity (34% of kraft mill capacity). 45% of the capacity was in Europe, 20% was in Japan, and 25% was in North America.[118] 92 % of oxygen delignification systems was in kraft mills, and 60% was in bleached softwoods.

Cost Impact: The capital cost of oxygen delignification systems was high. Estimates ranged between $20 and $30 million to retrofit equipment on an existing kraft mill where additional pulp washing was also required.[119] Generally, high consistency systems were more expensive than medium consistency systems because of the additional pulp press required. The cost of retrofitting could be far higher if a recovery boiler upgrade was needed -as described above for extended delignification. Some estimates suggested costs in excess of $100 million would be experienced if recovery boiler capacity was needed. [120]

118. Johnson, Tony, “Worldwide Survey of Oxygen Bleach Plants - Examples and Case Studies,” Proceedings, Nonchlorine Bleaching Conference, Hilton Head, SC, March 1992

119. McCubbin, Neil, “Costs and Benefits of Various Pollution Prevention Technologies in the Kraft pulp Industry.” in Proceedings of the International Symposium on Pollution Prevention in the Manufacture of Pulp and Paper: Opportunities & Barriers, August 18-20, 1992, Washington, D.C.

120. Lancaster, Lindsay M., et. al., “The Effects of Alternative Pulping and Bleaching Processes on Product Performance - Economic and Environmental Concerns,” in Proceedings of the Intenational Symposium on Pollution Prevention in the Manufacture of Pulp and Paper: Opportunities & Barriers, August 18-20, 1992

The chemical savings associated with oxygen delignification were proportional to the reduction in kappa number. As oxygen required only one eighth of the energy to produce as the chemically equivalent amount of chlorine, it was the cheapest of oxidizing bleaching agents. Oxygen systems used a similar amount of steam and electricity, but far less chemicals, significantly less water requiring pumping, and less wastewater requiring treating. Large scale mills required up to 150 tons of oxygen per day. If the mill installed its own oxygen generation facilities the cost per ton could be half that of imported liquid oxygen (on-site production could be economical for uses above 10 tpd). The provision of on-site pressure swing absorption oxygen makers to paper companies presented a significant new market for oxygen equipment suppliers such as Air Products and Liquid Air. Overall, savings per ton of pulp were greater for softwood than hardwood (due to the relatively larger chemicals savings for harder to bleach softwoods) being - $12 and - $4 respectively. Assuming a $17 million installed capital cost for a 1,000 tpd facility being depreciated, and operational savings of $9/ton the payback period of the investment was around seven years.[121] Of course, in any new facility, with savings in wastewater treatment capacity and bleaching chemical production capacity, the returns on a design incorporating oxygen delignification were much more rapid. The system was expected to be used in any new capacity to be built regardless of environmental requirements.

Pollution Prevention: The environmental benefits of oxygen delignification were two fold. First, the reduced amount of lignin carried forward in the pulp to the bleaching process reduces the levels of BOD by - 50%, and color in the effluent by - 70 %. Secondly, the use of an oxygen delignification stage ahead of any chlorine bleaching stages reduced the amount of chlorine or chlorine dioxide required for a given level of brightness; this resulted in a reduction in the amount of chlorinated organics formed. Various studies have shown this reduction to be between 35% and 50%.

121. United States Environmental Protection Agency - Office of Water Regulations and Standards, Office of Water Enforcement and Permits, Summary of Technologies for the Reduction of Chlorinated Organics from the Bleached Chemical Pulping Subcategories of the Pulp and Paper Industry, pp. 33, April 27, 1990; Washington D.C.

Advantages

1. Reduced chemical and water usage
2. Reduced effluent production
3. Relative safety of oxygen relative to chlorine
4. Lower operating costs
5. Improved brightness stability

Disadvantages

1. High capital cost
2. Increased complexity of operations
3. Increased difficulty in controlling pulp quality due to strength degradation
4. Potential fire hazard of high consistency systems
5. Impact on the chlorine-caustic balance can increase caustic price

Ozone Delignification

Process : Although ozone is an extremely powerful oxidizing agent, it was not used in pulping and bleaching processes until the early 1990s. Prior to that time, all attempts at using ozone had led to detrimental effects on pulp quality. Following a 10-year research effort, Union Camp concluded that it could use ozone to bleach pulp if it used a high consistency system and applied its knowledge of the reaction kinetics of pulp and ozone to carefully control process variables. At the company's mill in Franklin, Virginia, acidified, high consistency pulp was fluffed and reacted with ozone at atmospheric pressure. Using ozone in the bleaching process required the installation of on-site ozone generating capacity because the gas was too unstable to transported from off-site production. This equipment was a significant amount of the cost of the ozone bleaching plant capital cost.

Installed Base: . Union Camp produced 1,000 tpd of ozone bleached pulp at Franklin. Other plants at Monsteras in Sweden and Lenzing in Austria were producing kraft pulp using a medium consistency process. In 1993, Union Camp was marketing the technology in a joint-venture with the equipment manufacturer Sunds Defibrator to potential customers worldwide. There had been considerable interest in the process, and Union Camp expected to license the technology to several companies before 1995.[122] The patent for the process was held by Union Camp, and the equipment design and know how was provided by Sunds Defibrator.

Cost Impact: An ozone bleaching stage was more expensive than the chlorine bleaching stage it would replace. This was due to the requirement to press pulp to a high consistency prior to ozone treatment, the special reactor required, and the ozone generators and gas recycle system needed. Union Camp estimated that the cost of a new ozone bleach plant was 25-30% higher than the conventional alternative. The Franklin bleach plant cost $90 million fully installed. Oxygen delignification or extended delignification (or both) were considered prerequisite for an ozone stage, so the applicability of the process was limited to mills with the systems installed plus those willing to undertake multiple installations. However, especially for a greenfield site there were significant operating cost savings resulting from the reduction in bleach plant costs (smaller chlorine dioxide plant), and reduced water supply and wastewater treatment systems. Union Camp estimated operating costs are 30-70% below those of conventional bleach plants, particularly when compared with high substitution systems treating southern pine.

Pollution Prevention: Installation of an ozone bleaching system following an oxygen delignification process could profoundly improve the environmental performance of a bleach kraft mill. Emissions from the Franklin plant were very low because of the ability to recycle all of the effluent from the oxygen and ozone stages. Dioxin was non-detectable, total chlorinated organics were reduced by 70-99% in comparison to conventional processes; BOD,COD and color were all reduced by - 90%; and effluent volume was reduced by 45-90%.

Advantages

1. Reduced operating costs especially when bleaching softwood
2. Exceptionally low process emissions

122. Union Camp Technology Corp., Wells Nutt - President, Interview, August 3, 1993. Franklin, Virginia

3. Ability to manufacture totally chlorine free pulp (TCF) when used with a final peroxide finishing step
4. Relative safety of ozone compared to chlorine, and minimal inventory of ozone in the process

Disadvantages

1. High capital cost
2. Relative complexity of the process
3. Requirement for oxygen or extended delignification of pulp upstream

Improved Brownstock Washing and Screening

Process: Pulp was washed after the pulping process to remove the lignin and organic matter (black liquor) from the fibers, prior to screening to remove partially cooked fibers, shives, and other debris which could not be bleached. The screens only operated at low consistency (2% solids) so large amounts of water were required to dilute the pulp.

In the 1990s, new washing technology focused on reducing effluent flows, increasing energy efficiency and achieving more selective removal of lignin and other organics from the pulp. State-of-the-art washing systems used atmospheric or pressure diffusion washers, belts or presses to replace standard vacuum pressure units. These processes enabled washing to be carried out at higher consistencies, thus reducing the quantity of effluent produced and amount of energy used.

Installed Base: It is very difficult to determine how much the industry had invested in improved washing technology as it was done when modifying existing equipment, or replacing of old equipment. However, the importance of washing in reducing effluent flows was recognized as a significant part of achieving environmental requirements throughout the industry.

Cost Impact: As mentioned above the scale of upgrading of washing facilities varied widely from plant to plant dependent upon the type of changes carried out. Typical capital costs for extensive renovation of washing systems were approximately $10 million. The resulting reduction in operating costs ranged between $2 and $5 per ton.

Pollution Prevention: Better pulp washing reduced the amount of lignin moving forward through the pulping process, thus reducing BOD, COD, AOX and color in subsequent plant effluent.

Advantages

1. Relatively easy to retrofit due to smaller sized new technology
2. Could be added as and when required to spread capital expenditures
3. Worked well with new computer optimized process control systems

Disadvantages

1. Did not eliminate chlorinated organics formation later in plant
2. Increased recovery boiler loads

Bleaching Processes

Incremental Chlorine Addition and pH Control

Process: Westvaco developed a technique of splitting the addition of chlorine in the bleach plant as a way of reducing the propensity of pulp and chlorine to form chlorinated organics in the late 1980's. The company had discovered that if the concentration of the chlorine in each chlorination stage was closely controlled the quantity of dioxin and AOX formed could be dramatically reduced. The amount of chemical used was the same, but it was added in smaller charges at multiple points in the reactor. The close control of pH in the reactor helped reduce the formation of AOX even further.

Installed Base: Westvaco had installed multiple addition technology at all three of its bleached kraft mills. No other company was using this technology by the early 1990s.

Cost Impact: Westvaco reports that it spent $25 million modifying its five bleach lines, only half of this was the cost of the multiple addition technology the remainder being spent on additional chlorine dioxide capacity. Operating costs were unchanged as the total amount of bleaching chemicals used remained the same.

Pollution Prevention: Westvaco reported that reduction of up to a 96% in effluent dioxin had been observed. However, no reduction in total chlorinated organics BOD, COD or color were claimed.

Advantages

1. Relatively cheap modifications
2. Improved process control

Disadvantages

1. No real impact on chlorinated organics production
2. Careful pH control required to avoid cellulose damage
3. No reduction in BOD, TSS, or AOX

Chlorine Substitution

Process: Chlorine dioxide was a more powerful oxidizing agent than chlorine providing 2.63 times the oxidizing power of an equivalent mass of chlorine; this increased the number of oxidative reactions and reduced the formation of chlorinated organics. Chlorine dioxide could be substituted for some portion or all of the chlorine used in the bleach plant.

Chlorine dioxide had been widely used as a bleaching agent as early as the 1960's usually in the final stages of a bleach plant where its increased selectivity for lignin reduced cellulose degradation. In the early 1990s, the focus had been on using up to 70% chlorine dioxide in the initial bleaching stages to improve pulp and effluent quality. At substitution levels nearing 100%, pulp yield and brightness limits were slightly lower than for lower substitution levels, but so was the formation of chlorinated organics.

Like ozone, chlorine dioxide was unstable and therefore was not suitable for transportation and long-term storage. Thus, it had to be generated on site. The main method of generating chlorine dioxide was by the reduction of sodium chlorate. The sodium chlorate itself was manufactured offsite using an electrolysis process similar to that used to produce chloro-alkalis. There were several different reducing agents which were used to reduce the sodium chlorate including sulfur dioxide, methanol, and sodium chloride. The main difference between these processes was the byproducts they produced which could include chlorine, sulfuric acid, sodium sulphate and sodium chloride. The production of the byproducts often exceeded a plants need for these products, so in the late 1980's new processes were developed such as the R8/SVP-Lite, R9 and R6/Chemetics processes which generated few or no byproducts.

Installed Base: There was a large increase in the use of chlorine dioxide substitution beginning in the early 1980's with growth rates between 7-10% per year. This can be seen in the rapid increase in sodium chlorate production (90% of which is used by the paper industry). In 1987, 500,000 tons of sodium chlorate were used. By 1995, close to 1 million tons were expected to be produced.

The percentage substitution in North American plants increased with increasingly strict environmental regulations. In 1992, there were approximately 166 chlorine dioxide generators in North America, giving an installed capacity of 3,194 tpd, the majority of these used modem methanol based technology.

Different U.S. companies were pursuing different strategies with chlorine substitution, Georgia-Pacific increased substitutionlevels beyond 70% at its facilities. By contrast, Weyerhauser stated that the company intended to improve environmental performance using other techniques such as oxygen delignification, allowing higher relative substitution with their' existing capacity. European and Japanese manufacturers used chlorine dioxide as a final bleaching agent, relying on delignification techniques to remove the majority of lignin and color from pulp.

Cost Impact: A 30 tpd chlorine dioxide system cost approximately $16 million installed, this allowed 60% substitution at a 1000 tpd mill. This cost was relatively low compared to delignification techniques, and the displacement of chlorine gas by chlorine dioxide required only minimal modifications to the bleach plant. For most mills, substitution was the simplest, proven and most economical way of reducing chlorinated organics formation, while still achieving high pulp quality. Although chlorine dioxide could cost up to eight times the cost of elemental chlorine, almost three times less was required to oxidize the same amount of pulp. By using oxygen delignification and 70% substitution an a 1,000 tpd mill only 6.4 tons of chlorine and 5.7 tons of chlorine dioxide were needed in comparison to 41.7 tons of chlorine required at an equivalent mill without oxygen delignification and only 10% substitution. increased chlorine dioxide substitution also increased the amount of sodium hydroxide needed in subsequent extraction stages. Various studies had been performed which indicated that high substitution bleaching increased bleaching costs by approximately $3-4 per ton.[123]

Pollution Prevention: Chlorine dioxide substitution dramatically reduced the formation of chlorinated organics in the bleaching process because this reaction was proportional to the number of chlorine atoms consumed. Chlorine dioxide contained half the number of chlorine ions and was almost three times as oxidative as an equivalent chlorine atom. For high levels of substitution this resulted in less than a fifth of the chlorinated organics and non detectable dioxin levels being produced, when compared to conventional bleaching. Substitution had little effect on BOD or color.

Advantages

1. Relatively cheap, well proven technology
2. Easy to retrofit to existing facilities
3. Capacity could be added incrementally

123. Bettis,J, Bleach Plant Modifications, “Controls Help Industry Limit Dioxin Formation”, Pulp & Paper, pp. 76-82, June 1991

Disadvantages

1. Did not eliminate the use of highly corrosive chlorine compounds, limiting effluent recycling
2. Had little impact on BOD and color
3. Increases the quantity of caustic required in subsequent extraction stages
4. Chlorine dioxide more expensive to manufacture than chlorine

APPENDIX 2
DEINKING PULP PRODUCTION

The alternative source of pulp for paper product manufacture was made from recycled waste paper. Waste paper had to be graded prior to reprocessing, to ensure the grade was consistent with the intended end use. Old newspapers (ONP) and old corrugated containers (OCC) were the largest recycled papergrades with office waste paper being increasingly recycled Newsprint and office paper needed to be deinked before they could be reused.

The first step in the recycling process was “defiberization” - mashing up the old fibers with water and chemicals in a pulper (high speed agitator) to form a suspension of the fibers in water. This mixture was then run through several different screening processes to remove fillers, adhesive, plastics, staples, shives and dirt. Once the pulp had been washed, and some of the water had been removed it was ready for integration into the papermaking process or deinking if required

The deinking process evolved significantly between 1970 and 1990 from very simple washing processes to sophisticated flotation cell operation. The deinking process aimed to loosen the ink particles and removed them from the pulp without any loss of brightness or significant fiber degradation. The washing process required a surfactant that acted much like a laundry detergent. It lifted the ink particles off the paper and made them “hydrophilic” (water-loving) so they could be detached and washed away from the fiber.

The flotation system required that the surfactant make the ink particles “hydrophobic” (water-hating) to allow them to cling to air bubbles and accumulate in the foam of the flotation cells where they could be skimmed off. Alcohol derivatives were often used in the washing process, while fatty acid (soap-like) derivatives were used in floatation cells.[124] The flotation process used less water and chemicals but could not remove flexographic water-based inks which were being

124. Basta,N., Gilges K., Ushio S., “Paper Recycling’s New Look”, Chemical Engineering, pp. 45-48F. March 1991

used increasingly by newspaper publishers. A combination of these two processes which took advantage of the best aspects of both systems was becoming increasingly popular. The wastewater effluent and mill sludge had to be disposed of and approximately 30% of the original fiber mass was lost.

Generally the strength of secondary fiber was lower than virgin fiber and therefore could not compete at an equal cost. The major obstacle to increased use of wastepaper furnish was the cost of collection and sorting, contamination of one grade of waste paper with another could cause deinking and pulping problems.[125]

125. American Papermaker Staff Report, "Some Novel Approaches To Deinking Operations In the United States", pp. 36-38, American Papermaker, September 1992

APPENDIX 3
BLEACHING CHEMICAL SEQUENCES

A variety of bleaching sequences were used in producing high brightness chemically pulped paper grades. typically these involved reaction stages followed by extraction and washing. The following table (as presented in Pulp and Paper, November 1991) lists the chemicals used in pulp bleaching and the symbols used to describe them. For example, the sequence CEDED involved a chlorine bleaching stage followed by caustic extraction, further bleaching with chlorine dioxide, a second extraction, and finally a second chlorine dioxide polishing stage. An OZEP line would use oxygen delignificaiton, ozone bleaching, caustic extraction, and finally hydrogen peroxide bleaching. OZEP would be a totally chlorine free process.

C	Chlorination
C_D	Chlorination with chlorine dioxide substitution
E	Caustic Extraction
E_O	Caustic Extraction with oxygen reinforcement
0	Oxygen Delignification
Z	Ozone Bleaching
ZW	Ozone filtrate wash
P	Peroxide
H	Hypochlorite
Y	Sodium Hydrosulfite

Table 1
1990 Pulp and Paper Production
(thousand tons)

	Paper Production	Pulp Production
United States	71,519	57,214
Japan	28,086	11,328
Canada	16,466	22,835
China (People's Republic)	13,719	10,270
Germany (West)	11,873	2,339
U.S.S.R.	9,800	9,600
Finland	8,958	8,886
Sweden	8,426	9,914
France	7,049	2,200
Italy	5,601	676
Brazil	4,844	4,453
United Kingdom	4,824	595

Source: Pulp & Paper International: 1992 Intenational Fact & Price Book

Table 2
Paper Production by Market Segment
(thousand tons)

	United States	Canada	Japan	Germany (West)	Finland	Sweden	France	Italy	United Kingdom
Paper:									
Newsprint	5,997	9,068	3,479	1,118	1,430	2,273	422	233	696
Printing & Writing	20,097	3,599	7,218	5,008	4,766	1,655	2,773	2,242	1,387
Household/Tissue	5,264	472	1,366	828	167	283	329	261	440
Other	1,842	0	4,064	281	174	124	246	173	128
Paperboard:									
Greaseproof	511	0	0	94	40	22	0	58	15
Linerboard/Fluting	24,460	2,062	8,275	2,082	716	1,777	2,192	1,278	1,303
Sacks	2,596	493	648	62	434	837	197	80	81
Boxboard	6,871	449	2,242	859	972	1,323	330	715	465
Other	4,524	343	792	1,541	265	124	559	541	540
Total	72,162	16,486	28,084	11,873	8,964	8,418	7,048	5,581	5,055

Source: OECD: The Pulp and Paper Industry, 1990

Table 3
Pulp Production by Market Segment
(thousand tons)

	United States	Canada	Japan	Germany (West)	Finland	Sweden	France	Italy	United Kingdom
Pulp:									
Mechanical	5,772	10,537	2,047	1,496	3,293	2,953	558	449	595
Semi-Chemical	3,828	465	324	76	434	284	112	88	0
Bleached Kraft	25,002	8,802	6,950	0	4,198	3,551	838	0	0
Unbleached Kraft	20,024	1,360	1,771	0	671	2,097	474	0	0
Sulphite	1,416	1,451	31	661	102	733	221	54	0
Dissolving Pulp	1,173	221	187	106	188	296	0	30	0
Other Pulp	0	0	0	0	0	0	0	96	0
Total	57,215	22,836	11,310	2,339	8,886	9,914	2,203	717	595

Source: OECD: The Pulp and Paper Industry, 1990

Table 4
World Export Share of Paper and Paperboard

	1990	1985	1980
Canada	15.2%	22.2%	19.1%
Finland	13.7%	14.0%	13.7%
Sweden	11.8%	12.0%	13.4%
Germany West,	11.61	10.5%	8.9%
United States	7.8%	8.0%	10.6%
France	6.0%	4 7%	5.2%
Netherlands	4.5%	3.5%	3.8%
Austria	4.1%	3.1%	3.1%
United Kingdom	4.3%	3. 1%	3. 6%
Italy	3. 1%	3.0%	1. 9%

Source: UN Trade Statistics Yearbook, 1990

Table 5
World Import Share of Paper and Paperboard

	1990	1985	1980
Canada	2.6%	2.3%	1.6%
Finland	0.4%	0.5%	
Sweden	0.9%	1.0%	1.0%
Germany West	13.6%	10.6%	13 8%
United States	16.3%	24.5%	16.5%
France	9.2%	7.1%	8.3%
Netherlands	4.5%	9.2%	5. 3%
Austria	1. 0%	1.3%	1. 0%
United Kingdom	12.0%	10.6%	12.8%
Italy	5.0%	3.7%	3 . 4 %

Source: UN Trade Statistics Yearbook, 1990

Table 6
Balance of Trade in Paper and Paperboard
(million dollars)

	1990	1985	1980
Canada	6.382	4.315	3.619
Finland	6.570	3.021	
Sweden	5.367	2,453	2569
Germany (west)	(1.168)	(135)	(1.043)
United States	(4430)	(3898)	(1.258)
France	(1694)	(607)	(641)
Netherlands	(446)	(255)	(316)
Austria	1.360	456	420
United Kingdom	(3.908)	(2.048)	(1.925)
Italy	(1.003)	(188)	(1.108)

Source: UN Trade Statistics Yearbook. 1990

Table 7
World Export Share of Pulp and Waste Paper

Country	1990	1985	1980
Canada	30.92%	30.98%	33.36%
U.S.	23.62%	21.93%	20.81%
Sweden	11.44%	13.83%	14.38%
Finland	6.00%	6.81%	2.16%
Portugal	3.99%	3.52%	1.92%
Brazil	3.51%	4.21%	0.00%
Norway	2.34%	1.45%	2.16%
Spain	2.09%	1.42%	0.86%
France	2.23%	2.19%	0.86%
Chile	2.14%	1.45%	N.A.

Source: UN Trade Stanstics Yearbook, 1990

Table 8
World Import Share of Pulp and Waste Paper

Country	1990	1985	1980
Canada	1.56%	1.83%	1.32%
U.S.	16.27%	17.87%	17.60%
Sweden	0.87%	0.79%	0.51%
Finland	0.36%	0.32%	0.20%
Portugal	0.24%	0.23%	0.19%
Brazil	0.20%	0.05%	0.38%
Norway	0.32%	0.50%	1.39%
Spain	2.29%	2.20%	1.97%
France	7.50%	7.96%	9.16%
Chile	0.00%	0.00%	N.A.

Source: UN Trade Statistics Yearbook. 1990

Table 9
Balance of Trade in Pulp and Waste Paper
(million dollars)

Country	1990	1985	1980
Canada	5,000	2.369	3,199
U S	1.034	238	313
Sweden	1.795	1.060	1.384
Finland	959	527	195
Portugal	638	268	172
Brazil	563	339	(38)
Norway	341	75	75
Spain	(65)	(75)	(111)
France	(1004)	(512)	(831)
Chile	367	119	N A

Source: UN Trade Statistics Yearbook, 1990

Table 10
World Export Share of Newsprint

Country	1990	1985	1980
Canada	56.75%	68.25%	61.72%
Sweden	13.14%	8.88%	11.72%
Finland	8.66%	10.29%	12.73%
Norway	5.33%	4.23%	4.90%
U S	3.58%	2.69%	2.15%
Germany (West)	3 .16%	1.22%	0.89%
Netherlands	1. 69%	.59%	048%
New Zealand	1.31%	0.31%	1.76%
South Africa	039%	059%	N.A
UK.	1.42%	0.41%	0.65%

Source: **UN Trade Statistics Yearbook, 1990**

Table 11
World Import Share of Newsprint

Country	1990	1985	1980
Canada	0.00%	0.00%	0.00%
Sweden	0.00%	0.00%	0.00%
Finland	0.00%	0.00%	0.00%
Norway	0.00%	0.00%	0.00%
U.S.	47.07%	67.42%	49.18%
Germany (West)	9.05%	6.30%	8.94%
Netherlands	2.88%	1.92%	3.35%
New Zealand	0.12%	0.27%	0.00%
So. Africa	0.00%	0.00%	N.A.
U.K.	10.17%	9.66%	11.81%

Source: UN Trade Statistics Yearbook, 1990

Table 12
Balance of Trade in Newsprint
(million dollars)

Country	1990	1985	1980
Canada	5,044	3,959	3.144
Sweden	1,168	515	597
Finland	770	597	649
Norway	473	245	250
U.S	(4.141)	(3.564)	(2.633)
Germany (West)	(577)	(277)	(453)
Netherlands	(122)	(72)	(162)
New Zealand	105	3	90
South Africa	35	34	N.A
U.K.	(838)	(509)	(626)

Source: UN Trade Statistics Yearbook, 1990

Table 13
World Export Share of Printing and Writing Papers

Country	1990	1985	1980
Finland	16.25%	22.79%	18.98%
Germany (West)	15.30%	15.75%	12.89%
Austria	10.27%	7.56%	7.34%
France	10.09%	7.38%	8.97%
Sweden	9.26%	6.47%	6.89%
Italy	5.14%	5.66%	5.33%
Netherlands	5.65%	4.53%	4.69%
Belgium	4.71%	2.42%	4.52%
Canada	4.09%	6.88%	6.17%
Japan	3.05%	5.24%	5.79%

Source: UN Trade Statistics Yearbook, 1990

Table 14
World Import Share of Printing and Writing Papers

Country	1990	1985	1980
Finland	0.29%	0.16%	000%
GermanyWest	14.68%	12.87%	18.43%
Austria	1.45%	1.23%	098%
France	9.58%	8.41%	10.19%
Sweden	0.79%	0.65%	0.58%
Italy	4.05%	3.61%	2.99%
Netherlands	5.28%	5.20%	6.53%
Belgium	5.05%	4.30%	5.78%
Canada	2.89%	3.10%	2.26%
Japan	1.12%	0.99%	0.52%

Source: UN Trade Statistics Yearbook. 1990

Table 15
Balance of Trade in Printing and Writing Papers
(million dollars)

Country	1990	1985	1980
Finland	1, 736	1,444	1.037
Germany (West)	34	I36	(279)
Austria	957	400	349
France	34	(97)	(53)
Sweden	920	369	346
Italy	109	118	131
Netherlands	28	(62)	(92)
Belgium	(48)	(136)	(62)
Canada	124	230	217
Japan	208	268	289

Source: UN Trade Statistics yearbook, 1990

Table 16
World Export Share of Bleached Nondissolving Pulp

Country	1990	1985	1980
Canada	37.06%	39.55%	44.22%
U.S.	20.45%	17.76%	16.57%
Sweden	12.37%	15.50%	14.56%
Finland	6.94%	7.21%	9.25%
Brazil	5.05%	5.90%	N.A.
Portugal	4.87%	4.51%	2.17%
Spain	2.87%	1.95%	0.94%
Chile	2 35%	1.64%	N A.
France	1.37%	1.39%	0.72%
Belgium	1.12%	1.01%	1.07%

Source: UN Trade Statistics Yearbook, 1990

Table 17
World Import Share of Bleached Nondissolving Pulp

Country	1990	1985	1980
Canada	0.80%	1.13%	0.68%
U.S.	19.50%	22.20%	21.91%
Sweden	.52%	0.25%	0.25%
Finland	0.06%	0.06%	0.00%
Brazil	0.11%	0.03%	N A
	O 18%	0.29%	020%
Spain	2.12%	1.92%	1.95%
Chile	0.00%	0.00%	N.A.
France	9.57%	9.59%	10.55%
Belgium	2.13%	2.07%	1.65%

Source: UN Trade Statistics Yearbook, 1990

Table 18
Balance of Trade in Bleached Nondissolving Pulp
(million dollars)

Country	1990	1985	1980
Canada	4, 204	2,025	2,752
U.S.	(70)	(288)	(301)
Sweden	1.371	802	904
Finland	798	377	584
Brazil	573	310	N A
Portugal	544	222	125
Spain	68	(3)	(61)
Chile	273	87	N.A.
France	(1.041)	(456)	(603)
Belgium	(137)	(61)	(34)

Source: UN Trade Statistics Yearbook, 1990

Table 19
Segment Production Levels for
Georgia Pacific and Champion International

Georgia-Pacific	Capacity ('000 tons)	Champion International	Capacity ('000 tons)
Paper:		Paper:	
Communication	2.240	Uncoated Free Sheet	1,542
		Coated Free Sheet	555
Groundwood Papers	603	Coated Groundwood	733
		Uncoated Groundwood	271
		Newsprint	893
Tissue	573		
Containerboard and Packaging:		Containerboard and Packaging:	
Kraft Paper	342	Kraft Paper	99
Linerboard and Medium	2,941	Linerboard	391
		Bleached Board	284
Other Paperboard	629		
Market Pulp	1,866	Market Pulp	986

Source: Company Financial Documents

Table 20
Forest Resources of Major Pulp Producing Nations

	Total Land Area (thousand sq.km)	Forested Land Area (thousand sq. km.)	Share of Land Area Forests
United States	9,373	2.960	32%
Canada	9,976	4,364	44%
Sweden	450	278	62%
Finland	338	232	69%
Germany (West)	357	72	20%
Japan	378	253	67%

Source: World Bank World Development Report 1993

Table 21
Toxic Releases of the U.S. Pulp and Paper Industry
1989 Results of Toxic Release inventory

	Share of Pulp and Paper Emissions	Pulp and Paper Lrldusny share of Total Emissions
Methanol	37.8%	29.0%
Toluene	11.5%	11.2%
Hydrochloric Acid	8.6%	5.5%
Sulfuric Acid	7.4%	7.3%
Chloroform	6.4%	75.0%
Acetone	5.7%	7.0%
Ammonium Sulfate	4.2%	1.7%
Chlorine	3.2%	7.1%
Methyl Ethyl Ketone	2.6%	5.3%
Chlorine Dioxide	2.0%	87.7%
Top Ten	89.5%	

Source: 1989 Toxic Release Inventory (U.S. EPA)

Table 22
Per Capita Paper Consumption

Country	1990 (kg/capita)	1985 (kg/capita)	5 Year Annual Growth
Leaders:			
United States	311.4	282.9	1.93%
Finland	279.2	275.4	0.3%
Germany (West)	231.5	174.1	5.9%
Sweden	230.7	238.5	-0.7%
Japan	228.3	167.7	6.4%
Canada	215.3	199.4	1.5%
Switzerland	214.5	178.7	3.7%
Belgium	210.1	163.4	5.1%
Denmark	205.4	174.1	3.4%
Netherlands	203.2	171.0	3.5%
Others of Interest:			
Australia	164.8	149.2	2.0%
New Zealand	168.9	195.1	-2.8%
Brazil	27.6	26.8	0.6%
China	12.6	9.4	6.0%
U.S.S.R.	32.8	33.4	0.4%

Source: Pulp & Paper International:1992 International Fact & Price Book

Table 23
Largest Pulp and Paper Companies

Rank	Company	1990 Sales from Pulp and Paper ($ million)	Headquarters Country
1	International Paper	$10,610	U.S.
2	Georgia Pacific	$6,702	U.S.
3	Stone Container	$6,434	U.S.
4	Kimberly-Clark	$6,205	U.S.
5	Stora	$5,728	Sweden
6	James River	$5,400	U.S.
7	Scott Paper	$5,356	U.S.
8	Arjo Wiggins Appleton	$4,638	U.K.
9	Svenska Cellulosa	$4,291	Sweden
10	Champion International	$4,103	U.S.
11	Weyerhaeuser	$3,931	U.S.
12	Oji Paper	$3,526	Japan
13	Jujo Paper	$3,473	Japan
14	MoDo	$3,076	Sweden
15	Jefferson Smurfit Corp	$2,919	U.S.

Source: Pulp & Paper International: 1992 International Fact & Price Book

Table 24
Characteristics of Top 100 Paper Companies

	1981 Number	Average Production (OOO tpy)	1991 Number	Average Production (000 tpy)
North America	44	1453	35	2447
Europe	39	712	43	12436
Others	17	800	22	1308
Total	100	1047	100	1678

Source: CEPI/PPI , Clark D., 'The West European Paper Industry in 1993." Paper and Packaging analyst No. 13, May 1993, The Economist Economic Intelligence Unit

Table 25
Chemicals Used in Paper Production

Chemical	1990 (thousand tons)	Anticipated Annual Change (1990-2000)
Sodium Hydroxide	2,500	-1%
Chlorine	1.400	-5%
Sodium Chlorate	1,000	8%
Oxygen	800	3%
Sodium Sulfate	300	-1%
Titamum Dioxide	250	3%
Soda Ash	150	6%
Hydrogen Peroxide	80	9%
Ozone	<1	30%

Source: Chermicalweek, May 8, 1991

GUIDELINES ON DIOXIN

December 20, 1991

I.. Voluntary Goal of AOX Level in Effluent

All bleached pulp mills are requested to hold the amount of organic chlorine in effluent within AOX 1. 5 kg or less per pulp metric ton by the end of 1993.

II. Equipment and Operation

Followings are guidelines to the equipment and operation of pulp mills. These are in order to restrain the occurrence of dioxin in bleached sulfate pulp and dissolving pulp mills.

(1) To promote the delignification in cooking process

(2) To diminish lignin in bleaching process by fully washing in washing and screen processes.

(3) In Bleaching Process

a. to diminish chlorine use by the introduction of oxygen bleaching

b. to get down the chlorine adding rate to K value (index of the amount of lignin existing in pulp)

c. to partly replace chlorine with chlorine dioxide in chlorine stage

d. to use oxygen in a alkaline stage

(4) To operate the coagulation and sedimentation, and/ or biological .treatment in effluent treatment

(5) To dispose of the sludge, in principle, after burning

JAPAN PAPER ASSOCIATION

DAS PLAKAT


GREENPEACE
TEMPO
HÖRZU
stern
BUNTE
ELLE
JOURNAL
Umweltkiller Druckpapier

COMPETITIVE IMPLICATIONS OF ENVIRONMENTAL REGULATION IN

THE COMPUTER AND ELECTRONIC COMPONENT INDUSTRY

This case study was prepared by Ben Bonifant, Management Institute for Environment and Business. The research was conducted in collaboration with the U.S. Environmental Protection Agency and Hochschule St. Gallen. Copyright 1994 by MEB. The author gratefully acknowledges the assistance provided by Peter Crawford.

THE COMPUTER AND ELECTRONIC COMPONENT INDUSTRY
CONTENTS

EXECUTIVE SUMMARY

Introduction

Computer and electronic firms were affected by a variety of environmental issues in the late 1980s and early 1990s. Companies in these industries responded to these concerns with innovative programs and technologies. Their experiences support the conclusion that environmental improvement can yield financial improvement. However, they also demonstrate that an industry's structure will critically influence its ability to cost effectively and innovatively comply with demanding regulations.

As the computer and electronics industry grew in the 1960s and 1970s there were few concerns about environmental effects. There were no smokestacks, and from outside appearances the industry was free of the environmental concerns which were becoming important for manufacturers in heavy industries. Outward appearances did not necessarily tell the whole story, however. The processes used to manufacture computers and electronic components required the use of a wide variety of potentially harmful chemicals. If not handled carefully, heavy metals, organic solvents, and noxious gases could be released. Further, the industry's rapid growth had led to a separate set of problems. The growth was fueled by increasing demand for the industry's products. Increasing volumes led to concern about energy use by and disposal of these products.

Industry Structure

The computer and electronics industry was dominated by U.S. and Japanese firms. In 1992, U.S. firms supplied 62% of the world's computer hardware and 43% of semiconductors. Japanese firms manufactured 30% of computers and 43 % of semiconductors. This left only 9% of the computer market and 15 % of the semiconductor market to be shared by European and Southeast Asian companies. Only in printed wiring boards (PWBs) was there a greater international presence. Here, the U.S. accounted for 29 % of 1992 production, Japan 30%, Europe 16 % , and the rest of the world 25 % .

Governments were intimately involved in the early development and rapid growth of this industry. In the U.S., the unique needs of the Department of Defense spurred (and led to funding for) the earliest computer developments. Later recognizing the strategic importance of the industry, the U.S. government took a series of reactive measures to protect domestic health in the industry. The Japanese government similarly recognized the strategic value of the industry, but here, the focus was on commercial rather than military concerns. Targeted as a strategic industry, Japanese policy encouraged tariff protection of domestic markets, subsidization and coordination of research, and mechanisms to increase domestic demand. The strategic role in the national goals of the two nations was a subtle but important factor in the development of regulations to address the environmental effects of electronic manufacturing. Neither the U.S. nor Japan was likely to take an extreme position in regulating these industries which was not matched by the other.

Economies of scale and barriers to entry were important to the strategies developed by leading firms in the industry. IBM established a commanding position in the industry in the 1960s by erecting a competitive barrier which significantly increased the cost for customers to change suppliers. The company's System 360 line provided the first family of computers which allowed transfer of software from one system to another. IBM protected its position through substantial vertical and horizontal integration, ultimately supplying most of the electronic components, the software, and the computers themselves. The company became further entrenched in their customer's business by providing leasing arrangements and establishing an extensive service division. Competitors, whether U.S. or Japanese based, found it extremely difficult to break IBM's hold on the market. Only by identifying markets underserved by IBM did firms such as Cray Research and Digital Equipment Corp. capture modest shares of the computer market.

The increasing capabilities of semiconductor microprocessors coupled with a strategic decision by IBM led the company to lose dominance of the computer market. In 1981, the company recognized the growing role of personal computers in the market. Made possible by advancements in microprocessors, these systems were significantly less powerful than anything IBM manufactured. However, entrepreneurial firms such as Apple Computer had begun to reach revenue and income levels which attracted the attention of the large market leader. Rushing to enter the market quickly, IBM bought many of the components for its personal computer from outside suppliers. Notably, it chose Intel Corp.'s microprocessor and Microsoft's DOS operating system. The IBM personal computer quickly gained share and expanded the market segment's size. However, by sourcing components, IBM had left itself open to competition from "clone" manufacturers, companies which provided a computer which functioned in much the same way the IBM machines did.

Thus, the barriers to entry were substantially reduced in one segment of the market, and a variety of computer manufacturers were established in the 1980s. This, in turn, led to a proliferation of manufacturers farther up the supply chain. Several semiconductor manufacturers were established typically relying on the technical expertise of a founder and financing from a vibrant U.S. venture capital market. Both the computer and semiconductor markets were limited, however, by high capital costs for manufacturing facilities and their reliance on advanced technical knowledge. In the market for printed wiring boards, the manufacturing methods were well understood and capital costs to establish a small manufacturing facility were less than $1 million. Hundreds of small operations went into business in the 1980s most never achieving revenue greater than $6 million.

In Japan, the structure of the industry was quite different. Here, there was little opportunity for firms to develop in individual market areas. Large firms such as Fujitsu, Hitachi, and NEC which led in computer markets were highly vertically integrated producing many of their own components. Other firms which supplied the industry were tied closely to the computer manufacturers through intricate strategic alliances.

Environmental Issues

First local and then global concerns tarnished the electronics industry's clean image. Under the U.S. Federal Water Pollution Control Act of 1972 and the Clean Water Act of 1977 and the Japanese Water Pollution Control Law of 1970, wastewater from electronics manufacturing began to be regulated. Heavy metal contamination in releases from PWB fabrication facilities was specifically targeted for control. Plating and etching operations in these facilities led to high wastewater concentrations of copper, lead, and tin. Companies were forced to install water treatment systems and to take efforts to limit water use.

A second area of concern would lead to substantial control over certain materials used in electronics manufacturing. In the late 1980s concerns about the destruction of the ozone layer emerged as a critical environmental issue. A model had been established linking reduced ozone concentration in the stratosphere and increasing releases Of chloroflourocarbons (CFCs) in commercial and industrial processes. These materials were used throughout electronics manufacturing processes, primarily in cleaning and degreasing applications. In 1989, these manufacturers were responsible for 28% of Freon 113 released and 11% of trichloroethane released in the U.S. These two chemicals were among those many researchers had concluded were contributing to ozone destruction.

Finally, the industry was faced with the contribution its products made to the problem of global warming. Increased levels of carbon dioxide in the atmosphere were projected, if left uncontrolled, to lead to higher temperatures on the earth's surface resulting from the "greenhouse effect." Global warming concerns had led to efforts to reduce energy use because electrical utilities burned substantial amounts of coal. Computer use was estimated to account for 5 % of office energy use and was projected to increase to 10 % by 2000. Thus efforts were underway to reduce energy demands stemming from computer use.

Competitive Implications of Environmental Regulations

In the early 199Os, the latter two issues, reduction in energy use and elimination of CFCs from manufacturing were being accomplished with little identifiable effect on competitiveness. Increasing the energy efficiency of the computers themselves was not technically challenging. The U.S. EPA had determined that 30% of computers were left on all of the tune, and even those powered only during the day were often left unused. Simply by incorporating logics to power down the computer when not in use, as much as 70% of the energy used could be saved. Technology to accomplish this existed and had been used for several years in laptop computers. Manufacturers explained that energy efficient computers were not marketed because no one had ever asked for them. This changed when the U.S. federal government announced in 1993, that all future purchases of computers would need to meet a minimum set of energy use requirements outlined in the U.S. EPA's "Energy Star" program. Energy efficient computers yielded as much as $75 in energy savings to computer buyers while requiring no additional costs for the product.

In the case of CFCs, an international organization had been established to cooperatively identify and disseminate methods of production which did not require CFCs. Computer and semiconductor firms were able to use this and other information to rapidly remove CFCs from their operations. Surprisingly, some of the modifications which were made provided attractive rates of return and improved the quality of the cleaning process. Manufacturers explained that the use of CFCs was so pervasive that operators never questioned the potential for alternative means of production. The financial benefits of the changes were, however, very small when compared to the overall operations of the firms. As a result, managers in these companies chose to publicize their innovations. Greater benefit was felt to accrue through the publicity benefits than would be lost by failing to protect an innovation.

For printed wiring board manufacturers, no means of production had been identified which made it financially attractive to eliminate heavy metals from wastewater. However, innovative firms had found methods of substantially reducing the cost of dealing with releases, many of which depended on reducing the amount of metal released. Programs had been established by a wide variety of regulatory, public interest, and industry organizations to disseminate technologies which would allow firms to reduce their waste and lower their pollution abatement costs. Smaller firms were less able to absorb the vast amounts of information available and also were less able to undertake necessary capital projects than their larger rivals. As a result, smaller firms faced higher relative pollution abatement operating costs and environmental equipment made up a large share of their assets. These factors support the industry assertion that environmental regulations were accelerating the consolidation of the industry. These results indicate that creative methods are necessary when environmental regulations are developed for fragmented industries. Otherwise, those firms which are smaller than their rivals, but large enough to materially contribute to the environmental problem will suffer disproportionate effects of the regulation.

INDUSTRY STRUCTURE

Product

Product Description

In 1992, the world market for computers had reached $114 billion.[1] Providing a means to store, retrieve, and manipulate data, the market ranged from low powered personal computers designed for word processing and light analytical applications to sophisticated supercomputers built with associated software allowing rapid completion of massive numbers of individual calculations (see tables l-2 for a breakdown of markets). Every computer had at its heart one or more microprocessors with circuit patterns allowing data control and processing. These devices were called semiconductors because the useful characteristics of the materials were based on their ability to conduct charge across gates only when signaled to do so. Computers operated by providing a means to control the signals and a method of interpreting the resulting currents.

Computers stored data in memory chips. These devices were also semiconductors based on similar materials and technologies as microprocessors but relying on different types of designs. Electrical signals and power were carried within the computer through a series of printed wiring boards (PWB). PWBS were typically epoxy-glass boards on which had been patterned an intricate design of copper traces which carried current.

For the most part, the microprocessor was accessed through keyboard input and video display output. In addition to these components, computers included longer term memory storage devices (disk drives) and power supply units. Additionally, connectors were incorporated which allowed linking with additional input or output systems such as modems, printers, or data collection sensors. In some cases. these devices were included within the housing of the computer.

Substitutes

When the broad market of computers is considered, there were few substitutes for the products of the

1. U.S. International Trade Commission, "Global Competitiveness of U.S. Advanced-Technology Industries. Computers," Investigation No. 332-339, December 1993

industry. However, within the industry dramatic changes in markets had occurred as a result of substitution of one type of product in the markets of another. This flow of markets among segments had characterized the industry since its inception as new manufacturers entered the market by exploiting niche opportunities. These niches then, in many cases, expanded to a point where further segments could be targeted by additional entrants to the market.

In the 1950s and early 1960s a wide variety of computers were sold by a number of competitors. However, IBM dominated the market with sales which were almost ten times those of its closest rival.[2] In 1965, IBM introduced the System 360. For the first time a company offered several computers of differing performance which could all use the same software. The System 360 and subsequent 370 series became the standard computer architecture providing IBM with market shares of nearly 70% in the late 1960s.

Competitors hoping to enter the market searched for unique ways to address the special needs of niche market segments. Control Data and Cray Research, for example, served the high end of the market by introducing supercomputers in the early 1970s. On the other end of the market, DEC (Digital Equipment Corporation) was among the first companies to target a growing niche of the market when it introduced the first minicomputer in 1963. This product took market share away from IBM by addressing the needs of technically sophisticated users who desired access through time sharing arrangements.[3] It also dramatically expanded the market by providing a product to smaller organizations unable to justify the capital expense of the larger machines.

Apple Computer introduced the first commercially successful personal computer in 1977 taking advantage of significant advances in microprocessor capabilities. The company was able to reach sales nearing one half billion by 1981 when IBM turned its attention to this segment of the market. By 1985, IBM had far surpassed its rivals in personal computers achieving a market share in excess of 40%. However, it then

2. Flamm, Kenneth, Creating the Computer, Government. Industrv. and High Technology, The Brookings Institute, Washington, D.C. 1988

3. U.S. lnternational Trade Commission, “Global Competitiveness of U.S. Advanced-Technology Industries: Computers,” Investigation No. 332-339, December 1993

faced a new type of challenger. Instead of aiming at underserved niches of IBMs market, new competitors attempted to be as much like IBM as possible. Clone manufacturers led by Compaq and followed by AST Research, Dell, and Gateway 2000 eroded IBM's market share to less than 12% by 1992 (see table 3).

Production Process

The computers of the early 1990s were complex devices which functioned through the coordinated interaction of several distinct components. Manufacturers varied significantly on their level of integration in the production of these components. Some, like Gateways 2000 or Dell, performed only the final assembly stages of production. By contrast, several Japanese manufacturers had integrated far upstream completing many operations in-house which most U.S. manufacturers purchased from outside suppliers.

Three areas of the production process are particularly important to this discussion, semiconductor manufacturing, printed circuit board manufacturing, and mounting of sub-components on the printed circuit board. These steps represent only part of the overall computer manufacturing process. In this discussion, semiconductor manufacturing will be considered the first step in the computer production process. Upstream of this process, of course, manufacturers prepared materials and equipment used in semiconductor production. Beginning with pure silicon wafers, semiconductor manufacturers imprinted extremely fine circuits on the material and packaged the resulting product in plastic or ceramic casings. Similarly, printed circuit board manufacturers, produced a pattern of copper traces on a base material (also called a substrate and typically made of epoxy glass laminate). The packaged semiconductors and other electronic sub-components were mounted on the printed circuit board. Final assembly of the computer involved attaching several of these boards and other components - disk drives, keyboards, and monitors, which also contained printed circuit boards - into the product.

Manufacturing of semiconductors and printed circuit boards relied on photolithographic processes to produce circuit patterns. In semiconductor manufacturing, the objective was to selectively create impurities onto a layer of silicon dioxide.[4] Areas which had impurities introduced were said to be doped. By patterning the pure and doped areas of the silicon dioxide, the desired electrical performance was achieved.

The process required first growing a layer of silicon dioxide on the surface of the wafer. Then, a material known as a photoresist was applied to the surface. This was an organic material which was sensitive to ultraviolet (UV) light. Once exposed to W light, the substance reacted to form a hard solid material. The area which was not exposed could be removed using a solvent of either organic or aqueous nature. By controlling the areas which were exposed, and then removing the unexposed material, a pattern of photoresist was created on the surface of the silicon dioxide. The next step was to etch away the unprotected silicon dioxide and expose the underlying silicon to dopant (usually phosphene or arsene). Then, the photoresist could be removed and additional layers of silicon dioxide could be grown over the entire surface of the wafer. The process of coating, exposing, dissolving, and etching was repeated many times in wafer manufacturing.[5]

After the semiconductor wafer was manufactured, it was packaged, a step in which the individual dies (chips) were sliced off of the large wafer, encased in plastic or ceramic for protection, and connected to metal lead frames that would link the chip to the printed circuit board.[6] The steps involved in packaging the semiconductors and the subsequent testing steps were significantly more labor intensive than the preceding fabrication processes (which required significant capital and technological investment). As a result, the later steps were often transferred to lower cost labor production areas, notably Southeast Asia.[7]

4. A very small part of semiconductor manufacturing used germanium, gallium arsenide, or indium phosphide. These materials provided faster performance or other desirable properties but at higher cost or with trade-offs in other properties. Additionally, production methods had focused on continually improving silicon based systems. As a result, gallium arsenide semiconductors were produced for a very small part of the market for specialized military and high performance applications.

5. Weste, Neil and Kamiran Esbraghian, Principles of CMOS VLSI Design. Addison Westly, 1988 Chapter 3.1

6. Microelectronics and Computer Technology Corporation, Environmental Consciousness: A Strategic Competitiveness Issue for the Electronics and Computer Industry. Austin, 1993 p. 129-132

7. USITC, Industry & Trade Summary: Semiconductors (USITC publication 2708) December, 1993.

Like semiconductors, printed circuit boards performance relied on the patterning of one material with certain electrical characteristics within another material with differing electrical performance. Printed circuit boards used conductive copper layered over a base material made of an insulating substance. This base material (also called a substrate or dielectric) was usually made of an epoxy glass composite.[8]

Manufacturers received the substrate which had already been laminated with a thin (.00l" - .002") layer of copper foil. Holes were drilled in these boards which would later allow current flow from one side of the board to the other (more than 90% of the boards manufactured in the U.S. in 1990 were either double sided or multilayer meaning that copper circuitry was patterned on both faces of the board). Then, the board was exposed to an electroless copper addition process which initiated a copper surface on the hole walls. The boards were then coated with a photoresist material similar to that described for use in semiconductor manufacturing.[9] A pattern was exposed on the photoresist which covered the area of the board on which no copper would ultimately exist. More copper was deposited using an electrolytic deposition.[10] The copper which had been built up in the electrolytic process was then protected through the deposition of a material which was resistant to a copper etchant (usually tin or tin/lead). The photoresist material was then stripped away, and the underlying copper was etched from the surface. This left a pattern of the electrolytically deposited copper protected by the tin/lead etch resist,

A chemical process was used to remove the tin/lead and expose the conductive copper. A protective coating called a solder mask (similar to the photoresist) was then layered on the board. Holes were left in the solder mask which allowed application of solder (tin/lead) on the contact areas of the board. Areas which might experience frequent abrasion, particularly contact surfaces, were often then plated with nickel or gold for protection.

8. The explanation of the production of printed wiring boards draws on the explanation provided in Printed Circuit Board Basics, Michael Flatt, Miller Freeman 1992, San Francisco

9. By the early 1990s, dry film photoresist had become the primary type of imaging resist. This type of resist was applied to the copper surface in a simple laminating step. Previously, photoresist had been screen printed on the surface of the copper. A new system, liquid photoresist was beginning to be more widely used in the early 1990s because of its performance in manufacturing boards requiring very thin line width (less than .005").

10. Two separate plating processes were required because the electrolytic deposition of copper will only occur on conductive surfaces. The electroless process provides this conductive surface on the through hole walls, while the electrolytic process increases the copper thickness on all exposed areas.

Printed circuit board manufacturers typically provided boards in this solder mask over bare copper (SMOBC) condition. Then either the final producer or a different intermediary manufacturer would mount sub-components on the board. This process was called “stuffing” or “assembly” and two primary methods were employed. In one, sub-components were surface mounted by being placed on contact points and connected through reflow of solder material. In wave soldering, sub-components were inserted through the board and a wave of solder was passed against the pins thus making a connection. ln both surface mount technology and in wave soldering, a solder flux was used to facilitate solder attachment of the sub-components. After soldering, the rosin portion of the solder flux typically had to be removed in a cleaning process.

Economies of Scale

The economies of scale in semiconductor manufacturing have been well documented. Scale economies were encountered in both greater distribution of fixed costs and in more rapid acquisition of learning. The high level of capital costs associated with fabrication facilities made operating at maximum production levels a critical target for manufacturers. Extremely high research and development costs associated with semiconductor design also drove scale economies. By one estimate, there was an approximately 90% scale relationship, meaning that for every doubling of the size of a production facility, the unit costs were reduced 10% .[11]

Learning also drove important scale economies in semiconductor manufacturing. As a firm produced a new chip or worked within a new facility, it acquired skills specifically associated with that production. Yields improved and costs reduced. Although flattening somewhat in the late 1980s. the learning effect was traditionally expected to provide a 30% reduction in costs for each doubling in cumulative volume of chips produced.[12]

In printed wiring board manufacturing, scale economies were not as great, but could make the difference between profitability and losses. The primary areas of scale advantage for the largest firms were in

11. “Sherman, Stratford, “The New Computer Revolution, * Fortune. June 14, 1993. p. 68

12. Semiconductor Industry Association, “The Impact of the 1986 U.S. -Japan Semiconductor Agreement on DRAM Prices.”

greater spreading of selling expenses and of administrative expenses. For the smallest firms scale drove additional disadvantages in costs for buildings and machinery, inspection labor, and non-direct manufacturing labor such as inspection.

Entry and Exit Barriers

As discussed above, IBM Created a high entry barrier to other firms by achieving an industry standard with the introduction of its System 360 line of computers. Other firms only got around this barrier by providing products which were SO compellingly suited to the customer's needs that they were willing to learn a new standard. A new type of entry was encouraged, however, in the personal computer market once standards were established but not controlled by IBM.

IBM joined the personal computer market in 1981. In contrast to its strategy in mainframes (where IBM produced almost all of the components as well as providing software and servicing), the company made a strategic decision to purchase critical parts of the product from outside suppliers. In particular, IBM turned to Intel for the critical microprocessor and to Microsoft for operating software. Using outside suppliers allowed IBM to reach the market in 13 months and rapidly achieve a 40% market share.[13]

The strategy to use outside suppliers for critical components had unintended consequences on the competitive nature of the personal computer market for years to come. Other manufacturers were able to copy the IBM machines providing "clones" which to the user operated virtually identically to the IBM products. Initially, clone manufacturers such as Compaq achieved rapid growth simply by undercutting IBM's prices. Unburdened by large overheads and free of the costs associated with developing the standards for the product, early clone manufacturers found ample opportunity to beat IBM's cost position while still closely following the large company's lead in manufacturing strategy and distribution channels. Later entries to the clone competition found success by locating labor intensive operations in low wage countries or by eliminating distribution costs through direct marketing.

13. Carroll, Paul, Big Blues, Crown Publishers, Inc., September, 1993

Barriers to entry in component manufacturing varied enormously. In semiconductor manufacturing there were many while in printed wiring boards there were few. Semiconductor fabrication plants were being built at a cost of over $1 billion in the early 1990s. In the microprocessor segment of the market, large development costs also dissuaded new entrants. Additionally, software had been designed to work with existing (primariiy Intel's) microprocessors providing another barrier. In 1990, Intel had achieved a 53 % market share of microprocessors.[14] As a result, competitors such as Advanced Micro Devices were forced to follow Intel's lead in microprocessor design. In response, Intel jealously guarded development secrets, aggressively litigated patent claims, and accelerated development times in an effort to stay ahead of following competitors.[15] In 1993, Apple, Motorola, and IBM were attempting to challenge Intel's dominant position in microprocessors by designing and marketing an alternative chip called the PowerPC. Only by combining the capital access, design experience, and production skills of these three large firms could a credible challenge to Intel's position be made.

In memory chips, the entry barriers were also formidable. Again, the high cost of fabrication facilities discouraged most competitors. More important, however, were the large learning advantages which were held by firms which had experience in manufacturing memory chips. Incorporating learning effects into strategic behavior had been an important characteristic of competition in the memory chip market. Prior to 1986, Japanese manufacturers sold 64K memory chips in the U.S. at a price which was determined to be below the cost of production.[16] Facing foreign competitors who were unconcerned with short term results, such U.S. firms as Intel and Fairchild exited the market. Later, the U.S. Department of Commerce began to assess antidumping duties on the Japanese manufacturers. It appears, however, that the U S. firms had fallen too far behind to reenter the market for memory chips. In 1986, only two U . S .

14. Dataquest data included in Tyson, Laura D'Andrea, "Managing Trade and Competition in the Semiconductor Industry, " in Who's Bashing whom?, Institute for International Economics, Washington, D.C., 1992

15. "Intel: The Coming Clash of Logic," The Economist, July 3, 1993

16. USITC, 64K Dynamic Random Access Memory Components From Japan (investigation No. 731-TA-270, USITC publication 1862, June 1986.

merchant firms continued to produce the state Of the art 256K memory chip; eleven firms had produced 16K memory chips in 1980.[17]

In contrast to semiconductor manufacturing, barriers to entry in printed wiring board production were very low. A small PWB shop could begin operation with less than $1 million in equipment. In addition, the manufacturing technology was well understood, and design skills were not required (designs were supplied by the customer). Not surprisingly, PWB manufacturing was crowded with small operations, although consolidation was underway.

Buyers

Buyer Description

The segmentation of the computer market resulted from companies specifically designing the products' performance for the needs of targeted customer groups. Supercomputers were developed for the rapid calculation requirements of the government and research organizations and the markets for these devices remained in those areas. Mainframes and workstations were developed for specific areas of business computing (accounting and technical) and these continued to be the dominant customers of these suppliers. Personal computer markets were somewhat more diverse, but even here, business applications accounted for more than two thirds of sales. Educational applications and scientific users each accounted for 10% of the market, and the remaining sales were made to home users.[18] Dramatic price cutting by personal computer manufacturers in 1993 was anticipated to increase sales to all market segments, but home users were expected to experience the greatest relative increases.

Computer manufacturers were important, but by no means the only buyers for semiconductors and printed wiring boards. Telecommunications, consumer electronics, industrial instruments, automobile manufacturing, and military devices were other important markets for electronic components (see table 1). In Japan, the markets for consumer electronics were particularly important to the upstream suppliers

17. Howell, Thomas R., et.al., Creating: Advantage: Semiconductors and Government Industrial Policv in the 1990's Semiconductor Industry Association, 1992

18. U.S. Department of Commerce, International Trade Administration, "U.S. Industrial Outlook 1993," 26-15

for computer manufacturers while in the U.S., the high level of demand for military devices supported many of the developments in semiconductors and PWBs.

Distribution Channels

One of the critical areas of strategic competition in the computer market occurred in companies' selection of distribution channels. Three primary means of distribution were used, direct selling, intermediary sales, and mail order.

There were four primary types of intermediaries used by computer manufacturers, dealers, retailers, intermediary mail order houses, and value-added resellers. The largest of these channels, the dealers, dominated this segment with 44% of 1993 sales. Retailers, including such operations as superstores and mass merchandisers held 19% of the intermediary sales but were expected to grow with increasing home computer sales. Mail order and value-added resellers contributed 1 7 % and 15 % respectively.[19]

Suppliers

Computer manufacturers had varying strategies concerning making orr buying critical components. In the U.S., some manufacturers such as Apple or Compaq outsourced virtually all components while others, notably IBM, continued to produce many components in-house.[20] Japanese companies were much more integrated upstream than typical U.S. manufacturers. Hitachi, for example, not only produced its own semiconductors, but had operations producing semiconductor manufacturing equipment including steppers, ion implanters, and dry etchers.

Important suppliers to the U.S. computer industry included semiconductor manufacturers, printed wiring board manufacturers, monitor producers, and molders for plastic housings. Farther upstream were suppliers of semiconductor equipment, printed wiring board equipment, and chemicals. These markets could be broken down into the following categories:

19. Pope, Kyle, "Forecasts Aside, Dealers of PCs Thrive Again.' Wall Street Journal, February 1, 1994

20. The USITC estimated that IBM held an 11.2% share of the semiconductor market through captive sales. All other captive production was estimated to be 4.6% of the market. In printed wiring boards, the IPC estimated that captive manufacturing made up 31% of the 1992 market with ten manufacturers making up 67% of this.

Semiconductor Equipment: Equipment for semiconductor manufacturing was broken down into three primary areas wafer processing, assembly, and testing. World sales of semiconductor equipment were $8.5 billion in 1989 with more than 50% of this ($4.5 billion) occurring in the wafer processing area.[21] Devices used in wafer processing were based either on ultra pure chemical processes (diffusion and ion implantation equipment) or on Precise control of exposure to light (photolithographic equipment). Assembly equipment, on the other hand, required design of instruments for high tolerance mechanical processes which allowed rapid bonding of thin wires. Finally, testing equipment demanded the development of means for the automated analysis of semiconductor performance.

Semiconductor Materials: Although processing materials made up the largest part of semiconductor material sales at $4.7 billion in 1989, packaging material suppliers accounted for a significant $3.6 billion in sales. Processing materials included all items used in achieving the basic circuits on the chip and included $2.0 billion in silicon wafers, $1.1 billion in photomasks, and an additional $1.6 billion of other chemicals and materials. Items used in encasing the chip in ceramic and attaching wire fingers later used to electronically connect the semiconductor to a printed circuit board made up the market for packaging materials.[22]

Printed Wiring Board Equipment: Equipment for printed wiring board manufacturing was much less sophisticated than that used in producing semiconductors. Additionally, PWB production was less capital intensive yielding a smaller overall market. In the U.S., PWB manufacturers had capital expenditures equal to 4.9% of their sales in 1991. This resulted in spending of only $310 million.[23]

Printed Wiring Board Materials: In the U.S., supplies to PWB manufacturers made up a $1.5 billion market in 1992. The base products made up the largest share of this market with $664 million in

21. USITC, Global Competitiveness of U.S. Advanced-Technology Manufacturing Industries: Semiconductor Manufacturing and Testing Equipment: Report to the Committee on Finance, United States Senate (investigation No. 332-303 (final)), USITC publication 2434, September 1991.

22. USITC, Global Competitiveness of U.S. Advanced-Technology Manufacturing Industries: Semiconductor Manufacturing and Testing Equipment: Report to the Committee on Finance, United States Senate (investigation No. 332-303 (final)), USITC publication 2434, September 1991.

23. U.S. Department of Commerce, "1991 Annual Survey of Manufacturers"

laminate and $115 million in prepreg. Chemicals of various types made up the remainder of PWB material purchases.

Environmental Regulation

Environmental Risk Analysis

In the late 1980s and early 1990s environmental concerns began to be felt throughout the operations of computer manufacturers. Every department, from design to manufacturing to sales to legal faced increasing concerns associated with how their company's current and previous operations were affecting the environment. These concerns can be grouped according to the following four categories:

* Contamination of sites from previous manufacturing activities
* Chemical releases from on-going manufacturing
* Product energy use during operation
* Product disposal

Contamination From Previous Activities:

The computer industry was highly sought after by communities such as Silicon Valley and Boston's Route 128 area when it began to take off in the 1970s. It attracted high wage jobs, it was growing rapidly, and the processes used were viewed as "clean technologies." There were no smoke stacks like those associated with heavy industry.

Computer manufacturing, in fact, could be a very clean industry. However, the many processes used in putting together electrical components required the use of a wide variety of chemicals. Most of these chemicals did not become part of the final product, so, once used, they had to be removed from the manufacturing site. One particular procedure which caused a number of later problems was the storage of used chemicals in underground storage tanks prior to collection and disposal. Many of these tanks were later found to have been leaking, potentially allowing organic solvents to enter groundwater.[24] While most of these tanks had. been removed by the early 1990s, plumes of contaminants remained in the groundwater leading many surrounding areas to be identified on the National Priority List (NPL) of the

24. Howe, Charles, "Poison in Paradise," Datamation. August 15, 1984

U.S. EPA Superfund program. More sites were listed on the NPL from California's Santa Clara County than any other county in the U.S. Of the 29 sites, 23 resulted from activities in the electronics industry[25]

Chemical Release From On-Going Manufacturing:

The complex processes used to manufacture a computer demanded repeated operations where materials were selectively applied or removed, These processes employed a wide range of chemicals including caustics, heavy metals, and organic solvents. In particular, large amounts of chemicals were used in manufacturing components. Companies making components faced strict chemical use and disposal regulations throughout the U.S., Europe, and Japan and some regulations were particularly severe in California and Massachusetts, the areas in the U.S. where important clusters of these industries operated. In the early 1990s, four areas of chemical use were particularly important for environmental reasons.

* Release of metals from plating and etching operations in PWB manufacturing
* Release of organic solvents from PWB developing and stripping operations
* Release of organic solvents from cleaning operations in semiconductor fabrication
* Release of organic solvents from cleaning during board assembly (stuffing)

The goal of making a printed wiring board was to leave a thin trace of conductive material on a non-conducting surface. This was primarily done in a negative process which began with a solid copper film laminated on a glass/epoxy board. Because the trace was made by removing the unwanted copper, large quantities of metal needed to be removed from the manufacturing site. The wastewater from the etching baths typically had copper in such high concentrations that it was economically efficient to retrieve the material. Suppliers recognizing this opportunity had created systems which assisted PWR manufacturers in disposing of their wastewater. Companies such as World Resources Inc., for example, supplied sulfuric acid for etching the copper boards and then later collected the companies' process baths.

Many waste streams in PWB manufacturing were contaminated with metals but were not of sufficient concentration to make reclamation economic. in particular, plating bath and rinse waters from such areas as through hole and connector plating had levels of copper, lead, and tin which were too high for release

25. Smith, Ted and Woodward, Phil, "The Legacy of High Tech Development," Silicon Valley Toxics Coalition, January, 1997

in municipal systems, and too low to justify retrieval. Manufacturers were required to treat these streams lowering metals concentration prior to release.

Organic solvents used in developing and stripping early photoresist materials also posed an environmental concern for PWB manufacturers. In producing PWBs, photoresist films were layered on the copper surface of the copper-epoxy/glass laminate. The patterns which would eventually become the copper traces were then made through patterning on the photoresist by exposure to light (areas exposed became hard while unexposed areas remained unpolymerized). The photoresist was developed by removing the unexposed area.

Components were attached to the PWBs in a process called "stuffing or "assembly." Here components were placed on the board surface and electrical connections were made by soldering. In order to make a good solder connection, a flux material was used. This tacky, rosin like, material contained chemicals which reacted when heated with the oxidized layers of the metal surfaces exposing fresh area for a strong solder bond. After soldering, though, the flux had to be removed because it was felt to be a contaminate which could later damage the performance of the component. Prior to efforts to reduce their use, chloroflourocarbons (CFCs) were almost universally used to remove solder flux. This use and other cleaning operations in board manufacturing, chip fabrication, and other production operations made electronics manufacturers among the largest users of CFCs. As shown in table 13, the 1989 EPA inventory of U.S. toxic releases (TRI) indicated that 28% of Freon 113 releases, 11% of trichloroethylene releases, and 11% of 1 ,1 ,l trichloroethane releases resulted from electronics facilities.[26]

CFCs had received widespread attention because of the role many researchers had concluded they played in the destruction of the earth's stratospheric ozone layer. The ozone concentrated in a band 10-50 km above the earth's surface absorbed W-B radiation (ultraviolet light in the band between 280 and 315 nm). In the early 1990s. atmospheric scientist had concluded that the earth's surface was receiving increased levels of W-B. They estimated that increases were occurring at a rate of 5 % to 11% per decade in the northern hemisphere while in the southern hemisphere, increases of up to 40% per decade

26. U.S. EPA, Toxic Release Inventory

were occurring.[27] Scientist had further concluded that the reductions in ozone which allowed this increase in UV-B could themselves be caused by increased releases of CFCS.[28] CFCs were very stable compounds; so stable, in fact that they were not broken down by the natural processes that removed chemicals from the lower atmosphere. As a result, CFCs migrated to the upper atmosphere where over many years they were slowly broken down by solar radiation. The breakdown of CFCs released chlorine which then, through a series of chain reactions, broke down large quantities of ozone.

Product Energv Use During Operation:

Computer systems were estimated to account for 5 % of commercial electricity consumption in 1993 and usage rates were growing rapidly.[29] However, much of the energy used in office computer systems was wasted. Researchers had found, for example, that 30% of all computers were left on overnight. When a computer was left on at all times, energy costs were estimated at $105 while those that were turned off after working eight hours led to energy costs of only $35 annually.[30] Although screen saver programs (software which replaced an idle screen with images of swimming fish or flying toasters) had become popular, these products did nothing to lower the energy demands of the computer. The U.S. EPA estimated that more than $2 billion of energy was wasted on idle computers. Producing this energy contributed to global warming through carbon dioxide emissions and to acid rain through the releases of sulfur and nitrogen oxides. Surprisingly, despite the obvious potential savings to their customers, computer manufacturers were being compelled to develop energy efficient computers because of environmental concerns and not because customers viewed the energy savings as a feature which they valued.

27. Madronich, S., et. a!. , "Changes in Biologically Active Ultraviolet Radiation Reaching the Earth's Surface," in United Nations Environment Programme, Environmental Effects of Ozone Depletion: 1991 Update, November 1991

28. The story of how scientist and policy makers finally began to act on the conclusion that CFCs caused ozone destruction is a long and interesting one. The brief treatment included here is drawn from Ozone Diplomacy, Richard Eliot Benedick, Harvard University Press, Cambridge MA, 1991

29. U.S. EPA, Information Flier, "EPA Energy Star Computers," October 14, 1993

30. Nadel, Brian, "The Green Machine," PC Magazine, May 25, 1993

Product Disposal:

Computer manufacturers competed by providing increasing memory storage and calculation speeds to their customers. Advancements in hardware encouraged software developers to provide more features which only worked on the more powerful machines. As a result, computers users were enticed to upgrade often. Older equipment became obsolete in a mater of a few years. Some of this equipment was transferred to areas of the customer's organization which did not require the latest technology, some equipment was sold at steep discount on the second hand market, and still other equipment was donated to schools and civic groups. However, eventually all of this equipment required disposal and although electronic equipment had not been classified as a hazardous waste, manufacturers were concerned about their responsibility for disposal of products containing heavy metals and other contaminants. Concerns with disposal loomed in the future for most computer manufacturers in 1993, and did not significantly affect their companies' product design or manufacturing operations. However, at that time managers were beginning to consider how they might be strategically affected by new regulations on disposal. Among these, a German initiative requiring companies to "take back" their products after use was receiving considerable attention.[31]

Severity and Impact of Regulation

Manufacturers of electronic devices faced a variety of environmental regulations. Manufacturing areas were given limits on allowable releases of materials in their air and water discharges and in some cases, they were prohibited from using certain materials in production. As a result, facility managers had to consider environmental compliance among the many issues materially affecting the financial performance of their operations. As discussed above, companies which produced electronic components were relatively more affected by environmental concerns than were those firms which provided completed electronic devices.

In 1991, computer manufacturers in the U.S. reported that environmental abatement and control capital expenditures made up a modest 0.9% of all capital expenditures (similarly communications equipment

31. Cartron, Dominique, "Global Environmental Regulations and Their Effect on the Electronics Industry," The Microelectronics and Computer Technology Corporation, Austin. Texas, 1993

Suppliers reported 0.5 % of capital expenditures went for pollution control equipment - see table 14).[32] Operating costs were similarly low at 0.1% of the value of industry sales. Semiconductor manufacturers were more affected with 3.6% of capital expenditures ($106.2 million) spent on pollution control equipment and environmental operating costs at 0.4% of sales.[33]

The ability to control environmenta1 costs was critical to PWB manufacturers. In the U.S. in 1991, 5.6% of capital spending in this industry went toward pollution abatement and control. Operating costs amounted to 1.3 % of sales.[34] The great majority of these costs were associated with treating wastewater prior to release. For example, industry groups estimated that spending for wastewater treatment chemicals was more than $40 million which would account for more than half of the total reported operating costs for environmental control .[35] The effect on small firms was reported to be greater relative to their sales than that on larger firms. For example, environmental control equipment was estimated to represent 9.6% of the capital expenditures of firms with less than $6 million in sales between 1991 and 1994 while the same category of equipment made up only 5.9% of the capital expenditures of firms with greater than $30 million in sales.[36]

The costs described above capture only those from on-going production and do not include the entire effect of environmental regulations in the industry. All areas of electronics manufacturing were affected by environmentally driven limitations on materials used in production. Responding to evidence that chloroflourocarbons destroyed ozone in the stratosphere, eighty-one nations (as of December 1991) had accepted the Montreal Protocol calling for the total elimination of the substances by the year 2000 (the Montreal Protocol is discussed further below). Manufacturers were forced to find alternative methods

32. U.S. Department of Commerce, "Current Industrial Reports, Pollution Abatement Costs and Expenditures, 1991."

33. U.S. Department of Commerce, "Current Industrial Reports, Pollution Abatement Costs and Expenditures, 1991."

34. U.S. Department of Commerce, "Current Industrial Reports, Pollution Abatement Costs and Expenditures, 1991."

35. The Institute for Interconnecting and Packaging Electronic Circuits (IPC). "TMRC Analysis of the Market, Rigid Primed Wiring Boards and Related Materials for the Year 1992," June 1993

36. The Institute for Interconnecting and Packaging Electronic Circuits (IPC)

of production eliminating the widespread use of CFCs in solvent and cleaning processes. This required expenditures for research into new manufacturing techniques as well as evaluation of substitute materials. Suppliers also carried research costs as they searched for alternative materials which could be used by the industry. Additionally, those firms that had been identified as “potentially responsible parties” at Superfund sites experienced substantial costs. The average cost of cleaning up a Superfund site was $20 to $30 million during this period with comparable additional costs associated with the legal fees incurred as firms argued over the share of the cleanup costs to be borne by each party.

COMPETITION

United States

Competitiveness Overview

Firms based in the United States held a 61% share of the $114 billion global computer hardware market in 1992. This strong position represented a very modest drop from the U.S. share of 63% in 1988. In every market segment from personal computers to workstations to supercomputers, U.S. firms led the world market (tables l-6). United Nations trade statistics (based on site of manufacturing not location of headquarters) indicate a similarly strong position for the U.S. in this industry. In 1990,the U.S. maintained a trade surplus of more than $4 billion in computers and central processing units, Decentralized manufacturing by U.S. firms made the share of world exports significantly lower than the share of total production, but even here, the U.S. led with a 30% share.[37]

The U.S. position in electronic components was also strong but was by no means dominant. In 1992, U.S. based suppliers produced 42.6 % of semiconductors.[38] Semiconductor market shares had swung widely during the 1980s. In the early part of the decade, U.S. firms had dominated, producing more than 60% of all semiconductors. Then, as Japan took an increasingly important position in the supply of memory (specifically dynamic random access memory or DRAM) chips, the U.S. share had fallen below 40% in the middle of the 1980.39 Many industry analysts viewed the strength of the U.S. industry in the early 1990s as a sustainable position which would grow through the end of the decade.[40]

Globalization of operations had a significant impact on export positions of U.S. firms in semiconductors. United Nations data show that in 1990, producers operating in the U.S. exported $11.5 billion in

37. United Nations, "UN Trade Statistics Yearbook, 1990"

38. The USITC reported data based on location of manufacturing operations rather than the nationality of the firms headquarters. Using this measure, U.S. production of semiconductors was slightly less than 30% in 1992, with Japanese facilities responsible for approximately 35% of production.

39. Howell, Thomas R., et.al, Creating Advantage: Semiconductors and Government Industrial Policy in the 1990s Semiconductor Industry Association, 1992

40. Market share projections by VLSI Research put the U.S position above 50% by 2000

semiconductors making up 26.7% of world exports. The U.S. was also the largest importer of semiconductors with $10.6 billion of product being brought into the country.[41] Much of this trade, however, was within companies with base semiconductors being manufactured in the U.S., and then shipped to lower wage countries such as Singapore and Malaysia where labor intensive packaging and testing operations were completed. Data from the U.S. Department of Commerce highlight the impact of semiconductor parts exports showing that more than half of U.S. semiconductor exports were in the form of parts between 1986 and 1992.[42]

U.S. firms produced 29.2 % of the world's printed circuit boards in 1992. As in other categories of electrical components, exchange rate fluctuations had a significant effect on the comparable positions of the major supplying nations. A comparison can be made between 1987 and 1992 when exchange rates between the U.S., Japan, and Germany were similar. In those years, Japan's share of world PWB production remained approximately 30%. The U.S. had gained more than a share point increasing from 28 % to 29.2 % , and European manufacturers had lost more than 3 share points falling from 18.6% to 15.6% of world production.[43]

Leading Firms

Although the company experienced severe financial difficulties in the early 1990s, IBM remained by far the world's largest supplier of computer equipment. In 1992, IBM shipped more than $28 billion in hardware to its customers. The company supplied all areas of the hardware market with the dominant position in mainframes, the leading share of personal computer sales, the second leading share in supercomputers, and the third leading position in workstations (see tables 3 through 6). No other company participated in all four areas. Additionally, IBM achieved only 44% of its revenue from

41. United Nations, "UN Trade Statistics Yearbook, 1990"

42. USITC, Industry & Trade Summary: Semiconductors (USITC publication 2708) December, 1993. Department of Commerce data differs from United Nations data showing a significantly higher level of imports. As a result, although the UN data indicate a trade surplus of $800 million in semiconductors for the U.S., the Department of Commerce reported a trade deficit of $1.3 billion. While the reason for these differences is not clear, it is evident that the U.S. maintained a significant trade surplus with the European Community and had a large trade deficit with Japan and Korea. Unfortunately, neither data source breaks down semiconductor trade into subcategories.

43. The Institute for Interconnecting and Packaging Electronic Circuits, "TMRC Report on the World Market for Printed Wiring Boards and Substrate Materials for 1992,. Chicago, 11, June 1993

hardware operations; 18% came from software, 25% from service operations, and 14% from other areas such as typewriters.

Other leading U.S. computer firms had typically achieved their positions by identifying and developing a market area which IBM did not target. DEC in minicomputers and Cray Research in supercomputers represent examples of firms which were able to grow rapidly in the 1960s by targeting specific customer needs. In the late 1970s and 1980s Apple developed a new market on the low end of users needs when it introduced its personal computers and further expanded the market with the 1984 introduction of the Macintosh. Sun Microsystems provided more power to individual users through the introduction of the workstation in 1985. The pioneering work of these and other firms brought them periods of terrific financial success. Other firms rapidly followed their lead (and IBM inevitably entered the market area in which it had previously not participated) rapidly making each new segment of the computer industry very competitive.

In the U.S. computer manufacturers relied on suppliers for critical components. Intel, the producer holding more than 50% share of the microprocessor market, was critically important to the health of the U.S. computer industry. By providing increasingly powerful and fast microprocessors, Intel expanded the capabilities of personal computers. Other microprocessor firms such as Advanced Micro Devices and Cyrix put constant pressure on Intel by rapidly producing devices which operated similarly to Intel's products. Competition in microprocessors kept the cost of the devices low and accelerated the rate of innovation.

The limited economies of scale and low entry barriers discouraged the development of dominant market leaders in the supply of printed circuit boards. In 1992, only 13 U.S. firms had revenue greater than $50 million while more than 600 operated with sales of less than $5 million.[44]

44. The Institute for Interconnecting and Packaging Electronic Circuits (IPC). "TMRC Analysis of the Market, Rigid Printed Wiring Boards and Related Materials for the Year 1991,' June 1993

Distinctive Environmental Regulation in the U.S.

Two areas of regulation affecting the manufacture of computers and electrical components in the 1990s were the releases of metals in printed circuit board manufacturing and controls on the use and release of solvents. In the U.S., industrial discharges to water bodies were regulated by the 1972 Federal Water Pollution Control Act (FWPCA) and the 1977 Clean Water Act (CWA). The FWPCA outlined a system of technology based standards for industrial effluent release. Under the legislation, the federal government was given the responsibility of determining the appropriate effluent limits within classes of producers. Permits were initially also issued by the federal government, but over time, most states took over responsibility for permitting. The 1977 CWA brought greater attention to toxic pollutants whereas the FWPCA had emphasized control of conventional pollutants (suspended solids and oxygen demanding organic releases) .[45] Permits based on effluent standards resulting from the CWA put limits on the metals concentrations allowed in the releases from printed wiring board shops. The table below lists the allowable concentrations of metals in California (although local requirements often were more restrictive).[46]

Allowable Metals Concentrations in California Wastewater Releases

Metal	Maximum for any one day	Average for four consecutive days
Cyamide	1.9 ppm	1.0 ppm
Copper	4.5 ppm	2.7 ppm
Nitrogen	4.1 ppm	2.6 ppm
Chromium	7.0 ppm	4.0 ppm
zinc	4.2 ppm	2.6 ppm
Lead	0.6 ppm	0.4 ppm
Cadmium	1.2 ppm	0.7 ppm

45. Portney, Paul R., Public Policies for Environmental Protection, Resources for the Future, Washington, D.C., 1990

46. As reported in “Selecting a Waste Treatment System that Works, * James McCarron, Electronic Packaging & Production,

Achieving acceptable effluent levels required that PWB shops have wastewater treatment system. These could at times be extensive involving technologies such as ion exchange and plate-out equipment, Significantly, the regulations did not take into account the composition of the receiving waters or even the characterstics of the shops entry water. Producers at times claimed that the water which left their operations was substantially cleaner than that which had entered.[47]

As has been discussed, electronics manufacturing used large amounts of chlorofluorocarbons in the mid-80s. These chemicals were coming under increasing scrutiny because of their role in destroying stratospheric ozone. Beginning with the Vienna Convention for the Protection of the Ozone Layer. international organizations were taking actions to encourage national governments to take measures to protect the ozone layer. Taking effect on January 1, 1989, the Montreal Protocol established targets for CFC reductions (20% by mid-1993 and 50% by mid-1998). This measure was endorsed by 29 countries representing 83% of CFC consumption. Soon, however, increasing evidence was gathered indicating significantly greater damage to the ozone layer than had previously been measured. As a result, the London Revisions to the Montreal Protocol put more rapid targets in place for CFC reduction, 50% by 1995, 80% by 1997, and phase out by 2000. In December, 1991 there were 81 countries endorsing the London Revisions .[48]

The Clean Air Act Amendments of 1990 gave teeth to the commitments made by the U.S. to the Montreal Protocol. Title V of the Amendments established a phase out schedule which would eliminate the production and importation of CFCs, halons, and carbon tetrachloride by 2000. However, in February 1992, the Bush administration, responding to evidence of rapid destruction of the ozone layer. committed to accelerate the phase-out schedule from 2000 to 1995.[49]

47. Rob Scott, CEO Phase II, Interview, September 16, 1993

48. Cummings, Christopher and Arnold, Matthew, "The Montreal Protocol Case," in The Greening of World Trade. U.S. EPA, February 1993

49. U.S. EPA, Report to the Office of Air and Radiation to Administrator William K. Reilly: Implementing the 1990 Clean Air Act: The First Two Years, November 15, 1992

Although there were no regulations specifically addressing computer energy use in the U.S., the EPA had initiated a program which encouraged innovation in this area. Recognizing that energy efficiency in computer use provided a benefit to the user, the EPA set out to develop a voluntary program aimed at affecting buyer behavior. The agency established a set of guidelines which would qualify the computer to be affixed with an "Energy Star" label. The Energy Star designation provided quick identification for buyers that their purchase would meet a minimum level of energy efficiency. Additionally, all computers purchased by the federal government were required to meet the qualifications of the Energy Star program.

Characteristics of U.S. EPA Energy Star Program

Performance Requirements

* Computer or monitor must drop to a low power usage mode (less than 30 Watts) when inactive
* Printers must enter a low power mode of between 30 and 45 Watts (determined according to printer speed

EPA Role

- Provide recognition for participants
- Encourage public awareness of the economic and environmental benefits of energy efflcient computers
- Promote purchases of energy efficient computers
- Promote government purchases of of energy efficient computers

Source: U.S. EPA

Sources of Competitive Advantage in U.S. Firms

Factor Conditions

Computers were manufactured using widely available materials and with a limited amount of assembly labor.[50] The key factor in innovation and upgrading in the industry was a supply of well trained technically sophisticated workers.[51] In the U.S., many schools offered graduate and undergraduate students programs which supported the computer industry. Notably, programs at the Massachusetts Institute of Technology, the California Institute of Technology, and Stanford University had built strong reputations for innovation and encouraged faculty and students alike to develop and market new technologies. The proximity to these universities offers some explanation for the clustering of computer firms on the Route 128 corridor in Massachusetts, and in the Silicon Valley in California.

so. In 1991, U.S. computer and office equipment manufacturers incurred payroll expenses for production workers of only 3.9% of sales (compared to 9.4% average for all manufacturing industries).

5 1. Research and development costs in 1990 were 15.4 % of sales for computer and office equipment manufacturers and 8.6% of sales for electronic component producers. R&D for all industries averaged 3.2% (National Science Foundation data).

In addition to individuals who developed their skills through formal training, the computer industry (particularly in the 1970s and 1980s) seemed to offer a unique opportunity for bright young entrepreneurs who fell outside of traditional backgrounds. During following World War II and taking off after the 1960s the industry developed a subversive character which many in that period found attractive. The financial requirements were initially very low for innovative individuals to explore and develop new products. Because, there was no need to have access to large corporate or university laboratories, many of the most important developments in the industry came from small start-ups or even, as widely report& for Apple Computer, were achieved in the founder's garage.[52]

Domestic Demand Conditions

The earliest stages of the development of the computer occurred because of the special needs of the military. During World War II, the military had recognized that advanced automated means were necessary to counter the rapidly advancing sophistication of enemies' encoding systems. After the conflict, the military identified other areas including guidance systems, air traffic control, and aircraft design which could benefit from improved computational methods. Funding flowed to university programs (dominated by the Whirlwind project at the Massachusetts Institute of Technology) and to private firms (initially to the Engineering Research Associates, a private firm started for the purpose of building on computer advances made during the war).[53]

Military demands also helped to fund the developments which would later lead to IBM's dominance of the commercial computer market. Advances which the company made while working on air defense and guidance programs for the government are credited with positioning IBM for its later introduction of the System 360 computer line.[54] In fact, between 1949 and 1959, government programs were responsible for 68% of IBM's research funding. The government share of research costs dropped through the 1960s

52. See for example, Accidental Empires by Robert Cringely, Harper Business, New York, 1993

53. Flamm, Kenneth, Creating the Computer: Government. Industrv. and High Technology, The Brookings Institute, Washington, D.C., 1988

54. Flamm, Kenneth, Creating the Computer: Government. Industrv. and High Technologv, The Brookings Institute, Washington, D.C., 1988

and 1970s.[55] However, given the high cost of developing the first computers, and the uncertainty of their eventual success, it is unlikely the later commercial market could have developed without the early government funding.

Participants in the early government programs were quick to recognize the opportunity for commercial applications of computer technology. In the U.S., this market surged in the 1960s encouraged by IBM's technical (standard platforms) and marketing (leasing contracts rather than direct sales) innovations. With the introduction of the personal computer, buyer sophistication concerning computer hardware reached a new level. For many computer buyers, gathering information on hardware crossed the border from a professional task to a hobby. Popular magazines provided information to these buyers offering critiques on computer performance, hints on software, and even gossip about the personal lives of industry leaders. A core of highly informed buyers pushed companies to provide ever faster, more powerful, and cheaper products.

U.S. electronic component manufacturers enjoyed large domestic demand in the early 1990s but manufacturers feared an erosion of their key markets. One measure indicated that the U.S. share of all electronic equipment had slipped from 41% in 1986 to 29% in 1992.[56] Although the electronics industry was considered among the most global of any manufacturing area, a loss of domestic markets could be devastating for upstream suppliers. The Semiconductor Industry Association estimated that in 1991, U.S. semiconductor manufacturers supplied 70% of the domestic market while their share of the overall world market was only 39% (as will be discussed later, Japan was in a similar position with 86% of home market and 47% of the world market).[57]

55. Flamm, Kenneth, Targeting the Computer: Government Support and Intemational Competition, The Brookings Institute, Washington, D.C., 1987

56. USITC, Industry & Trade Summary: Semiconductors (USITC publication 2708) December, 1993

57. Howell, Thomas R., et.al., Creating Advantage: Semiconductors and Government Industrial Policy in the 1990, Semiconductor Industry Association, 1992

The U.S. market for printed wiring boards was also strong in the early 199Os, although here also manufacturers were concerned over loss of their markets as a result of their customers moving production to low wage developing countries. In 1992, 28.9% of the world PWB market was in the U.S.[58]

The U.S. demand for semiconductors and PWBs was smaller than that in Japan, causing concern for many industry analyst. However, the U.S. demand for these products had a higher portion of computer, military, and telecommunications applications. The Japanese markets were dominated by consumer electronics applications. In many cases, the design aspects of the U.S. markets led those of the Japanese markets (while those demanded by the Japanese markets typically led production developments). Responding to these differences, the U.S. share in some subsegments of the market were dominant (while the Japanese share was similarly dominant in others). For example, the requirements in the U.S. for two sided and multi-layer epoxy/glass PWBs led to technical advances in this area by domestic suppliers. Japanese demand, on the other hand, had a higher weight of l-sided boards based on a paper substrate. ln semiconductors, despite the often cited loss of the memory chip market, the U.S. had remained the leading supplier of microprocessors and application specific integrated circuits, components associated with areas where the U.S. led in the end-product.

Related and Supporting Industries

The strength of the U.S. computer industry was inescapably linked to the health of the nation's semiconductor manufacturers. Computer firms counted on new software developments to encourage customers to buy new upgraded systems. The software, in turn, required advances in microprocessors to allow expanded and quickly functioning features. As the leading developer of microprocessors, Intel Corp. had a great deal of leverage over the industry. The early 1990s had been particularly successful for the company as it achieved after tax return on sales of 17-18% from 1990 through 1992, and an astounding 26% in 1993.[59]

58. The Institute for Interconnecting and Packaging Electronic Circuits, "TMRC Report on the World Market for Printed Wiring Boards and Substrate Materials for 1992, " Chicago, 11, June 1993

59. Intel Corporation, 1992 Annual Report

U.S. firms were in a much less desirable position in a second critical supporting industry. In memory chips, the U.S. had suffered devastating loses in market share during the 1980s. A concerted effort by Japanese manufacturers (discussed below) which included cooperative research among firms, government funding of research, and less than fair market pricing in the U.S., had driven the U.S. share of the DRAM chip market from greater than 70% in 1978 to less than 20% in 1986. As a result, many U.S. computer firms relied on Japanese companies for DRAM chips.

Semiconductor firms also relied on related and supporting industries. Here, also, the coordinated efforts of the Japanese government and industry in the early 1980s had eroded a previously dominant U.S. position. Photolithographic imaging equipment was a critical area of technology in semiconductor manufacturing. In 1982, the U.S. share of the market for this equipment was 58%; by 1989, the U.S. share had diminished to 18 % . Two Japanese firms, Nikon and Canon, supported by government research projects, had taken over market shares of 38% and 24% by introducing equipment advances. On the other hand, U.S. firms continued to lead in chemical deposition and ion implantation equipment.[60]

U.S. firms held only 17 % of the market for semiconductor materials in 1989. In many cases, the U.S. position had been eroded because companies were sold to Japanese or European manufacturers, and many firms continued to produce semiconductor materials in the U.S. Although these firms continued some manufacturing in the U.S., in some areas there had been an almost complete elimination of U.S. ownership of operations. In silicon wafer production and in ceramic packages, the U.S. position was negligible.[61]

Critical supplies for the printed wiring board industry included glass/epoxy prepreg and dry film photoresist. U.S. suppliers of these materials led technical developments. In particular, DuPont, the

60. USITC, Global Competitiveness of U.S. Advanced-Technology Manufacturing Industries: Semiconductor Manufacturing and Testing Equipment: Report to the Committee on Finance, United States Senate (investigation No. 332-303 (final)), USITC publication 2434, September 1991

61. USITC, Global Competitiveness of U.S. Advanced-Technology Manufacturing Industries: !Semiconductor Manufacturing and Testing Equipment: Report to the Commitee on Finance, United States Senate (investigation No. 332-303 (final)), USITC publication 2434, September 1991

leading supplier of photoresist led such technical efforts as the development of aqueous soluble photoresist materials.

Strategy, Structure, and Rivalry

Three factors combined to make the U.S. computer and electronic components markets highly competitive: in the early stages of each of these industries, the key technologies were made available to the public at large, a single individual could provide the critical technical insights needed by a new entrant to the market, and a sophisticated market of venture capital investors had developed to support new firms.

The earliest computer designs were funded by the government and completed in the academic environments of Princeton and MIT. This had a profound effect on the accessibility of early innovations. For example, one of the first computer projects was led by John Von Neumann at Princeton. Reports of the project's progress and technical insights were published by team members and, thus, made available to all potential entrants in the early computer industry.[62] The free exchange of technical information remained a characteristic of the industry until large commercial markets became evident.

The pioneers of the computer industry often did not remain patient with their early organizations. In the 196Os, Ken Olsen gathered experience with IBM prior to starting DEC. Similarly, Gene Amdahl had led the design of early IBM computers prior to starting his own firm. Defections of key technical personal had been a characteristic of the industry even at its inception. William Norris, one of the earliest computer designers, left Sperry Rand to found the Control Data Corporation (CDC). Later Seymour Cray left CDC to found Cray Research. Both of these firms were located in Minneapolis, Minnesota where a cluster of computer firms had developed, many of which could be traced back to the early founding of the Engineering Research Associates firm there in 1945.

Much like the first computer designs, the earliest insights in transistors were rapidly introduced to the public domain. Also paralleling the computer industry, the U.S. semiconductor industry grew as key technologists in one firm left to begin their own operations. The first transistors were developed in the

62. Flamm, Kenneth, Creating the Computer: Government. Industry. and High Technology, The Brookings Institute, Washington, D.C., 1988

Bell Telephone laboratories in 1948. William Shockley later won the Nobel prize for his innovative development of the "bipolar" transistor which allowed current flowing in one direction to control the flow of current along a second path. As required by earlier antitrust settlements, Bell made the technology widely available. Shockley, himself, took advantage of the free use of the innovation and initiated his own firm in 1955. In turn, several scientists left Shockley Semiconductor Laboratories to form Fairchild Semiconductor from which Gordon Moore and Robert Noyce departed in 1968 to begin Inte1.[63] Later entrepreneurs would leave Intel to start still other firms.

The Role of Government

There is perhaps no other industry in which the role of government was more important than that of electrical devices and electronic components. U.S. government agencies, particularly the Department of Defense and the Bureau of Census were the first organizations to recognize potential applications for the computer. Government funding for academic and commercial development was crucial to the industy's early growth. However, the U.S. government's role in shaping the electronics sector went well beyond that which it played as a leading buyer.

In the 196Os, Japanese manufacturers had overtaken U.S. firms and gained dominating share of world markets for televisions and other consumer electronic devices. In the 1980s manufacturers of computers and electronic components used this experience to gain the attention of policy makers. A similar loss of production capacity for computers and semiconductors, they argued, would damage all downstream users of these products and, further, endanger national defense because of the role of these products in many of the devices used in modem warfare.

A series of International Trade Commission investigations conducted throughout the 1980s found that Japanese manufacturers were selling semiconductors at well below the cost of production. By protecting home markets and aggressively pricing in foreign markets, the Japanese manufacturers, it appeared, were attempting to take advantage of the scale and learning curve advantages which could be gained by rapidly

63. Zaks, Rodney, From Chips to Svstems: An Introduction to Microprocessors, Sybex, Berkeley, 1981

achieving large market share positions. U.S. firms, unable to sustain the large losses necessary to combat the Japanese pricing, quickly exited the market.

By 1986, the U.S. share of the worldwide DRAM market had plummeted to a point below 20 % . Semiconductor manufacturers in other segments such as EPROMs (electrically programmable read only memory), SRAMs (static random access memory), and ASICS (application specific integrated circuits) feared that without a response to the Japanese practices, these markets would be similarly lost. U.S. manufacturers were dissatisfied with the response of the Japanese government to an early 1980s pact, The High Tech Working Group Agreement, and encouraged the U.S. government to achieve more substantial action.[64]

In 1986, the two governments set a new framework in the US-Japan Semiconductor Trade Arrangement. In a side letter (initially a confidential document among the negotiators but later made public), the Japanese government agreed to encourage manufacturers to use more non-Japanese semiconductors. A goal of 20% of the Japanese market was recognized. Despite the Japanese commitments, U.S. firms saw a reduction in their share of the Japanese market in the year following the agreement. In response to the apparent lack of efforts, the U.S. government imposed trade sanctions on a variety of Japanese consumer electronics. Soon after, Japanese electronics companies began to work more closely with U.S. firms to incorporate U.S. semiconductors in their products. Additionally, pricing for Japanese semiconductors in the U.S. were returned to a more competitive level .[65]

The opening of the Japanese market is estimated to have yielded more than $1 billion in incremental revenue to U.S. firms. However, the agreement also provided an opportunity for Japanese firms to take advantage of the dominant position they had established in the DRAM market. Several authors have concluded that the rapid run up in DRAM prices which occurred in the late 1980s can be linked directly

64. Howell, Thomas R., et.al., Creating Advantage: Semiconductors and Government Industrial Policv in the 1990, Semiconductor Industry Association, 1992

65 Howell, Thomas R., et.al., Creating Advantage: Semiconductors and Government Industrial Policy in the 1990&, Semiconductor Industry Association, 1992

to MITI establishment of production and export guideposts.[66] Between the first quarter of 1986 and the second quarter of 1989, prices for 256K DRAMs increased by more than 50%.[67] The benefits accrued primarily to the leading Japanese semiconductor firms, but they can also be seen in the results for Micron Technology, one of the two remaining U.S. DRAM producers. In 1988 and 1989, the company enjoyed after tax returns of 33% and 24% after having suffered losses in 1986 and 1987.[68] Although the Semiconductor Trade Agreement has been blamed for allowing the "cartelization" of the DRAM market, it has also been credited with stemming the U.S. loss of position in other segments of the semiconductor market such as EPROMs and with increasing the U.S. share of the Japanese market.

The U.S. government also played a role in the semiconductor industry by encouraging means for coordinated research and development Basic research, assumed to be of value to all industry participants, was conducted without fear of antitrust actions by organizations such as the Microelectronics and Computer Technology Corporation (MCC) and the Semiconductor Research Corporation. In the case of SEMATECH, a research consortium aimed at advancements in semiconductor manufacturing technology, the federal government provided approximately half of the organizations $200 million in 1992 funding.[69]

Japan

Competitiveness Overview

Japan ranked second behind the U.S. in computer production with a 30% share of the world market in 1992 (having improved on a 26% share held in 1988).[70] Japanese firms provided equipment in the supercomputer, mainframe, and personal computer segments, but in the early 1990s, no Japanese

66. See for example, Tyson, Laura D'Andrea, "Managing Trade and Competition in the Semiconductor Industry" in Who's Bashing Whom?, Institute for International Economics, Washington, D.C., 1992

67. Data from Dataquest presented in Tyson, Laura D'Andrea, "Managing Trade and Competition in the Semiconductor Industry" in Who's Bashing Whom?, Institute for International Economics, Washington, D.C., 1992

68 Micron Technology, company financial information

69. SEMATECH, 1992 Annual Report

70 U.S. International Trade Commission, "Global Competitiveness of U.S. Advanced-Technology Industries: Computers," Investigation No. 332-339, December 1993

company had achieved a significant position in workstations. Supplying primarily domestic demand, Japan held a fairly low share of world exports of computers. In 1990, Japan is reported to have supplied only 10% of internationally traded computers and central processors.[71]

Leading Firms

In contrast to developments in the U.S., the Japanese computer industry was dominated by firms which had been in existence long before the invention of the transistor. Several firms, including NEC and Fujitsu, had provided equipment to the nation's telecommunications industry while others such as Toshiba had been involved in the production of electrical equipment (Hitachi had been in both markets).[72]

Fujitsu was the largest Japanese manufacturer of high end computer products ranking as the world's second leading producer of supercomputers (behind Cray Research of the U.S.) and the second leading producer of mainframes (behind IBM of the U.S.). In both cases, Fujitsu was estimated to have approximately 40% of the revenue of the leading firms.[73] NEC was Japan's largest producer of personal computers. Supported by a 53% share of the home market, NEC ranked behind only IBM in share of world personal computer production.[74]

Although computer and electronic component manufacturing had become critical in firms which also supplied electrical equipment, in several leading firms, it remained one (important) division of a larger diversified organization. Information systems and electronics provided 38% of Hitachi's 1993 revenue for example while power and industrial systems, consumer products, and materials provided the remainder .[75] Toshiba similarly received 49% of 1993 revenue from information systems and electronic

71. United Nations, "UN Trade Statistics Yearbook, 1990"

72. Fransman, Martin, The Market and Beyond: Cooperation and Competition in Information Technology Development in the Japanese System, Cambridge University Press, Cambridge, 1990

73. U.S. Intenational Trade Commission, "Global Competitiveness of U.S. Advanced-Technology Industries: Computers," Investigation No. 332-339, December 1993

74. Schlender, Brenton, U.S. PCs Invade Japan, Fortune, July 12, 1993

75. Hitachi Ltd., 1993 Annual Report, Year ended March 31, 1993

devices with the rest derived from heavy electrical apparatus and consumer products activities.[76] In other firms such as NEC and Fujitsu, computer and communications operations and the supporting components production dominated the firm's revenue.

Major Japanese computer firms were highly vertically integrated and the same large firms which led Japanese computer production also led in semiconductor sales. NEC had been the world's largest semiconductor manufacturer throughout the late 1980s, but the company had moved to the second position behind Intel in 1993. As has been noted, Japanese firms held a commanding share of the world memory chip market and were very strong in such areas as application specific integrated circuits. Behind NEC's 1993 semiconductor sales of $6.4 billion were Toshiba, Hitachi, and Fujitsu at $5.8 billion, $4.7 billion, and $3.3 billion respectively.[77]

Even in printed wiring boards, Japanese production was dominated by large firms. In 1991, only 31% of the Japanese production was supplied by firms with less than 300 employees. Further, these small and mid-sized firms were losing share as in 1990, these suppliers had provided 43 % of Japanese production.[78]

Distinctive Environmental Regulation in Japan

Japanese electronics manufacturers faced environmental regulations very similar to those in the U.S. Here, water pollution was controlled through a set of effluent guidelines established through national legislation and air releases (of CFCs) were regulated as a result of the nation's participation in the Montreal Protocol.

Environmental issues were thrust into the Japanese national consciousness with the outbreak of "Minamata disease" in 1956. Damaging the central nervous system, this disease resulted from the release of methyl-mercury byproducts from Chisso Hiryo Co.'s production of acetaldehyde in Minamata City. The chemical had bioaccumulated in fish which were subsequently eaten by the local population. Ultimately

76. Toshiba Corporation, 1993 Annual Report, Year ended March 31, 1993

77. VLSI Research Inc., Press Advisory, "1993 Top Ten Semiconductor Companies," November 23, 1993

78. "Printed Circuit Boards," in Japan Electronics Almanac '93/'94, Dempa Publications, Inc., Tokyo/New York, 1993

affecting more than 5000 people, the emergence of this ailment led the Japanese government to begin to control the environmental effects of the country's growing industrial complex.[79] In 1958, the central government passed two measures, one regulating effluent releases from industry, and the other addressing water conservation. However, these early measures were thought to be limited in scope and lacked strong enforcement. Only in the 1970s did the Japanese government begin to regulate on a national level in a way that significantly affected industry's effluent releases.

Allowable Metals Concentration in Japanese Wastewater

Metal	Concentration
Cadmium	0.1 mg/l
Cyanide Compounds	1 mg/l
Lead	1 mg/1
Hexivalent Chromium	0.5 mg/l
Copper	3 mg/1
Chromium	2 mg/1

Source: Japan Environment Agency

Effluent standards were set in the Water Pollution Control Law of 1970 establishing permissible limits for eight parameters. Prefecture governments could establish more strict criteria if the local needs warranted. Other parameters such as polychlorinated biphenol were added as their impact on human health were determined. Then, in 1993, responding to revised drinking water guidelines from the World Health Organization, the Japanese government expanded the list of substances to 23.[80] The permissible limits on several metals important to the printed wiring board industry are included in the attached table.[81]

Japan passed the "Law Concerning the Protection of the Ozone Layer through the Control of Specified Substances and Other Measures" (known as the Ozone Layer Protection Law) in May of 1988. This law established the methods by which Japan would follow through on the commitments it made by

79) Environment Agency, Government of Japan, "Quality of the Environment in Japan, 1992"

80. Environment Agency, Government of Japan, "Water Pollution Control Administration"

81. These values are reported in mg/1 as they were provided in the source document ("Water Pollution Control Administration"). Taking a liter of water as 1 kilogram, 1 mg/l would be equivalent to 1 ppm. Given this, the Japanese limits on cyanide and copper are roughly similar to the "average of four monitoring days" limits reported for California above. Japan's limits on cadmium and chromium are more strict while California requires significantly lower lead content.

participating in the Montreal Protocol. As in other participating countries, Japanese businesses were required to phase out the use of CFCs and carbon tetrachloride by 2000 and trichloroethane by 2005.[82]

Sources of Competitive Advantage in Japan

Factor Conditions

As has been stated, electronics manufacturing was not dependent on traditional types of factor endowments. Materials made up a minimal part of the overall value of the devices and most of those that were used were widely available. Japan's electronics industry was supported by a highly specialized workforce. Tokyo University, Tohoku University, and Kyoto University all participated in the early development of the computer industry in Japan. In most cases, these institutions worked closely with industrial partners so advances made in the academic environment were rapidly transferred to the commercial arena. Students participating in these programs were among the best in the nation. MITI had targeted a strong computer industry as critical to the nation's health. This sort of targeting had a profound effect on the professional choices of students. Targeted industries represented status, and the helpful guidance of MITI increased the odds that the computer industry would provide greater opportunities for growth than other, integrated areas. Finally, when the government and industrial efforts began to pay off, companies such as NEC and Fujitsu began to look like very secure environments in which to dedicate one's lifetime employment efforts. All of these factors helped the computer industry to attract a committed highly capable workforce.

Domestic Demand Conditions

The Japanese demand for computers was not unusually large or sophisticated in any way which would lead demand in other nations. It was, however, critically important to the health of Japanese computer makers. As in other targeted industries, government programs were established in the computer market which benefited manufacturers while imposing higher costs on buyers. By imposing higher tariff rates on computers in the early 1960s. the Japanese government intended to foster the embryonic industry. Encouraged by this and other government actions (discussed below), Japanese manufacturers set out to

82. Environment Agency, Government of Japan, "Quality of the Environment in Japan, 1992"

match the technical performance of the leading U.S. performers. By 1966, Japanese firms had claimed more than 50 % of the home market .[83]

Japanese demand for computers was primarily driven by industrial needs. Unlike the government and defense buyers in the U.S., Japanese industrial buyers were not often willing to finance the very high expenditures incurred in developing leading edge computer technologies. Therefore, Japanese manufacturers followed closely U.S. innovations, incorporated them into their designs, and then provided them to their protected markets.

In the personal computer market of the early 1990s, an additional characteristic of Japanese demand further protected the market but also limited its size. Japanese writing, kanji, incorporates thousands of characters making keyboard input extremely difficult. Partially for this reason, personal computer penetration was only 115 per 1000 people in Japan in 1993 (as compared to 308 in the U.S.).[84] The difficulty in supporting a kanji system delayed U.S. firms' entry in the Japanese market. However, developments associated with adapting to kanji provided few benefits to Japanese producers which were transferable to other markets.

For semiconductor manufacturers, the home demand was instrumental in driving the strong Japanese competitive position. Initially, the industry was fostered by procurement contracts from Japan's large telecommunications company, Nippon Telephone and Telegraph (NTT). Contracts with NTT in Japan paralleled closely those by the DOD in the U.S. NTT demanded leading edge technology and subsidized its development. The company also worked closely with its suppliers as products were prepared. A significant share of these benefits were enjoyed by NTT's family of primary suppliers including NEC, Fujitsu, and Oki. Some analysts have suggested that later advantages for Japanese firms in high volume

83 Fransman, Martin, The Market and Beyond: Cooperation and Competition in Information Technology Development in the Japanese System, Cambridge University Press, Cambridge, 1990

84 Schlender, Brenton, "U.S. PCs Invade Japan," Fortune, July 12, 1993

semiconductors owes substantially to NTT's early needs while the U.S. emphasis on design can be traced to the demands of the U.S. DOD.[85]

A second area of strong home demand for the Japanese semiconductor industry was in consumer electronics. Japanese production of consumer products was more than ten times that of the U.S. in the early 1990s.[86] As much as 30 % of the Japanese market for semiconductors was driven by this sector. Here again, the demand emphasized low cost and mass production rather than advanced design.

Related and Supporting Industries

The Japanese computer and electronic devices industries were supported by the nation's strong position in semiconductors. This in turn, synergistically supported and was supported by a strong semiconductor equipment industry. Japanese growth in semiconductors spurred a concurrent development of a domestic semiconductor equipment industry. Between 1979 and 1983, home demand was credited for the growth in share of world markets for Japanese suppliers from 15 % to 25 % in wafer processing, and 7 % to 2 1% in test equipment.[87] The growth of the semiconductor equipment industry continued to be tightly tied to that of semiconductors throughout the 1980s. In 1989, 76% of Japanese demand for semiconductor equipment was satisfied by domestic suppliers.[88]

Worldwide, the Japanese share of semiconductor equipment had risen from 18% in 1980 to 39 % in 1988.89 This had been driven by three factors, the dominant home market position described above, selective acquisitions by Japanese firms of U.S. suppliers, and technical innovations by Japanese

85 Howell, Thomas R. et. al., The Microelectronics Race: The Impact of Government Policv on International Competition, Westview Press, Boulder, 1988

86. McKinsey and Company, "Productivity in the Consumer Electronics Industry," in Manufacturing Productivity, McKinsey Global Institute, Washington, D.C., October, 1993

87. U.S. Department of Commerce, "A Competitive Assessment of the U.S. Semiconductor Manufacturing Equipment Industry, Washington, D.C., 1985

88. USITC, Global Competitiveness of U.S. Advanced-Technology Manufacturing Industries: Semiconductor Manufacturing and Testing Equipment: Report to the Committee on Finance. United States Senate (investigation No. 332-303 (final)). USITC publication 2434, September 1991

89. U.S. Department of Commerce Bureau of Export Administration, "National Security Assessment of the U.S. Semiconductor Wafer Processing Equipment Industry, " April, 1991

companies (at times achieved through government programs). Technical leadership, of course, reinforced the home market position of Japanese suppliers, but where technologies were equal (or near equal), Japanese manufacturers tended to purchase domestically. High levels of vertical integration encouraged this behavior as, for example, Hitachi grew to become one of the world's ten largest semiconductor equipment suppliers. Technical leadership was most evident in the area of photolithography. In the mid-8Os, Nikon overtook Perkin Elmer and GCA Corp. when it introduced a stepper which far surpassed earlier technologies.[90]

Strategy, Structure, and Rivalry

Although U.S. observers often saw Japanese manufacturers as a unified competitive force, this view underestimates the fierce domestic competition existing for the home market. Patient capital markets and traditions of lifetime employment drove an emphasis on market share rather than near term profitability by Japanese producers in many industries. This was especially evident in electronics and semiconductors. In fact, this approach explains the distinctly different strategies by U.S. and Japanese manufacturers in the 1980s.

Japanese manufacturers were protected in their home markets for both computers and semiconductors. Domestic firms competed along traditional lines of price, performance, technical leadership, and service. However, manufacturers recognized the large learning and scale benefits in these industries and struggled to achieve high production levels. Foreign markets (especially in the U.S.) were targeted to provide greater scale and more rapid learning.

Whereas U.S. firms approached the market with a traditional desire to achieve returns for current capital investment (and fund technical efforts), Japanese firms were in a race to most rapidly acquire production learning and in turn build market share. The differing goals led to diametrically opposed responses to a reduced demand for semiconductors in 1985. While U.S. firms attempted to remain profitable through production cut backs and reductions in spending on research and development, Japanese firms kept production high and flooded the U.S. market with chips which were priced well below their cost of

90 U.S. Department of Commerce Bureau of Export Administration, "National Security Assessment of the U.S. Semiconductor Wafer Processing Equipment Industry," April, 1991

production. This strategy was only made possible because Japanese manufacturers were part of larger companies which could support losses in semiconductor divisions through the financial strength of other areas.

As a whole, the Japanese approach resulted in the rapid departure of U.S. firms from the targeted segments of the semiconductor industry. Collectively, Japanese firms achieved their goal of dominant market share. However, multiple large Japanese suppliers (six with sales in excessive $2.4 billion in 1993) continued to compete.

The Role of Government

While the U.S. government's role in the computer and electronic component industry was typically reaction oriented, the Japanese government, through MITI and other agencies, was an active participant in the development of the nation's industry. Government actions in Japan included, protecting the domestic market from foreign products through high tariffs, the establishment of organizations which would foster domestic demand, and the subsidization and coordination of research.

Japanese tariff rates for computers and semiconductors remained above 10% through the 1960s and 1970s.[91] In addition rigid import controls allowed MITI to further limit the number of items which were brought in even with these tariffs. In the 198Os, after a home industry had been established, the Japanese rates were brought into parity with other computer producing countries.[92]

The Japanese government also fostered the development of the young industry through the establishment of the Japanese Electronic Computer Corporation (JECC). This organization, subsidized by the Japan

91. Flamm, Kenneth, Targeting the Computer: Government Support and International Competition, The Brookings Institute, Washington, D .C., 1987

92. U.S. International Trade Commission, "Global Competitiveness of U.S. Advanced-Technology industries: Computers," Investigation No. 332-339, December 1993

Development Bank, provided low interest financing for the purchase of Japanese built computers. Strict "domestic content" rules made the influence of JECC felt far up the supply chain for electronic devices.[93]

The Japanese government encouraged technology development through its laboratories in MITI and Nippon Telephone and Telegraph (NTT). Firms which were later to lead the Japanese computer and electronics industry such as Fujitsu and NEC took their first steps into the market using developments from these laboratories.[94] Later, the Japanese government's role incorporated fostering and coordination along with direct subsidization. In particular, in the VLSI research project of 1976-1980, MITI coordinated the research efforts of five leading electronics firms into six laboratories exploring basic developments of semiconductor manufacturing.[95]

93. Flamm, Kenneth, Targeting the Computer: Government Support and International Competition, The Brookings Institute, Washington, D.C., 1987

94 Fransman, Martin, The Market and Bevond: Cooperation and Competition in Information Technologv Development in the Japanese Svstem, Cambridge University Press, Cambridge, 1990

95. Fransman, Martin, The Market and Bevond: Cooperation and Competition in Information Technologv Development in the Japanese System, Cambridge University Press, Cambridge, 1990

EFFECTS OF REGULATION ON COMPETITIVE ADVANTAGE

Direct Effect on Product

Energy used to power an idle computer was truly a wasted resource. That energy use represented costs to the computer's user and its production contributed to environmental problems such as global warming and acid rain. Despite these facts, computer users did not become aware of the potential benefits of more energy efficient computers until the early 1990s. At that time, the U.S. EPA developed a program under which computers which met minimum standards of energy efficiency would be labeled with a sticker (using an "Energy Star" logo). Using technology developed for laptop computers, most manufacturers were quickly able to provide systems which easily met the programs requirements.

The Energy Star program was given a strong boost in 1993 when the Clinton administration issued an executive order stipulating that all computers purchased by the federal government meet Energy Star requirements. Inspired by those stated intentions of the world's largest purchaser of computers, manufacturers rapidly provided compliant systems. In October of 1993, the U.S. EPA reported that manufacturers representing approximately 70% of U.S. computer sales had developed computers which met the requirements.[96] While the government's purchase decision had an important accelerating effect on the Energy Star program, manufacturers anticipated that other markets would rapidly develop. Among the 136 firms producing energy efficient computers in late 1993 were the Japanese firms NEC and Toshiba, companies unlikely to anticipate sales to the U.S. govemment.[97]

The development of energy efficient computers represented a win-win for the computer suppliers and their customers. For the buyers, energy efficiency was provided without additional costs. Thus, a 50-75 % savings in the operating cost of the system could be acquired at no expense. Although the operating cost of a computer was often overlooked by buyers, it could represent a significant share of the life cycle cost

96. U.S. EPA, Information Flier, "EPA Energy Star Computers," October 14, 1993

97. Japanese firms were not developing energy efficient computers merely for the U.S. market. In the early 1990s most Japanese electronics manufacturers had established energy use reduction targets for their products. Hitachi, Fujitsu, and NEC explicitly targeted production of more energy efficient products in their environmental plans.

of the computer. Buyers of Energy Star computers could potentially save $75 annually on a system which had capital costs of $1500.

Computer suppliers were able to provide energy efficiency at no additional costs and without having to incur large R&D expenses (much of the technology was simply transferred from laptop computers). For the existing base of computers, a company called PC Green Technologies, Inc., had introduced an external device which would put computers and peripherals into a sleep mode when not being used. The product was being sold for $89.95 and reportedly could yield $100 annually in energy savings.[98] Manufacturers benefited from the improved image supplying energy efficient devices could provide. Capitalizing on this some manufacturers extended the Energy Star concept to develop “Green PCs” which utilized increased recycled material, were designed for ease of disassembly for future recycling, and were shipped in ways that minimized packaging.

Direct Effects on Production Process

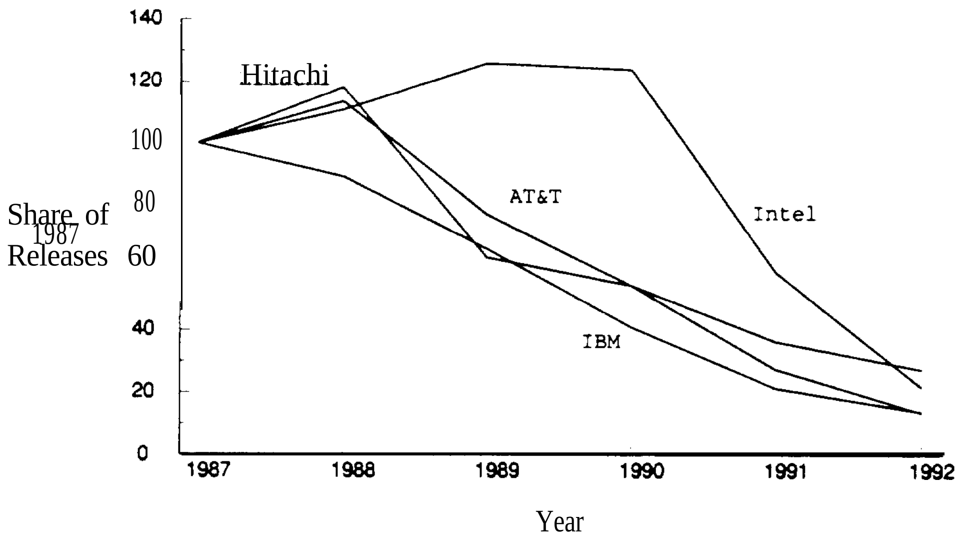
Environmental concerns affected the computer production process in a number of ways. Notably, the elimination of CFCs from the manufacturing process and the requirement for controlling discharge from plating operations (in PWB production) dramatically influenced the materials and processes used in making computer and electronic components. In some cases, companies supplying materials to computers and device manufacturers saw entire markets disappear and others appear as a result of environmental initiatives. In a few instances, responding to environmental challenges affected the competitive position and strategies of the companies themselves.

Analysts were initially very concerned about the effect of the Montreal Protocol on the electronics industry. It was feared that if all countries did not join in the effort to eliminate the use of CFCs, those countries which did would see electronics manufacturing operations move to those which did not. Given these early worries, the ability of the industry to remove the substances from their production in less than a decade provides an impressive example of how industry can innovatively respond to a compelling (and legally addressed) environmental problem.

98 “Computer Users Save $ and Power with New Gizmo,” PC technologies, Inc., Company Press Release, Feb. 1, 1994

Many electronics manufacturers achieved the goals of the Montreal Protocol well in advance of the initiative's schedule. Large firms from around the world such as AT&T, Hitachi, IBM, and Intel (and many others) made public commitments to achieve CFC free production in the years 1993-1995. Information provided by these companies typically showed 30-50% reductions in CFC use in the late 1980s. Much of these reductions resulted from simple house-cleaning types of efforts. Storage vessels were covered, solvent was recycled, and awareness programs were implemented. [99]

Reduction in CFC Use Major Electronics Firms



Note: IBM data are for CFC-113 only; Intel data include all ozone depleting substances
Source: Company Environmental Reports

99. See for example, Patell, James and Marcy Trent, "AT&T Environment and Safety," The Management Institute for Environment and Business, Washington, D.C., 1993 or Fujitsu Company, "CFC-113 Replacement by Aqueous Cleaning Systems, " Ichiro Yoshida, Fujitsu Limited

Cost Saving Pollution Prevention Programs
For Eliminating CFCs From Electronic Manufacturing

Source	Project	Capital Investment	Annual Return	Payback Period
ICOLP	AT&T use of terpene immersion cleaning of printed circuit boards replacing CFC process		28% reduction in operating costs	
ICOLP	Motorola implementation of terpene cleaning of printed wiring boards		81% reduction in operating costs	
EPA/SEDUE/ CANACINTR A	Addition of recycling and engineering controls to electronics cleaning	$11,000	$5,248 annual operating savings	
AT&T	Substitution of "no clean" solder flux for material which previously required perchloroethylene cleaning			Less than 12 months
Defense Contractor	Replacement of PWB cleaning with terpene process (per line of 500 boards/day)	$37,000	$18,000 annual operating savings	
Fujitsu	Shift from solvent cleaning and degreasing of PWBs to mechanical and aqueous methods in one facility	¥106,000,000	¥660,000 annual operating savings	

Many of the steps taken in the first phase of CFC reduction addressed areas where material was being wasted. Reducing the amount of solvent which evaporated or was replaced prematurely allowed plants to continue production while using significantly lower volumes of CFCs. Elimination of the materials was a very different undertaking. Manufacturers targeting CFC-free production had to examine every area where CFCs were used and either develop processes where these steps were removed or identify suitable substitutes which performed the function previously achieved by the CFCs.

As the concerns about destruction of the ozone layer developed, the prospect of eliminating all CFCs from electronics production had initially seemed a formidable challenge. Companies first responded to calls for CFC elimination by pointing out that the link between the chemicals and the measurements of the ozone hole remained ambiguous and certainly did not justify the enormous costs to be borne by business if CFCs were to be phased out. Many factors contributed to the industry's change in posture, but David Chittick, Vice President for Environment and Safety for AT&T, has suggested that three were pivotal :[100]

1) One manufacturer's development of a process for using a cost competitive, biodegradable solvent as a replacement for CFCs in flux removal processes.[101]

2) Northern Telecom, a large telecommunications company took the lead by committing to eliminate CFCs from manufacturing by the end of 1992. Once one firm had announced that CFC elimination was possible, others followed.

3) The United Nations Environmental Programme (UNEP) formally concluded that all areas of CFC use could be eliminated if existing technologies were readily transferred.

Encouraged by the Global Change Division of the U.S. EPA, the electronics industry began to support the possibility of eliminating CFCs within, or even ahead of, the Montreal Protocol schedule. In September of 1989, executives from AT&T and Northern Telecom working with the U.S. EPA invited representatives from fifteen other electronics firms to join a cooperative effort to find methods of reducing CFC use. Later named the Industry Cooperative for Ozone Layer Protection (ICOLP), the organization offered a means of providing and acquiring information on new technologies.[102] ICOLP was a truly international undertaking with the initiating North American firms being joined by such Japanese companies as Hitachi, Matsushita, and Toshiba, and recognizing as affiliate members such organizations as the Russian Institute of Applied Chemistry and the Korea Anti-Pollution Movement.

The primary goal of ICOLP was information exchange. The organization provided information in the form of workbooks suggesting means of reducing and replacing CFCs in the manufacture of electronic components. Also, ICOLP established a internationally accessible database called OZONET. The database, which could be accessed for free through a variety of EPA, United Nations, and corporate

100. Chittick, David, "The Transfer of Non-chlorofluorocarbon Technologies: A Case-Study in Industry Cooperation," Advanced Technology Assessment System Bulletin, Spring, 1992

101. The chemical used was a terpene solvent extracted from oranges. Other manufacturers later employed terpenes derived from cantaloupes, lemons, and other natural sources.

102. Long, Fredick and Arnold, Matthew, The Power of Environmental Partnerships, Dryden Press, 1994

systems provided similar information. Finally, ICOLP representatives led workshops and demonstration projects in developing countries. [103]

Although some capital expenditure was required to implement many of the technologies suggested by ICOLP, the payback period for such investment was surprisingly short: often less than one year.[104] The benefits came from significantly lower chemical Costs, reduced waste disposal costs, or process savings from eliminating production steps. In several cases, manufacturers realized that cleaning steps used in production were not required either for performance or appearance reasons. More often, alternative cleaners were employed. Vendors of substitute cleaners had quickly recognized the opportunities available for successful CFC replacement materials. ICOLP's publications provided one means of promoting new technologies. Through this and other methods, large and small chemical suppliers provided replacement materials for what had once been a $250 - 350 million market for CFC solvents,[105]

The industry response raises two important questions. First, if CFCs could be eliminated while providing a cost advantage, why hadn't manufacturers pursued these technologies in the absence of regulation? Secondly, if there was an economic gain to be achieved, why did manufacturers provide valuable technical information to the cooperative industry program?

Several factors contribute to the answer to the first question. First, industry representatives pointed out that many of the technologies had, in fact, been under development for many years. AT&T's investigation of a terpene solvent extracted from orange peels had been initiated several years before concerns about the ozone hole emerged. The early investigations had been initiated because the substance

103. Kerr, Margaret and Chittick, David, "The Industry Cooperation for Ozone Layer Protection: It's Conception and Purpose," Industry Cooperative Ozone Layer Protection Information Flier

104 See for example, U.S. EPA/ICOLP, "Aqueous And Semi-Aqueous Alternatives for CFC-113 and Methyl Chloroform Cleaning of Printed Circuit Board Assemblies," June 1991 and U.S. EPA/ICOLP, "Alternatives for CFC-113 and Methyl Chloroform in Metal Cleaning," June 1991

105. In a 1989 case study of Du Pont's strategy for CFC replacement, Forest Reinhardt, quotes a Dupont manager saying, "We now see the ozone/regulatory situation as a marketing opportunity for substitutes." At the time, Du Pont was the world's leading supplier of CFCs. Reinhardt, Forest, "Du Pont Freon Products Division (A)," National Wildlife Federation, Washington, D.C., January, 1989

had been recognized as a potentially very useful, cost effective solvent.[106] More often, however, manufacturers suggested that the benefits associated with changing cleaning and degreasing processes were very small compared to the overall level of value added in their operations. Manufacturers had to compare the costs of development, the potential fire hazard, and the unknown health effects of some substitutes with the relatively small returns anticipated from modifying their operations. In short, using CFCs was the accepted means of dealing with cleaning and degreasing needs for the industry. Without the pressure of regulation no manufacturer was willing to take on the risk of trying innovative methods. Once pressured, manufacturers found that both the physical and the financial risks of innovating had been overstated and projects were identified which not only eliminated CFCs but provided traditionally acceptable rates of return.

The question of why manufacturers chose to cooperate initially seems more difficult. Why would those manufacturers who had solved their environmental problems be so quick to put their innovative methods into the public domain; particularly if the new methods were financially attractive? The answer is a combination of public relations, financial analysis, and core competencies.

As noted above, many programs aimed at eliminating CFCs were financially attractive; however, these savings were minor compared to the overall costs incurred in production. The companies decided that there was much more to be gained by enhancing an environmental image than from withholding the technology from competitors. This was particularly important to an industry which had its clean image bruised by its appearance on a number of Superfund sites. By the early 1990s, the ethic which had engendered participation in ICOLP was being rewarded as again, electronics was perceived to be among the most environmentally sound industries. In 1993, when Fortune magazine ranked the environmental leaders, five of the ten companies cited were computer or electronics manufacturers.[107]

106. Boyhan, Water, Senior Staff Engineer, AT&T, Interview, January 14, 1994

107. Rice, Faye, "Who Scores Best on the Environment?" Fortune, July 26, 1993. The ten leaders cited in the article were: AT&T, Apple Computer, Church & Dwight, Clorox, Digital Equipment Corp., Dow Chemical, H.B. Fuller, IBM, Herman Miller, and Xerox.

Firms were further encouraged to publicize their CFC reducing innovations because any competitive advantage would surely have been short-lived. The innovations typically had more to do with new materials or equipment than with changes in electronics so the companies instituting the new technologies were reliant on suppliers. Suppliers had incentives to transfer technologies to other manufacturers limiting the advantage the initial firm could hold.

Printed Wiring Board Manufacturers:

Printed wiring board manufacturers also faced the need to eliminate CFCs from their operations. In many cases, the methods used by the larger computers and electronics firms could be adopted in the PWB operations. However, in the area of photolithography, PWB manufacturers had unique needs for CFCs.

The image on the printed wiring board was made by selectively removing areas of a copper laminate leaving behind thin traces of metal to provide a conductive path. Prior to etching operations the copper traces were isolated using a polymer layer called a photoresist. This material first had to be "developed" through a photolithography process in which unexposed regions of the material were removed (yielding a protective image which would become the copper trace). After the etching process, the protective layer of photoresist was removed in a stripping process.

In 1992, the U.S. market for dry film photoresist was approximately $123 million and U.S. manufacturers exported an additional $55 million of product.[108] Imports in the U.S. accounted for less than 5% of use. Three suppliers, DuPont, Hercules, and Morton International dominated production.

Beginning in the 1960s. the DuPont company supplied a "dry film photoresist" which was a tri-layered sheet of polyethylene, a reactive photoresist, and Mylar.[109] The protective polyethylene and Mylar were removed as the photoresist was laminated on the surface of the copper-epoxy/glass substrate. After exposure to light, the material was developed using methylchloroform; and after etching it was stripped

108 USITC, Dry Film Photoresist From Japan: Determination of the Commission in investigation No. 731-TA-622 (Final), USITC publication 2630, April 1993.

109 The description of this process and further information on developments of solvent and aqueous soluble photoresists were provided by John Lott, Senior Technical Consultant, DuPont Electronics

using methylene chloride. Water rinses removed the solvent from the surface of the board. DuPont had further provided means of removing the solvent from the water and of recycling the methy1chloroform in the developing process.

Because of water discharge requirements, many manufacturers began to demand a system which would minimize chlorinated solvents in their wastewater. DuPont and other dry film manufacturers responded in the mid-1970s by introducing dry film photoresists which could be developed and stripped using aqueous materials (sodium bicarbonate or high boiling glycol ethers). Thus, when the 1990 Clean Air Act requirements demanded elimination of CFCs, those manufacturers who had not previously switched to an aqueous soluble system had a ready alternative. The costs for both the PWB manufacturers and the photoresist supplier were roughly comparable for aqueous and solvent soluble systems. Further, because of the long period over which the market moved from solvent to aqueous systems (allowing all photoresist suppliers to develop comparable products), there was little effect on the relative position of the three primary suppliers.

PWB manufacturers were also faced with a need to control releases of toxics (primarily metals) in their wastewater. As has been noted, the cost associated with these controls ranged dramatically among producers with a trend toward higher costs for smaller manufacturers. In fact, in the late 1980s, a number of programs were initiated to provide information on how PWB manufactures could reduce metals releases.[110] The reports offer a variety of suggestions, most of which could be categorized as follows:

* Water use reduction
* Modification of drag-out procedures (reducing the waste carried on the boards from one process to the next)
* Segregation of waste streams
* Increased metals recovery
* Innovative treatment chemicals

110. See for example U.S. EPA, “Guides to Pollution Prevention: The Printed Circuit Board Manufacturing Industry, ” June 1990; California Department of Health Services Toxics Substances Control Program, “Waste Audit Study of the Printed Circuit Board Manufacturing Industry,” June 1987; and Minnesota Technical Assistance Program, “Metal Recovery: Etchant Substitution, September, 1988

Typically, the reports offered case studies which demonstrated the potential savings which could be achieved by adopting innovative waste treatment methods. In addition, commercial organizations such as Training and Technology Inc. (TNT Inc.) began providing assistance in PWB wastewater reduction as part of their businesses.

The opportunities to reduce costs while improving environmental performance were confirmed at a variety of sites (see attached table). Additionally, PWB manufacturers were discovering that efforts to understand their waste products provided insights which led to cost reductions outside of the waste treatment area. In a study of 33 process innovations in ten PW companies, Andrew King found that 13 were initiated by pollution control managers; cost reductions resulted in 12 of these. In the two firms which had attempted to track the value of innovations from the pollution control department, it was estimated that savings in materials costs were 2% of sales.[111]

Cost Saving Pollution Prevention Programs For Printed Wiring Board Manufacturing

Source	Project	Capital Investment	Annual Return	Payback Period
U.S. EPA	Change in wastewater treatment chemicals	Negligible	~$150,000	
TNT Inc.	Implementation of water reuse system		$50,000 - $100,000	Less than 11 months
Minnesota Technical Assistance Program	Substitution of hydrogen peroxide/sulfuric acid etchant for sodium persulfate	$11,000	$14,880	
California Department of Health Services	Installation of ion exchange system to reduce sludge generation	$16,000	$4,800	
California Department of Health Services	Installation of airspargers and flow restrictors for water use reduction	$1,000	$480	
Digital Equipment Corp.	Installation of ion exchange treatment system	$1,200,000	$490,000	

The Rio Grande Technology Foundation further demonstrated the possibilities for improving financial performance while reducing the impact of PW manufacturing on the environment. In "Project Ecocircuit," a public/private alliance (with participation of the Los Alamos National Laboratory, the New Mexico Economic Development Department, New Mexico State University, QUATRO Corp., Honeywell Incorporated, Digital Equipment Corporation, and Micrographics Corporation) set out to design an

111 King, Andrew, "Innovation From Differentiation: Pollution Control Departments and Innovation in the Printed Circuit Industry, " IEEE Transactions in Engineering Management, forthcoming

advanced PWB manufacturing facility which minimized the effect on the environment and improved operating performance over existing facilities. Using existing technologies, the team designed a facility which could achieve annual revenue of $8-11 million with a reduction in waste management costs from the 2-11% reported for existing facilities to a level of 0.5 % The revenue per employee was projected to increase from existing levels of $62,000-$93,000 to $174,000-$240,000 (a 160% increase) and the cost for a typical multilayer board was projected to be lowered from $65-75 to $50-60. In 1994, the team was soliciting participation in a demonstration project where they anticipated the capital costs of building a prototype facility to be $7.2 million.[112]

The vast amounts of material providing a variety of waste (and cost) reduction opportunities provides an explanation for the range in environmental compliance costs. In short, manufacturing PWBs was a complex process utilizing a wide variety of potentially toxic materials. Responsibly using and controlling those materials was similarly a complex undertaking. Large firms with the (internal or contracted) resources to sift through the large amounts of data could, in fact, bring down their compliance costs. Smaller firms, unable to explore all waste reduction options, and lacking the capital to implement many of them found their environmentally driven operating costs rising with increased regulation.

The structure of the PWB industry at the time of regulation was more important to the resulting competitive effects than the regulations themselves. As has been noted, Japanese regulations were similar in stringency to those in the U.S. Using copper as an indicator, regulations in Southeast Asia are said to have been somewhat less strict but still in the 5 - 10 ppm range which required similar costs to address as the 3 ppm requirements in the U.S. and Japan.[113] In fact, it seems unlikely, that if U.S. regulations could be addressed for as little as 1% of sales that regulation would be a more compelling reason for industry to migrate than the labor costs advantages (labor costs were more than 20% of expense for most PWB manufacturers).

112. "Project ECOCIRCUIT: A Clean Printed Wiring Board Factory Design," Rio Grande Technology Foundation, Albuquerque, NM, January 1994

13 Friedricbkeit, Hans J., "Germany's PCB Industry: On the Brink of Disaster?" PC FAB, September, 1992

Industry representatives often pointed to environmental costs as a driving factor in the U.S. drop in share of world production of PWBs from 40.2% in 1980 to 29.2% in 1992. Similarly, environmental costs played a role in the consolidation of the industry from 2000 firms to 900 in roughly the same period.[114] If, however, U.S. regulations were similar to those in the countries which gained share, why didn't similar patterns emerged in those countries? The answer seems to lie in the structural ability of firms to achieve low cost compliance. Larger firms, whether in the U.S., Japan, or Southeast Asia, benefited from the difficulty smaller firms encountered in responding to regulation. Only in the U.S. were small firms an important part of the industry as Japanese producers were supported by integrated operations and Southeast Asian production typically represented transplantation of operations from large manufacturers.

114. Custer, Walter, "An Overview of the PCB Market," Circuits Assembly, September, 1993

CONCLUSIONS

From its inception, the computer and electronics industry enjoyed a reputation of being among the most environmentally sound sources of knowledge-driven, high-paying jobs. The U.S. industry was stung in the mid-1980s as Superfund investigations revealed a legacy of a young industry which had depended on a variety of metals, solvents, and poisonous gases to fuel its rapid growth. The need to respond to past disposal actions was combined with increasing concern about existing operations forcing the industry to critically examine the effect its production had on the surrounding environment.

The experiences of the industry suggest the importance of industry structure in determining the competitive effects of environmental regulation. Large firms which have both the resources to investigate innovative means of compliance and the access to capital to implement those methods are in a better position to respond to regulation than small enterprises constrained by limited availability of technical personnel and restricted sources of investment funds.

In the case of the development of energy efficient computers, technology existed and was quickly incorporated into commercial products. Once the benefits of providing this technology were recognized and encouraged through the signaling of government purchasing intentions, all of the leading firms (in fact, almost all of the industry) responded. There was little competitive advantage to any one firm since their innovations were either led or quickly matched by competitors.

In the case of CFC reductions, the costs associated with eliminating the substances from production were minor compared to the overall operations of the leading firms. In fact, these firms found greater benefits from enhancing their image through cooperatively responding to the environmental challenge than from protecting their own innovative means of eliminating CFCs. Because of this cooperative response, and because most firms in these industries were large enough to assimilate the information provided by the leading firms, little competitive advantage was gained by any one firm.[115]

115. Suppliers did find new markets for innovative materials. In some cases, as in the substitution of aqueous and aliphatic cleaners, new markets were gained at the expense of the previously used materials (CFCs). In others, such as dry film resist suppliers incorporated modifications in their products which were required to maintain competitive

The effects on the printed wiring board industry was very different than those associated with the production of computers or semiconductors. Where the later two industries had important economies of scale and large barriers to entry, the U.S. PWB industry provided few barriers to entry and had traditionally provided limited scale economies. As a result, this industry was much more fragmented when environmental concerns became an important part of their operations. Despite concerted efforts by industry and regulatory groups, the smaller firms were experiencing disproportionately high pollution abatement and control costs in the early 1990s. Additionally, environmental costs were frequently cited as a contributing factor to the U.S. loss of world share in PWB manufacturing. However, controls in countries gaining share were as rigorous as those in the U.S. The evidence suggests that it was not the regulations themselves, but the regulations coupled with the fragmentary industry structure which made environmental issues a factor in the declining U.S. market. [116] Small U.S. firms simply could not assimilate the vast amounts of information needed to respond to environmental regulations in a cost effective manner. Finding themselves in a higher cost position, these firms lost market share to their larger competitors, whether they be domestic or foreign.

The experiences of the U.S. electronics manufacturers should not be considered unique. In any industry where environmental regulations are uniformly applied, technology is readily available, and firms have roughly similar investment resources, the regulations are unlikely to yield competitive advantage to any one company (or the companies of any one nation). However, even with similar regulations, firms with unique technologies or with greater resources to investigate and implement more cost effective technologies can benefit from those regulations. Further, if the industry structure differs from one nation to another, environmental regulations can contribute to changes in international trade and movement in shares of international markets.

position.

16. Pollution abatement and control is hardly the only (or perhaps even a leading) factor in the decline of the U.S. position. Other contributing factors included differential wage rates, exchange rate changes, and movement of the buying industries (computer and electronic manufacturing) to non-U.S. locations. This discussion merely points out how environmental controls can be a factor in competitiveness when the regulations themselves appear very similar.

Table 1
World Manufacturing of Computers and Components
Share of World Production
(by firm headquarters location)

	Computer Hardware[1]	Semiconductors[2]	Printed wiling Boards[3]	Semiconductor Equipment[4]
Year	1992	1992	1992	1990
United States	61%	42.6%	29%	45%’
Japan	30%	43.4%	30%	44%’
Europe	8%		16%	
Other	1%	14.9% (inc. Europe)	25%	9% (inc. Europe)

[1]Source: U S. ITC. “Global Competitiveness of U.S. Advanced-Technology Industries: Computers”
[2]Source: Semiconductor lndustry Association, "Status Report and Industry Directory: 1994-1995”
[3]Source: The Institute for Interconnecting and Packaging Electronic Circuits, "TRMC: Report on the World Market for Printed Wiring Boards and Substrate Materials for 1992”
[4]Source: U.S. ITC, “Global Competitiveness of U.S. Advanced-Technology Manufacturing Industries: Semiconductor Manufacturing and Testing Equipment"
[5]3% of sales are by U.S.-Japan Joint Ventures

Table 2
1992 End Use Markets for Electronic Components

Market Segment	Semiconductor Share of World Market[1]	Merchant Primed Wiring Boards Share of U.S. Marker’
Computer	**43%**	**45.0%**
Consumer Electronics	25%	4.2%
Telecommunications	13%	16.4%
Industrial/Instruments	11%	15.7%
Automotive	5.5	10.4%
Military/Government	3%	8.3%

‘Source: U.S. ITC, “Industry and Trade Summary: Semiconductors”
‘Source: The Institute for Interconnecting and Packaging Electronic Circuits. "TMRC Analysis of the Market: Rigid Printed Wiring Boards and Related Materials for the Year 1992”

Table 3
Computer Hardware Manufacturers
personal Computers 1992 Revenue

Company	Headquarters Country	Revenue ($ Million)
IBM	U.S.	$5,941
NEC	Japan	$5,849
Apple	U.S.	$5,599
Compaq	U.S.	$3,784
Fujitsu	Japan	$2,330
Matsushita	Japan	$2,209
Dell	U.S.	$1,752
Toshiba	Japan	$1,558
Total Market		$46 Billion

Source: U.S. ITC Global competitiveness of U.S. Advanced Technology Industries Computers

Table 4
Computer Hardware Manufacturers
Workstations 1991 Revenue

Company	Headquarters Country	Revenue ($ million)
Sun Microsystems	U.S.	$3.112
Hewlett Packard	U.S.	$1,712:
IBM	U.S.	$937
DEC	U.S.	$937
Silicon Graphics	U.S.	$814
Intergraph	U.S.	$568
Total Market		$10 Billion

Source: U.S. ITC Global Competitiveness of U.S. Advanced Technology Industries Computers

Table 5
Computer Hardware Manufacturers
Mainframes & Minicomputers 1992 Rcvcnue

Company	Headquarters Country	Revenue ($ million)
IBM	U.S.	$20,823
Fujitsu	Japan	$8,036
Hewlett-Packard	U.S.	$4,496
Hitachi	Japan	$4,418
DEC	U.S.	$3,413
NEC	Japan	$3,026
Unisys	U.S.	$2,442
Siemens	Germany	$2,075
Total Market		$56 Billion

Source: U.S. ITC, Global Competitiveness of U.S. Advanced Technology Industries: Computers*

Table 6
Computer Hardware Manufacturers
Supercomputers 1992 Revenue

Company	Headquarters Country	Revenue ($ million)
Cray Research	U.S.	$649
IBM	U.S.	$263
Fujitsu	Japan	$261
Convex	U.S.	$163
NEC	Japan	$134
Intel	U.S.	$94
Thinking Machines	U.S.	$88
Hitachi	Japan	$49
Total Market		$2 Billion

Source: U.S. ITC, Global Competitiveness of U.S. Advanced Technology Industries: Computers*

Table: 7
Computers and Central Processing Units
Share of World Exports

Country	1980	1985	1990
United States	45%	33%	30%
United Kingdom	10%	9%	16%
Japan	5%	10%	10%
Germany	18%	11%	9%
Ireland	5%	12%	9%
France	5%	6%	5%
Singapore	0%	1%	3%
Netherlands	2%	3%	3%

Source: UN Trade Statistic Yearbook

Table 8
Computers and Central Processing units
Share of World Imports

Countrv	1980	1985	1990
United States	NA	NA	9%
United Kingdom	13%	15%	11%
Japan	8%	7%	6%
Germany	18%	15%	14%
Ireland	2%	1%	1%
France	9%	11%	12%
Singapore	1%	1%	2%
Netherlands	7%	7%	6%

Source: UN Trade Statistic Yearbook

Table 9
computers and Central Processing units
Balance of Trade
(million dollars)

Country	1980	1985	1990
United States	n.a.	n.a.	$5,078
United Kingdom	($95)	($422)	$1,068
Japan	($129)	$324	$1,026
Germany	$75	($345)	($1,760)
Ireland	$152	$1,058	$2,116
France	($136)	($495)	($1,759)
Singapore	($23)	($27)	$353
Netherlands	($191)	($286)	($785)

Source: UN Trade Statistics Yearbook

Table 10
Microcircuits (Semiconductors)
Share of World Exports

Country	1990	1985	1980
United States	26.7%	13.9%	17.0%
Japan	17.9%	20.0%	13.4%
Republic of Korea	9.5%	6.3%	5.6%
Singapore	6.6%	7.8%	11.8%
Malaysia	6.4%	12.5%	n.a.
Germany	6.4%	5.9%	7.9%
United Kingdom	5.3%	7.4%	4.4%
Hong Kong	4.0%	4.3%	3.7%
France	3.7%	3.6%	2.3%
Italy	2.1%	2.1%	1.3%

Source: UN Trade Statistic Yearbook

Table 11
Microcircuits (Semlconductors)
Share of World lmports

Country	1990	1985	1980
United States	26.6%	34.6%	40.4%
Japan	6.5%	5.5%	7.0%
Republic of Korea	6.9%	2.1%	1.2%
Singapore	7.6%	6.1%	4.0%
Malaysia	3.6%	2.1%	n.a.
Germany	7.4%	10.4%	13.4%
United Kingdom	7.0%	9.2%	6.1%
Hong Kong	6.8%	5.9%	4.9%
France	4.9%	5.0%	6.1%
Italy	5.9%	4.7%	3.9%

Source: UN Trade Statistic Yearbook

Table 12
Microcircuits (Semiconductors)
Balance of Trade
(million dollars)

Country	1990	1985	1980
United States	$807	($2,743)	($1,786)
Japan	$5,078	$1,716	$320
Republic of Korea	$1,314	$499	$259
Singapore	($214)	$161	$434
Malaysia	$1,330	$1,245	n.a.
Germany	($224)	($603)	($452)
United Kingdom	($510)	($274)	($159)
Hong Kong	($1,001)	($232)	($116)
France	($387)	($201)	($287)
Italy	($1,461)	($334)	($190)

Source: UN Trade Statistic Yearbook

Table 13
Chemical Releases by U.S. EIectrical Device and Electronic Component Manufacturers

Chemical	Pounds Released	Share of Industry Releases	Total Releases of TRI Reporting Industries	Electrical Device and Component Share of Total
I. I I Trichloroethane	20,946.321	14 37%	185,026.191	11. 32%
Freon 113	19,287.519	13.23%	67,837.298	28.43%
Xylene	I5, 161.270	10.4%	185,442.035	8.18%
Dichloromethane	9,170.339	6.29%	130,355.581	7.04%
Sulfuric Acid	8,640.177	5.93%	318,395.014	2.71%
Acetone	8,513.166	5.84%	255,502.000	3.33%
Tolene	5,943.189	4.06%	322,521.176	1.84%
Trichloroethylene	5,516.372	3.78%	48,976.806	11.26%
Glycol Ethers	5,047.653	3.46%		
Ammonium Sulfate	4,879,304	3.35%	750,649,064	0.65%
		70.74%		

Source: U.S. EPA Toxics Release Inventory

Table 14
Pollution Abatement Capital Expenditures
By U S Electrical Device and Electronic Component Manufacturers

	1991 Total Capital Expenditures (million)	1991 Environmental Capital Expenditures (million)	Share of Total Expenditures
Printed Circuit Boards	$311.1	$17.5	5.6%
Semiconductors	$2,945.0	$106.2	3.6%
Communications Equipment	$1,114.4	$5.4	0.5%
Computer and Office Equipment	$1,938.6	$16.6	0.9%

Source: U.S. Department of Commerce, "Annual Survey of Manufacturers," and "Current Industrial Reports: Pollution Abatement Costs and Expenditures"

Table 15
Pollution Abatement Operating Costs
By U.S. Electrical Device and Electronic Component Manufacturers

	1991 Value of Industry Shipments (million)	1991 Environmental Operating Costs (million)	Share of Total Shipments
Printed Circuit Boards	$6,352.9	$81.3	1.3%
Semiconductors	$29,668.1	$116.4	0.4%
Communications Equipment	$37,945.9	$45.8	0.1%
Computer and Office Equipment	$27,418.5	$71.3	0.1%

Source: U.S. Department of Commerce, "Annual Survey of Manufacturers," and "Current Industrial Reports: Pollution Abatement Costs and Expenditures"

COMPETITIVE IMPLICATIONS OF ENVIRONMENTAL REGULATION IN

THE PAINT AND COATINGS INDUSTRY

This case study was prepared by Ben Bonifant, Management Institute for Environment and Business. The research was conducted in collaboration with the U.S. Environmental Protection Agency and Hochschule St. Gallen. Copyright 1994 by MEB. The author gratefully acknowledges the guidance that was provided by Claas van der Linde of Hochschule St. Gallen.

THE PAINT AND COATINGS INDUSTRY
CONTENTS

EXECUTIVE SUMMARY

Introduction

During the late 1980s and early 1990s, industrial users of paint often faced strict environmental regulation on their operations because of the large volumes of solvents released in the surface coating process. These manufacturers turned to their paint suppliers demanding products which not only performed acceptably in all traditional characteristics but also incorporated significantly reduced amounts of organic solvents. U.S. paint manufacturers' need in the 1980s and 1990s to provide innovative solutions offers an example of how suppliers can be affected by regulations aimed at their customers. As regulations were promulgated, industry managers were forced to choose appropriate areas to dedicate development resources. Factors influencing these decisions included expected development time and costs, resource availability of the innovating firms, and anticipated market size for innovative products. Where the paint companies successfully developed compliant coatings, their customers were provided with opportunities for compliance at dramatically lower cost than would have been incurred in adopting control equipment solutions. Where paint manufacturers possessed technologies which were less environmentally damaging, the regulations spurred experimentation by their customers and in some cases allowed entry into markets where the suppliers had previously not participated.

Market Overview

Worldwide production of paints and coatings was estimated to be $35 billion in 1990 with North American firms manufacturing almost 40% of this total. The market comprised three types of coatings: those sold to contractors and homeowners for interior and exterior wall covering, those sold to industrial manufacturers for product coatings, and those sold for special purpose applications. The first segment, known as architectural coatings was the largest making up 38% of the market. Original equipment manufacture (OEM) product coatings made up 32% of the 1990 U.S. market, and special purpose coatings made up 21% .[1] Special purpose paints were on items outside of a manufacturing site and for industrial purposes. Autobody refinishes made up almost half of this segment.

1. The U.S. Department of Commerce categorized an additional $910 million market in its measurement of "Paints and Allied Products." Making up 7.3% of the total, allied products included dopes, thinners, pigment dispersions, and other similar products.

Three types of firms produced paints. The largest suppliers such as PPG Industries, Sherwin Williams, and ICI-Glidden provided coatings to several areas of the market. These firms dedicated large resources to maintain strong positions in large market segments. Often, they had integrated upstream to independently produce resins for their formulations or they had integrated downstream to market their products directly to customers through company owned stores.

A second type of firm provided specialized coatings to narrow segments of the OEM or special purpose markets. Suppliers to the largest market segments (BASF in automotive manufacturing and refinishing for example) ranked among the largest paint firms. Those which concentrated on smaller segments such as marine coatings or wood furniture manufacturing sometimes dominated in their markets, but typically ranked as only mid-sized suppliers.

A third type of firm focused only on architectural coatings. Although major paint companies including Duron and Benjamin Moore had achieved large industry positions producing primarily architectural coatings, hundreds of small firms also supplied this segment; most with revenues of less than $5 million.

Environmental Regulations

Paints were applied to protect and enhance the appearance of a surface. Solvents in the coating facilitated application and assured a smooth finish, but were not part of the final coating. Eventually, all of the solvent evaporated from the coating and was either captured and controled or was released as air emissions. In 1985, surface coating operations accounted for 27 % of all industrial emissions of volatile organic compounds (VOCs). When exposed to sunlight, these VOCs contributed to the formation of tropospheric (lower atmosphere) ozone. Regulations aimed at reducing tropispheric ozone levels targeted precursers including VOCs.

With the passage of several state regulations in the 1960s and 1970s as well as the Clean Air Act Amendments of 1977, users of industrial coatings began to be regulated in the United States. In accordance with the Clean Air Act Amendments of 1977, the EPA provided Control Technique Guidelines (CTG) and New Source Performance Standards (NSPS) as aids for the state regulators and permit writers. These documents focused on individual types of manufacturers and provided guidance in methods of reducing emissions for their industry. Typically, they offered practical limits on the VOC content of coatings. Alternatively, manufacturers who chose not to change coatings could comply by adding control equipment to their operations.

While the U.S. led other industrial countries in the regulation of coating application, Germany, the Netherlands, and the U.K. began adopting similar regulations in the late 1980s. As in the U.S., these regulations focused on OEM operations. While these regulations had an important effect on several industries in Europe, the U.S. regulations remained the most strict.

In the OEM segment, competition in the paint market had always been based on the manufacturers' ability to provide a coating which satisfied the variety of customer performance requirements. Environmental regulation defined a new type of performance need - lower solvent content. As a result, the goal of reducing VOC emissions by reducing solvent became the primary focus of research and development in the U.S. paint industry throughout the 1980s and early 1990s. Paint suppliers hoped to provide formulations which employed lower amounts of solvent and thus could be used without control equipment. Therefore, without being directly regulated themselves, paint suppliers were dramatically affected by the regulations. As suppliers working under existing competitive systems, the paint companies had strong incentives to provide low cost solutions to their clients' regulatory requirements.

By 1991. the annual EPA survey of sources of VOC emissions demonstrated that paint regulations had had an impact. In that year, 1.86 million metric tons of VOCs were emitted by industrial surface coating operations. This represented a 15 % reduction from the 2.2 million metric tons emitted in 1986. During the same period, other industrial sources of VOC emissions increased by 5 % .

Industry Performance at the Time of Regulation

U.S. paint manufacturing showed modest sales increases in the late 1980s with compound annual growth of approximately 4% between 1986 and 1991 (22% overall growth during the same period VOC emissions fell 15 %). In 1991, the Department of Commerce reported that the value of shipments had reached $12.9 billion. Also during the late 198Os, the U.S. share of world exports held firm at approximately 9 % and the balance of trade grew substantially from $150 million to $320 million.

Effect of Regulation on Competitiveness

The influence of environmental regulations On the international competitiveness of the U.S. paint firms was modest in the early 1990s. At that time new regulations were just beginning to take effect in a few European countries and no regulations existed in Japan for coating processes. However, it can be seen that the U.S. position in world trade in paints remained strong even as manufacturers were compelled to dedicate increasing resources to low VOC developments. These developments were likely to find increasing international markets as regulation took effect in other countries.

ln at least one case, the more stringent environmental regulations in the U.S. were a factor in encouraging the transfer of technology from Europe to the U.S. market. The manufacturer, having dedicated more than a decade of research efforts to water-borne automobile coatings, possessed a technology which was judged to be superior by several North American auto manufacturers as they explored their options under new regulations. The coating manufacturer entered a licensing arrangement with existing suppliers to access these customers. As regulations began to focus on automobile refinishes, the supplier was preparing to enter the market independently.

Within the U.S., the industry's response to regulations on different segments of the market is instructive on how supplying industries react to pending regulation. When California regulated wood furniture manufacturers, the relatively small coatings suppliers were unable to dedicate large resources to the demands of a regional part of their markets. Facing few alternatives to adopting expensive control equipment (in addition to high wage rates and other regulations), many manufacturers left the region. In time, and facing regulations on wood furniture manufacturers across the U.S., coatings suppliers were able to develop acceptable water-borne systems. Similarly, when the large automobile coatings market faced regulation suppliers rapidly developed alternative products.

Regulations on architectural coatings drove results which demonstrate the differing responses of suppliers depending on their resource availability. When architectural coatings were regulated in California, many small suppliers fought bitterly against the concept of reduced VOC requirements. Meanwhile, large producers (even in other parts of the country) anticipating a huge developing market opportunity dedicated large resources to innovative products which could be used with less adverse impact on the environment.

The characteristics of innovations in the paint industry have implications for any other regulated area. Here, as in many other areas, the innovations have not occurred within the regulated industry itself. Instead, new approaches were developed by suppliers at least one step up the value chain. In the case of new resin systems, the new developments were several steps upstream. These upstream industries must choose how to dedicate scarce resources. They will dedicate these resources to methods of lower cost environmental compliance when the regulations are structured to allow creative methods, the market for innovations is large relative to the required development investment, firms possess the needed resources, and the decision makers in the regulated area are receptive to new approaches of achieving compliance.

INDUSTRY STRUCTURE

Product

Product Description

The earliest development of the paint industry in the U.S. began with the first needs for coating and protecting residences. Paint companies were primarily pigment manufacturers who prepared powders of coloring by grinding naturally occurring materials. Until the middle of the nineteenth century, professional painters would combine pigments with an oil or varnish and thinners. In 1867, D.R. Averill prepared the first generation of ready mix paints. These emulsions of pigments in oil, zinc oxide, lead acetate, and lime water were initially found to be unacceptable by many painters. However, they set the stage for later developments by other manufacturers which increased the consistency and the quality of the product.[2] These developments dramatically changed the market for paints. Consistency began to depend on the manufacturer and not the skills of the journeyman painter. Also, the door was opened to less sophisticated buyers performing do-it-yourself activities on their homes.

The large market for coatings of rail cars and early automobiles spurred the initial growth in original equipment manufacturer (OEM) markets. Manufacturers began searching for innovative resins which could provide coatings which were more durable, faster drying, or less costly. Early substitutions for resins included coumarone, pheno-formaldehyde, and nitrocellulose. Concurrently, new solvents derived from coal and petroleum processes were being utilized. In the period following World War II, the technical sophistication of manufacturing paint increased substantially. As a result, the proliferation of small start up paint companies had decreased dramatically. From that time forward, the paint industry experienced a continuing consolidation.

The paint and coatings market was a large diverse industry in the early 1990s with a wide variety of applications and customers. OEM paint markets naturally followed the growth and decline of their manufacturing customers. Similarly, markets for architectural coatings were closely tied to construction activity. Not surprisingly then, the market for paints and coatings has been closely tied to the movements

7 Sherwin Williams, Annual Report 1991, “125th Anniversary 1866-1991

of the economy as a whole. Within the market, share shifts from low solids to high solids and waterborne coatings were the most notable developments in the early 1990s. Systems requiring no solvents, radiation cured and powder coatings, were also showing growth significantly greater than the rest of the market.

Once applied, paints and coatings formed thin continuous layers used to protect and decorate surfaces. As supplied to the user, paint and coatings were primarily made up of three components: resin, pigments, and solvents. After application and drying, only the resin and pigment systems remained in the paint as the solvent evaporated. The resin was a polymer material which made up the primary substance of the coating and provided its protective properties. Several polymers were employed by paint manufacturers for resin systems including alkyds, urethanes, acrylics, and polyesters. Pigments were carried in the resin to offer decorative features and in some cases assist in protecting the substrate from UV degradation. Inorganic materials such as titanium dioxide and aromatic organic materials including phthalocyanines were examples of widely used pigments.

Solvents were used in paints solely to facilitate application of the resin and pigment system to the substrate. Originally mixed into a powdered resin/pigment system at the site of application, the solvent most commonly used in the late nineteenth century was turpentine. Fossil fuel distillates began to be utilized as their availability became more widespread in the early 1900s, and following developments in the last half of the twentieth century, there was a progression toward greater use of water. By 1990, in most applications, solvents constituted 10% to 50% of the coating system; however in a few areas such as wood furniture coatings, solvents could make up 75% of the system.

Application of paints demanded a tradeoff. High solvent content could yield low viscosity and allow rapid application. However, this could also lead to dripping and running. With lower solvent content, the paint was not only more difficult to apply but it might not provide an acceptably smooth finish. As a result, paint formulators typically used several solvents. The use of water as the primary solvent, for example, did not necessarily mean that some petroleum derived solvents were not employed as well.

Substitutes

Because the paint and coatings industry was defined to include almost all types of chemical surface coverings. there were few substitutes for the products of this industry. Significant trends toward greater use of wallpaper or pre-treated paneling could have had a measurable effect on the architectural coatings market, but dramatic changes in consumer preferences in these areas were unusual, Similarly, for OEM (original equipment manufacturer) coatings, a dramatic shift in styles toward materials which did not require coatings would be required to significantly affect the size of this industry. Had, for example, the DeLorean automobile with its stainless steel body panels initiated a national trend, the $970 million market for automobile coatings might have been threatened.

Production Process

Paint manufacturers were primarily formulators. They determined the combination of raw materials which satisfied the user's coating needs and supplied that formulation to their customers. The manufacturing process was a series of steps aimed at providing a uniform mix and sizing of component materials. There were five primary steps in this process. A premixing step where pigments, resins, and some solvents were combined, produced a paste of homogeneous composition. The pigment particle size was then reduced in a dispersion process. The next two steps involved thinning the material with additional solvents and then filtering the resulting product. Finally, the paint was packaged for delivery to customers .[3]

As a rule. only the largest paint firms performed significant levels of research and development. These development efforts involved formulating combinations of proprietary and commercial resins, solvents, pigments, and additives and performance testing. In the most concentrated markets such as automobile or appliance coatings, the manufacturers worked closely with the customer to develop a coating which provided a customized combination of performance characteristics.

3. Randall, Paul M "Pollution Prevention Methods in the Surface Coating Industry, " *Journal of Hazardous Materials, Elsevier Science Publishers B. V. I Amterdam, p. 282*

Smaller firms relied on raw material manufacturers to provide formulation assistance. Lacking the resources to dedicate to basic research and development, these firms followed very closely the recommendations of their suppliers concerning constituent combinations.

Economies of Scale

Scale economies were modest in paint production because fixed costs which could be reduced by increasing volume were limited. Notably, spreading of research and development costs (4-6% of revenue for most large producers in the U.S.) and advertising costs (approximately 1% of architectural coatings sales in the U.S.) provided an advantage to larger firms. In operations, increasing batch size had the expected advantages in reducing average manufacturing costs. However, large manufacturers had limited advantage over regional producers in this area because the cost of distribution quickly overtook the advantage of increasing batch size. All of the largest manufacturers had adopted strategies of regional manufacturing to limit distribution costs.

Despite the limited economies of scale, the paint and coatings industry was consolidating (in terms of establishments) in both the United States and in Europe. In 1980, it is estimated that there were more than 1800 firms manufacturing paint in Europe. By 1990, that number had fallen to 1500 (an annual decline of more than 2%).[4] In the United States, consolidation was also occurring. With a reduction of almost 1% annually, the number of firms producing paint in the United States declined from 1600 in 1977 to 1400 in 1992.[5]

Entry or Exit Barriers

Two significant barriers existed for new suppliers attempting to gain a position in these markets. The first barrier, particularly important in OEM markets, was the need for relationships with buyers which allowed joint development of new products. Buyers had highly specialized requirements which demanded

4. Information Research Limited. "A Profile of the West European Paint Industry, Ninth Edition," London, 1990

5. Rauch Associates, Inc. "The Rauch Guide to the U.S. Paint Industry," Bridgewater, N.J., 1990

that manufacturers dedicate significant technical resources to match coating characteristics to application needs. Often, the coatings were formulated for specific products produced by individual manufacturers. Smaller companies lacked the access to large OEMs and therefore could not anticipate their developing needs. The second barrier for entering large OEM markets was the requirement of coordinated development with manufacturers of application equipment. Product development required familiarity with the systems as well as access to advance information on innovations occurring in application technology. Coordinated development ultimately emerged where large buyers drove cooperative research between the dominant coatings suppliers and the major providers of application equipment, For example, in 1989, Union Carbide developed the Unicarb system, an innovative method of paint application for industrial uses (discussed further in a later section). Bringing the product to market required coordinated development with Nordson, a spray equipment manufacturer as well as with coatings suppliers such a Akzo, BASF. Gaurdsman, Lilly and PPG Industries.[6]

Buyers

Buyer Description

Customers required coatings to provide protection and enhance appearance. Additionally, depending on the surface to be coated, customers made selections based on price, ease of application, abrasion resistance, weather resistance, smoothness of finish, and non-toxicity. After the mid-1970s, customers also demanded that products comply with a variety of local, state, and national regulations requiring that coatings not exceed specified levels of volatile organic compounds (VOCs).

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In a sense. the coatings market could be characterized as a continuum with one end occupied by the fragmented, poorly informed buyers undertaking infrequent home improvements. Many suppliers with products of varying quality supplied this end of the market; mass marketing skills and strong distribution channels represented strategic assets. On the other end of the continuum, market segments were dominated by a few highly informed buyers of coatings for original equipment manufacturers. Technical

6. “Supercritical CO_2 As a Solvent: Update on Union Carbide’s Process.” *Modern Paint and Coatings, June, 1990*

abilities to match product performance to narrowly defined customer needs and direct selling skills were required for success in these markets.

Distribution Channels

In the United States, architectural coatings made up 38% of the total 1990 market (table 7). Large firms successfully supplying this segment possessed strong commercial distribution systems. The three primary channels of distribution were:

* Company owned stores
* Distribution contracts with large mass merchandisers
* Lumber and specialty retail stores

Additionally in the 1980s. the rapid development of large home improvement centers such as Home Depot had presented an additional growing channel to the “do it yourself” part of the market.

A number of large companies such as Sherwin-Williams operated company owned stores in order to control product presentation and achieve additional trademark recognition through buyer familiarity with the store and its signage. Smaller firms such as Dunn Edwards and Duron had achieved similar advantages on a regional level. Other firms though, such as PPG with its Lucite and Olympic paints, developed strong brand recognition while selling through national retailers.

Direct sales and specialized services were used in selling to the OEM market because there were only a few very knowledgeable buyers. Because a small number of people had control over very large - purchase decisions. the paint companies devoted significant resources to keeping these individuals informed of technological and performance developments.

Suppliers

The primary suppliers to the paint and coatings industry were producers of synthetic chemicals who manufactured resins, solvents, and pigments, usually from coal and petroleum feedstocks. International firms such ad as Rohm & Haas. Reichhold Chemical. Dow Chemical, and Union Carbide Chemicals and Plastics Co. were important suppliers to the industry throughout the world.

Many of the largest U.S. suppliers of coatings Including PPG, Sherwin Williams, and Lilly Industries had integrated upstream into manufacturing proprietary resins. Their innovations in basic resin chemistry had provided them with strategic advantages in several market segments. PPG's development of electrodeposition coatings for automotive underbodies in the 1970s and Glidden's developments in latex paints in the late 1940s were examples of innovations in resin chemistry which had allowed a firm to establish a dominant position in a market segment which lasted for decades.

Environmental Regulation

Environmental risk analysis

Three types of regulations affected the U.S. paint industry:

* Production regulations required paint manufacturers to track their emissions more closely, invest in control equipment, and explore opportunities for waste minimization.

* Site restoration regulations involved the identification and clean-up of previously disposed waste. Although this type of regulation was not unique to the U.S., the Superfund requirements were the most far reaching.

* Users of paints and coatings were regulated to limit the emissions resulting from application processes. In many instances. the most cost effective means of remaining in compliance was to adopt coatings with lower solvent content. Paint manufacturers were, then, indirectly affected as their customers pressured them to provide compliant coatings.

As much as 70% of some coatings were made up of organic solvents. Therefore, the paint industry and its customers maintained important use and disposal responsibilities. Limitation of emissions was desired because of the role solvents played in the formation of low level ozone. In the troposphere (lower atmosphere), the formation of ozone was undesirable because it was thought to cause adverse health effects and harm vegetation.[7]

The solvents were volatile organic compounds (VOCs) which were precursors to the formation of ozone. In the presence of sunlight, VOCs reacted with nitric oxide (NO) resulting in increased levels of nitrogen dioxide (NO,). Since the ratio of NO, to NO was in equilibrium with the formation of ozone, the increased level of NO_z led to increased levels of ozone.[8] Regulations aimed at reductions of tropospheric ozone were focused on reducing emissions of the precursors.

In 1991 35% of all VOC emissions were thought to result from mobile sources, primarily automobiles. The remaining 65% occurred at stationary sources and were associated with solvent use, hazardous waste disposal, surface coating, petroleum marketing, petroleum refining, and chemical manufacturing. Surface coating contributed 11% of all VOC emissions.[9] As a result, paint users were targeted for emission reductions in a series of air regulations

1991 U.S. National VOC Release Estimates

Source	Releases (million ton)	Share
Industrial Releases (excluding coatings)	6.0	35%
Transportation Sources	5.1	30%
Surface Coatings	1.9	11%
Forest Fires and other burning	1.0	6%
Solid Waste Disposal	0.7	4%
Fuel Combustion	0.7	4%
Miscellaneous Organic Solvent Use	1.6	9%

Source: U.S. EPA
Figure 1

Severity and Impact of Regulations

In the U.S., paint manufacturers claimed that the cost of compliance with site restoration regulations was unnecessarily high. Following a survey of its members, the National Paints and Coatings Association

7. Reducing the formation of ozone in the troposphere should not be confused with efforts to stem destruction of the ozone layer in the stratosphere (where ozone protects the earth from harmful ultraviolet radiation).

8. U.S. Environmental Protection Agency, "Control Techniques for Volatile Organic Compound Emissions from Stationary Sources, Third Edition," 1986, p. 2-4 through 2-6

9. U.S. Environmental Protection Agency, "National Air Pollutant Emission Estimates, 1900 - 1991." October 1992

concluded that its members were spending $7 million a month on Superfund negotiations in 1992.[10] Strikingly, the organization concluded that of $600 million spent prior to the survey, $400 million had been spent on transaction costs (litigation and administrative fees). Only $200 million had actually been spent on cleaning up sites.[11] While these costs represent less than 1% of annual revenue for the industry, they were not evenly spread across manufacturers. The survey found that 33 % of respondents were not affected by any Superfund clean-ups, and an additional 26% were involved at only one site. The costs incurred on different sites varied dramatically with S50,OOO to $150,000 typically being required for a paint manufacturers experience on a single site (where they were often small contributors to the total volume of waste disposed)[12]

The operating cost of compliance with production regulations was modest. In 1989, U.S. paint manufacturers had capital expenditures for pollution abatement equipment of $9 million while total capital expenditures were $271 million (thus total capital expenditures were less than 2% of sales for the year and capital expenditures for environmental controls were 3 % of that).[13]

Pollution abatement operating costs were higher, but still represented only a small part of the overall cost of paint production. In 1990, U.S. paint and coating suppliers incurred $91 million in pollution abatement operating costs with $43 million of this going for the disposal of hazardous wastes. The total operating costs for pollution abatement represented approximately 0.7% of the value of shipments for 199O.[14]

10. Superfund refers to the Comprehensive Environmental Response Compensation and Liability Act. Passed in 1980. this legislation required that manufacturers fund remediation of sites in which they had disposed materials,

11. National Paint & Coatings Association, "Improving the Superfund: Correcting a National Public Policy Disaster, " 1992

12. National Paint & Coatings Association, "improving the Super-fund: Correcting a National Public Policy Disaster, " 1992

13. U.S. Department of Commerce, "Manufacturers' Pollution Abatement Capital Expenditures," 1990

14 U.S. Department of Commerce, "Manufacturers' Pollution Abatement Capital Expenditures," 1990

From a strategic standpoint, production and remediation expenditures represented costs which needed to be controlled. In most cases, however, responsibility for these costs remained in the environmental affairs, government affairs, and legal departments of paint manufacturing firms. By comparison, the regulations on paint users put new demands on broad areas of the organization. The companies' customers were demanding fundamental changes in formulation of the product. As a result, the sales, research, production, and purchasing organizations were affected. The upper management of the firms were faced with decisions of resource allocation to determine how best to respond to this major change in the industry's markets. For these reasons, the regulations affecting the use of the product were the most important environmental issue affecting the paints and coatings industry in the 1990s. Figure 2 summarizes the implementation of regulations aimed at controlling VOC content in the leading paint supplying countries. The following sections discuss these regulations and the characteristics of competition in each of these nations.

Timeline of Important Regulatory and Environmental Events

1754	First U S paint manufacturer. Davoe Raynolds. is founded
1867	D.R. Averil leads development of "ready-mix-paints"
1948	Glidden introduces water-borne housepaints
1966	California adopts Rule 66 regulating VOC content of paint
1977	U.S Clean Air Act Amendments require development of Control Technique Guidelines for industrial coating operations.
1986	TA Luft regulates industrial coating operations in Germany
1986	Dutch government adopts KWS2000 targeting 50% reduction of VOC emissions by 2000
1990	U.K. passes Environmental Protection Act requiring the development of Guidance Documents for permitters regulating coating operations
1990	U. S. Clean Air Act Amendments target VOC reductions in eleven previously unregulated industries as well as requiring the development of a National Rule on VOC content of architectural coatings.
1991	23 countries sign United Nations European Commission for Europe protocol targeting 30% VOC reduction by 2000

Figure 2

COMPETITION

United States

Competitiveness Overview

The 1990 worldwide coatings market was estimated at $35 billion. The United States and Canada made up almost 40% of this total with an estimated market of $13.5 bi!lion. Western Europe and Japan followed with market sizes of $11.5 billion and $4.5 billion respectively.[15] The U.S. Department of Commerce estimated the production of paint and allied products at $12.8 billion in 1990, having grown from a value of $10.2 billion in 1985 (an annual growth rate of 4.6%) (table 7).

Because there was only a modest scale economy in the manufacturing process for paint, and shipping costs could quickly overwhelm the value of the product if the material were to be transported over long distances, firms strategically located manufacturing facilities to optimize the trade-off between scale advantages and increased shipping costs. Even within the U.S., firms produced in multiple locations. For these reasons most countries also shipped very little paint internationally, and the volume which was exported was dominated by shipments to neighboring nations.

This also means that trade data could only be used to get a first indication of a nation's competitive position. However, those nations which had large shares of the world trade in paint along with positive trade balances appear to have been the home for innovation and development in this industry. In 1990, the. U.S. had a 9.2 % share of world export of paints ranking behind West Germany at 24.6%) the Netherlands at 10.7%. and the U.K. at 10.1%. However, the U.S. had the second strongest balance of trade in paints in 1990 at $3 18 million trailing behind only West Germany at over $800 million (tables l-3).

15. "In Paints and Coatings, Change is the Only Constant," Chemicalweek, October 31, 1990

Leading Firms

Manufacturers in the paint industry fell into three segments.

* Diversified Suppliers
* Application Specific Suppliers
* Architectural Coating Suppliers

Diversified Suppliers

The largest producers, characterized in the U.S. by PPG and Sherwin Williams, manufactured coatings for a variety of end-use areas. These firms held large shares in many of these segments, but also participated in areas where their share was very small, often after having acquired firms focused on these areas. At rimes, these firms unified the strategic management of their acquisition, but manufacturing facilities and sales efforts often remained focused on narrow market segments. In the late 1980s and early 1990s, a few large firms began rationalizing their businesses by returning to more narrow market segments. For example, in 1993. Lilly Industries and ICI-Glidden reinforced areas where each firm possessed a strong position. ICI traded its liquid industrial coatings business (and cash) for Lilly's packaging coatings business, an area where ICI was a recognized world leader.[16]

U.S. Total Value of Shipments of Original Equipment Manufacturer Paint

Category	1990 Value (million)
Transportation Coatings:	
Automobile Finishes	$967
Truck, Bus, and RV Finishes	$199
Other Transportation Finishes (inc. aircraft and rail)	$77
Container and Closure Finishes	$487
Metal building Product Finishes	$345
Wood Furniture	$339
Nonwood Furniture and Fixture Finishes	$251
Machinery and Equipment Finishes	$200
Paper, etc. Finishes	$89
Wood and Board Flat Stock Finishes	$67
Appliance, Heating Equipment, and Air Conditioning	$65
Electrical Insulating Coatings	$28
Powder Coatings	$244
Other Industrial Product Finishes	$327

Source: U.S. Department of Commerce. Current Industrial Reports, Paint and Allied Products. 1991

Figure 3

16. The Glidden Company, "ICI Paints Agrees With Lilly Industries on Business Transfer," Company Press Release, March 2, 1993

Application Specific Suppliers

Many coatings firms focused exclusively on narrow segments of the OEM or special purpose market. Working closely with their customers, these firms developed technical expertise in balancing the various needs of these industrial manufacturers. Depending on the segment size, these manufacturers could rank among the largest in the industry. BASF and DuPont, for example, sold coatings primarily to automobile producers and refinishers. Achieving large shares in these markets made these firms among the largest coatings suppliers in the world. In other segments, even the leading suppliers were fairly small. With revenues below $100 million, companies such as Ameron, or Guardsman were dwarfed by the largest coatings suppliers, but they held large market shares in specific segments such as aerospace coatings, or wood furniture finishing.

In the OEM coating segment, almost all sales were made directly to the customer through the producer's sales force. In addition to providing specific formulations for the customer's needs, paint suppliers provided a variety of services to their largest clients which could encompass all aspects of coating the customer's products. PPG, for example, assisted in incorporating its paints into customers' existing equipment, advised customers on other types of equipment to use, and in some cases, even managed the entire painting process on a contract basis.[17]

The most consolidated areas of the OEM market were automobile with three primary suppliers (PPG, BASF, and DuPont), can coating with two primary suppliers (ICI and Dexter), and wood furniture finishing with four primary suppliers (Lilly Industries, Gaurdsman, Valspar, and Akzo-Reliance). These segments made up 7.8 %, 3.9%, and 2.8 % of the total market for coatings, repectively .

During the 1990s, strong firms participated in foreign markets in ways other than direct export, primarily by purchasing existing assets from local owners. In OEM coatings, U.S. firms had followed their clients in their pursuit of global markets. As automobile, beverage can, and appliance manufacturing firms

17. PPG Industries, Inc., William V. Warnick - Director, C&R Manufacturing, Interview Pittsburgh, PA, February 25. 1993

located operations internationally, the coating companies serving those firms purchased local firms to maintain longstanding relationships. Technology was transferred to the local facilities from the U.S. and applied in existing equipment. PPG, for example, became one of the five largest paint suppliers in Europe through strategic acquisitions in Italy, Germany, Spain, France, and the U.K. A substantial share of this revenue resulted from sales of electrodeposition coatings for automobile underbodies, technology developed in the U.S. but later transferred throughout the world.

Architectural Coatings Suppliers

The third group of companies were those providing architectural coatings (interior and exterior housepaints) to a regional market. While a few of these firms provided paints to some OEM or specialty segments, they focused primarily on regional sales to trade and consumer buyers. Larger firms in the U.S. included Benjamin Moore ($350 MM 1990 sales), Kelly Moore ($175 MM), and Pratt & Lambert ($140 MM) but hundreds of companies fit into this category with most having revenues of less than $5 million. While a few of these firms were very strong on a regional level, they all faced significant competition from diversified national firms, As a result, the smaller producers competed in niche markets, by providing private label products to smaller retailers, and by pursuing continual cost reductions. The strength of the national market leaders was demonstrated by the positions of the two largest manufacturers of architectural coatings, Sherwin Williams and Glidden (ICI) with market shares of 15.9% and 13.2%. respectively.[18]

The largest producers of architectural coatings also manufactured products which they categorized as industrial maintenance coatings. These products had similar characteristics, but often had been modified to offer application specific properties. Coatings used for chemical manufacturing facilities, for example, needed to provide greater corrosion resistance and durability than standard house paints. Similarly, paints used for corrosion protection on bridges needed to have specialized protective qualities. Sales of industrial coatings were primarily made directly to those responsible for facility maintenance for whom cost was a significant consideration.

18. “Prospects Improve for a Mature U.S. Market,” Chemicalweek, October 31, 1990)

Distinctive Environmental Regulation in the United States

California led the regulation of paint emissions with the adoption in Los Angeles County of Rule 66 in 1966. The developers of this rule had determined, through the use of 8-hour smog chamber tests, that hydrocarbons had differing levels of photochemical reactivity and categorized substances into three classes based on their tendency to produce ozone. All facilities were compelled to remain below allowable emission levels for each category. In order to stay within the limits of regulations, paint users were required to maintain production at a level which kept emissions within compliance, adapt control equipment to collect and destroy paint emissions, or begin to use paints using innovative solvent systems which were described as California compliant.[19]

The first federal initiatives aimed at reducing VOC emissions resulted from the passage of the Clean Air Act Amendments of 1977. As required in the legislation, standards were established for acceptable levels of ambient ozone. States were compelled to develop plans for reaching compliance in non-attainment areas. The areas most out of compliance and thus requiring the most strict new standards were the LA Basin, the northern New Jersey/New York City region, Houston, and Chicago.

The 1977 Amendments required that the EPA provide guidance to the states in developing their implementation plans through the development of Control Technique Guidelines (CTGs). In addition, the EPA was responsible for developing new source performance standards (NSPS). These were rules governing the characteristics of new facilities regardless of whether or not they were in a non-attainment area. Control Technique guidelines were based on reasonably available control technologies while the NSPS outlined the best demonstrated technology (CTGs were less strict than the NSPSs).

Control Technique Guidelines provided emission reduction options for selected industry segments. Among the first were CTGs for the following industries: cans, coils, paper, fabrics, automobiles, light duty trucks, metal furniture, insulation magnetic wire, large appliances, miscellaneous metal parts, graphic arts, and flat wood paneling. Many of the guidelines were framed around a concept of allowable

19. California Air Resources Board, Daryl Bums, Telephone interview March 10, 1993

VOC content of the coating. For example, the CTG for automotive coatings put limits of VOC content at 1.2 lb/gallon excluding water for prime coats, 2.8 lb/gallon excluding water for guide coat and top coat, and 4.8 lb/gallon excluding water for paints used in final repair.

As a base CTGs were aimed at establishing methods for facilities to achieve an emission level equivalent to using existing coatings with a control system capturing 90% of emissions and achieving a destruction rate (efficiency of the system in reducing the materials to carbon dioxide and water) of 90%. However, some easing of the regulations was permitted to encourage the adoption of substitute coatings rather than end-of-pipe treatments. Negotiations with industry were conducted to establish requirements which could be met by existing coatings. The guidelines were also structured to allow manufacturers to use control devices if coatings containing higher VOC levels were chosen for performance reasons.[20]

Although efforts were made to target large, growing industries with high contributions to ozone levels, CTGs were not issued for several areas with substantial VOC emissions. Notably, no CTG was issued for automobile refinishing primarily because of the recognition of the difficulty of achieving acceptable enforcement on tens of thousands of facilities. Similarly, no CTG was issued for architectural coatings because of the difficulty in enforcing a use regulation on a consumer product. In wood furniture coatings, no cost effective technology existed to reduce the very high levels of VOC content.

The 1990 Clean Air Act Amendments required that the EPA provide an additional eleven CTGs to the states. The Agency was responsible for identifying nine of these. Two were specified, aerospace coatings and ship building and repair. Aerospace manufacturers actually lobbied to have a CTG developed specifically for their industry. Given the unique demands of coatings used on a fuselage, aerospace manufacturers had been concerned that their coatings would be regulated according to the CTG for miscellaneous metal products.

20. U.S. Environmental Protection Agency, James Berry - Section Chief and David Salman - Industrial Engineer. Interview January 19, 1993

The 1990 amendments required that regulation of architectural coatings be accomplished through the development of a national rule. As with CTGs the focus of the national rule was to be on allowable levels of VOCs. The EPA included industry opinions in the rule making process by adopting a regulatory negotiation (reg-neg) process. The EPA provided information to manufacturers through this process, and industry was allowed to provide comments and proposals to the reg-neg for VOC levels with which they felt they could comply. Additionally, manufacturers were invited to "have seats at the negotiating table" where they could voice their recommendations for the developing regulations.

Sources of Competitive Advantage

Factor Conditions

Basic factor conditions were not a critical source of competitive advantage to the paint industry in the 1990s. Unlike the case in the early 1900s, the importance of factor conditions decreased significantly in the paint industry over the second half of the twentieth century. Originally, the industry required a ready source of such naturally occurring raw materials as linseed oil and turpentine. The availability of these materials had been a major factor in the early establishment of the industry in Louisville, Kentucky and Cleveland, Ohio.[21] However, developments in organic chemistry resulted in a move away from naturally occurring materials throughout the middle part of this century.

With a limited reliance on natural production factors, the critical input to the U.S. paint industry was the knowledge of a specialized labor pool. The development of the industry relied on the creativity of individuals focused on providing new types of coatings through developments in resin and solvent chemistry. Following the many developments in organic chemistry occurring during the World War II, the ultimate raw materials of many paints were petroleum and coal distillates which had been modified and polymerized to enhance desired properties. As a result, in the major centers of U.S. paint manufacturing, Cleveland, Louisville, and Chicago, industry associations worked closely with academic

21. Schulenberg, Fred, "America's Great Coating Centers: Cleveland, Part I," American Paint and Coatings Journal, January 5, 1987, and Schulenberg, Fred, "America's Great Coatings Centers: Louisville, Part I," American Paint and Coatings Journal, May 19, 1986

programs to develop strong programs in Polymer science and coating technology.[22] Notably programs at Case Western Reserve University, the University of Akron, and Kent State University (all near Cleveland) as well as the University Of Louisville had built strong ties with industry and frequently worked with the industry in technical development.

Domestic Demand Conditions

It has been noted above that paint and coatings markets must be segmented to understand the underlying demand conditions. In the (1990) $4.9 billion U.S. architectural coatings market, buyers tended to make purchases infrequently. These customers made purchase decisions based on price, convenience of the purchase site, brand familiarity and ease of use of the product (particularly those that chose water-borne products). As a result, suppliers to this part of the market focused on cost controls and productivity improvements. Additionally, many manufacturers developed extensive distribution systems with company owned or franchised stores. Customers would seek advice in these stores concerning application methods, clean up requirements, and color matching. In larger companies such as Sherwin Williams, information would then be fed back to research and development areas to satisfy emerging customer needs.

In the OEM marker and the special purpose market, however, highly sophisticated buyers reviewed a large variety of candidate coatings before selecting one which provided the required combination of properties. Paint manufacturers that were able to satisfy these changing needs on a continuing basis grew (and at times declined) with the industries they supported. The geographic grouping of the paint industry in Cleveland and Chicago owed its development to traditional partnering of OEM manufacturers of automobiles, carriages, and farm equipment with their coatings suppliers.

OEM buyers were, of course, concerned about price, but performance characteristics and ease of application were often more important than simple cost per gallon comparisons. This attitude was driven by the importance of the coating in marketing the product, particularly as compared to the overall selling

22. Schulenberg, Fred, “Americas’s Great Coatings Centers: Cleveland, Part IV.” American Paints and Coatings Journal, March 30, 1987 and Schulenberg, Fred, “America’s Great Coatings Centers: Louisville, Part III,” American Paints and Coatings Journal. June 16. 1986

price. For example, the total coating cost of a grand piano selling for $10,000 would be only approximately $25. However, the appearance of the instrument would dramatically affect its appeal to customers. A similar comparison was often made concerning the coating costs of automobiles. In this industry, several manufacturers pointed out that the “paint sold the car. ”

Process characteristics were a major concern of OEM buyers. The ability to improve transfer efficiency or reduce coating time could quickly offset higher costs of materials. Sophisticated OEM buyers looked at the total cost of coating and then made comparisons of the expected impact on the product’s attractiveness to customers.

Because paint suppliers needed to be well informed on all aspects of the customers needs, strong relationships developed between the firms. Having made specialized developments, paint suppliers became aligned with particular segments of the market. Buyers would signal emerging needs and encourage new developments by the primary suppliers to the industry. In areas such as automobile and aerospace manufacturing, where the U.S. had led development at one time, coatings suppliers often led new developments later adopted by foreign manufacturers.

Related and Supporting Industries

The simplicity of paint manufacturing resulted in limited reliance on supporting industries for process equipment and services. However, modern paint companies depended on developments in polymer chemistry to provide innovative products to their customers. It is not surprising, then, that the strong positions of Germany, the Netherlands, and the United Kingdom identified above were supported by leading chemical industries. Although not leading, the U.S. chemical industry was strong in many areas and had particular success in polymer chemistry.

In each country with a competitive paint manufacturing industry, a cluster of industries supported by synthetic organic compound production was evident (see figure 1). These manufacturers provided the intermediary processes required to modify simple organic substances derived from naturally occurring sources (primarily coal and petroleum). Paint manufacturers developing new ways of satisfying buyers’

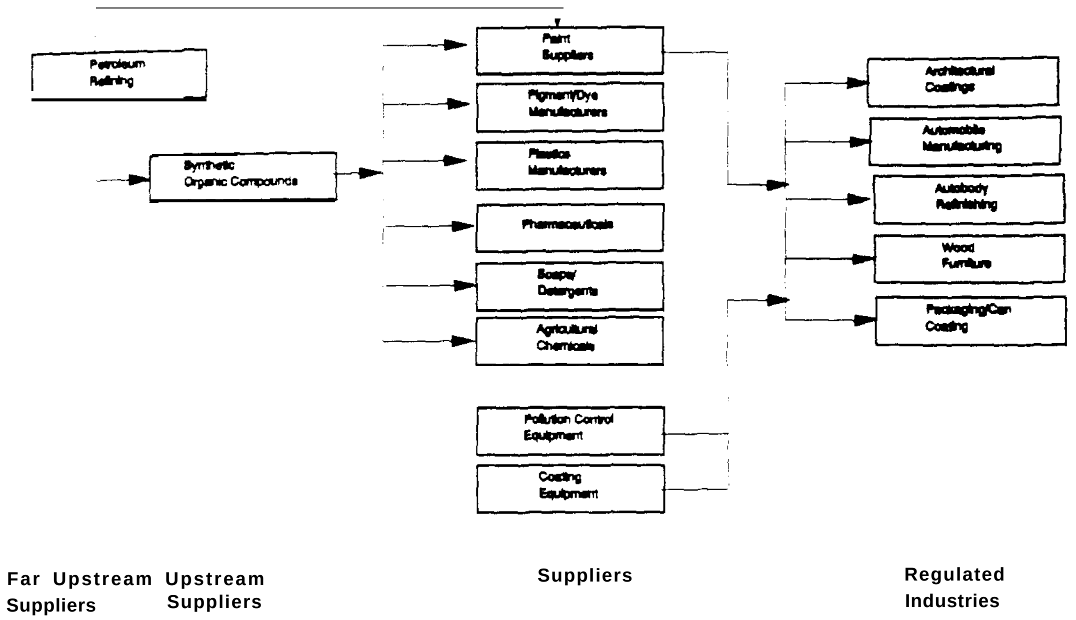

Figure 4: Industry cluster for paints and coatings manufacturing

demands relied on this industry to provide unique chemistries with previously unavailable combinations of properties. Typically, in countries where the synthetic organic compound industry was strong, other downstream industries besides paint were also strong. Other industries relying on innovative synthetic organic compound firms included plastics, pharmaceutical, soaps and detergents, and argicultural chemicals.

Strategy, Structure and Rivalry

In the U.S. the architectural coatings market was served by a large number of mostly small firms. In its early days the paint market was easy to enter, particularly in Chicago, Louisville, and Cleveland. The availability of raw materials, the relationship with customers, and the ready access to rail and canal distribution systems provide some explanation for why the coatings industry became important in these cities. Once the industry started, the low capital cost needed to enter the market encouraged many individuals to leave the firms where they received their training and begin their own operations. Firms such as Peaslee-Gilbert (a strong early manufacturer and later a part of Devoe Raynolds) and Sherwin Williams developed reputations as the training ground for later entrepreneurs. Many of the new firms were started within a few miles of the firm where the founder had learned the business.

The intense rivalries among the small entrepreneurial firms yielded continued improvements in the areas most important to customers. Improvements in customer service and product quality and performance resulted. While each of the major paint manufacturers recognized that investments in research and innovation were of primary importance, they adopted different strategies. Sherwin-Williams, for example, invested in process technologies, such as new methods of milling pigments. The company developed a system that ground pigments fine enough to remain in suspension in the oil. This ensured a high quality of ready-mix paint. The Glidden Company researched better substitutes for paint media and solvents which led to the first nitrocellulose lacquers and other quick drying finishes. Continued emphasis on new materials led the company to introduce the first water-borne latex household paint in 1948. Reliance Universal, Inc. was an early leader in emphasizing research into custom formulations and applications for specific customers. The company then supported its investments into this strategy by adopting decentralized production, locating its plants close to customers.[23]

Germany

Competitiveness Overview

In 1990, West German paint production was approximately 12% of world total at $4.3 billion. This demonstrated annual growth of approximately 4% from 1985 production of $3.6 billion (no data was available for unified Gerrnany).[24] In 1990, West Germany had a commanding position with 25 % of world exports of paints and the largest positive trade balance of any country, $800 million (tables 1 and 3).

23. Schulenberg, Fred, "America's Great Coatings Centers: Louisville, Part II." American Paints and Coatings Journal, May 26, 1986

24. "Restructuring Continues in Europe, " Chemicalweek, October 3 1, 1990

Leading Firms

The major suppliers of paint in Germany were chemical companies which had forward integrated in a movement reported to have begun with the acquisition of Glasurit Werke Winklemann by BASF in 1965. In 1990, following further acquistion, BASF led manufacturers in German paint production with an estimated 25% share .[25] Hoechst (through its subsidiary Herberts), the British firm, ICI and the Dutch firm, Akro followed, each estimated market shares of more than 5%. [26]

ln 1985, BASF completed the largest investment in the U.S. paint industry ever undertaken, Reportedly to expand its position in automobile OEM and repair finishes, the company purchased the coatings operations of Inmont for a price of $1 billion. In 1992, the U.S. operations of the company had revenue of $975 million (including sales of printing inks and dyes).

Distinctive Environmental Regulations

Concerns with tropospheric ozone and thus emissions of VOCs were receiving growing attention in Europe in the early 1990s. As seen in Table 11, the level of VOC emissions was fairly well correlated with a nation’s production. As a result, the leading producer nations took the lead in implementing regulations on the sources of VOCs.

On November 19, 1991, 23 countries signed a United Nations European Commission for Europe (ECE) protocol for reduction of VOCs. The aim of the agreement was for each country to achieve a 30% reduction in emissions by 2000. The definition of the base year was left to the signatory countries so that those such as Denmark or Switzerland where many controls were already in place were not unfairly penalized for their prior efforts. Additionally, less industrialized countries, Hungary, Bulgaria, Ukraine,

25 Information Research Limited, “A Profile of the West European Paint Industry,” London, 1990

26. Information Research Limited, “A Profile of the West European Paint Industry,” London, 1990

and Greece which had comparatively low ambient VOC levels agreed to "standstill" emissions at 1987 levels.[27]

Although the signing of the protocol was the first step leading to regulations on paint composition and use, individual nations were expected to develop their own plans for reaching VOC reduction goals. By 1992, implementation systems were already seen to vary and decisions concerning when to address paint emissions versus automobile, petroleum marketing, chemical manufacturing and other areas differed among the signatory countries. At that time, the countries which were closest to direct regulation of coatings application were Germany, the UK. and the Netherlands (see below for discussions of specific regulatory approaches in the UK and the Netherlands).

In Germany, efforts to improve air quality originated with the 1974 Bundesimmissionschutzuerdnung (BIMSchV). or Federal Immission Control Act. As in the use of CTGs in the U.S. Clean Air Act, the German legislation required implementation of the program in the Lander (states) according to recommendations in the Technical Instructions on Air Quality Control (TA Luft). The TA Luft was amended and updated periodically including changes occurring in 1986 and 1991. Until 1991, the primary impact on the paint industry was a requirement to receive formal approval for plants using more than 250 kg/hour of solvents. Manufacturers emitting higher levels were required to demonstrate equivalent reductions at other facilities. The impact on the paint industry was modest.

The l991 amendments to TA Luft increased the stringency of requirements in the use of coatings. Regulations on coating processes in automotive manufacturing, for example, put limits on emissions of 60 grams of organic solvent emissions in the waste gas of the overall facility per square meter of car body

27 Dutch Ministry of Housing Physical Planning and Environment, "The ECE Protocol on VOC Emissions Elucidated," VOC Newsletter, February, 1992

surface covered.[28] As seen in table 12, this requirement was more strict than similar regulations in the U.K., but substantially higher than reported results of the best performing facilities in the U.S.

In other surface coating areas, the limits were based on allowable mass concentration of organic solvents in the waste gas (20 mg/m^3 in spray booth areas, for example). Outside auditors using established guidelines performed yearly assessments to assure compliance. Switzerland, Austria, and Denmark traditionally used TA Luft as a model for their regulations, so similar rules on OEM coatings were anticipated to be implemented in these countries.

The Netherlands

Competitiveness Overview

Although the Netherlands only accounted for 3.9% of all world exports in 1990, the country was responsible for 11 .O% of paint shipments (table 1). The Dutch balance of trade in the industry had risen from $106 million in 1985 to $268 million in 1990 (table 3). These values represented almost one third of the total production of the nation which was estimated in 1990 to be $898 million.[29]

Leading Firms

The Dutch paint industry was perhaps the most concentrated in all of Europe with Akzo controlling more than 40 % of the market followed by the Belgian owned Sigma Coatings with 25 % Smaller shares were supplied by Herberts of Germany and Kemira Color of Finland.[30]

In 1989, Akzo acquired Reliance Universal of the U.S. for $275 million. The acquisition was driven by an expressed desire to enter the large steady market for U.S. coatings. Reliance Universal with $320 million in revenue had been held for several years by the Tyler Company, a holding company with very

28 The regulations go on to require “full use of the possibilities to further reduce the emissions by employing varnish systems which are poor in or free from solvents, highly effective coating procedures, air circulation procedures or by waste gas cleaning, particularly in the spraying areas.”

29 “Restructuring Continues in Europe,” Chemicalweek, October 31, 1990

30 information Research Limited, “A Profile of the West European Paint Industry,” London, 1990

limited participation in the firms operations. Tyler Company had acted as a white knight acquirer in a much earlier unfriendly takeover attempt of the firm.

Environmental Regulations

VOC reductions in the Netherlands were being targeted by a set of cooperative agreements established by KWS2000.[31] Attempting to reduce emissions by 50% by 2000, partnerships which included industry local government, and the federal government were formed to find solutions. Permit systems were to be used to monitor progress. The process was intended to be highly cooperative and extremely flexible in its ability to incorporate new information. In the following quote, representatives of Projectbureau KWS2000 described how the permit system was used to update facility performance once new information about technology was developed:

"In 1989, two projects were subsidized, demonstrating the use of water-borne and powder coatings for production of metal furniture. These projects were successful. Based on this, the Measure Group, supported by the Task Group Paint, set in a number of actions. First a list was compiled of all companies producing metal furniture. Second, the report was sent to these companies, and the corresponding authorities. The authoritities were requested to take note of the content of these reports and to introduce the consequences into relevant permits. Third, the companies themselves were approached by an advisory institution, in order to inform the companies of this development, and to ascertain that they will indeed make the necessary arrangements. Lastly, the authorities will once again be approached some time in the future to find whether the measure has indeed been incorporated into the permits.[32]

31. KWS2OOO's name is derived from the abbreviation for the Dutch word koolwaterstoffen meaning hydrocarbon and the goal of 50% reduction in emissions by the year 2000.

32. Projectbureau KWS2000, personal communication from Waldo Kaiser and Dominic Shrijer, March 12, 1993

In 1992, this program had had only a limited impact on the paint industry. However, as industrial firms exhausted the most easily targeted areas for reduction, coatings operations were beginning to be examined for potential opportunities.

United Kingdom

Competitiveness Overview

The British paint industry was characterized by slow growth throughout the late 1980s. Production was estimated at $2.0 billion in 1985 and had grown less than 1% annually to $2.1 billion in 1990,[33] In 1990, the UK was responsible for 10.9% of world exports of paint as compared to a 5.5% share of all exports and the paint industry possessed a positive balance of trade of almost $230 million (tables 1-3).

Leading Firms

ICI, based in the UK. was the worlds largest manufacturer of paints and coatings. In 1990, the firm had a 20% share of its home market. [34] Scandinavian firms Crown-Berger (owned by Casco-Nobel of Sweden) and Macpherson (owned by Kemira of Finland) followed with estimated 12.5% and 9.5% shares. Britain's other internationally strong producer Courtaulds held an 8.5% share of the home market.[35]

ICI and Courtaulds had developed strong U.S. positions through acquisitions. In 1986, ICI had purchased the Cleveland firm Glidden, at that time the third largest coatings company in the U.S. The acquisition was consistent with ICI's explicit strategy of globalization. ICI acquired Glidden for $580 million, when the company had pre-tax profits of $60 million on sales of $650 million.[36]

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33. "Restructuring Continues in Europe," Chemicalweek, October 31. 1990

34. Information Research Limited, "A Profile of the West European Paint Industry," London, 1990

35. Information Research Limited, "A Profile of the West European Paint Industry," London, 1990

36. Imperial Chemical Industries PLC, "Major Acquisition Makes ICI World Paints Leader, Company Press Release, August 15, 1986

Courtaulds had also expanded its presence in the U.S. coatings market through acquisitions. In 1987, the company purchased Porter Paints of the U.S. for $140 million gaining a strong position in the midwest and southwest of the U.S. for architectural coatings. Porter Paints had been a privately held family business with sales in 1987 of $120 million.[37] Courtaulds' U.S. OEM and industrial coatings positions were further strengthened through the purchase of Products Research and Chemical for $260 million in 1989 and Desoto Industrial Coatings for $135 million in 1990.[38] As a result of these transactions, Courtaulds ranked among the ten largest suppliers of coatings in the U.S. in the early 1990s.

Environmental Regulations

In the UK, passage of the 1990 Environmental Protection Act was expected to put demands on reducing VOC emissions from coating operations. Again, the primary federal responsibility was to provide assistance to local regulators and permit writers in methods of achieving emissions reductions. Guidance documents stipulating VOC content in industrial coatings were provided by Her Majesty's Inspectorate of Pollution. These documents outlined the "best available technology not exceeding excessive cost" (BATNEEC) for reducing emissions in industrial processes outlined in the Environmental Protection Act. Guidance documents were issued in a wide variety of areas affecting paints and coatings operations including vehicle manufacturing, wood furniture coating, refinishing of automobiles, and many others. In fact, the Environmental Protection Act may have covered more areas of industry than the regulations in any other country. However, as can be seen in tables 12 and 13, compliance requirements under the British regulations were less strict than those found in the rules of other countries.

"Rest of World" Markets

Large coatings manufacturers had entered the rapidly growing markets of Southeast Asia and Latin America by building new facilities. In the early 1990s, architectural coatings sales here were reported

37. Courtaulds Coatings Inc., "Porter Paint Co. Acquired by Courtaulds," Company Press Release, October 26, 1987

38. U. S. Department of Commerce, "Foreign Direct Investment in the United States," 1990 Transactions

to have grown by more than 10% ,[39] making these regions significantly more attractive than home markets growing only at the rate of GDP. ICI, Sherwin Williams, Akzo, BASF, and Courtaulds had all made significant investments in these growing markets. Additionally, the two large Japanese manufacturers Nippon and Kansai had expanded markets into Southeast Asia. Although environmental regulations were limited in these markets, several manufacturers reported that production facilities in these areas were built to the most stringent environmental requirements of any of the geographies in which they had facilities.[40]

39 "ICI Paints Chief Cites Growth in the New Hot Market: Asia," Chemical Week October 14, 1992

40 PPG Industries, Inc. Douglas B. Atkinson - Director Interview, February 25, 1993

EFFECTS OF REGULATION ON COMPETITIVE ADVANTAGE

Methods of Achieving Environmental Goals

As has been stated above, the first VOC paint regulations in the United States focused on the OEM segment of the market. Local rules, primarily in California, addressed manufacturers, but also put regulation on the content of architectural coatings. While compliance in architectural coatings was achieved almost exclusively through substitution of raw materials, manufacturing facilities have achieved lower VOC emissions in a variety of ways:

* Substitution of new materials in the solvent/resin system
* Development of coatings which did not require solvents
* Adoption of application techniques with higher transfer efficiencies
* Development of application devices which did not require solvents
* Installation of control systems to capture and destroy or recover emissions

The following tables summarize how the adoption of these technologies affected the regulated groups and their suppliers. In cases where original equipment manufacturers were affected, the impending regulations were initially anticipated to drive substantial costs for abatement equipment. Many analyses of the impact of an environmental initiative stop at that point. However, as seen in these tables, projecting from the existing situation exclusively in the regulated industry overlooks the potential for innovation by that industry and, perhaps more importantly, by its suppliers.

The ability to offset the anticipated environmental costs for their customers led to strategic opportunities for a variety of coatings and equipment suppliers. Which firms benefited from these opportunities depended on their available resources, their ability to innovate, and the willingness of their customers to take risks in incorporating new technologies. Similar factors affected the opportunities in the market for architectural coatings; although here, regulators were potentially more influential in forcing customers to adopt new coatings.

Competitive Effects of Automobile Coatings Regulations on the Industry and Its Suppliers

Method	Automobile Paint Suppliers	Automobile Companies
High Solids Paint Systems	* Increased costs associated with development of new products	• Expenditures for control equipment which reported to be as high as $20-40 million in single facilities. Auto companies claimed environmental capital and operating costs of over $40 per vehicle
		• Diminished ability to achieve optimum surface finish
	* Share shift and lincensing opportunities for innovative firms	
Waterborne Paint Systems	* Increased costs associated with development of new products	* Capital expenditures of approximately $20 million per facility where sufficient space was available. Alternatively. similar additional costs for flash ovens in new paint lines
	* Share shift and licensing opportunities for innovative firms	Substantially improved appearence over high-solids paint systems
Powder or Radiation Cured Coatings Where Applicable		* Reduced coating costs through material savings

Competitive Effects of Wood Furniture Coatings Regulations on the Industry and Its Suppliers

Method	Equipment Suppliers	Coating Suppliers	Wood Furniture Companies
Adopt Control Technologies			• Expenditures for abatement equipment
Supercritical CO_2 Delivery Device	• New market for suppliers of innovative equipment	• Share shift opportunities for innovative suppliers	• Equipment costs which were 20-33% of those anticipated for abatement equipment
			• Lower coatings costs from reduced solvents
			• Improved working conditions
			• Improved surface appearance
Waterborne Coatings		• Share shift opportunities for innovative suppliers	

Competitive Effects of Architectural Coatings Regulations
on the Industry and Its Suppliers

Method	Architectural Coating Suppliers	Architectural Coating Users
Waterborne Paint Systems	l share shift opportunity for innovative suppliers	l Comparable cost to solvent-borne
		l Reduced odor and fumes from painting

Direct Effects on Product

OEM Markets for Innovative Products

Regulations on OEM coatings processes threatened to force substantial costs on manufacturers. Facility managers faced a choice between high costs for control equipment or adoption of innovative but developmental coatings which initially were not thought to provide the performance of previously used coatings. In response, suppliers undertook research efforts attempting to develop products which provided the required performance and could limit the need for control equipment. In a few large market segments which enjoyed competition from large technically sophisticated suppliers, dramatic changes in product technology occurred. However these investments were limited by traditional constraints on industrial innovations. Smaller suppliers simply did not possess the resources necessary for extensive technical efforts. The fragmented nature of the OEM coatings market, further worked against substantial research investment. Smaller market segments, although potentially large emitters of VOCs did not attract large investments because the potential rewards for the innovative suppliers were smaller. The ability of manufacturers to meet regulation with innovation was dependent on the structure of their own industry as well as that of their suppliers. The contrast between large concentrated industries and smaller fragmented markets can be seen in the following discussion of the automobile and the wood furniture markets as each of these industries faced increasing regulation on their releases of VOCs.

The market for transportation (automobile, truck, and other vehicle) coatings was the largest segment of the OEM market. In the U.S. alone, the 1990 sales for this segment were more than $1.2 billion. In addition, the market for autobody refinish coatings (categorized as special purpose because the product was not "original equipment") had sales of more than $1.2 billion. These markets were supplied by large integrated Firms such as Dupont, BASF, and ICI. All of the major suppliers served this market as part of diversified chemical operations.

Painting an automobile was a complex process involving the application of several layers of coatings with baking processes in between. Each of these layers utilized differing formulations and application methods. As a result, concerns with solvent emissions varied depending on the step of the process. For example, very small amounts of VOCs were released in the application of the protective electrodeposition coat (E-coat) which was performed using a dip process in a water-borne coating.[41]

The application of the E-coat was followed by a primer surfacer and then a color coat. A great deal of attention had been focused on options for reducing the solvent content of the color coat. In the 1960s, two types of systems were used for color coats in the U.S. GM applied a monocoat lacquer while Ford and Chrysler employed low solids enamel systems.[42] In response to a 1972 amendment to California's Rule 66, GM needed to change to a water-borne enamel system at its South Gate, California and Van Nuys, California assembly plants.

Unrelated to environmental concerns. the automobile industry faced a new challenge in the late 1970s. At that time, European imports were being marketed which had a clearly superior appearance than U.S. manufactured vehicles. European firms, notably BMW and Mercedes Benz, had introduced a new technology to their operations. Instead of searching for a single monocoat material which offered color, metallic. gloss, and protective properties, they used a two stage basecoat/clearcoat method. The basecoat could be formulated to control the metal components of the coating as well as incorporate high pigment loadings. The clearcoat could be engineered for gloss, "distinctness of image," and durability.

41. PPG Industries, William V. Wamick - Director Coatings and Resins Manufacturing, Interview, Pittsburgh, PA, February 25, 1993

42. Jamrog, Robert, "Automotive Water-Borne Coatings: Clean Air Legislation is Pushing Automakers Toward Water-Borne Basecoats," Products Finishing, October, 1993

The U.S. automobile industry shifted to basecoat/clearcoat technologies during the 1970s and early 1980s. However, regulations were such that any new plant would need to reduce emissions to the level achieved by those GM plants using water-borne enamels in California. GM, anticipating opening three new plants in 1980 and viewing the requirements based on water-borne enamels as inappropriate for plants where the two step basecoat/clearcoat was going to be applied, sued the EPA claiming the agency had built its regulation around obsolete technology. Further, GM positioned the discussion as an important competitive issue. They argued that if the U.S. auto makers were forced by the regulations to use the poorly performing enamels, they would surely lose additional market share to European and Japanese imports.

A compromise was reached in which manufacturers were granted innovative technology waivers to the New Source Performance Standards. The innovative technologies were based on achieving lower emissions while employing basecoat/clearcoat. Similarly, existing facilities were allowed more time to bring down emissions following the release of a Federal Register Notice from the Reagan Administration which encouraged extending the compliance deadlines.[43]

After some disappointing attempts at using water-borne basecoats, the U.S. manufacturers began to adopt systems which were solvent-borne but higher in solids content. Increasingly strict regulations pushed the manufacturers to reduce solvent content to the point where performance trade-offs were again being made. With high solids, gloss and distinction of image were compromised.[44]

European manufacturers watched U.S. developments closely. They anticipated growing regulations in their own markets (as occurred in Germany, Sweden, and the U.K.) and were anxious to avoid the performance trade-offs required by high solids basecoat/clearcoat systems. This led European automobile manufacturers and their coatings suppliers to work together to find an acceptable waterborne technology

43. U.S. Environmental Protection Agency, David Salman - Industrial Engineer, Interview October 5, 1993

44. Jamrog, Robert, "Automotive Water-Borne Coatings: Clean Air Legislation is Pushing Automakers Toward Water-borne Basecoats, " Products Finishing, October, 1993

which would match the appearance of low-solids solvent-borne basecoat/clearcoat systems, In 1986, Volvo began using a water-borne basecoat developed by ICI in its Gothenburg, Sweden facility. The coating used an aqueous microgel technology supplied by ICI which the company had begun to research in the late 1970s.[45]

Water-borne basecoats of this type were quickly adopted at new installations by other manufacturers. At the same time, BASF was developing a different technology which proved successful for water-borne basecoats. By 1993, nine plants in Germany and two in other parts of Europe were using water-borne basecoat systems.

BASF and ICI began to transfer their technologies to the U.S. later in the decade. Although Imnont had researched water-borne systems prior to its acquisition by BASF, much of the technology used in the systems sold in North America relied on developments made in the European operations. DuPont and PPG, the only other two U.S. suppliers of basecoats licensed the ICI technology.

By 1993. industry leaders estimated that 20% of the world's automobile plants were using water-borne basecoats[46] In North America, four plants were using systems based on the ICI technology, two were using BASF, and one used multiple suppliers. Further, BASF was planning to provide water-borne basecoats to the $1.3 billion U.S. autobody refinish market by 1993.[47] ICI, which had not previously supplied refinish paints in the U.S., had announced a similar entry into this market.[48]

U.S. automobile manufacturers were quick to point to achievements in emissions reductions which occurred between the 1970s and the 1990s. In that time, average releases of VOCs per vehicle were

45. IDAC, Dr. J. Pearson, Managing Director, IDAC UK, Telephone Interview, August 23, 1993

46 "Environment Drives Automotives: Waterborne High-Solid Paints Spread," Chemicalweek. October 13, 1993

47 "Bodyshops Go Green," Polymers Paint Colour Journal

48. Wall, C., "Environmental Breakthrough for Refinish Paints," Polymers Paint Colour Journal

estimated to have been reduced from 15.5 pounds to 3.5 pounds, an 80% reduction.[49] They were just as quick to point out that these improvements were achieved at high cost in technology development, capital equipment, and possibly reduced sales resulting from lowered product attractiveness. Requirements outlined in the 1990 Clean Air Act Amendments put additional demands on the industry requiring even greater reductions, particularly in siting new or significantly modified facilities. Potential innovations which were being considered to meet these requirements included further adoption of water-borne base coat systems as well as utilization of powder coating systems for primer and clear coat operations.[50] If successful, these modifications were anticipated to bring the total release per vehicle to 1.5 pounds.

In contrast to the automobile companies. wood furniture manufacturers were often small firms with thin profit margins. The coatings market for this industry was much smaller with 1990 U.S. sales of $340 million. Although this segment was fairly highly concentrated with four primary suppliers, its small size resulted in relatively low revenue for any one manufacturer. In southern California, rule 1136 required 93% reductions of VOC emissions from coating operations in this industry by 1996. Interim deadlines in 1989, 1990, and 1994 required substantial reductions. As the first deadlines approached, manufacturers were faced with a dilemma; few could afford control equipment and existing low solvent technologies were felt to be of substantially lower quality than higher solvent coatings. A study by the General Accounting Office in 1991 estimated that between 1 and 3% of these firms chose to relocate in Mexico in the years between 1988 and 1990.[51] In addition, as many as 11% of other affected wood furniture manufacturers may have moved to other parts of the U.S. While many factors affected the

49. American Automobile Manufacturers Association, Interview, Bill King, May 27, 1993

50. United States Council for Automotive Research, "Plant Emissions Latest Big Three Research Target," Press Release, February 18, 1993

51. United States General Accounting Office, report on wood furniture manufacturer relocation to Mexico, April 24, 1991, B-243621, GAO/NSIAD-91-191

decision of these firms to move, 78% cited stringent air pollution control requirements as a significant factor in their decision (83% cited the high costs for workers' compensation insurance and wages).[52]

Representatives of the South Coast Air Quality Management District reported in 1990 that the stringency of the regulations had been intended to prod furniture manufacturers into developing new low solvent coatings.[53] These regulators may not have considered that even the largest suppliers achieved revenues from this segment of less than $100 million.

The requirements in southern California did highlight increasing concerns for wood furniture coatings. However, although supplying firms began intensive research efforts, the development of compliant coatings which had acceptable performance took several years and the process required cooperation with suppliers as well as customers (the wood furniture manufacturing industry).[54] By the early 1990s, significant improvements in the performance of water-borne coatings had been made in this segment and few companies were then moving operations.[55] However, for the estimated 1,000 - 7,000 workers who were displaced, the innovations came too late.[56]

Development of No-Solvent Coatings

Achieving higher transfer efficiencies and lowering solvent content was not merely an environmental issue. Anything less than 100% transfer efficiency implies some level of wasted material. Overspray, the paint which is not deposited on the product, must be collected and disposed. Solvent is included in the paint merely to be released later. Obviously, elimination of solvent or improved transfer efficiencies could reduce cost. This fact led manufacturers to explore the potential of radiation cured and powder

52. United States General Accounting Office, report on wood furniture manufacturer relocation to Mexico, April 24, 1991, B-243621, GAOINSIAD-91-191

53. Kraul, Chris, "A Warmer Climate for Furniture Makers," The Los Angeles Times, May 14, 1990

54. Lilly Industries, Inc., 1991 Annual Report, "Research and Development: Our Foundation for the Future"

55. Lilly Industries Inc., Bob Bailey - Vice President of Marketing, Telephone Interview, February 11, 1993

56. United States General Accounting Office, report on wood furniture manufacturer relocation to Mexico, April 24, 1991, B-243621, GAO/NSIAD-91-191

coatings. These materials offered the possibility of solvent free coating application with almost 100% transfer efficiency.

Radiation cured coatings used low molecular weight monomers which reacted to form a film when exposed to UV light or electron beams. Powder coatings were typically applied through an electrostatic deposition process and then exposed to heat. When the coating reached its melting point a thin resilient film was formed. The prospect of increasing environmental regulations limiting VOC emissions spurred growing interest in both radiation cured and powder coatings in the early 1990s. Expansion of these markets was anticipated by most paint market analysts.[57] In 1990, however, radiation cured coatings and powder coatings each constituted only about 2% of the total paint market.[58]

The primary limitation on radiation and powder coatings was the difficulty in achieving acceptable finishes when applying the material to non-uniform surfaces. Radiation coatings could only be applied to flat surfaces so applications were limited to such areas as flat wood paneling and printing applications. Using electrostatic processes, powder coatings could be applied to more varied surfaces. However, appearance problems were still being overcome in the early 1990s. Although increasing advances were expanding the markets for these coatings into such areas as automotive finishes and metal furniture paints, the largest markets for powder coatings remained in areas of simple geometries. In 1992, appliance coatings accounted for 21 % of powder coating markets and coatings for simple automotive parts (such as underbodies and wheels) made up 15 %.[59]

OEM Markets for Innovative Equipment

Some regulations in California addressed transfer efficiency as well as solvent content of the coating. Transfer efficiency was a measure of the ratio of the amount of coating deposited on the substrate to the

57 U. S. Department of Commerce, U. S. Industrial Outlook, 1993, "Paints and Coatings," p. 11-8 through 11-9

58. U. S. Depart of Commerce, Current Industrial Reports, Paints and Allied Products, 1990

59. Powder Coatings Institute, "Powder Coatings - Markets and Applications," Gregory J. Bocchi, Executive Director, 1993

total amount of coating used in the painting process. Using a low VOC paint in a process with poor transfer efficiency would provide little benefit overall in reducing VOC emissions. As a result, in those areas where manufacturers had options in application devices, tables were developed which applied a transfer efficiency rating to each device. Higher VOC content was permitted with higher transfer efficiency.[60] Rules 1136 and 1151, promulgated by the South Coast Air Quality Management Board (SCAQMB), attempted to achieve a minimum of 65% transfer efficiency. The rules stipulated that if spray guns were used they had to have a maximum nozzle pressure of 10 psig (pounds per square inch, gauge). Spray equipment which complied with this rule was termed High Volume/Low Pressure, HVLP, and used high speed turbines rather than compressed air to atomize the coating.

Industry challenged the equipment specifications of rules 1136 and 1151. Manufacturers claimed that many factors affected transfer efficiency and that spray equipment was potentially less important than other issues.[61] Further, they suggested that use of HVLP equipment would increase spray time and thus increase costs of manufacturing operations.

A comprehensive study of spray painting systems used in wood furniture manufacturing concurred with manufacturers' worries about the equipment. In this study, four types of coatings were used in six types of spray equipment. An expert and a novice painter coated doors and window frames to determine the influence of different factors in reducing VOC emissions. The researchers concluded that using water-borne coatings and having painters become more proficient were the most effective methods of reducing VOC emissions. Surprisingly, in about half of the cases, using HVLP equipment resulted in lower transfer efficiency than using conventional airspray systems (and required more time). Air assisted HVLP equipment provided a desirable combination of reduced spray time and lowered VOC emissions.[62]

60. U.S. Environmental Protection Agency, James Berry - Section Chief and David Salman - Industrial Engineer, Interview January 19, 1993

61. Schrantz, Joe and Bailey, Jane, "Under the Gun to Conform in California," Industrial Finishing, June 1989

62. Snowden-Swan, Lesley, "Transfer Efficiency and VOC Emissions of Spray Gun and Coating Technologies in Wood Finishing," Battelle Pacific Northwest Laboratories, Pacific Northwest Pollution Prevention Research Center, November, 1992

Improving transfer efficiency provides a clear example where better environmental performance could be coupled with attractive economics. However, the study discussed above suggested that the methods required by SCAQMB were not necessarily the best means of achieving these goals. These results suggest that regulators must be cautious in being overly prescriptive in identifying means of achieving environmental improvement even when those means should provide economic advantages. Subtle differences in facilities, in products, and - as in this case - operator skill can substantially influence anticipated outcomes.

One of the most innovative approaches to reducing VOC emissions from paint application was the Unicarb system developed by Union Carbide in 1989. Rather than look to other types of liquids to replace existing solvents, the company developed a system which took advantage of the solvent-like properties of carbon dioxide under high pressure. Termed "supercritical," the highly pressured carbon dioxide replaced the "cutting solvent" which was used to carry the resin and pigment through the application device. It volatilized prior to deposition on the product, similar to a cutting solvent. Coalescing solvents which remained in the system ensured a smooth layer and uniform film thickness.[63]

The Unicarb system was initially developed in response to environmental concerns, but the earliest applications of the technology were in locations where VOC regulations were not particularly strict.[64] The company suggested that additional benefits spurred manufacturers to switch to the Unicarb system. Some of the advantages claimed by the company included:[65]

* Improvement in working conditions because carbon dioxide is odorless
* Improvement in safety because carbon dioxide is not flammable
* Superior coating performance through the use of higher molecular weight resins

63. Union Carbide Chemicals and Plastics Company Inc., "Unicarb System for Spray Coating: A major Advance in VOC-Reduction Technology," Company Promotional Literature

64. Union Carbide Chemicals and Plastics Company Inc., Dr. Dave Buzby - Development Scientist, Telephone Interview, March 8, 1993

65. Union Carbide Chemicals and Plastics Company Inc., "Unicarb System for Spray Coating: A Major Advance in VOC-Reduction Technology,' Company Promotional Literature

* A more uniform surface than other low VOC systems
* Low capital expenditure compliance option

The company claimed that the cost of removing VOCs using the Unicarb system ranged from one-third to one-fifth that of using carbon absorption or incineration systems.[66] Union Carbide chose to market neither coatings nor application equipment. Instead, the technology was being licensed to several firms specializing in each of these areas.

Architectural Coatings Markets for Innovative Products

In architectural coatings, the trend toward lower solvent products had continued since the first introduction of water-borne coatings by Glidden in 1948.[67] Many of the advantages driving this trend were summarized in an industry response to the EPA during negotiations over the adoption of architectural coatings rules in 1993:

"As with all highly competitive markets, reducing product costs and introducing technological innovation are among the chief means by which a company can increase its market share. This fact has been largely responsible for the shift from solvent-borne products -- a shift that has both reduced manufacturers' cost by reducing the solvent content of products and responded to consumers' demand for products that have less odor and are easier to clean up. [68]

However, the same document went on to identify five deficiencies in water-borne paints as compared to solvent-borne systems:

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66. "Supercritical CO_2 as a Solvent: Update on Union Carbide's Process," Modem Paint and Coatings, June 1990

67. Yerak. Rebecca, "No-smell Coating: New Glidden Paint Safe for Environment," The Plain Dealer, Cleveland, Ohio, July 21, 1992

68. "Responses: Questions and Issues Raised by State, Environmental, and EPA Members of the AJM Reg-Neg Committee Concerning the Industry Caucus Proposal of January 6. 1993," Response Submitted to the Full Reg-Neg Committee on February 11, 1993

* Water-borne products were more sensitive to surface conditions

• Water-borne coatings could be more difftcult to apply

• Water-borne paints dried quickly but "cured" slowly

*Water-borne paints did not cure at lower temperatures

* Water-borne products generally formed a softer film than solvent-borne coatings

Thus, the message from producers of architectural coatings was in support of regulations which had an accelerating effect on existing market trends. However, flexibility was desired to allow continued production of coatings for applications with requirements closely matched to the characteristics of high solvent coatings. Unfortunately, regulators could never be sure that specific coatings would only be used for the narrow applications for which they were intended. Therefore, regulators tended to demand lower solvent levels in all coatings intended for consumer purchase.

Limitations to Innovation

Clearly, the regulations affecting VOC emissions showed a variety of approaches to innovation. However, in a series of legal challenges (primarily in California) and responses to pending regulation. industry raised some concerns about the ability to innovate within the structure of the regulations. The primary issues which were raised follow:

l An industry sponsored group in California won a lawsuit against pending architectural coatings regulations making,among other claims, the assertion that the rules would encourage the use of inferior coatings. It was argued that consumers would be forced to use more paint, or repaint more frequently, and therefore. VOC emissions could be exacerbated by the regulations.

l Again primarily in California. manufacturers complained that tests for measuring transfer efficiency were poorly designed. It was asserted that lower VOC coatings used in application systems with lower transfer efficiency would continue to yield high emissions.

l In the U.S. none of the regulations rewarded the advantages of thinner coatings. Because thinner coatings required less paint to cover a surface, less VOCs would be released in using a thinner, rather than a thicker coating. Although not addressed in the regulations, the thickness of the coating could significantly affect the amount of paint used and thus the VOC emissions resulting from coating a surface. Automotive coatings, for example, ranged for 2.4 to 3.8 mils (a 58% difference).

l Some industry groups claimed that focusing regulations only on coatings operations did not allow firms to be in compliance by achieving equivalent reductions in emissions in other areas of operations. At times industrys intentions appear to have been more to be provocative than practical. For example. the South Coast Finishers and Fabricators Association (SCFFA) recommended to me South Coast Air Quality Management District that emissions targets set for wood funiture manufacturers could be met more cheaply by adopting car pooling and staggered shifts (so travel would occur at less congested times). It was argued that reducing the emissions from employees' cars would more than achieve the goals set for the coatings

Traditionally, water-borne architectural coatings had been priced at or below the price of solvent-borne systems .[69] However, manufacturers have reported that raw material costs for totally new paint technology may initially have been 20-30% higher.[70] The confusion on this issue was not cleared up even after extensive study by the State of California Air Resources Board. In July of 1989, the Technical Review Group of the Architectural Coatings Committee concluded, "the economic impact to consumers from reformulating coatings can be either positive or negative and is difficult to estimate.[71]

The primary cost concern to industry had not been the change in raw material prices. In the early 1990s, the cost of developing new formulations was the most important concern for many firms. At a minimum, the development of a new coating required the dedication of two researchers with access to necessary laboratory and pilot production facilities.[72] Development typically took two to four years with the latter stages requiring long-term performance testing.[73] Particularly when changing to water-borne systems, production facilities could be required to be modified to handle new materials in the formulations.[74] Clearly then, the development of a new coating could reach costs in the hundreds of thousands of dollars.

As has been described. the structure of the architectural coatings industry was very different than that of OEM coatings suppliers. In 1990, the three largest manufacturers accounted for 36.5% of the market. Meanwhile, hundreds of small manufacturers, with little or no development capabilities were producing

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69 "Responses: Questions and Issues Raised by State, Environmental, and EPA Members of the AIM Reg-Neg Committee Concerning the Industry Caucus Proposal of January 6, 1993," Response Submitted to the Full Reg-Neg Committee on February 11, 1993

70. Courtaulds Coatings, Stanley Hope - Manufacturing & Environmental Manager, Interview, April 13, 1993 and Glidden Co., Jim Sainsbury - Manager Products Regulation, Interview, February 18, 1993

71. California Air Resources Board Stationary Source Division, "ARB-CAPCOA Suggested Control Measure for Architectural Coating: Technical Support Document," July 1989, p. 22

72. Courtaulds Coatings, Stanley Hope - Manufacturing & Environmental Manager, Interview, April 13, 1993 and Glidden Co., Jim Sainsbury - Manager Products Regulation, Interview, February 18, 1993

73. Glidden Co., Jim Sainsbury - Manager Products Regulation, Interview, February 18, 1993

74. Courtaulds Coatings, James K. Chapman - Vice President Manufacturing & Distribution, Interview, April 13. 1993

small quanities of material. Adopting highly restrictive or technology forcing regulations would likely provide a strategic advantage to the largest firms who could spread the cost of development over the greatest volume. In fact, some of the largest producers had already dedicated large investments to providing paints with reduced VOC emissions.

In 1992 Glidden introduced the first architectural coating to employ no organic solvents at all. Using an innovative resin system developed by Rohm & Haas Chemical Co., the company was able to eliminate even the coalescing solvents which were normally needed to assure a smooth surface finish.[75] The company highlighted the additional benefits of low odor and ease of clean up, but the primary motivation for its development was the recognized market for environmentally friendly products.[76] However. by having no VOCs, the product formulation was well beyond the requirements of even the most stringent California regulations. As has been noted earlier, Glidden became part of the ICI paints World Group in 1986. The management of this organization had concluded that long term regulatory trends would reward those companies which developed technical expertise in areas where negative environmental impacts of products could be reduced.[77]

When Glidden set out to develop a solvent free product. the company decided that to be successful, the paint would have to achieve the desired environmental benefits with no reduction in performance. A particular difficulty was to assure acceptable hardness of the coating (this was important for trim areas such as windows and doorways). The solvent which was part of existing water-borne coatings was used as a coalescing agent promoting a harder paint surface. Achieving the required hardness in a solvent free coating required using a 100% acrylic resin system. This resulted in raw material costs substantially higher than those for many other Glidden products. Pricing was comparably higher. One source

75. Yerak, Rebecca, “No-smell Coating: New Glidden Paint Safe for Environment,” The Plain Dealer, Cleveland, Ohio, July 2 1, 1992

76. The Glidden Company, “Glidden to Remove Petroleum-Based Solvents From Architectural Paints: First Solvent-Free Traditional Paint to Arrive in June,” Company Press Release, May 28, 1992

77. Glidden Co., David Maurer - Product Planning Manager, Telephone Interview, August 27, 1993

reported pricing 50% higher for the solvent free paints than for traditional latex brands.[78] Within Glidden's existing channels Of distribution, this price difference appeared dramatic. However, the company pointed out that if a comparison was made to other paints with high acrylic content the pricing was more similar.[79] Most of these were sold through paint stores where customers were more likely to make purchase decisions based on subtle characteristics of performance. Glidden, on the other hand, had marketed its coatings through large retailers and home improvement stores where price was more important.

Glidden marketed the acrylic resin water-based product in the U .S and Canada and anticipated entry into Australia. In the U.K.. ICI used a different formulation for its VOC-free paint. British customers routinely used different paints for trim than they used for walls. Trim paints were formulated from alkyd resins which provided a very hard glossy surface. The paints used on the larger wall areas (flat paints) could be softer and were mostly latex type. Without the need for high hardness, ICI had developed a different type of solvent free paint which did not require coalescing solvents, The differing approaches demonstrates that in some cases, even with similar environmental requirements, different market characteristics lead to different innovations.

Indirect Effects on Pollution Control Industries

Regulations aimed at reducing VOC emission from coatings focused on achieving reductions equivalent to employing control devices with high levels of efficiency. Although this could require a significant capital expenditure, some manufacturers chose to modify production facilities rather than substitute new coatings. In coil coating lines (products used for metal building siding and other applications), manufacturers used medium and high solids coatings with incinerators on the ovens to bum the solvents[80]

78. Yerak, Rebecca, "No-smell Coating: New Glidden Paint Safe for Environment," The Plain Dealer, Cleveland, Ohio, July 21, 1992

79. Glidden Co., David Maurer - Product Planning Manager, Telephone Interview, August 27, 1993

80. Lilly Industries Inc., Bob Bailey - Vice President of Markertng. Telephone Interview, February 11, 1993

CONCLUSIONS

Innovation is an important part of improving the quality of the environment while maintaining a strong industrial base. As demonstrated by paint suppliers, firms will dedicate large resources to these innovations when the regulations are structured to allow new approaches to compliance and the management of the firm feels the market being created is sufficiently large to provide returns on the resources dedicated to achieving new developments.

1) If regulations are likely to be met by supplier innovations, the size and resource availibility of those -firms will significantly affect their response to new requirements on their products.

The actions taken by architectural coatings manufacturers demonstrated the effect of varying resources on the response of industry to new regulations. For firms affected by regulation, the availability of resources may not be equivalent. Large firms may be able to quickly respond to regulations with innovative solutions which satisfy all product performance needs including regulatory compliance. At the same time, smaller firms, unable to match the development budgets of their larger rivals, may have no option but to resist and delay the regulations as much as possible.

This conflict could be seen in the early response to regulations on architectural coatings. In 1993 there were hundreds of manufacturers of architectural coatings. The top five supplied more than 45% of the market and each had sales of more than $180 million, but the typical architectural coatings firm had revenues of less than $5 million. In 1993, the regulatory negotiation was on-going concerning a national rule for VOC reduction in architectural coatings. Regulations which demanded rapid compliance or significant changes in product formulations would be expected to provide competitive advantages to the larger manufacturers with the resources to devote to research and development of new coatings. Smaller firms would not be able to keep up. As was already evident, as regulations began to take effect in California, large firms had begun to innovate with lower VOC formulations - even achieving a no VOC system - while many smaller firms had resisted regulation through litigation. Without some form of intervention, these firms could have become the losers in the trade-off between achieving regional environmental goals and maintaining the existing characteristics of the industry's competitiveness. On the other hand, protecting small firms by adopting less rigorous standards or allowing longer implementation periods would have required accepting reduced environmental benefits.

2) Supplying firms will only respond to regulations with innovations in those markets which are large enough to justify their dedication of research resources.

The response of the paint industry in different OEM markets provides insights to the importance of the size of the market for innovative approaches to compliance. OEM manufacturers made significant progress in reducing the level of VOC emissions resulting from their coating operations between 1986 and 1991. The 15 % reduction in these emissions which resulted was achieved through the use of a variety of methods including material substitution, equipment changes, and adoption of control devices. In each of these areas, the products and equipment needed to achieve lowered emissions were developed by supplying industries to the ultimate manufacturer. For the upstream industries, the promulgation of regulations either created or significantly altered the industry's market. In every case, the upstream innovations provided additional options for lowering VOC emissions in coating operations. As a result, many manufacturers were able to reach (and at times exceed) compliance at costs significantly lower than would have been possible had regulations exclusively demanded the use of pollution control equipment.

As it became clear that automotive manufacturers would progressively move toward water-borne coatings, the large size of this market provided satisfactory justification for suppliers to research and improve these products. On the other hand, when only California regulated wood furniture manufacturers, the small size of the market and the technical difficulties encountered delayed manufacturers from achieving compliant coatings. Lacking innovative, lower cost solutions, some manufacturers found it impossible to compete with unregulated manufacturers and moved operations. Even as national regulations were being developed in 1993, it was unclear whether manufacturers would be able to supply all wood furniture markets with water-borne coatings which performed comparably to solvent-borne systems.

3) Those companies which target long term trends will be best positioned to benefit when regulations are adopted.

When U.S. automobile manufacturers were first regulated for VOC emissions, they responded by adopting the best then available option, high solids coatings. At that time, no suitable water-borne base coat was available. However, ICI had conducted more than a decade of research in hopes of developing a water-borne coating which could match the performance characteristics of solvent-borne base coats. Although ICI's customers were not likely to be regulated until the mid to late 1990s the company was able to achieve benefits from their research by licensing U.S. suppliers to use their technology. Additionally, the applicability of the technology to the larger automobile refinishing market, facilitated the company's entry into a market in the U.S. where it had previously not participated.

The characteristics of innovations in the paint industry have implications to any other regulated area. Here, as in many other areas, the innovations have not occurred within the regulated industry itself. Instead, new approaches were developed by suppliers at least one step up the value chain. In the case of new resin systems, the new developments were several steps upstream. These upstream industries must choose how to dedicate scarce resources. They will dedicate these resources to methods of lower cost environmental compliance when the regulations are structured to allow creative methods, the market for innovations is large relative to the required development investment, firms possess the needed resources, and the decision makers in the regulated area are receptive to new approaches of achieving compliance.

TABLE 1
World Export Share Developme
Paints and Varnish

Country	1980	1985	1990
West Germany	23.1%	23.8%	24.6%
United Kingdom	11.9%	10.5%	10.1%
Netherlands	11.1%	10.6%	10.7%
United States	9.1%	9.8%	9.2%
France	7.5%	7.4%	7.1%
Belgium	4.9%	5.3%	5.5%
Japa	4.1%	6.2%	4.7
Italy	4.6%	[illegible]	5.0
Finland	2.1%	1.5%	1.6%
Switzerland	1.7%	2.0%	2.2%

Source. UN Trade Statstics Yearbook1990

TABLE 2
World Import Share Development
Paints and Varnishes

Country	1980	1985	1990
West German	7.8%	7.2%	9.3
Unite Kingdom	4.1%	5.1%	6.0
Netherla	6.0%	6	5.8%
United States	1.1%	2.7%	3.0%
Fran	9.6	8.4%	9.5
Belgiu	5.8%	4.9%	6.2%
Japan	2.1%	2.0%	1.7%
Italy	4.7%	4.8%	5.4%
Finland	1.4%	1.2%	1.4%
Switzelan	3.3%	3.1%	3.1%

Source UN Trade Statistic Yearbook, 1990

TABLE 3
Trade Balance Development
Paints and Varnishes
(thousands)

Country	1980	1985	1990
West Germany	$347.768	$353.753	$802,815
United Kingdom	$176.558	$120.377	$229.077
Netherlan	$127,169	$106,361	$267.967
United States	$173.315	$151.23	$317.536
France	($14.668)	($5.260)	($65.685)
Belgium	$283	$16,115	($543)
Japan	$49.100	$90.492	$154.060
Ita	$11,881	S2.965	$10.323
Finlan	$17,97	$9.029	$16.268
Switzerland	($25.412)	($17.663)	($25.609)

Source: UN Trade Statistic Yearbook 1990

TABLE 4
World Export Share Development
All Pigments and Paints

	1980	1985	1990
West Germany	25.6%	24.7%	24.0%
United Kingdom	13.2%	11.5%	10.9%
Nertherlands	9.4%	9.0	8.0
United States	7.0	7.3%	10.1%
France	8.5%	8.9%	7.3%
Belgium	6.6%	6.5%	7.0%
Japan	4.6%	6.8%	6.0%
Italy	4.6%	4.4%	4.1%
Finland	2.6%	2.7%	2.4%
Switerland	2.7	3	2.1 %

Source: UN Trade StatisticYearbook1990

TABLE 5
World Import Share Development
All Pigments and Paints

Countr	1980	I985	1990
West Germany	8.7%	8.3%	9.7%
United Kingdom	3.9%	5.0%	6.0%
Netherlands	5.7%	5.5%	5.4%
United States	2.5%	6.7	5.7%
France	9.4	7.9%	9.2
Belgium	5.1%	4.2%	5.2%
Japan	2.4	3.1%	2.8%
Italy	5.3%	5.1%	6.1%
Finland	1.2%	1.0	1.1%
Switzerland	3.5%	3.2%	3.1

Source: UN Trade Statistic Yearbook, 1990

TABLE 6
Trade Balance Development
All Pigments and Paints
(thousands)

Country	1980	1985	1990
West Germany	$820,153	$775,732	$1,702,246
United Kingdom	$446,536	$308,755	$596,105
Netherland	$196.671	$168.586	$302.945
United States	$215.683	$38.210	$572,1
France	$6,	$60,53	($156,331
Belgium	$93,683	$113.392	$244,462
Japan	$112,336	$178,9	$388,461
Italy	($5.267)	623.449)	($190,595
Finland	$70.195	$81,693	$150.749
Switzerland	($l9.309)	($4715	$83.305

Source: UN Trade Statistic Yearbook, 1990

TABLE 7
U.S. Total Quantity and Value of Shipments of Paint and Allied Products

Category	1988 Value(milllon)	1989 Value (million	1990 Valu (million)
Architectural Coatings	$4426	4,525.3	$4.913 6
Product Coating OEM	$4.1045	$4.220.1	$4,032
Special Purpose Coating	$2251.8	$2.493.5	$2.781.5
Miscellaneous Allied Products	$1052.3	$1092.7	$1.170.7
Total	$11,835.4	$12,331.6	$12.898.4

Source. U.S.. Department of Commerce, Cut-rent Industrial Reports, Paint and Allied Products, 1991

TABLE 8
European Paints and Coatings Production
(millions)

Country	1985	1990
West Germany	$3,583	$4,312
France	$2,111	$2,585
United Kingdom	$2,028	$2,111
Italy	$1,585	$1,993
Netherlands	$735	$898
Spain	$640	$751
Belgrum	$439	$544
Sweden	$465	$504
Switzerland	$345	$439
Denmark	$379	$417

Source: Chemicalweek, October 31, 1990

TABLE 9
Leading U.S. Architectural Coatings Manufacturers
(millions)

Company	1989 U.S Sales
Sherwin-Williams	$750
Glidden	$620
Benjamin Moore	$350
PPG Industries	$303
Desoto	$180
Kelly Moore	$175
Valspar	$170
Grow Group	$160
Pratt & Lambert	$140
Porter Paint	$105

Source: Chemicalweek October 31. 1990

TABLE 10
Volatile Organic Compound Emissions of Selected Industrialized Countries

Country	GDP ($ billion)	Population (million)	VOC (millionton)	VOC/GDP lb/SK	VOC per capita lb/capita
U.S.A	5,673	252.5	16.9	6.57	148
Austria	164	7.8	0.5	6.72	141
Sweden	230	8.5	0.4	4.22	114
France	1,032	57	2.77	5.92	107
U.K.	913	57.6	2.7	6.52	103
West Germany	1,234	63.7	2.6	4.64	90
Netherlands	249.l	15	0.5	4.16	69
Italy	969	57.8	1.53	3.48	58

Sources: ‘Handbook of Intenational Economic Statistics, 1992; U.S. EPA ‘NationalAir Pollution Emission Estimates, 1900-1991, October 1992,’ U S. Department of Commerce. ‘Western Europe Office, Country Profiles; VOC Newsletter, 8/92, Projectbureau KWS 2000.The Hague The Netherlands: Statistics Sweden ‘The Swedish Environment, 1991; Centre Intcrprofcssionnel Technique D’Etudes de la Pollution Atmospherique (CITEPA). ‘Emissions De COV; Reglementations Francaisc Et Europenne, TechniquesDe Reduction’ 1992: U.K. Department Environment, Personal Communication from Norman Horrocks,‘Reducing Emission of VOCs: A U.K. Strategy.‘; Federal Ministry for theEnvironment, “Environmental Protection in Germany,” June 1992; Project Group Hydrocarbons 2000. ‘Control Strategy for Emissions of Volatile organ Compounds Project KWS 2000. Department of Air Pollution , Ministerio Del Ambiente,Personal Communication, M. Gusparini M. Rizz

TABLE 11
Comparison of Regulations: Automotive Manufacturing

Allowable emissions per vehicle (assuming 110 square meters of surface area per vehicle and using performance results reported by American Automobile Manufacturers Association for U.S. values)

	United States	Germany	United Kingdom
Emissions (grams)	1,590	3.850	6,600
Emissions (pounds)	3.5	8.5	14.5

TABLE 12
Comparison of Regulations: Wood Furniture Manufacturing

Allowable solvent content in coating materials

	Southern California	United Kingdom
Clear Topcoats	275 g/l	400-435 g
Pigmented Coatings	275 g/l	525 g/l

COMPETITIVE IMPLICATIONS OF ENVIRONMENTAL REGULATION IN

THE REFRIGERATOR INDUSTRY

This case study was prepared by Claas van der Linde, Hochschule St. Gallen. The research was conducted in collaboration with the Management Institute for Environment and Business (MEB) and the U.S. Environmental Protection Agency. Copyright © 1994 by MEB.

THE REFRIGERATOR INDUSTRY
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EXECUTIVE SUMMARY

In 1987, the Montreal Protocol, an international environmental agreement to reduce and phase out chlorofluorocarbons (CFCs), catapulted the world's refrigerator makers from a slow life that for many decades had seen no major product innovation into one where they would be forced to either innovate within an extremely short time period and engage in major technical development or else quit their industry.

CFCs were believed to be major depleters of the ozone layer in the stratosphere, causing increased skin cancer and global warming. Since refrigerators depended on them as coolants and as blowing agents used in the production of foam insulation, the stipulations of the Montreal Protocol, which initially required a CFC ban by the year 2000, then by 1995, were a massive threat to the refrigerator industry.

The Montreal Protocol was not a law by itself, it merely required its signatory countries to enact legislation requiring the phaseout of CFCs and other ozone-depleting substances at the latest by the date it stipulated. In most cases the regulation that was subsequently enacted by the individual countries followed the deadline recommended in the protocol. Germany was the only nation to require an earlier phaseout date, forcing its refrigerator industry to search and find even faster a safe substitute for CFCs, but providing it at the same time with an opportunity to gain a first mover advantage over foreign competing nations.

Any CFC substitute that was researched had to be not only in compliance with the stipulations set forth by the Montreal Protocol, but also be at least as energy efficient, be safe to the user, and be as economical as possible. Energy efficiency was particularly important, because many countries either had energy efficiency laws (as was the case in the U.S.) or very demanding customers (as was the case in Germany) which provided pressure to offer only energy efficient appliances. Safety was also an important concern. Many countries, including the U.S. and European countries, had laws regulating appliance safety.

By the early 1990s it had become evident that there were two major technological avenues that could be followed to comply with the Montreal Protocol. One involved the use of hydrofluorocarbons (HFCs) as coolants and hydrochlorofluorocarbons (HCFCs) as blowing agents for insulating foams. HFCS were in compliance with the Montreal Protocol and thought to be safe to the refrigerator's user. However, they were slightly less energy efficient - a disadvantage that could be offset by small changes to the refrigerators design. They were also more expensive than CFCs, causing in Germany an average increase in refrigerator prices by some 5 % to 8 % . Their major drawback was that, while not dangerous to the earth's ozone layer. they were a powerful greenhouse gas that was thought to contribute to global warming and climate change. There was no regulation on HFCs, but the slight risk that they might be regulated Sometime in the future meant that refrigerator makers which focused on HFCs risked focusing on a transitory solution.

HCFCS were an even riskier substitute - from an environmental as well as from a competitive point of view. Refrigerator insulation foams blown with HCFCs were economical, provided sufficient energy efficiency and posed no safety risk. However, HCFCs contributed to global warming and posed a risk to the ozone layer. For this reason, the Montreal Protocol required their phaseout by the year 2020. Thus, manufacturers developing HCFC-based insulation foams followed a dead end; they could be sure to be forced once again to convert their production to a new technology in the foreseeable future.

The other major technological route to follow besides employing HFCs and HCFCs involved the use of hydrocarbons. Hydrocarbons, such as propanes, butanes, isobutanes. or pentanes, could be used both as refrigerants and as blowing agents for polystyrene insulating foams. They were environmentally benign, could easily be obtained all over the world, and were very cheap. Theoretically hydrocarbons provided better energy efficiency than HFCs and HCFCs, although practically hydrocarbon-blown insulations were slightly less efficient, requiring somewhat thicker insulations. Hydrocarbons were explosive and thus represented a certain safety risk during refrigerator production as well as during refrigerator usage, but this risk could be minimized to acceptable levels by introducing suitable safety equipment. Like HFC- and HCFC-based systems, refrigerators employing hydrocarbons cost some 5% to 8% more than CFC-based refrigerators. Unlike HFC- and HCFC-based systems, they did not pose any environmental risks and thus were certain never to be banned for environmental reasons, rendering research efforts and production equipment obsolete.

By early 1994, most refrigerator makers in the world were focusing on the HFC/HCFC alternative with all its environmental risks. The only exception was Germany, where, after a sometimes agonizing struggle to decide which technological route to choose, most refrigerator makers had decided to adopt the hydrocarbon route which did not pose any environmental risks and with further research and experience was likely to be as cost-efficient as the HFC/HCFC route. How was it possible that the German refrigerator industry, a highly competitive industry representing 11.1% of the world's refrigerator production and 13.4% of the world's exports of refrigerators, had chosen a technological route that was difficult from that chosen by the rest of the world?

There were several reasons, among them stricter and earlier regulation, which had sensitized producers and consumers to the issue -- a very demanding and environmentally conscious home market -- as well as a chance event in the form of a pressure campaign by an environmental group that had hit precisely at the right time and at the right place.

The first hydrogen-based refrigerator had been built in Germany by the small East German manufacturer Foron after the environmental pressure group Greenpeace had acquainted it with the technology and awarded it a small $15,000 development contract. Greenpeace also conducted a publicity campaign that prompted a large number of environmentally conscious Germans to place orders for the newly developed refrigerator. The extraordinary success of the campaign convinced not only Foron that the hydrocarbon-technology had real market potential, but also its West German competitors, who had initially developed HFC/HCFC-based refrigerators. Subsequently, one competitor after another announced similar hydrocarbon-based refrigerators.

At the same time as the Greenpeace campaign in Germany, there had been a more formal program in the United States, that had also aimed at facilitating change and innovation in the refrigerator industry. The Super Efficient Refrigerator Program (SERP), had been a $30 million contest conducted by the U.S. Environmental Protection Agency and some 25 utilities to develop a CFC-free refrigerator that would exceed federal energy efficiency standards by at least 25 % However, unlike the case in Germany, SERP had not led to true innovation concerning environmental friendliness. There were a number of possible reasons why SERP had not lived up to its environmental innovation potential.

SERP had placed only very small emphasis - 3% of the maximum score achievable to the winner - on environmental friendliness beyond and above the requirement not to use CFCs.

The contest had been overly restrictive with respect to the eligibility of potential contest entrants who were required to have large production facilities and a strong distribution network. This unnecessarily limited the group of potential contestants and with it the number of innovative solutions entered into the contest.

The American market was not nearly as environmentally conscious as the German market, resulting in less demand pressure on American producers to develop environmentally sound products.

Competition had focused for too many years on marketing and distribution. Given the vast geographical area of the United States and dealer networks that changed only very slowly, the industry was paralyzed and made it incapable of technology competition, more so than the German refrigerator industry which had never been assured of its geographical markets.

U .S, manufacturers lacked the technical capabilities. In Germany, an early voluntary agreement had forced manufacturers to innovate and reduce the CFC-content in the insulating foam by 50%, providing them with valuable experience. U.S. manufacturers had not received such early warnings in the form of voluntary agreements from their government. Forced to phase out CFC-based blowing agents, they lacked the necessary experience and simply substituted CFCs with HCFCs, a stop-gap measure which would force them to convert once again in the foreseeable future, since HCFCs were also to be phased out under the Montreal Protocol.

Overly strict liability laws combined with unflexible safety laws were another hindrance to innovation in the U.S. They prevented the refrigerator industry from adopting hydrocarbon-based refrigerants which might pose a very slight risk of explosion - a risk that in Germany had proven to be negligible.

It was claimed that many technically and economically feasible alternatives such as the hydrocarbon technology were not attractive to the U.S. refrigerator industry, because they were not patentable. Likewise, alternative refrigerants like hydrocarbons were said to be not attractive to refrigerant manufacturers because they were non-chemical alternatives and their adoption would effectively force them out of the market. In the absence of strong pressure from sophisticated refrigerator buyers, as was the case in Germany (where 70,000 people had been willing to pre-order an environmentally friendly refrigerator that was not even in production), lack of patentability and unattractive profit expectations for refrigerants could indeed have contributed to the U.S. industry's hesitance to convert to truly environmentally benign solutions.

* A fact that may have contributed to the U.S. refrigerator industry's aversion to risk the development of new and truly environmentally friendly refrigerators was General Electric's $450 million pre-tax charge to replace 1.1 million newly-designed refrigerator compressors that proved defective in 1988.

* A general obstacle to energy efficiency innovation that affected U.S producers was that the buying decision for refrigerators tended to be dominated by initial cost rather than total life-cycle cost considerations. Even if economically irrational, buyers often opted for refrigerators that were less expensive to buy in the first place but more expensive to operate in the long-run. The fact that the buying decision for a particular refrigerator model often was made by a person other than the ultimate user who would have to pay the energy bills also led to precedence being given to initital cost over total cost.[1] Either case resulted in the purchase of less energy efficient, thus environmentally unfriendly refrigerators, and provided producers with a disincentive to develop energy-saving refrigerators. A possible solution for overcoming this obstacle to innovation was introducing regulation that would require sellers to provide information about total life-cycle cost, but the effectiveness of similar labeling regulation had proven to be limited in the past. A second, more theoretical, solution was increasing energy prices to force users to incorporate energy use considerations fully into their purchasing decision. A third solution, and one which had proven to be very effective in the U.S., was support of demand-side management programs offered by utilities in the form of cash rebates to customers which bought new, energy efficient refrigerators or discarded old, energy intensive ones (see below).

1. ZVEI Zentralverband der Elektrotechnischen und Elektronischen Industrie: Werner Scholz. Personal communication to the author.

INDUSTRY STRUCTURE

Product

Product Description

Refrigerators were used to cool perishable foodstuffs to low temperatures, thus inhibiting the destructive action of bacteria, yeast, and mold. They were used both in private households as well as in commercial settings. Almost every refrigerator in use in the 1990s was based on the vapor-compression principle, whereby a gas was first heated by compression, then cooled down to ambient temperature and then further cooled by letting it rapidly expand. The first usable refrigerator was believed to have been built by an American physician, John Gorrie, in 1844, although the vapor-compression principle had been known for centuries.

The basic active components of a vapor-compression refrigerator were a compressor, a condenser, an expansion device (which could be a valve, a capillary tube, an engine, or a turbine), and an evaporator. A gas refrigerant was first compressed, usually by a piston compressor. It was then led into the condenser, a long and winding tube surrounded by air or water which removed some of the heat energy and cooled the vapor down to ambient temperature. Next, the cooled vapor was passed through an expansion valve into the evaporator, an area of much lower pressure. As it evaporated and drew the energy of its expansion from its surroundings, the refrigerant cooled down to temperatures, which were considerably lower than the food compartment surrounding the evaporator, thus cooling the food compartment. In a final step, the refrigerant was fed back into the compressor for a next cycle in the cooling process.[2] Since World War II the predominant refrigerant used had been a freon gas, usually the chlorofluorocarbon CFC-12, which had been preferred for its energy efficiency, low toxicity, stability, and its well-known physical properties (see Tables 4, 5, and 6). However, freons were harmful to the environment and thus were to be phased out under international and national agreements and laws (see below).

The other critical element besides the active refrigeration system was the refrigerator's passive insulation

2. Encyclopaedia Britannica, 15th ed., S.V. "refrigeration"

which facilitated maintaining low temperatures and low energy usage. Most refrigerators consisted of a thermoformed plastic inner liner and a steel outer case with polyurethane foam insulation in between. Until the early 1990s the blowing agent used for the polyurethane foam had also usually been a freon gas, typically CFC- 1l. Thus, both the refrigerator's refrigerant and its insulation posed environmental threats.

Substitutes

Possible substitutes for refrigerators ranged from a number of alternative food preservation techniques such as drying or canning to different storage techniques such as a cold basement or outside storage spaces in cold climates. The fact that in Western societies almost every household had at least one refrigerator indicated, however, that most of these substitutes were actually complements.

Production Process

The production of refrigerators had much in common with the production of automobiles. As in automobile production the basic steps were stamping, casting, machining, body assembly, and final assembly. Automated and flexible production systems were quite common. Many parts such as compressors, electric motors, heating elements, belts, or valves were sourced from outside suppliers and many producers, particularly in Germany where appliance makers traditionally had been characterized by low degrees of backward integration, were striving to decrease their share of in-house production. Parts of strategic importance to the performance or quality of the appliance, however, were typically developed and produced in-house.

As in the automobile industry, there was continuous upgrading of existing product lines. Every eight to ten years a new product generation was introduced. The shift to a new generation was estimated to cost some DMlOO million, including product development and retooling costs.

Buyers

Buyer Description

Refrigerators were bought by private and commercial users to be operated in both newly built or existing premises and as initial installments and replacements. Refrigerators for private use in existing homes were almost always bought as replacements, because use in most European countries as well as the United States penetration oil rates were close to 100%.

The most important purchasing criteria for domestic refrigerators in the approximate order of their importance were:

* reliability and durability, i.e. high quality (through brand name recognition),
* low price.
* low noise,
* appearance,
* low operating costs (energy consumption), and
* environmental soundness.

Other purchasing criteria were:

* ease of use and cleaning,
* prompt and efficient service.
* easy to understand instructions, as well as
* added features, such as special lights, separately accessible compartments, or glass shelves.

Still other criteria were assumed as a "given" and thus did not greatly influence the purchasing decision. These included:

* a low risk of fire,
* no odors,
* a convenient defrost system, and
* stable temperatures.

The purchasing decision for a refrigerator for private use was often made by someone other than the ultimate end user, representing a disincentive to buy energy-saving, expensive refrigerators, because the end user and not the buyer would ultimately pay the energy bills. This was often the case in countries such as the U.S. or Switzerland (but not Germany), where apartments were often leased with fully furnished kitchens and the decision of which refrigerator model to buy was made by the apartment's lessor.

Distribution was highly important and the distribution networks of the large established manufacturers could constitute almost insurmountable entry barriers for industry newcomers. Hence, large market share shifts could only be achieved through takeovers. Service networks were of less strategic importance for refrigerators than for many other appliances, such as washing machines, dryers, or dishwashers, because there were fewer mechanical parts requiring service in a refrigerator.

Distribution Channels

There was a large variety of distribution channels in the refrigerator industry, ranging from specialized appliance stores to furniture stores to department stores to discount stores to kitchen remodelers to builder-contractors to plumbing contractors. The relative importance of these channels differed considerably from country to country. Specialized appliance stores accounted for two thirds of all appliance sales in Germany and even more in Italy. In France, only one third of all appliance sales were made through specialized stores, the rest going through supermarkets and so-called hypermarkets.

Suppliers

A critical part of the refrigerator industry was the suppliers of refrigerants and blowing agents for insulating foams, which, until the mid-1980s, had been primarily CFCs. CFC production was dominated by a small number of large chemical firms with world-wide operations. In the late 1980s, during the last years of full capacity CFC-production, the American firm DuPont had been the world's largest producer of CFCs with an estimated world market share of 25%. They were followed by ICI of the U.K., Atochem of France and Allied-Signal of the U.S., each with about 10% of the world market.[3] The three leading German chemical firms, Hoechst, BASF and Bayer, also engaged in the production of CFCs, but on a much smaller scale than the firms mentioned above.

Environmental Regulation

Environmental Risks

Three different aspects of a refrigerator gave rise to environmental concern: Chlorofluorocarbons (CFCs) in the refrigerator's refrigerant and its insulation, the refrigerator energy usage, and a possible risk to the user from electro-magnetic fields (EMFs).

3. "ICI to Invest 60 M Pounds on Plants Making Alternative to CFCs." Financial Times, November 23, 1988, p. 9.

Most refrigerators made since the 1940s used as a refrigerant a chlorofluorocarbon (CFC) which had been found to damage the ozone layer. This layer was a concentration of ozone gas about 25 miles above the surface of the earth, that blocked out harmful ultraviolet light and played an important role in regulating the earth's climate. CFCs, when released into the atmosphere, slowly rise into the stratosphere, where they break down and release Chlorine. The chlorine then reacts with the naturally occurring ozone, permitting more ultraviolet radiation to reach the earth and contributing to global warming, For- CFC-based coolants there was a risk of their being released to the atmosphere accidentally during production, through damages to the cooling system during use, accidentally or on purpose during service, and, most likely. upon disposal. Until the mid- 1980s, when the problem had been recognized, refrigerator disposal had usually meant that its CFCs were simply released, although a recovery was technically feasible and, indeed, had been mandated by law in the early 1990s in many countries, including the U.S. and Germany. In addition to the CFCS outright release to the atmosphere, there was a risk posed by the refrigerator's compressor oil which usually absorbed some of the CFC, thus creating additional environmental damage upon product disposal.

In 1990, 260,000 tons of CFC were consumed worldwide as coolants or refrigerants with 207,000 tons (79.6%) used to air condition buildings and automobiles. Another 19,000 tons (7.3%) were used in refrigeration systems, mostly for domestic refrigeration (9,500 tons), followed by industrial (4,500 tons) and commercial (4,500 tons) refrigeration. The remaining 34,000 tons (13.1%) were used in heat pumps and other industrial purposes.[4] A conventional refrigerator used about 420 to 450 grams of CFCs - 120 to 150 grams in the refrigerant, the remaining 300 to 600 grams in the insulation (see below)[5]

CFCs were also contained in the refrigerator's insulation. Most refrigerators employed rigid polyurethane foams as insulation. These foams were light and fire resistant, could be used as structural building materials and had good insulation properties. Their major drawback was the blowing agent used to produce the foam, usually the chlorofluorocarbon CFC- 11. It was environmentally damaging not only

4. UNEP 1991a, cited in Cohen and Pickaver 1992, 12.

5. "Umweltrelevanz und Entsorgungspfade von Kiihl- und Gefriergertiten. Anhvort der Bundesregierung auf Kleine Anfrage." In: Umwelt No. 6/1993, p. 230.

during the production stage, but also during the refrigerator's use and its disposal. A conventional refrigerator's urethane insulation contained between 300 and 600 grams of CFC.[6] During a refrigerator's lifetime a considerable percentage of the CFC contained in the insulation was diffused and released to the environment, thereby damaging the environment and resulting in an average loss of insulation capacity of 40% after 15 years.[7]

In 1990, global consumption of CFCs for all foam applications amounted to 168,000 tons. The amount used for appliance insulation purposes was difficult to determine, but it did not exceed 106,000 tons (63 %).[8]

The environmental risk associated with the disposal of refrigerators with CFC-based refrigerants and insulation had led to recycling programs in many countries, but the actual costs of refrigerator recycling were difficult to determine. A German-designed machine for the recycling of refrigerators which allowed recovery and liquefaction of 97% of the CFCs cost DM2.5-3.0 million and had an annual capacity of 168,000 refrigerators.[9] Assuming a seven-year write-off period and a rate of recycling at full capacity, this would amount to a cost of only DM2.13-2.55 per refrigerator. To arrive at a final cost of disposal one would of course have to factor in transport and labor costs, as well as capital costs other than the recycling machine itself and any costs or benefits of final disposal.

A second environmental issue concerning refrigerators was their energy consumption, which, to the extent that the electricity used had been produced by burning fossil fuels, contributed to global warming. Refrigerators and freezers were major users of electrical energy, accounting for approximately 20% of

6. "Umweltrelevanz und Entsorgungspfade von Ktihl- und Gefriergeraten. Antwort der Bundesregierung auf Kleine Anfrage." In: Umwelt No. 6/1993, p. 230.

7. "Kampf urn Gkokuehlschrank: Greenpeace widerspricht der Kritik von Konkurrenten." Siiddeutsche Zeitung, October 29, 1992, p. WS5.

8. UNEP 1991b, cited in Cohen and Pickaver 1992, 31.

9. "Germany: Kahl-Gruppe/Berthold Wachtel Develops Plant for Recycling Refrigerators." Handelsblatt, October 4, 1991, p. 24 (Reuter Textline).

Figure 1

Environmental Regulation in Germany: Refrigerators					
Focus / Media	**Suppliers**	**Production**	**Usage**	**Service**	**Disposal**
Market Incentives					
Voluntary Agreement	Voluntary early phase-out of CFC-productlon	Voluntary CFC-phaseout, Voluntary energy efficiency standards, Voluntary energy labeling			
Eco-Labels		<u>Blue Angel Label awarded to environmentally friendly products</u>			
Disclosure Requirements	Presence of ozone-damaging CFCs to be revealed (FCKW-Halon-Verbots-Verordnung)	<u>Presence of ozone-damaging CFCs to be revealed (FCKW-Halon-Verbots-Verordnuna</u>			
Direct Regulation	CFC-ban after 1995 (Montreal Protocol, EC directive); CFC-ban after 1994 (FCKW-Halon-Verbotsverordnung)	CFC-ban after 1995 (Montreal Protocol, EC directive); CFC-ban after 1994 (FCKW-Halon-Verbotsverordnung)	CFC-ban after 1995 (Montreal Protocol. EC directive, CFC-ban after 1994 (FCKW-Halon-Verbo!sverordnung)	CFC-ban after 1995 (Montreal Protocol, EC directive); CFC-ban after 1994 (FCKW-Halon-Verbotaverordnung)	CFC-ban after 1995 (Montreal Protocol, EC directive); CFC-ban atter 1994 (FCKW-Halon-Verbotaverordnung). Abfallgesetz <u>Take-back of used refrigerators (Elektronlk-Schrott-Verordnunq. not yet enacted)</u>
Other		<u>TechnIcal products to be sold only with safety attest [Gerateslcherhelts-</u> sesetz)			

normal typeface small impact — <u>underlined medium impact</u> — **bold: large impact** the domestic electricity usage in the U.S.[10] The data was similar for Germany, where some 21.4% of the country's domestic electricity usage and some 4.5 % of its total electricity usage was for refrigerators and freezers.[11] The average British refrigerator used 1.9kWh per liter of volume, compared with commercially available models in Denmark which used 0.4kWh and models under development which used just 0.2kWh. Freezers in the U.K. used 2.4kWh per liter of volume, compared with 0.9kWh for mass-produced models already available (woods of Canada and AEG of Germany) and with just 0.4kWh in models being developed during the late 1980s (see Table 3).[12]

A final environmental concern involving not only refrigerators but any electric appliance were the electro-magnetic fields (EMFs) which they emitted. While some biological effects from EMFs had been established, such as on the pineal gland, which regulated circadian rhythms, scientific research about the dangers from EMFs was far from conclusive. In any case, its possible dangers could be reduced sharply by dividing a refrigerators electrical circuits into parallel circuits running in opposite directions which would cause the fields to cancel each other out. In 1994, EMFs were neither the subject of any environmental regulation nor the target of any innovative efforts by manufacturers.

Current Environmental Regulation

Refrigerators were the subject of a considerable amount of regulation all over the world. Most regulation concerned the production and use of CFCs, while some concerned the refrigerator's energy usage. The most important "law", however, was not a law: The "Montreal Protocol on Substances that Deplete the Ozone Layer" of 1987, amended in 1990 and 1992, was an international treaty which required the more than 75 countries that had signed it to enact regulation concerning the use and production of chlorofluoro-carbons (CFCs) and hydrochlorofluorocarbons (HCFCs), two substances which, among other uses, were employed in refrigerators. The original Montreal Protocol of 1987 had required freezing the production of CFCs at their 1986 levels, followed by progressive reductions in production. In 1990, the protocol

10. Harkness. 1992.

11. "Umweltrelevanz und Entsorgungspfade von Kiihl- und GefriergerAten. Antwort der Bundesregierung auf Kleine Afrage." In: Umwelt No. 6/1993, p. 230.

12. "The Real Problem with Fridges." The Financial Times. Power Europe. Energy Section. March 16, 1989.

was amended and the Year 2000 was set as a CFC-phaseout date. The protocol's 1992 amendment established the year 2020 as a phaseout date for HCFCs and moved the CFC-phaseout date up to 1995 (Table 6).

In Europe, the Montreal Protocol had been responded to, both, by a directive passed by the European Community, as well as by specific laws passed by the respective member countries. The European Community directive, passed in 1992 at the urging of the German government, called upon the member countries to ban production and consumption of CFCs by the end of 1995. The specific German law was the FCKW-Halon-Verbots-Verordnung (CFC-Halon-Prohibition-Decree).[13] It had already been enacted in 1991, but had set an even stricter deadline than both the EC directive and the 1992 Montreal Protocol amendments. After 1994. it was prohibited in Germany to use or produce CFCs, to import or produce appliances containing CFCS, to release CFCs to the environment (making recycling of old refrigerators mandatory). The law made Germany the world's first country to have completely phased out CFCs and firmly established Germany as a first-mover with respect to CFCs.

The FCKW-Halon-Verbots-Verordnung was accompanied in Germany by several voluntary agreements. On May 30. 1990. German producers of CFCs had signed a voluntary, but binding agreement with the German minister of the environment that required them to cease producing as well as take back and recycle the substances mentioned in the Montreal Protocol by the end of 1995. The FCKW-Halon-Verbots-Verordnung, which was subsequently drafted, specifically took this agreement into account.[14] This first voluntary agreement was followed on July 15, 1992 by a "voluntary binding announcement" by the six German producers of refrigerators who pledged to have converted 10% of their production to CFC-free technologies by the end of 1993. On April 22, 1993 they submitted another binding announcement to the German Ministry of the Environment and pledged to have converted not 10%, but

13. Bundesgesetzblatt 1991.

14. "FCKW-Ausstiegskonzept endgultig beschlossen. Umwelt Nr. 611991.

75% of their production by the end of 1993, and to completely exit CFC-technologies by mid-1994 in their both their domestic and their foreign plants.[15]

In most countries, refrigerators were also the subject of safety regulations which impacted upon a manufacturer's choice of cooling technologies, refrigerants, etc. The respective law in Germany was the Geratesicherheitsgesetz which decreed that technical products could only be sold if they did not endanger the life or health of their user or other third persons. Unlike safety regulation in many other countries, the German Geratesicherheitsgesetz did not prescribe specific technologies which could or could not be used, relying instead on a certification system under which products could only be sold after a prototype had received a so-called Sicherheitszeichen-Genehmigungs-Ausweis (safety mark award certificate) from an independent, government-acknowledged (but not government-owned) testing agency.[16] In early 1994 a European Community directive on refrigerator safety had not yet been enacted, but the draft of the EN 378 European Refrigeration Standard was said to be modelled closely after the German law.[17]

Particularly in Northern Europe, refrigerator disposal was also frequently regulated. In Germany, the FCKW-Halon-Verbotsverordnung (see above) the Abfallgesetz (waste law), a law dealing with waste disposal in general, as well as the Altdlverordnung (waste oil decree), a decree dealing with waste oils including refrigerator compressor oil, already had some influence on refrigerator disposal. There was not yet, however, a law dealing specifically with refrigerators or appliances. The German Elektronik-schrottverordnung (electronic waste decree) was intended to address this issue.[18] Originally intended for enactment by January 1994, but subsequently delayed for at least one year, this much debated law was to require all manufacturers and importers of electric and electronic appliances to take them back after their useful life and recycle them.

15. "Deutsche Hersteller versprechen fir Mitte 1994: Deutsche Kiihlschranke ohne FCKW." Stiddeutsche Zeitung, April 23, 1993.

16. TUV Product Service, 1992.

17. Greenpeace: Glitscher, W. Personal communication to the author

18. Bundesminister fiir Umwelt, Naturschutz und Reaktorsicherheit, 1992.

Many Countries including the United States, also regulated a refrigerator's energy consumption. In Germany, there was no specific regulation concerning energy consumption, but a voluntary program for energy efficiency targets for white goods combined with energy labelling. This program had been established at the urging Of the government with efficiency improvement targets ranging from 3-5% for electric cookers, 7-10% for washing machines, 10-15 % for dishwashers and 15-20% for refrigerators and freezers. All targets had subsequently been exceeded by a wide margin.[19]

Besides outright regulation and voluntary agreements, German refrigerator makers also had to decide on whether to adhere to the requirements of the German Blue Angel label. This was Europe's first and oldest eco-label which only products meeting specific environmental requirements were allowed to carry. The Blue Angel, introduced by the German government in 1977, was supported but not controlled by the government and had considerable impact on purchasing decisions. It was awarded by the so-called Jury Umweltzeichen (environmental labelling jury) comprised of representatives from industry, environmental protection organizations, consumer associations, trade unions, the press, governmental advisory bodies, and the states. For a refrigerator to qualify for the label, it had to employ CFC-free coolants and insulation materials. be energy efficient, and provide information on proper disposal practices.[20]

Focus of Regulation

In most countries regulation affecting refrigerators focused on the product and its disposal, to some extent also on the production process and on product maintenance. Legislation concerning product use was not existent.

Type of Regulation

Most regulation concerning refrigerators took the form of outright command-and-control regulation or performance standards. In addition, and this was particularly true for Germany, voluntary agreements

19. "Energy Efficiency Signals from Brussels." Financial Times, October 16. 1991, Survey Section, p. V.

20. "First Refrigerator to Bear 'Blue Angel': Environmentally Friendly Symbol Introduced". BNA International Environment Daily, April 1 1993.

or announcements as well as labelling schemes were important. There was no refrigerator regulation taking the form of market incentives in Germany.

COMPETITION

Germany

Competitiveness Overview

With a 1990 production volume of 5.042 million refrigerators and freezers, representing a world production share of 11.1 %, Germany was the world's third largest unit producer of domestic refrigerators and freezer, behind the United States and Japan. It was followed by China, Italy, South Korea, Brazil and the United Kingdom (Table 1). Data to show comparative refrigerator production by value was unavailable, but it would have shown Germany as the world's second-largest or even largest producer of refrigerators, for the country's refrigerator industry focused on the high end of the market, leading to much higher unit values than those in competing countries.

ln most countries the refrigerator industry was oriented primarily towards its own domestic market. The German refrigerator industry, however, was export oriented. With a 1990 world export share of 13.4%, West Germany was the second largest exporter of domestic refrigerators and freezers. West Germany was surpassed only by Italy which accounted for 28.7% of the world's exports of refrigerators and freezers, but followed by the United States. With $394.9 million, Germany ran the world's second highest trade balance for refrigerators in 1990 (Table 2).

Leading Firms

The German domestic refrigerator industry consisted of six firms: Five were located in West Germany, while the sixth was based in the East German state of Saxony. The largest producer was Bosch-Siemens Hausgerite (BSHG) with a 1991 refrigerator and freezer production of 2.3 million units. Headquartered in the Bavarian town of Munich, BSHG was owned 50% by Siemens and 50% by Bosch, two leading German producers of electric and electronic goods. The firm distributed its products separately through Siemens Elektrogerate of Munich and Bosch-Hausgerate of Stuttgart under the Siemens and Bosch names, respectively, as well as under the Constructa-Neff name. Besides refrigerators and freezers, the firm's product range covered washing machines, dryers, dishwashers, heating appliances, water heating appliances, vacuum cleaners and other small domestic appliances, drink-dispensing machines, air conditioners, as well as TV, video, hi-fi and portable audio equipment. In 1992, BSHG had 23,600 employees and total sales of DM7.0 billion for an operating income of DM270 million. 55.3% of the firm's sales were achieved within Germany, the remaining 44.7% abroad. In 1993, BSHG had expanded its refrigerator plant in Giengen in South Germany to an annual production capacity of 2 million units, making it the world's largest production facility for refrigerators.[21] Like its other German competitors, Bosch-Siemens competed primarily on the European markets. To extend its reach into the American market Bosch-Siemens had begun in 1992 to cooperate with Maytag from the U.S.[22]

An estimated annual production of 1.2 million refrigerators made Liebherr-Hausgerate, based in Ochsenhausen in South Germany, the second largest producer of refrigerators in Germany. Liebherr was the German market leader, accounting for more than 30 % of the German market for freezers and 23 % of the German refrigerator sales.[23] Unlike its German competitors, who all produced a full line of domestic appliances, Liebherr concentrated on refrigerators and freezers. In 1991, Liebherr-Hausgerlte had sales of DM727 million and 2,100 employees.

AEG Hausgerate of Nuremberg was the second largest appliance maker in Germany and, with an estimated annual production of 600,000 units, thought to be Germany's third largest producer of refrigerators. AEG Hausgerate was a subsidiary of the large German electrical and electronics goods company AEG which in turn was owned by the largest German corporation, the luxury-car-maker Daimler-Benz. In 1992, AEG Hausgerate had some 10.000 employees, sales of DM2.66 billion, and a net income of DM60 million Its chief operating subsidiaries included AEG Telefunken Hausgerate, Duofrost Kiihl- und Gefriergerate and Rondo Hausgerate. Refrigerators and freezers were built at a plant in Kassel. AEG was not as shy as its other German competitors in cooperating with other firms or sourcing from competitors. It bought lower-priced refrigerators from Merloni of Italy, and was also thought to have acquired refrigerators from Foron Hausgerate, formerly dkk Scharfenstein. During the late 1960s and early 1970s AEG Hausgertite had followed an expansion-by-acquisition strategy and

21. "In Giengen entsteht die weltgrbt3te Uihlschrank-Fabrik." Stiddeutsche Zeitung, September 7, 1993, set: Wirtschaft.

22. "Bei Haushaltsgersten rollt die ijko-Welle." Siiddeutsche Zeitung, May 21, 1993.

23. "First Refrigerator to Bear 'Blue Angel': Environmentally Friendly Symbol Introduced". BNA International Environment Daily, April 1, 1993.

acquired the German producer of built-in kitchens Alno, the German domestic-appliance-makers Neff, Zanker and Kuppersbusch, the household goods side of Linde, three-quarters of a Brown Boverie subsidiary, and a 20 % minority share of Zanussi of Italy, then the largest European producer of domestic appliances. AEG subsequently failed to consolidate its takeovers and had to divest Alno, Neff and the minority share in Zanussi, as well as close the ultra-modem freezer plant it had acquired from Linde. After severe financial difficulties AEG in 1983 applied under the German Vergleich scheme for court protection from its creditors. It was subsequently acquired by Daimler-Benz which failed to consolidate it into its own line of businesses (automobiles and aircraft). In 1992 Swedish Electrolux acquired 10% of AEG Hausgerate's capital and in late 1993 announced its intention to acquire the remaining 90% in a transaction estimated to be worth DM1 billion.[24]

Bauknecht was located in Stuttgart, the capital of the South German state of Baden-Wurttemberg. Bauhecht had 1990 sales of DMl .17 billion, of which DM292 million were attributable to its cooling freezing-division. Its net profit amounted to DM11.2 million. With DM1.6 billion, Bauknecht's sales had been substantially higher in 1981. Bauknecht had been family-owned until 1982, when as a result of mismanagement and wrong product-positioning, it had run into financial difficulties and sought court protection from its creditors. Bauknecht was subsequently bailed out by the home appliance division of the Dutch electrical goods giant Philips, which, in turn, had been sold to Whirlpool of the United States in 1987.

Miele of Gutersloh between the North German cities of Hannover and Cologne was often nicknamed the "Mercedes" of the appliance business, because of its concentration on the production of luxury, high-quality, high-price units. Miele was the only family-owned appliance maker in Germany. In 1989, Miele's turnover was DM2.6 billion. More than 80% of it was accounted for by household appliances, primarily washing machines, tumble-dryers and dishwashers, and to a lesser extent refrigerators. Foreign sales accounted for 56% of turnover; nevertheless, Western Europe generated 97% of the group's turnover, with EC countries accounting for more than 80%. In 1990, Miele employed 14,400 employees of whom some 60% were based in Germany. Like most of its competitors, Miele attributed part of its

24. "Demontage des Elektrokonzems AEG." Neue Ztircher Zenung. December 12, 1993, no. 287. p. 30.

growth to acquisitions, having acquired the German appliance producers Cordes and Imperial in 1986 and 1989, respectively.

The sixth German producer of refrigerators was Foron, formerly dkk Scharfenstein. Based in the Saxonian town of Scharfenstein in the former German Democratic Republic, Foron was much smaller than its West German competitors. Due to its successful introduction of the first truly environmentally friendly refrigerator to the German market in 1992, however, Foron had made a major impact on the German refrigerator industry and was generally acknowledged as a most important innovator (see below), In 1993, Foron had 670 employees and sales of DM200 million for an unspecified net loss. For 1994 the firm expected sales to increase to DM250 million and to post a profit for the first time since its privatization in late 1992.[25]

An important force in the German white goods market besides the manufacturers themselves was the mail order company Quelle. Quelle did not engage in actual production but bought OEM appliances from other producers, primarily from Zanussi in Italy, but also from an Electrolux plant in the United Kingdom, from AEG, as well as from Foron. Quelle was thought to have a German market share of 10%, mainly in the lower to medium price segment.

The United States

Competitiveness Overview

The United States was the world's largest producer of refrigerators. In 1990, 7.8 million refrigerators and freezers were produced in the U.S., translating into an approximate world production share of 17.3 % (Table 1). The U.S. were also a significant exporter of refrigerators and freezers and accounted for a world export share of 10.7 % and a trade surplus of $157.1 million (Table 2). The U.S. domestic appliance industry was dominated by five firms who accounted for 96% of the U.S. market. Despite industry complaints about sharp competition, excess capacity and pressure on margins, the Federal Trade

25. "Foron macht mit dem oko-Ktihlschrank Furore. " Siiddeutsche Zeitung. July 26, 1993.

Commission 1991 was believed to be examining possible price-fixing by the five large appliance makers[26]

Leading Firms

The leading U.S. refrigerator producer was General Electric with a 1990 domestic market share of 35.0%, followed by Whirlpool with 23.0%) White Consolidated (Electrolux) with 18.0%, Maytag (13.0%), and Raytheon (7.0%).[27]

General Electric Appliances was a subsidiary of GE, the leading American electric and electronics goods multinational. Headquartered in Louisville, Kentucky, GE Appliances produced refrigerators at its large Appliance Park plant in Louisville, as well as in Bloomington, Indiana, and in Decatur, Alabama. General Electric was part of a European alliance of appliance makers, that included Thomson Electromenager of France, GEC of the United Kingdom, Fagor, the leading Spanish white goods group, and the Italian producer Ocean.[28] In 1992, GE Appliances had sales of $5.7 billion for an operating profit of $467 million.

Whirlpool Corp. was the world's leading manufacturer and marketer of major home appliances and the United States' second largest refrigerator maker. Headquartered in Benton Harbor, the company manufactured in 12 countries and marketed products under 10 major brand names in more than 120 countries. Most of Whirlpool's refrigeration production was concentrated in Evansville, Indiana. In 1991, Whirlpool had completed the acquisition of the appliance division of the major Dutch electronics goods producer Philips, giving it, among others, control of the German appliance maker Bauknecht. In 1990, 63 % of sales and 79% of profits were sourced from North America. Home appliances accounted for 97% of total turnover in the same year. Turnover for 1990 was $ 6.6 billion, up 5.3% from 1989, for a net income of $72 million, down from $187 million in 1989.

26. Tait, N. and van de Krol, 1991.

27. Investext, March 18, 1991. Cited in: Gale Market Share Reporter 2nd Edition 1992.

28. Dawkins, 1992.

The third largest producer of refrigerators in the U.S. was White Consolidated, a subsidiary of the Swedish appliance maker Electrolux since 1985/86. Headquartered in Cleveland, Ohio, White produced a large range of appliances but was particularly strong in the U.S. refrigeration and cooker markets. The firm sold its refrigerators under the brand names of, among others, Frigidaire, Kelvinator, Tappan, and Eureka.

Maytag, headquartered in Newton, Iowa, was the fourth largest appliance manufacturer in the U.S. It sold refrigerators under the Jenn-Air brand name and, since 1989, under the Maytag name. After a $23 million operating loss showing in its European markets in 1990, Maytag had consolidated its European operations and entered into an alliance with Bosch-Siemens Hausgerate in hopes of improving its European market share. In 1990, Maytag had sales of $3 billion, for a profit of $99 million.

The Raytheon Appliance Group was the U.S. ' fifth-largest seller of refrigerators, which were sold under the Amana name. The group was a division of Raytheon, based in Lexington, Massachusetts, a producer of military weaponry systems, civil aircraft, appliances, and environmental services. In 1992, the Appliance Group had sales of $1.1 billion for an operating income of $34 million.

Distinctive Environmental Regulation in the United States

Like every developed country, the U.S. had signed the Montreal Protocol, which initially required them to ban CFCs at the latest by the year 2000, then by 1995. The Montreal Protocol had been responded to in the U.S. by provisions in the Clean Air Act Amendments of 1990 requiring the phaseout of CFCs by 2000. In 1992. in a presidential order issued by then-President Bush that anticipated the 1992 Montreal protocol amendments by a few months, the deadline had been moved up to the end of 1995.

Besides outright regulation of CFCs, the U.S. had also introduced some innovative market incentives to speed up the phaseout. Federal excise taxes had been imposed on ozonedepleting chemicals and on imported products containing or manufactured with these chemicals. The taxes on CFC-11 and CFC-12, both used in refrigerator manufacturing, were at $1.37 per pound in 1991. In 1992 they rose to $1.67

per pound, and reached $3.35 by early 1993, making CFCs more expensive than their newly developed replacement refrigerant HFC-134a.[29]

Refrigerator energy usage was regulated in the U.S. by law. Authorized by the National Appliance Energy conservation Act (NAECA) of 1987, the U.S. Department of Energy (DOE) in 1990 had issued strict refrigerator energy standards which had to be met for 1993 production. On average, these standards required a 25-30 % additional efficiency increase over the Act's 1990 requirements and possible further efficiency increases for 1998.[30] Specifically, a 18ft^3 top-mount refrigerator manufactured in the U.S. in 1990 could consume between 750 and 860kWh/year, while a refrigerator of the same size manufactured in 1993 was required to consume only 689kWh/year.[31] A further increase in U.S. energy standards was expected for 1998.

In addition to energy efficiency regulation, there was also regulation requiring manufacturers to disclose their product's energy efficiency. As a result of the U.S. Energy and Policy Conservation Act of 1975, the Federal Trade Commission required since 1979 efficiency labels for seven appliance categories including refrigerators.

A distinct feature of the United States was the amount of conservation and load management services that utilities offered to their customers. By 1990, more than 500 utilities had offered over 1,000 "demand-side management" (DSM) programs, many in the form of rebates to customers who bought new energy efficient appliances or discarded old ones.[32] The best-known of these DSM-programs was the Super Efficient Refrigerator Program (SERP). a $30-million contest to develop an energy efficient, CFC-free refrigerator (see below). DSM-programs were a result of the fact that it could be more profitable for a utility to sell less rather than more energy due to the increased cost and difficulties of locating new power

29. "Household Consumer Durables; Household Appliances." U.S. Industrial Outlook, Chapter 37, January 1992." DuPont's CFC-Phaseout Ahead of Schedule." The Weekly Home Furnishings Newspaper, March 15, 1993, vol. 67, no. 11, p. 124.

30. Waidron 1992, I

31. EPA February 1992, p. 6.

32. EPA February 1992, p. 102.

plants to produce more energy. The increase in DSM programs was also a result of new or stricter environmental regulations that made it more attractive to shut down old, high-emission power plants rather than rebuilding them, as well as pressure from environmentally concerned customers and pressure groups. By promoting a change towards more energy efficient appliances and signaling to producers that there was a market for energy efficient appliances, DSM-programs were a possible means of fostering innovation in the refrigerator industry.

Unlike the case in most northern European countries, appliance disposal was not yet considered an environmental problem in the United States. Even though the country was running out of landfill space, there was not yet federal legislation requiring the take-back or recycling of disposed appliances.

Responses to Environmental Regulation in the U.S.

Characteristic of the American refrigerator industry was the fierce competition over marketing, distribution and sales combined with a lack of competition over product features, technology or environmental safety. When it was required to develop new technological alternatives to CFC-based refrigerants and insulations, the U.S. refrigerator industry, which, like most of its international competition, had not engaged in any real product innovation since the 1950s, was very slow to respond. In 1994, most American refrigerators were focusing on the same technology: HFC-134a as refrigerants and some type of HCFC (which was to be phased out by 2020 under the Montreal Protocol) as blowing agent for the insulation foam.

Japan

With a production of 5.048 million refrigerators and freezers in 1990, representing a world production share of 11.1% , Japan was the world's second largest producer country (Table 1). However, most of the production was aimed towards the domestic Japanese market. Japanese domestic appliance makers were uncompetitive internationally. Japanese refrigerators and freezers accounted for only a 3.2% world export share in 1990 (Table 2). There were ten large producers of refrigerators in Japan, including Matsushita Electric Industrial Company, Toshiba, Hitachi, Sanio, and Sharp.

Like all signatory countries of the Montreal Protocol, Japanese firms were required to have phased out the use of CFCs after 1995 and the use of HCFCs after 2020. The Japanese law regulating the CFC-phaseout was the "Law concerning the Protection of the Ozone Layer through the Regulation of Specified Substances and Other Measures" which had first come into effect on July 1, 1989.[33] As was the case in the United States, Japanese regulation concerning CFCs was as strict as it was in Germany, nor did Japanese phaseout deadlines anticipate those of the Montreal Protocol, as was the case in Germany, and, to a much lesser extent, in the U.S.

Japanese firms were not a driving force in the global search for CFC-replacements. Instead they continued to invest heavily in environmentally harmful coolants and insulation and were reluctant to begin early conversion of production lines to new products. In February 1992, for instance, the same month that the major German refrigerator producers announced they would all market truly environmentally friendly non-CFC, non-HCFC, and non-HFC refrigerators, Japanese companies were still at the research stage and announced a three-to-six-year, $5 million joint-study of the safety of HFC-32 for use in aerosols and refrigerators.[34]

Production of the first CFC-free refrigerators in Japan only started in early 1993 and sales began in October of 1993. Initially announced in August 1992 as being up to 40% more expensive,[35] an estimate which by August 1993 was lowered to l0-15% ,36 the new Japanese refrigerators did not employ any innovative technologies, relying instead on HFC-134a as refrigerants and HCFC-141b and HCFC-22, two substances to be phased out under the Montreal Protocol after 2020, as insulation blowing agents. In international comparison, Japanese refrigerators were very expensive and price-uncompetitive. A typical

33. Masuda, 1991.

34. "Japanese Companies Announce Project to Test CFC Substitute." Agence France Presse, February 4, 1992.

35. "Electric Appliance Makers to Produce CFC-Free Refrigerators, Starting in 1993." The Bureau of National Affairs, International Environment Reporter Current Report Japan. August 12, 1992, vol. 15, no. 16, p. 522.

36. "Ten Manufacturers to Begin Sales of CFC-Free Refrigerators in October." The Bureau of National Affairs. International Environment Reporter Current Report Japan. August 25, 1993, vol. 16, no. 17, p. 622.

350-liter, CFC-free refrigerator cost $1,500-2,000 - about three times the price of U .S .-made products.[37]

The slow speed of innovation and the fact that German firms were innovating faster and had chosen a direction that could be more promising, was even acknowledged by the Japan Electrical Manufacturers' Association, whose head of planning in early 1993 stated that Japanese manufacturers should ignore the German development as long as it had only been in the hands of a small east German company. Now, that Bosch-Siemens and the other big German producers had also adopted the new technology it was perceived as a threat in Japan, but: "Japan has chosen to go the road of HFCs and HCFCs, so things can't be changed so quickly. "[38]

Italy

With an estimated world production share of 9.0%) Italy was the fifth largest producer of refrigerators and freezers in the world (Table 1). The Italian refrigerator industry was very export intensive and had been for many years the world's leading exporter of refrigerators and freezer. In 1990, Italian firms accounted for 28.7% of the world's exports of refrigerators and freezers and a trade surplus of $964 million, almost 2.5 times higher than that of Germany, whose refrigerator makers accounted the world's second highest trade surplus (Table 2). Unlike their German competitors which concentrated on the high end of the market, Italian producers of refrigerators focused more on the medium-price segment of the market. The leading Italian firms were Zanussi. a subsidiary of the Swedish domestic appliances giant Electrolux, Merloni Elettrodomestici, Candy, and Ocean. In recent decades Italian firms had expanded considerably by acquiring domestic as well as foreign firms. Thus Merloni had bought Colston of the United Kingdom in 1979, Indesit of Italy in 1987, the fitted kitchen specialist Scholtts of France in 1989, and Fundicao de Oeiras of Portugal of 1989. Likewise, Candy had bought Rosieres of France 1987, the European operations of Kelvinator in 1981, Zerowatt of Italy in 1985, and Gasfire of Italy in 1986, while Ocean had bought the Italian firm San Giorgio in 1984.

37. "Ten Manufacturers to Begin Sales of CFC-Free Refrigerators in October." The Bureau of National Affairs, International Environment Repotter Current Report Japan. August 25, 1993, vol. 16, no. 17, p. 622.

38. "Germans Beat Japanese in Making CFC-Free Refrigerators. " Kyodo News Service, Japan Economic Newswire, February 27, 1993.

There was no regulation in Italy, concerning refrigerators, that was distinctively different from European standards. Italian firms were not renowned for seeking innovative solutions to address the CFC-problem.

Sweden

Sweden accounted for Only 3.3 % of the world's exports of refrigerators and freezers in 1990. The country was not renowned for the competitiveness of its indigenous refrigerator industry, but only for the fact that it was home 10 Electrolux, the largest European producer of appliances. Electrolux was a conglomerate of about 500 firms, of which about half were in Sweden. Overall the group has a presence in 48 countries. Its main areas of interest were large household appliances, vacuum cleaners, sewing machines, and home electronics. Beginning in the 1970s Electrolux had followed a very aggressive acquisition strategy. Among Electrolux' acquisitions had been Arthur Martin (France, 1976), Therma (Switzerland, 1977), Zanussi (Italy, 1984), Ibelsa-Zanussi (Spain, 1984), Zanker (Germany, 1985), White Consolidated (USA, 1986), Thorn-EM1 Appliances (United Kingdom, 1987), Corbero (Spain, l988), Domar (Spain, 1988), Buderus Juno (Germany, 1989), and AEG Hausgerate (Germany, 1994). These acquisitions had allowed Electrolux to increase its European market share from 8% in 1980 to 22% in 1988.[39]

Electrolux manufactured refrigerators and freezers in Italy, Sweden, Finland and Spain with the largest refrigerator plant being the Arthur Martin Company in France, which marketed its products under the Arthur Martin and Faure brand names. In 1990, Electrolux had sales of SEK82.4 billion ($14.64 billion) for a net income of only SEK741 million ($131.6 million).

Environmental regulation concerning refrigerators was stricter in Sweden than in many other countries. In 1992, for instance, Sweden had proposed an immediate ban on all products containing CFCs, HCFCs and other ozone-harming products where alternatives existed. This went beyond the then 1997 CFC

39. Serafin 1991. 119

phase-out agreed by the EC, and Sweden, which had applied to join the EC, was warned by the EC that the move would be a barrier to trade because it would rule out the export of refrigerators and other products which used ozone-depleting substances.[40]

Sweden had had its own form of the Super Efficient Refrigerator Program (SERP) two years before the American program (see below) had been launched. In 1990, the Swedish energy authority ran a competition for an efficient, environmentally-friendly refrigerator which did not damage the earth's ozone layer. Five companies took part and the first prize, an order for 500 refrigerators, had gone to Electrolux for a system which used HCFC-123 instead of CFC-11 as a polyurethane foam insulation blowing agent (which still had the potential to damage the ozone layer and contribute to global warming), used 30% less electricity and cost 30% more.[41]

40. "EC 'trying to stop Sweden from barring all CFCs'". The Daily Telegraph September 19, 1992, p. 10.

41. "Sweden: Electrolux Produce an Environmentally Friendly Refrigerator." Reuter Textline: Dagens Industri, August 21, 1990, p. 7, 14.

By 1994, a number of different technologies that addressed the environmental problem posed by refrigerators had been developed or were under consideration. There were several new refrigerants, new cooling methods, new blowing agents for insulations, and new insulation methods. Methods to improve energy efficiency had been devised and concepts to address the disposal problem were being discussed. Judging the competitive implications of these technologies required not only assessments of their effects on product and production costs, but also had to take into account their environmental friendliness, energy efficiency, safety, and effect on utility.

Refrigerants and Cooling Methods

HFC-134a

The most commonly cited technological solution to the environmental threat posed by CFCs in refrigerants was their replacement with hydrofluorocarbons (HFCs). Particularly, the hydrofluorocarbon HFC-134a was the primary focus of development efforts for refrigerator makers all over the world with the exception of Germany, where refrigerator makers had changed their focus from HFCs to hydrocarbon (see below). HFCs had been developed soon after the ban on CFCs had been announced by the major CFC-producers who had poured hundreds of millions of dollars into their development and production facilities (see below) and praised them as environmentally friendly, safe, and energy- and cost-efficient replacements (Table 4).

However, by early 1994 it appeared as if HFCs were neither as environmentally friendly, nor as safe, nor as energy efficient, nor as cost-efficient as their producers asserted. Unlike CFCs, HFCs did indeed pose no threat to the earth's ozone layer as their so-called ozone depletion potential (ODP) was zero. They were, however, powerful global warming gases. One kilogram of HFC-134a had the global warming potential (GWP) of 1.2 to 3.2 tons of CO_2 - the world's major greenhouse gas. The global warming potential of the worldwide production of about 200,000 tons of HFC-134a predicted by the chemical industry, equalled roughly that of all CO_2 emissions of an industrialized nation the size of

France or England.[42] While there was not yet any legally binding agreement to reduce or stop further growth of emissions of gases contributing to global warming, there was a definitive likelihood of such an agreement to be signed in the future. The United Nations Convention on Climate Change which had been drafted during the Earth Summit on Environment and Development in Rio de Janeiro in 1992, did not yet contain binding limits, but was due to be revised, possibly as early as late 1994. Should the Parties to the Climate Convention decide to limit the use of HFCs or even ban them, those refrigerant producers and refrigerator makers who had placed all their development efforts on HFCs would once again have to develop new refrigerants.

HFC-134a was not a cheap CFC-substitute. Its production process - basically a two-stage process which required the production of CFC and its subsequent dechlorination into HFC - made it inherently more expensive than CFC, because there was always one additional production step. In 1992, and in the absence of taxes on CFCs, as was the case in Germany, HFC-134a was ten times as expensive as CFC-12: DM50/kg for HFC-134a compared to DM5/kg for CFC-12.[43] Other sources estimated a price differential of five times.[44] Given the small amount of refrigerant needed, 80 grams and an average refrigerator price of DM500, the higher price of HFCs did not pose a major problem, for it translated into a very small price increase of only DM1.80-3.60 or 0.35-0.7%.

However, HFC-134a was not an easy drop-in replacement for CFCs, as was sometimes asserted. It required modified compressors and synthetic compressor oils which were ten times more expensive than conventional oils for use with CFC-based refrigerants (DM15-30/kg).[45] In fact, the British HFC-134a producer ICI estimated the cost of converting existing cooling equipment in Europe alone to be around DM100 billion.[46]

42. Greenpeace. Greenfreeze: The World’s first CFC- and HFC-free Refrigerators. N. p.. n. y.

43. Schwarz and Leisewitz, 1992, 31.

44. “ICI to Invest 60 M Pounds on Plants Making Alternative to CFCs.” Financial Times, November 23, 1988, p. 9.

45. Schwarz and Leisewitz, 1992, 32.

46. Europa Chemie no. 23, 1992, p. 2. Cited in: Schwarz and Leisewitz, 1992. 3.

The final impact on a refrigerator's cost was difficult to judge, because manufacturers did not release the necessary numbers. In early 1994, CFC-free refrigerators on average cost some 6-8% more in Germany, regardless of the chosen refrigerant (HFC or hydrocarbon) and insulation method (blown with HCFCs or hydrocarbons, see below) .[47] In a Price-sensitive market these price increases could be considered significant. They were, however, much lower than some initial predictions which had estimated the conversion to result in 40% price increases in Japan.[48] and 30% in Sweden.[49]

Hydrocarbons

Instead of HFCs, CFC-based refrigerants could also be substituted by hydrocarbons, usually isobutanes or a mix of propane and butane. Hydrocarbon-based refrigerants were first introduced in Germany in the early 1990s, but they were far from being a new technology. Until the 1920s, propane-based refrigerants had been used in many refrigerators. Only with the development of CFCs which were not flammable and thus could not explode had hydrocarbon-based refrigerants become forgotten. By early 1994, they had become the technology of choice, because they represented the environmentally safest solution. Hydrocarbons had no ozone depletion potential, and, unlike the case of HFCs, only a negligible global warming potential (Table 4). Thus. there was no danger of hydrocarbon-based refrigerants being banned in the near future, a scenario that was possible with HFCs.

Hydrocarbons were flammable and thus posed a risk of explosion during refrigerator production as well as during usage. A common consensus was that the risk of explosion during production could be well controlled, although this required adding very expensive safety equipment. Initially, the situation had not been clear with respect to the refrigerator's safety during its usage. For many months after the first announcement of hydrocarbon-based refrigerants, opponents had maintained that they presented an uncontrollable danger of explosion. These voices were subdued in December 1992 when the official

47. "First Refrigerator to Bear 'Blue Angel': Environmentally Friendly Symbol Introduced". BNA International Environment Daily, April 1, 1993.

48. "Electric Appliance Makers to Produce CFC-Free Refrigerators, Starting in 1993." The Bureau of National Affairs, International Environment Reporter Current Report Japan. August 12, 1992, vol. 15, no. 16, p. 522.

49 "Sweden: Electrolux Produce an Environmentally Friendly Refrigerator." Reuter Textline: Dagens Industri, August 21, 1990, p. 7, 14.

German safety testing agency, the Technischer Uberwachungsverein awarded its seal of approval to the first German refrigerator using a hydrocarbon-based refrigerant. By 1994, there was a common consensus in Europe that hydrocarbons using modem sealing technologies were a safe technology for refrigerators. In fact, the new EN 378 European Refrigeration Standard was expected to permit without restrictions up to one kilogram of inflammable refrigerants like hydrocarbons in small hermetically sealed refrigerators, although only 20 grams were required for a household refrigerator.[50]

Like HFCs, hydrocarbon-based refrigerants used as a “drop-in” replacement for CFCs in a conventional refrigerator were less energy efficient than CFCs. Research demonstrated, however, that theoretically hydrocarbons were energetically more efficient than CFCs and HFCs.[51] The theory proved to be right, when German firms managed to improve the energy efficiency of hydrocarbon-based refrigerators from an initial disadvantage of 12% to an equal match with CFC-based refrigerators.[52]

An initial drawback of hydrocarbon refrigerants had been the fact that they could only be used for cooling down to one temperature, preventing manufacturers from offering refrigerators with freezer compartments. The first hydrocarbon-based refrigerator in Germany, for instance, had no freezer compartment. By 1994, however, technological advances, particularly a switch away from the initial propane/butane mix towards isobutanes, allowed to offer combine refrigerator/freezers with hydrocarbon coolants.[53]

Hydrocarbon-based refrigerants were less expensive than HFCs. Unlike HFCs which were produced only by a limited number of multinational chemical firms, propane or butane could be obtained almost anywhere on the world and it was cheap, DM6-7/kg, compared to DM5O/kg for HFC-134a.[54] Even

50. Greenpeace. Greenfreeze: The World’s first CFC- and HFC-free Refrigerators. N. p.. n. y.

51. See, for instance, Diihlinger, 1991.

52. Greenpeace. Der Kiihlschrank-Krimi. Short Chronology of the dkk ScharfenstetiForon events. No place, no year.

53. Liebherr-Hausgertite GmbH: Futterer, B., Kaufm&nischer GeschPfisfiihrer. Personal communication to the author.

54. Schwarz and Leisewitz, 1992, 31.

compared to CFC-12 which cost less than DM5/kg it had a price advantage, because the required amount of propane/butane was less than 50% of the required amount of CFC-12. Other economical advantages of hydrocarbons were that they could be used with ordinary mineral oil instead of costly synthetic oils as was necessary with HFCS. Hydrocarbons could even be retrofitted in existing CFC appliances. And disposal of hydrocarbon-based refrigerators promised to be less costly, because the propane, butane, or isobutane could simply be burned in the end and did not have to be vacuum-pumped out and recycled.

Other Coolants

Besides HFCs and hydrocarbons, other environmentally benign coolants were being researched for their practical and commercial feasibility in the early 1990s. Discussed most often were ammonia-based coolants, which were energetically more efficient than CFCs and were particularly appropriate for achieving very low temperatures. For this reason, ammonia-based systems were primarily used in large scale commercial refrigeration applications.

Other Cooling Technologies

Manufacturers also researched alternative cooling techniques, that were altogether different from the predominant vapor-compression principle. However, none of these techniques was at a development stage that would allow it to be used commercially within the next future.

One alternative cooling technology was based on the Stirling motor. Still in the early development stage (although Stirling motors had been researched for decades), they were expected to cost about 20% more than existing domestic refrigerators, but be very safe since they were operated with helium, posed no risk whatsoever to the ‘environment, and were predicted to be 80% more efficient than conventional vapor compression machines. Another technology had been proposed by researchers from California. Their system used very high energy sound waves which caused inert gases to oscillate so they could cool their surroundings. [55]

55 Price. 1990.

Foam Blowing Agents and Insulation Methods

HCFCs

Similar to the debate over CFC-substitutes - HFCs or hydrocarbons - was the debate over alternative blowing agents for refrigerator insulations. Most refrigerator makers in the world were trying to meet the 1995 deadline for a CFC-phaseout by converting to blowing agents on the basis of hydrochlorofluorocarbon, usually HCFC-22, HCFC- 141 b, HCFC- 142b or HCFC-22/142b blends, However, these blowing agents could at best only be a stop-gap measure for they had to be phased out by 2020 according to the Montreal Protocol.

HCFCs had a much smaller ozone depletion potential than CFCs, somewhere between 2 and 11%. However, this measure ignored their short- to medium-term impact, as it was usually calculated over 500 years. HCFCs disintegrated much faster in the atmosphere and thus had a much larger effect on a short term basis. As a result, HCFCs produced in the 1990s were expected to hit the ozone layer precisely during the period of highest risk of extraordinary ozone loss, at a time when it was most sensitive to additional damage.[56] The problem was increased by the fact that HCFCs also were powerful global warming gases that were estimated to be 300 to 4,100 times more potent global warming gases than carbon dioxide (Table 5). Many observers thus considered HCFCs as “part of the problem, not part of the solution” and expected the deadline for their phaseout to be moved up, as had been the case several times with the deadline for CFCs. Producers developing HCFC-based blowing systems thus were developing into a dead-end and would at some foreseeable future be forced to convert their production once again.

HCFCs were more expensive than CFCs, resulting in an increase in the price of the insulation foam. In 1990, for instance, HCFC-22, a commonly proposed substitute blowing agent for insulations to be used in deep freezers and commercial refrigerators, was some 3 to 4 times more expensive than a conventional CFC.[57]

56. Greenpeace. Greenfreeze: The World’s first CFC- and HFC-free Refrigerators. N. p., n. y”

57. Marsh, 1990.

Hydrocarbons

Given the fact that HCFCs were an agreed-upon transitory solution, it was amazing that almost all refrigerator makers In the world were concentrating their development efforts on their use as substitute blowing agents. The only exception was Germany, where the leading manufacturers concentrated on the use of hydrocarbons, such as n-pentane or cyclopentane, as a blowing agent alternative.

Hydrocarbon-based blowing agents had the advantage of being environmentally benign, thus there was no threat of any regulation requiring their phaseout. However, the insulating properties of pentane-blown foams initially were not as good as those of foams that had been blown with HCFCs, In order to maintain the same level of energy efficiency, manufacturers thus had to slightly increase the thickness of the refrigerator's walls, leading to a small reduction in the refrigerator's capacity. For instance, in 1992, a German refrigerator with pentane-blown insulation required a capacity reduction of 5 liters to 150 liters.[58] Many refrigerator makers maintained that this capacity reduction was unacceptable, although it was questionable if the user would even notice this capacity reduction of 3.3 % _ Further technical improvements subsequently allowed German producers to produce energy efficient refrigerators with hydrocarbon-blown walls that were as thick as HCFC-blown walls. In 1994, for instance, Bosch-Siemens introduced the world's most energy efficient refrigerator in its class, a 130 liter refrigerator with hydrocarbon-based coolant and insulation, walls of standard thickness and an energy consumption of only 0.46kWh per 24 hours.[S9]

Hydrocarbons were explosives. This led to increased production costs because manufacturing systems had to be made explosion proof. Retrofitting an existing foam production system to hydrocarbons was estimated to increase foam costs by 20-25 % while adding explosion proofing measures to a new system was thought to lead to an increase of only 5% .[60]

58. Schwarz and Leisewitz, 1992, 18.

59. Greenpeace: Glitscher, W. Personal communication to the author.

60. Greenpeace: Glitscher, W. Personal communication to the author.

Other Insulation Technologies

Besides research into which type of blowing agent to use for insulation foams, there was also considerable development work concerning other non-foam insulation technologies. Most often discussed were vacuum isolation panels (VIPs), made of thin plastic film walls that had been filled with zeolite powder and then evacuated. VIPs had exceptionally good insulation properties and were environmentally benign, but were still very expensive in 1994. The first refrigerators with vacuum panels had been introduced almost simultaneously in early 1993 by AEG in Germany and by Sharp in Japan.[61] The AEG model used VIPs on the side walls and polyurethane in the comers and used 15% less electricity than current models, AEG planned to introduce by 1995 models that only used vacuum panels and would require only one-third to one-half the electricity of current models, but be about one-third more expensive. The leading producer of VIPs in Europe and the United States was the German firm Degussa, in Japan it was Sharp.

Energy Consumption

Besides the fundamental decision on what kind of cooling technology and insulation method to choose, there was a large number of possible small changes a refrigerator maker could make to the hermetic system and the cabinet that did not directly affect the environment, but increased energy efficiency and thus indirectly improved the environment. Among the possible ways to improve refrigerator energy efficiency were more efficient compressors, variable speed fans and defrost that only worked when necessary, improved heat exchangers, changes to the refrigerator's evaporation system, thicker insulations, advanced gaskets, as well as better latches.[62] Manufacturer's experimented with all these technologies, but as of early 1994 no consensus concerning their cost effectiveness had been reached.

Refrigerator Disposal

Refrigerator disposal was a great concern to both regulators and consumers, particularly in Germany and the Northern European countries, but less so in the United States and even less in Japan. The

61. "First Refrigerator to Bear 'Blue Angel': Environmentally Friendly Symbol Introduced". BNA International Environment Daily, April 1, 1993. "High Cost Hindering Adoption of VIP, CFC-Free Refrigerators." The Nikkei Weekly, March 8, 1993, p. 13.

62. EPA February 1992, p. 102.

fundamental decision concerning refrigerants and insulation blowing agent - HFCs and HCFCs or hydrocarbons - had a great impact on the ease and environmental safety with which a refrigerator could be disposed of. HFCS and HCFCS posed considerable threats to the environment and had to be recycled using costly equipment, while hydrocarbons were much more benign.

In Germany, the upcoming Elektronikschrottverordnung, a law that would force manufacturers themselves to take back discarded appliances, put particular pressure on the industry to devise and facilitate economically feasible recycling methods.

In 1993, for instance, Miele announced that it was able to recycle 90% of a washing machine, although this was not yet economically viable. Miele is among several German manufacturers embossing plastic components with a code indicating the type of polymer used, enabling scrapped components to be sorted.[63]

Two Different Routes to Achieving Change

By early 1994 it appeared to be clear that German and American manufacturers were pursuing different routes on their way to substituting CFC-based refrigerants and insulations - and that the German route, propane-butane or isobutane as refrigerants and insulations blown with pentane or cyclopentane or vacuum panels, appeared to be more promising, ecologically and economically, than the American route, where HFC-134a-based refrigerants had become the accepted choice. To understand why these different routes had been chosen, it is necessary to describe the most important events on both sides of the Atlantic which had led to these choices.

Greenfreeze and the Adoption of Hydrocarbon Refrigerants in Germany

The decisive events in Germany were those surrounding the East German firm dkk Scharfenstein’s introduction of the first truly environmentally friendly refrigerator which contained neither CFCs, HFCs, nor HCFCs. Under communism, dkk Scharfenstein had been the only refrigerator manufacturer in East Germany, selling 1 million refrigerators and freezers annually and employing 5,500 workers. After the

63. Erlick, 1993.

unification of the two Germanies in 1991, annual production fell dramatically to 176,000 refrigerators and 54,000 freezers, which translated into annual sales of $48 million and a loss of $57.8 million. The firm had to reduce its workforce to 1,800 in 1991, followed by a further reduction to 600 in 1992.

At the same time, the German section of the environmental organization Greenpeace was investigating the commercial feasibility of a new, truly environmentally-friendly refrigerator technology which had been invented at the Hygiene-Institut in Dortmund, Germany a few years ago and was using neither CFCs, nor HFCs or HCFCs, relying instead on a mixture of propane-butane as a refrigerant. In early 1992, shortly before a public conference where all German refrigerator makers with the exception of dkk announced they would concentrate on HFC-134a as a replacement for the soon-to-be-banned refrigerant CFC, Greenpeace approached dkk for the first time to investigate if it would be interested in the new HFC- and HCFC-free technology. A curious circumstance made dkk particularly attractive to Greenpeace: Like competing products, dkk's refrigerators employed CFCs as refrigerants, but unlike its competitors, its insulations were already CFC-free. The lack of appropriate production facilities in the former GDR had forced dkk to innovate around this disadvantage and develop a CFC-free polystyrene insulation that compensated its slightly inferior insulation capabilities with a higher material thickness (38mm instead of 3Omm). Following a series of meetings between representatives from Foron, Greenpeace and the Dortmund Hygiene-Institut, Greenpeace sent another signal in July 1992 and awarded dkk a small contract valued at DM26,OOO to produce 10 working prototypes of the world's first refrigerator that would be completely CFC- and HFC-free and instead use a mixture of propane and butane as refrigerant and a polystyrene insulation blown with pentane.[64] The same month, dkk's owner, the German privatization agency Treuhandanstalt. announced its intention to liquidate dkk, following the termination of merger negotiations with Bosch-Siemens which had considered buying the firm.

With an inferior product, monthly losses of DM3 million and the threat of being liquidated, dkk was desperate for a new innovative product and decided to risk the commercial development of the first refrigerator which contained neither CFCs, HCFCs or HFCs. In a reversal of its traditional practice of refusing to actively promote commercial products, for the first time in its history Greenpeace ran a

64. Greenpeace. Greenfreeze: Die Chronologie einer umweltreclmischen Revolution. N. p,, n. y.

publicity campaign for the new "Greenfreeze" asking Germans to send in pre-orders for the new refrigerator which was tentatively priced at DM600-700, some DMl00 higher than the market price for conventional refrigerators containing CFCs .[65] The campaign irritated Treuhand officials, but quickly found favor in Bonn, where politicians eager to display environmental concern urged that the company be saved. In a letter to Birgit Breuel, the Treuhand president, the Gem Environmental Minister Klaus Topfer urged the Treuhand to "use every possibility to maintain this company's capability for existence. "[66]

The campaign also irritated the German Chemicals Industry Federation (VCI) which, representing the producers of the substitute refrigerant HFC-134a, publicly contended that hydrocarbon-based refrigerators used 40% more energy than CFC-based refrigerators and that polystyrene insulation was less effective than other insulators. A spokesman of the Industry Federation was quoted as describing the direction of this development as a dead-end.[67] Hoechst, the largest German producer of HFC-134a, also publicly denounced the "Dortmund mixture" as being energetically inefficient .[68] By the time of these denouncements dkk had already proven that the propane-butane mixture was not only as efficient, but theoretically even more efficient than CFC. Greenpeace also countered that, while the polystyrene insulation was indeed less efficient than conventional foams, this disadvantage had already been addressed by making it slightly thicker, reducing an average refrigerator's volume by a mere 5 liters from 145 to 150 liters.

The established West German competitors initially ridiculed dkk's new technology. Their general reaction was: "A refrigerator which works with cigarette lighter gas? Ridiculous! If that would work,

65. Culp and Mapleston, 1993.

66. Protzman, 1992.

67. "DKK Scharfenstein may be saved by CFC-Free Refrigerator." Frankfuner Allgemeine Zeitung, July 22, 1992 (Reuter Textline).

68. Greenpeace. Der Ktilschrank-Krimi. Short Chronology of the dkk Scharfenstein/Foron events. No place, no year.

everybody would have done it by now. "[69] A spokesman for the German electrical and electronics industry association ZVEI explained that dkk's propane-butane mixture was a considerable safety risk because of its inflammability, and the press spokesman for Bosch-Siemens said that the dkk refrigerator was only an apparent solution to environmental concerns, because there was no question of it matching the level of energy usage of conventional appliances.[70] When it became obvious that the Greenpeace campaign, which was attracting tremendous publicity in the German media, was beginning to threaten their own products, Bosch-Siemens, AEG, Bauknecht, Electrolux, Liebherr, and Miele reacted and sent a joint letter to their trading partners. The letter stated that the insulation material and the refrigerant used in dkk's refrigerator were less efficient than their own technologies, and also that hydrocarbon-based coolants were technically unsound and posed a significant risks of explosion during the refrigerator's usage.[71] The letter did not meet its sender's objectives, resulting instead in a public outcry and precisely the kind of media attention that dkk and Greenpeace needed. Saxony's finance minister immediately described the letter as "immoral discrimination against a competitor" .[72] A short time later, after Greenpeace had intervened at the German antitrust office, the letter's senders were required to sign a declaration that they would cease distributing the letter.[73] The alleged risk of explosion, though theoretically possible, was proven to be negligible, when in December 1992 the refrigerator received the required safety mark award certificate from the Bavarian testing agency Technischer uberwachungsverein (TUV). This established that the refrigerator's 20 grams of propane/butane refrigerant - the same amount that was contained in a cigarette lighter - was a safe alternative.[74]

69. Greenpeace. Der Kiihlschrank-Krimi. Short Chronology of the dkk ScharfensteinIForon events. No place, no year.

70. "DKK's 'Eco-Fridge' Given 'Blue Angel' Award, but still Little Interest from Western Manufacturers." Frankfurter Allgemeine Zeitung, August 8, 1992, p. 13. (Reuter Textline).

71, "Germany: Established Manufacturers Criticize DKK Scharfenstein's 'Eco-Fridge'". Reuter Textline: Frankfurter Allgemeine Zeitung, October 5, 1992, p. 16.

72. "Germany: Established Manufacturers Criticize DKK Scharfenstein's 'Eco-Fridge'". Reuter Textline: Frankfurter Allgemeine Zeitung, October 5, 1992, p. 16.

73. Greenpeace. Greenfreeze: Die Chronologie einer umwelttechnischen Revolution. N. p., n. y.

74. TiiV Product Service (ed.), December 9, 1992.

The publicity made the campaign, which initially cost $68,000, extraordinarily successfu.l[75] The ‘ German fridge ” or “Greenfreeze” as it had come to be called, received worldwide media attention. Less than four weeks after its start in August 1992, the campaign had attracted pre-orders for 70,000 refrigerators from environmentally conscious German customers plus an order for 20,000 units with an option for another 50,000 by Quelle, the leading German mail-order company.[76] (Unprecedented in the appliance industry, particularly for a product that was not even on the market.) That August, dkk was also visited by the German minister of the environment who declared that the “Greenfreeze” stood good chances of becoming the first German refrigerator to be awarded the prestigious Blue Angel eco-label. Shortly thereafter, the Treuhandanstalt announced it would not liquidate the firm, but invest DM5 million into the further development of the refrigerator. In November 1992, when a consortium of investors from Berlin and the firm’s management acquired the firm, it was renamed Foron Hausgerate and pledged to invest DM35 million over the following years,

With Foron’s future existence assured, Greenpeace changed its tactic and began to focus on the other German manufacturers. With advertisements and private negotiations it tried to convince them of the merits of the new technology. In February 1993 the sensation was perfect: Not only did Foron officially introduce its new refrigerator to the market, but, during the world’s largest appliance fair, Domotechnica, in Cologne. Bosch-Siemens, Liebherr and Miele announced the introduction of new refrigerator models that would work with propane and butane as refrigerants and employ insulations blown with pentane. Within only seven months, from September 1992, when they had contended that the propane/butane technology was not only inefficient but also dangerous, to February 1993, when they announced refrigerators using the same technology, the firms had made a complete turnaround. In March 1993, with Foron having successfully begun mass-producing its new refrigerator, Greenpeace formally terminated its relationship with Foron - after a campaign that had cost it DM500,OOO and had reached all its intended goals .[77]

75. Protzman, 1992.

76. Greenpeace: Glitscher, W. Personal communication to the author.

77. “Der TijV gibt dem ijko-Ktilschrank seinen Segen.” Siiddeutsche Zeitung, December 18. 1992.

In the following months the "Greenfreeze" proved to be extraordinarily successful. Not only was it awarded the expected Blue Angel eco-label, Foron's management was also presented with the environment award by the renowned Bundesstiftung Umwelt (Federal Foundation Environment). Most importantly, it met with very strong demand in the German market even though it was more expensive than competing products containing CFCs. By July 1993, five months after production had begun, Foron had already sold 35,000 units. Demand was outstripping production capacity which had reached its limits with 800 units a day, preventing Foron from selling an additional 75,000 units in 1993 for which there was demand. [78]

Foron's technology proved to be not only a small environmental niche but within a very short time became the dominating technology in Germany. By May 1993. Bosch-Siemens and Liebherr had converted their entire insulation production to pentane-blown foams. In November 1993, a few months after it had converted its insulation production from CFC-12 to HFC-134a, market pressure forced AEG to convert a second time, this time to foams blown with cyclopentane. By February 1994, Bosch-Siemens, Liebherr, and AEG had announced that they would convert the major part of their refrigerator production to the Greenfreeze technology.[79]

An interesting observation concerning the "dkk/Foron incident" was that the boldest and quickest innovative solutions in Germany had been announced by the four German firms who had their home base in Germany. while the two foreign-owned German producers had been much more timid. Specifically, the four early movers with completely CFC- and HFC-free refrigerators on the market - Foron, followed by Bosch-Siemens, Liebherr, and Miele - were German-owned firms. The other two producers in Germany, who had been late and very hesitant to convert were owned and controlled by foreign firms: Bauknecht by Philips which itself was a subsidiary of Whirlpool and AEG by Electrolux. It could be argued that the German-owned firms, being closer to the German market, had been forced to respond faster to the advanced environmental needs of the German customer, than the foreign-owned firms which also had to respond to signals from other, possibly less advanced markets.

78. "Foron macht mit dem Oko-Ktihlschrank Furore. " Suddeutsche Zeitung, July 26, 1993.

79. Greenpeace. Greenfreeze: Die Chronologie einer umwelttechmschen Revolution. N. p., n. y.

It was also interesting to ask whether the "dkk Scharfenstein incident" was a result of environmental regulation or of the pressure provided from Greenpeace's actions. While it is difficult to separate the two reasons from one another, it is probably fair to say that the Greenpeace action would not have met with such a success, would it not have been for clear regulatory signals by the German government - aimed at both producers and consumers - that conventional refrigerators were environmentally unsafe and had to be phased out.

SERP and the Adoption of HFG134a Refrigerants in the U.S.

What Foron had done in Germany - force innovation onto an industry which had not seen any real product innovation for decades - the Super Efficient Refrigerator Program (SERP) had tried to do for the refrigerator industry in the United States. SERP was a $30 million contest to develop and market a refrigerator that would use no CFCs and exceed 1993 federal energy-efficiency standards by 30 to 50%. It was sponsored by, among others, the U.S. Environmental Protection Agency and 25 electric utilities who. based upon the number of residential customers they served, had committed between $150,000 to $7 million fo the prize money which was to be paid out to the winning manufacturer in the form of cash rebates per refrigerator sold. Consumer savings from reduced energy usage due to the program were projected by SERP at from $240 million to $480 million annually.[80]

The award was made based on a complicated scoring formula which assigned a weight of 75% to the economic efficiency of each proposal, 22 % on the manufacturer's technical and corporate capabilities, and 3% on other special attributes, such as non-chlorine HCFC-substitutes. A winning entry had to be CFC-free, but HCFCs were perfectly acceptable and only 3% of the maximum score could be gained by developing a HCFC-free technology .[81] In fact, no additional points could be scored with a HFC-free refrigerator. Thus, SERP provided no incentives to develop a truly environmentally friendly technology.

80. "Whirlpool, Frigidaire Named Finalists in Utility Contest for Efficient Fridge." Electric Utility Week (formerly Electrical Week), p. 2, December 14, 1992.

81. SERP Inc., 1992

SERP also placed much emphasis on "corporate reliability", demanding that contestants had mass-production facilities as well as a national distribution and service network. This requirement restricted the contest to large, established refrigerator manufacturers and effectively excluded small, potentially more innovative firms such as the small refrigerator maker Sun Frost of Arcata, California, which claimed to produce a refrigerator that not only met the contest's requirements but also was the world's most energy-efficient .[82] Likewise, Foron, the developer of Germany's "Ecofridge", would have been excluded from SERP and thus would have been unable to perform its role of catalyst for change that it had played in Germany.

SERP was launched in 1990 with 14 contenders to compete for the prize. After a first round of eliminations in December 1992 only two were left: Whirlpool and Frigidaire Corp. In June 1993 SERP announced Whirlpool to be the winner. The winning entry was energy efficient, but not truly environmentally friendly by German standards for it used HFC-134a as a refrigerant.

SERP had brought about some change, but the question remains whether it could have fostered more innovative solutions. It was stated already that the contest may have been overly restrictive with respect to potential entrants and that it did not place real emphasis on environmental friendliness. However, there were other factors beyond these which also limited the extent of innovation. The German hydrocarbon technology would not have been eligible for entry because U.S. safety laws were not as flexible as German safety laws and prohibited the use of explosive refrigerants (even if the amount of refrigerant used equalled that in a cigarette lighter which was deemed "safe"). In the U.S. there was also always the threat of multi-million dollar liability lawsuits. should a refrigerator really happen to explode. Finally, the U.S. refrigerator industry was probably even less accustomed to product innovation than the German refrigerator industry. Competition, though fierce, had been based for too many decades on non-product issues such as marketing and distribution. In February 1993, at a time when the major German refrigerator makers were already marketing or had announced they would market hydrocarbon-based refrigerators, American manufacturers were still fighting that technology. A spokesman of Whirlpool was quoted: "We are still not certain that the propane-butane mixture does not bring the danger of

82. ECONEWS August 1992.

explosion" "This technology has been around for over 20 years. Why should it work today if it was not acceptable then?'[83]

Competitive Effects in Supplier Industries

Supplier Indutries

Probably more affected by the ban on CFCs than the refrigerator industry itself were the suppliers of refrigerants which had been asked to either develop non-ozone depleting refrigerants within a very short the period or to exit their business and leave the field to suppliers of alternative, perhaps non-chemical refrigerants such as propane or butane. Anticipating a world-wide annual market of 200,000 tons valued at DM10 billion for the CFC-replacement HFC-134a, the leading CFC-producers had invested heavily in research and production facilities. Until mid-1992, the two major refrigerant suppliers, DuPont and ICI. had already invested DM700 million each into research of and production facilities for the replacement refrigerant HFC- 134a.[84] Hoechst, a refrigerant producer from Germany, was known to have invested at least DM50 million to build a HFC-134a-plant with an annual capacity of 10,000 tons.[85] Production of alternative lubricants was also costly. In 1992 ICI announced a DMl8 million investment to set up production for a HFC-134-compatible lubricant.[86]

The high stakes involved led to some rather drastic actions from refrigerant makers. In 1990, when the signatory states of the Montreal Protocol were meeting in London to discuss, among other topics, a future ban on HCFCs which were known to be environmentally damaging but considered to be a stop-gap measure until the development of safer replacements. ICI and DuPont, in a joint announcement, threatened to halt all further investments into safe CFC alternatives if HCFCs were banned within a time period that would nor allow them to recoup their investments. ICI and DuPont said they needed at least

83. Kabel, 1993.

84. Europa Chemie no. 23, 1992, p. 2. Cited in: Schwarz and Leisewitz, 1992, 3.

85. "West Germany: Hoechst is to Reduce CFC Production by 50% by 1992/1993." Blick auf Hoechst, December 1. 1989 (Reuter Textline, Chemicals Business News Base, February 15, 1990).

86. "France: Oil for Refrigerating Machines - ICI Expands French Production." Europa Chemie, April 6, 1992, p. 2 (Reuter Textline, Chemicals Business News Base, May 15, 1992).

a 30-year life-cycle to recoup a fair profit from their HCFC-plants.[87] Perhaps not altogether coincidental. ly, during that year's talks the Montreal Protocol signatory states agreed to a HCFC-phase-out by the year 2020.

The CFC producers had also been forced to innovate in the area of blowing agents for isolating foam. Due to a considerable extent to the voluntary agreement between producers and the German government to cut CFC-contents in foams by 50%, German foam producers had begun very early to search for formulas for less CFC-intensive foams. In 1989, for instance, the leading German chemicals producer Bayer announced it had developed a method to partially replace CFCs by water. The water reacted with isocyanate and formed carbon dioxide, to be used as a blowing agent for rigid polyurethane foams. The new method, which could be used without modification in existing processing plants, cut CFC-usage in polyurethane foams by 50% and did not affect the insulating properties of the foam. It was adopted within a short time by most European producers of refrigeration units.[88] Pressure from the voluntary agreement had thus provided Bayer with a valuable first mover advantage.

American foam formulators, on the other hand, had not been pressured to innovate early to reduce CFC-contents. As a result, U.S. refrigerator makers, when required by the Montreal protocol and domestic law to cease CFC-usage, were initially unable to do so while still meeting U.S. minimum electricity efficiency requirements. Some German firms were able to do due to their prior experience with innovative CFC-reducing methods.[89]

International Effects

By early 1994 the new hydrocarbon technology which had been developed in Germany was still too new as to allow estimates of its acceptance in foreign markets. There were some who said that the 5% price differential was too high to make the technology competitive on foreign markets, such as the French

87. "UK: Firms Threaten Research Into CFC Alternative." The Guardian, June 23, 1990, p. 2 (Reuter Textline).

88. "Bayer Reduces Use of CFCs in Production of Rigid Polyurethane Foams." Kunststoffe German Plastics, November 23, 1989, p. 5 (Reuter Textline: Chemical Busmess NewsBase, February 27, 1990.

89. Liebherr-Hausgerate GmbH: Futterer, B., Kaufrn&nnischer Geschiftsfiihrer. Personal communication to the author.

market.[90] Others said that the price differential would only be temporary and might even turn into a price advantage given further experience and improvements. Indeed, it seemed as if there was considerable potential for the new technology to be adopted abroad. In November 1993, for instance, the Australian appliance manufacturer Email announced it would begin production of “Greenfreeze” refrigerators in 1994.[91] Likewise, by early 1994, Greenpeace had already presented the refrigerator in China, Japan, and lndia where it had met with great interest.

lt was unequivocally accepted that Greenfreeze had provided German manufacturers with a first-mover advantage, but the exact value of this first-mover advantage was still subject to debate: The basic hydrocarbon technology was old and not patentable, allowing any foreign competitor to develop similar models. In addition, in the refrigerator industry success on foreign markets continued to be less a function of superior technology, depending still to a large extent on the manufacturer’s existing distribution network.

90. Liebherr-Hausgerate GmbH: Futterer, B., KaufrMnnischer Gesch~ftshihrer. Personal communication to the author.

91. Greenpeace. Greenfreeze: Die Chronologie einer umwelttechnlschen Revolution. N. p., n. y.

APPENDIX

Table 1

Domestic Refrigerators and Freezers
World Production

	1985		1990		Annual Compound Growth
	Units (1000s)	Share of Total	Units (1000s)	Share of Total	
AFRICA	892	2.5%	994	2.2%	2.2%
Canada	510	1.4%	NA	NA	NA
U.S.	6,419	18.0%	7,817	17.3%	4.0%
NORTH AMERICA	7,313	20.6%	8,821	19.5%	3.8%
Brazil	1,706	4.8%	2,441	5.4%	7.4%
SOUTH AMERICA	2,173	6.1%	3,016	6.7%	12.1%
China	1,448	4.1%	4,631	10.2%	22.1%
Japan	5,354	15.1%	5,048	11.1%	-1.2%
South Korea	1,864	5.2%	2,827	6.2%	8.7%
ASIA	11,488	32.3%	15,704	34.7%	6.5%
Denmark	915	2.6%	NA	NA	NA
France	436	1.2%	596	1.3%	6.5%
West Germany	2,788	7.8%	5,042	11.1%	7.7%
East Germany	973	2.7%			4.0%
Italy *	3,357	9.4%	4,082	9.0%	5.0%
Spain *	1,082	3.0%	1,268	2.8%	4.0%
U.K.	1,266	3.6%	1,312	2.9%	0.7%
Sweden	510	1.4%	NA	NA	NA
EUROPE	14,593	41.0%	16,757	37.0%	2.8%
TOTAL	35,567	100.0%	45,292	100.0%	5.0%

Note: A * denotes data from 1989 instead of 1990.
Source: U.N. lndustrial Statistics Yearbook. Statistisches Bundesamt.

Table 2

Domestic Refrigerators and Freezers
International Trade Data

	1986			1990		
	World Export Share	World Import Share	Trade Balance	World Export Share	World Import Share	Trade Balance
Italy	28.9%	1.8%	$478.1	28.7%	2.7%	$964.3
West Germany	15.6%	9.5%	$91.7	15.6%	13.4%	$394.9
United States	4.7%	13.8%	-$188.1	10.7%	6.3%	$157.1
Denmark	8.2%	1.1%	$124.8	8.3%	1.1%	$265.8
South Korea	4.6%	0.1%	$80.3	4.7%	0.5%	$156.0
Yugoslavia	3.2%	0.2%	$52.2	4.2%	0.4%	$141.3
Sweden	5.2%	2.5%	$44.0	3.3%	2.9%	$11.8
Japan	11.0%	0.2%	$190.7	3.2%	1.6%	$61.0
Spain	1.8%	1.5%	$2.8	2.8%	7.4%	-$173.3
Austria	2.9%	2.5%	$1.7	2.3%	2.5%	-$9.8
Other	13.9%	66.8%	NA	16.2%	61.2%	NA
Total	$1,775.2	$1,958.5	NA	$3,718.5	$3,718.5	NA

Note: Amounts in $ millions.
Source: U.N. Annual Trade Statistics, Vol. II.

Table 3

Energy Efficiency of Selected British Electrical Appliances (kWh per Year)		
Appliance	U.K. Average	Best Available
Refrigerator/Freezer ($0.5m^3$)	1,100	75 - 180
Freezer	l,000	80 - 180
Refrigerator ($0.2m^3$, Frost-Free)	450	30 - 80
Washing Machine	400	40 - 120
Dishwasher	500	50 - 240
Clothes Dryer	520	10 - 90
Color TV	340	70

Note: Volumes are for illustration only; average includes a wide mixture of sizes. Fridges discussed have no frozen food compartment. Freezers are manual defrost.

Source: UK Friends of the Earth. Quoted in: "The Real Problem with Fridges." The Financial Times. Power Europe. Energv Section. March 16. 1989.

Table 4

Refrigerants and Alternative Technologies: Advantages and Disadvantages			
Name	Usage	Advantages	Disadvantages
CFC-12 (CF2C12)	Traditional standard coolant for domestic and commercial refrigerators (produced by ICI, DuPont, Hoechst. Kali-Chemie and many others)	Good cooling properties; very well-known; low production costs	GWP 7300 times higher than Co2; ODP equivalent to 0.9 kg of CFC-11; remains 130 years in atmosphere; to be phased out after 1993 (Germany). 1995 (U.S., EC, Montreal Protocol)
HCFC-22 (CHF2C1)	CFC-12 replacement (produced by DuPont, ICI)	Suitable for very low-temperature supermarket refrigerators	GWP 1500-4100 times higher than CO2; ODP equivalent to 0.04-0.06 kg of CFC-II, remains 15 years in atmosphere; to be phased out by 2020 (Montreal Protocol)
CFC-115	Traditional coolant for process and cold storage warehouse refrigeration		To be phased out after 1994 (Germany), 1995 (U.S., EC, Montreal Protocol)
HFC-134a (C2H2F4)	CFC-I2 replacement primarily for use in domestic refrigerators; offered by most established refngerator manufacturers (produced primarily by DuPont, ICI, also by Hoechst, Elf Atochem. AustmontiFemtzzt-Montedtson)	No ODP; requires little product design changes because of chemical similarity to CFC-12	GWP 1200-3200 times higher than CO,; remains 16 years in atmosphere; requires compressor and compressor oil redesign; cost 5 times as much as HFC-152 a to produce, 3-5 % less energy efficient as CFC-12
HFC-143a (CH3CF2)	CFC-12 replacement	No ODP	GWP 1300 times higher than CO2; remains 54 years in atmosphere; flammable
HFC-152a (CH3CHF2)	Possible CFC- 12 replacement for residential refrigerators and freezers	No ODP; easy to manufacture, 5% more energy efficient. low toxicity	GWP 140-510 tunes higher than CO2; remains 1.7 years in atmosphere; flammable
CFC/HCFC-502	Possible CFC-12 replacement for low temperatures; blend of CFCs and HCFCs		GWP. ODP; to be phased out (Montreal Protocol)
Hydrocarbons [propane-butane mix, isobutane)	CFC-12 replacement primarily for use in domestic refngerators; was well established before the use of CFCs; (first offered by Foron (ex dkk Scharfenstein) of Germany. followed by a number of German producers)	Negligible GWP; no ODP; 50% less costly that HFC-134a; widely available: theoretically more energy efficient as CFC-12. can be used with existing vapor-compression technology with little changes	Slight risk of explosion; initially less energy efficient as CFC-12 in practice; can't achieve very low temperatures; US legislation forbids use of propane in domestic refrigerators
Ammonia (vapor-compression cycle)	Alternative refrigerant used in the majority of German and American cold storage applications; used in domestic refrigeration before the advent of CFCs; being researched in Germany and the U.S. for domestic refrigeration	No GWP. no ODP: well-known and -proven technology, said to be technically superior to HFC-134a and typically about 4% its cost	Risk of explosion

Refrigerants and Alternative Technologies: Advantages and Disadvantages			
Name	Usage	Advantages	Disadvantages
Ammonia-water mix (absorption cycle)	Absorption system using ammoma as refrigerant; well established for domestic and industrial refrigeration; used in 5% of the German household market	No GWP. no ODP	Risk of explosion; efficiency comparable to conventional vapor-compression systems only if primary or waste heat from a combined heat and power unit is available
Adsorption cycle (zeolite-water mix)	Alternative technology using zeolite (a naturally occurring hygroscopic) mineral in a heat pump with natural gas a heat source; being researched in Germany for use in mobile coolers, domestic refrigeration and air conditioning	No GWP, no ODP	Unproven technology
Stirling cycle (helium)	Stirling heat engine powered by helium: being researched by European and American manufacturers	NO GWP, no ODP; predictions are for an 81% efficiency increase over conventional vapor compression machines	Unproven technology: limited supply of helium may become an obstacle to widespread use
Vote: GWP = Global Warming Potential. ODP = Ozone Depletion Potential.			

Table 5

Refrigerator Insulations: Advantages and Disadvantages			
Name	Usage	Advantages	Disadvantages
CFC-11 (CFC13)	Traditional standard blowing agent for polyurethane foam insulation	Good insulation; well known	GWP 3500 times higher than CO2; serious ODP; remains 120 years in atmosphere; to be phased out after 1994 (Germany), 1995 (U.S.. EC, Montreal Protocol)
HCFC-22 (CHF2Cl)	Blowing agent for polyurethane foams, CFC-11 replacement	Not flammable	GWP 1500-4100 times higher than CO2; ODP 0.04-0.06 kg of CFC-11, remains 15 years in atmosphere; to be phased out by 2020 (Montreal Protocol)
HCFC-123 (CHC12CF3)	Blowing agent for polyurethane foams, CFC-11 replacement	Not flammable	GWP 85-310 times higher than CO,; ODP equivalent to 0.013-0.022 kg of CFC-11: remains 1.6 years in atmosphere; high toxicity, to be phased out by 2020 (Montreal Protocol)
HFC-134a (C2H2F4)	Blowing agent for polyurethane foams, CFC-11 replacement, (produced primarily by DuPont. ICI, also by Hoechst, Elf Atochem, Ausimont/Ferruzzi-Montedison)	Not flammable, no ODP	GWP 1200-3200 tunes higher than C02; remains 16 years in atmosphere
HCFC-141b (CH3,CCl2F)	Blowing agent for polyurethane foams, CFC-11 replacement, (used by several European and Japanese firms)		GWP 440-1500 times higher than CO2;ODP equivalent to 0.07-0.11 kg of CFC-11; remains 8 years in atmosphere, flammable, unknown toxicity, to be phased out by 2020 (Montreal Protocol)
HCFC-142b (CH3CClF2)	Blowing agent for polyurethane foams, CFC-11 replacement	Low toxicity	GWP 1600-4700 times higher than CO2; ODP equivalent to 0.05-.06 kg of CFC-11; remains 19 years in atmosphere. to be phased out by 2020 (Montreal Protocol)
Carbon-dioxide (CO2)	Possible blowing agent for polyurethane foams, CFC-1 I replacement	No ODP	GWP; remains some 120 years in atmosphere
Cyclopentane	Blowing agent for polyurethane foams, CFC-11 replacement, used or researched by several German firms (produced among others by Exxon)	Low toxicity	Dangerous to handle; less effective insulator than CFC-11
N-pentane	Possible blowing agent for polyurethane foams, CFC-11 replacement		
UPT	Possible blowing agent for polyurethane foams (fluoride compound), CFC-11 replacement		

Refrigerator Insulations: Advantages and Disadvantages

Time	Usage	Advantages	Disadvantages
Vacuum lnsulation Panel (VIP)	Airtight plastic sheets filled with silica particles under a vacuum (developed among others by AEG. Sharp, Matsushita. Toshiba)	No ODP; no GWP; much better insulation than CFC-based polyurethanes allow thinner walls or better energy efficiency	Twice as expensive as polyurethane foam; reliability data unavailable; still difficult to produce

Note: GWP = Global Warming Potential. ODP = Ozone Depletion Potential.

Table 6

Important Milestones in the History of the Refrigerator Industry	
1928	Financed by Frigidaire Corporation the first modern refrigerant, CFC-12, is developed at General Motors' research laboratories.
1931	Production of CFC-12 and CFC-11 begins in the U.S.
1940s	Additional refrigerants such as CFC-113 and CFC-114, as well as HCFC-22 are developed. Falling prices and their superior safety characteristics result in CFCs and HCFCs becoming the refrigerant of choice for most commercial and domestic cooling applications.
1950s	With the vapor-compression principle having been universally accepted for refrigerators, refrigeration technology will remain basically unchanged from now on until the early 1990s.
1974	"Stratospheric Sink for Chlorofluormethanes: Chlorine Atom-Catalyzed Destruction of Ozone" by Molina and Rowland is published in Nature, alerting for the first time to the ozone-depleting characteristics of CFCs.
1978	The U.S. bans the use of CFCs in non-essential aerosol spray cans.
1985	The Vienna Convention on the Ozone Layer is adopted by 19 countries and the European Community, agreeing in principle on the reduction of CFCs to protect the earth's ozone layer. The world's leading CFC producer, DuPont, as well as the U.S. Chemical Manufacturers Association urge the United States to withdraw from negotiations.
1987	The Montreal Protocol on Substances that Deplete the Ozone Layer is signed, freezing production and use of CFCs at 1986 levels and reducing the amounts by 50% over the ensuing 10 years (the Protocol will eventually be signed by 76 countries, but not India or China as well as many developing countries). For the first time in history production of an environmentally harmful substance is globally banned. U.S. firms support withdrawal, European firms oppose it.
1990	The London Amendments of the Montreal Protocol call for a 50% reduction of CFCs by 1995 and a total ban by the year 2000. The Clean Air Act Amendments are enacted in the U.S., requiring the phaseout of CFCs, halons, and carbon tetrachloride by 2000, methyl chloroform by 2002, and HCFCs by 2030.
1991	The German FCKW-Halon-Verbots-Verordnung (CFC-Halon-Prohibition-Decree) is enacted, prohibiting the use of CFCs by January 1995, thus making Germany the world's first country to completely phase out CFCs.

Important Milestones in the History of the Refrigerator Industry

1992	Sponsored by the U.S. EPA and financed by 25 public and private power utilities, the Super Efficient Refrigerator Program (SERP) is launched. It offers a $30 million price to the firm which develops and delivers 300,000 to 500,000 CFC-free refrigerators and exceed U. S energy-efficiency standards by at least 30 % . The U.S. Congress and the European Community (in April 1992) both pass legislation to ban production and consumption of CFCs by the end of 1995 (EC). Germany pledges a CFC-ban by the end of 1994. The Montreal Protocol is once again tightened to require a CFC-ban after 1995 and to also include restrictions on HCFCs which will have to be phased out by 2020.
1993	The East German firm Foron, formerly dkk Scharfenstein, begins to market the world's first CFC- and HCFC-free refrigerator. It uses hydrocarbons - a mixture of propane and butane - as a refrigerant. Other major German producers, which had previously denounced the technology as unsafe, also announce propane-butane refrigerator. Other German refrigerator makers, after initially having rejected the Foron product as unsafe, begin to market similar propane-butane refrigerators. The Super Efficient Refrigerator Program (SERP) announces Whirlpool as the winner of its $30 million contest to develop an environmentally friendly and energy-efftcient refrigerator. The winning entry uses HFC-134 as a refrigerant, thus still contributing to global warming.

Table 7

Glossary
Blowing Agent: A gas used to process plastic into insulation and packaging foam. Chlorofluorocarbon (CFC): Known widely as CFCs, these chemicals in recent years have been shown to deplete ozone in the atmosphere. An international treaty - the Montreal Protocol - as well as national laws will ban production for most uses by 1995. The main class of CFCs, known as chloromethanes and including CFC-11 and CFC-12, achieved stunning success as refrigerants, replacing flammable chemicals such as ammonia. Freon: DuPont's trade name for chlorofluorocarbons used as refrigerants, solvents, or blowing agents. Greenhouse Effect (Global Warming): Naturally occurring water vapor and carbon dioxide trap infrared rays from the sun, warming the atmosphere. Without this, the earth's average temperature would be 20 degrees below zero instead of 60 degrees Fahrenheit. Human activities have increased the amount of carbon dioxide and trace gases in the atmosphere, which traps more of the sun's infrared rays, Because warmer air holds more water vapor, the warming effect would be compounded. In the view of many scientists, the average temperature of the earth is already increasing. Anticipated effects of global warming include sea level rise and a change in the areas that are suitable for farming. Hydrochlorofluorocarbon (HCFC): A chlorofluorocarbon with a hydrogen atom, which makes it much more reactive in the lower atmosphere than a simple CFC. Because their life span is shorter, HCFCs are less likely to reach the upper atmosphere and deplete the ozone layer. Hydrofluorocarbon (HFC): A fluorocarbon that contains no chlorine and has no known effect on the ozone layer, but contributes to global warming. HFCs being considered to replace CFCs include HFC-134a for refrigeration and auto and residential air conditioning, HFC-143 for refrigeration, HFC-152a for many refrigeration and air conditioning applications and HFC-123 for commercial air conditioning. Ozone: An unstable form of oxygen formed when three oxygen atoms bind together. Atmospheric oxygen normally consists of two oxygen atoms. At ground level oxygen irritates the lungs and is a major component of smog. In the upper atmosphere, it forms the protective ozone layer. Ozone Layer: A high concentration of ozone gas about 25 miles above the earth, blocking much of the harmful ultraviolet radiation from the sun. Increased ultraviolet radiation causes cataracts and, in light-skinned people, skin cancer. It also reduces crop yields and may harm such life forms as phytoplankton, which are part of the basis of the marine food chain. Refrigerant: A chemical used in air conditioning and refrigeration systems. It absorbs heat when it evaporates, removing it from the air that is to be cooled. The heat is later released away from the cooled space when the chemical is compressed into a liquid state.

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COMPETITIVE IMPLICATIONS OF ENVIRONMENTAL REGULATION IN

THE DRY CELL BATTERY INDUSTRY

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THE DRY CELL BATTERY INDUSTRY
CONTENTS

EXECUTIVE SUMMARY

Throughout the twentieth century and well into the 1980s, dry cell battery technology had remained more or less the same. All dry cells were based on a simple chemical reaction discovered by Alessandro Volta in 1796.

Towards the end of the 198Os, however, significant changes were forced onto the dry cell battery industry, due to two major developments:

* The electronic appliance sector exerted strong demand pressure onto the industry, because it required ever-smaller, lighter and more powerful batteries to power portable goods such as computers, camcorders, and telephones.

* There was also growing environmental concern over the highly toxic metals mercury and cadmium that were contained in the batteries that were produced at the time. They threatened to be released into the soil in landfills or, even worse, to the air if waste containing batteries was incinerated.

German legislators and producers reacted primarily to the second development as the following overview of the history of German legislation concerning batteries shows:

* At a comparably early stage, in 1988, a voluntary agreement between legislators and the German battery industry had been reached with the goal of preventing having to recycle all batteries. Otherwise, German manufacturers feared, legislation to that extent might be enacted at a later stage. The agreement required the industry to reduce the mercury in non-rechargeable batteries and to pay for the recycling of cadmium-containing cells as well as those batteries, whose mercury content could not be reduced. If fulfilled to satisfaction no further legislation would follow, but doing so required high return rates of “to-be-recycled” batteries.

* By the early 1990s, it had become clear that the requirement could not be met. Even though public awareness of the environmental risks associated with batteries had risen substantially, lack of technical understanding prevented successful sorting of batteries, a critical prerequisite for high recycling rates.

* In 1994 recycling of all batteries or levies was thus envisioned by German legislators.

Market pressures and environmental regulation spurred significant research and development activities all over the world. On one hand, this led to the reduction of mercury in non-rechargeable batteries.

Over a period of several years German producers spent approximately \$26 million, equal to about 3% of a single year's revenues, to achieve this goal. On the other hand, alternatives to cadmium-containing rechargeable cells were developed, after it had become clear that the cadmium could not be eliminated. Commercially viable alternatives were found in rechargeable alkaline, nickel metal hydride and lithium batteries.

As a result of the major world-wide research efforts, new product innovations had been developed, which were technologically more advanced than the hazardous waste containing batteries they were intended to replace. The expenditures into the "greening" of the batteries were more than offset by new batteries that could be sold at a higher price because of their higher energy density or rechargeability.

The competitiveness of the German producers, however, had decreased in the wake of these developments. Even though German legislation might have led to first mover advantages, German producers were not able to reap them. In Japan and to a lesser extent in the United States, however, pressures from demanding customers and supporting industries had led to superior and more innovative product developments.

INDUSTRY STRUCTURE

Product

Product Description

Dry cell batteries were to be separated from so called wet cell batteries used in cars and industrial applications. Dry cells were used in many portable applications such as telephones, computers, calculators, game-boys, etc., as well as in stationary equipment provided that the power needed was not very large. Wet cells on the other hand were used, whenever there were fairly large power requirements, They were, as a rule of thumb, far heavier than dry cells. (Figure 1 shows the most important types and formulations of dry cells as well as their typical uses.)

The technology of converting electrical energy to chemical energy and back again dates to Alessandro Volta's 1796 wet cell. All batteries worked on the same principle: electrodes of two different materials exchanged ions through a liquid or gel-like electrolyte. The movement of ions created an excess of electrons at the negatively charged anode. When a charged battery was connected to a circuit, the excess electrons flowed through the circuit to the positive terminal, creating current.

The standard dry cell battery (zinc carbon) was developed decades ago, as were most of the chemical reactions used in them and in the more "modem" batteries as sources of power.[1] Mercury's use in batteries using zinc as anode was to act as a so called inhibitor which inhibits the selfdischarge of the battery.[2] Although there were far more advanced technological alternatives available, the market share of the standard battery in the dry cell batteries market was in excess of 40% in the early 1990s.[3]

1. Dreyfuss 1984, 103.

2. Hiller 1990. 1.

3. ZVEI estimate for German share of batteries disposed in 1992, cited in Baumann / Muth 1993, 5. Nickel metal hydride and lithium batteries are excluded.

Figure 1

Dry Cell Battery Types

Battery Type	Formulation	Common Name	Comments
Primary Cells (non-rechargeable)	Zinc Carbon	Standard Batteries	All uses
	Alkaline Manganese	Long Life Batteries	All uses. typically whenever more power and longevity required
	Lithium	Lithium Batteries	Expensive. therefore whenever extreme small size. extreme longevity and very small self-discharge rate is of benefit. ie hearing aids, pacemakers photographic equipment etc
	Mercuric Oxides	Button Cells	Hearing aids, photographic equipment
	Sliver Oxides		Electronic watches, Calculator
	Zinc Air		Hearing aids
Secondary Cells (rechargeable)	Nickel Cadmium	NiCad	All uses. except where high self-discharge rate is disadvantage Today primarily used in camcorders, portable computers, portable phones etc
	Nickel Metal Hydride	NiMH	Uses as NiCad, but even higher self-discharge rate (approx. 2% per day)
	Lithium	Lithium Ion	Primarily used for audio and video equipment, mobile telecommunications and personal computers

Source: Europile 1991, 2. Silberg 1993, 60.

During the 1980s; dry cell batteries became the object of a hard-fought, high-stakes technological race. Because of the ever-increasing market for portable goods such as calculators, electronic games, walkmans, laptops, palmtops, telephones, vacuum cleaners, and power drills whose market drivers were size, weight, longevity and power. Manufacturers scurried to improve existing batteries and develop new ones for those products.[4]

4. Dreyfuss 1984, 103.

In the sector of primary batteries (non-rechargeable), the first outcome of research and development expenditures had been the alkaline battery in the 1970s. Although the alkaline battery had better longevity than the standard zinc carbon battery, it was still fighting for greater consumer acceptance and larger market shares, in comparison to standard batteries in the early 1990s. Rechargeable batteries because of their targeting of the longevity market primarily competed with the alkaline sector. Thus their growth did not affect the sales of comparably cheap standard batteries, but rather the alkaline sector.[5] The market share of alkalines in Germany was approximately 35% in 1992.[6] A second alternative to standard zinc carbons, the lithium battery, was developed in the 1980s. It promised to be better still with regard to longevity.

Button cells had a total market share of approximately 8% in the early 1990s in Germany.[7] In the secondary (rechargeable) cells segment, the research and development efforts first led to the development of nickel-cadmium cells (NiCads), followed by nickel-metal-hydride (NiMH) batteries. The latest development, which was expected to arrive on the market in the mid-1990s was the rechargeable lithium cell. In the early 1990s, NiCads had a market share of approximately 12% in Germany, NiMHs had only just been introduced.[8]

Lithium batteries were even more powerful than other dry cell batteries. They were extremely small and had the additional advantage that their self-discharge rate (amount of energy lost by battery not in use) was very small even over long periods of time. Due to their high price, their use up to the early 1990s had been limited to specialties where the battery's price was not critical such as pacemakers, hearing aids

5. Key note (1991), 11.

6. ZVEI estimate for German share of batteries disposed in 1992, cited in Baumann / Muth 1993, 5. Nickel metal hydride and lithium batteries are excluded.

7. ZVEI estimate for German share of batteries disposed in 1992. cited in Baumann / Muth 1993, 5. Nickel metal hydride arid lithium batteries are excluded.

8. ZVEI estimate for German share of batteries disposed in 1992, cited in Baumann / Muth 1993, 5. Nickel metal hydride and lithium batteries are excluded.

and other specialty applications. Batteries containing lithium were smaller but less compatible with products on the market in the early 1990.[9]

Whereas the market for primary batteries seemed fairly divided with regard to typical uses of the individual types - each battery type had typical uses for which it was suited best - there was the principal substitutability of primary by secondary batteries. Most types of secondary batteries could be recharged 300 to 1500 times, [10] an advantage, which more than offset the higher initial cost of the battery and its recharger. Panasonic, a producer of both single-use and rechargeable batteries, estimated that, depending on battery type and usage, alkaline batteries were several hundred to several thousand times more expensive than rechargeables.[11]

By the early 1990s, however, many consumers were still unaware of these advantages. In addition rechargeables could not be used for all applications that were suitable for primary batteries, because of some inherent technological restrictions. The most important was their high self-discharge rate, which for instance. prevented their use in smoke detectors and flash-lights. Thus, despite their obvious economic advantages, it was unclear how acceptable rechargeable batteries would become for consumer goods users. [12]

The development of the rechargeable batteries market to some extend depended on battery rechargers, which had to be fast and efficient in order to gain acceptance with the consumer.[13] Beginning in the mid-198Os, with the development of advanced electronic controls that regulated the recharging process, there had been considerable progress in this field and most manufacturers predicted large growth rates in for the future. A very important development in the rechargeable field was the nickel metal hydride battery. It functioned similar to nickel cadmium batteries (NiCads), but contained less toxic metals.

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9. Silberg 1993, 60.
10. Baumann/ Muth 1993, 63.
11. Melnykovych 1993.
12. Melnykovych 1993.
13. Silberg 1993, 60.

Even more hopes were put into the rechargeable lithium cell. In 1993, their market in Japan was $952 million and was expected to grow to $2.38 billion by the year 2000.[14] Lithium ion technology offered an even higher energy density than NiMHs.[15] Companies strong in end products, such as Sony or A&T Battery, were expected to challenge the leaders in the rechargeable battery market, Sanyo and Matsushita Battery, who together commanded around 80% of Japan's NiCad battery market in the early 1990s.[16] In 1992, most manufacturers agreed, that two to three years were still needed to remove technical glitches and reduce the cost of lithium batteries to make them competitive to Nicad or NiMH batteries.[17]

A strong pressure to innovate in the battery industry was spurred to a considerable extent by demand from the electronic goods industry. While electronics manufacturers produced ever smaller and more clever machines, the sleepy battery business had barely changed. Most portable devices had become so light that batteries accounted for 25% of their weight by the early 1990s, compared with 10% a decade earlier. With advances in microchip technology having made even tinier electronic products possible, battery makers were scrambling to come up with lighter, more powerful and longer-lasting batteries.[18] This led to:

* Toshiba America Consumer Products to introduce a line of mercury-free alkaline batteries;[19]

* Rayovac to announce a rechargeable alkaline battery that was based on a new technology developed by Battery Technologies of Canada;[20] and

* Duracell to appeal for standard sizes in the rechargeable battery market (as in primary market) to improve its competitiveness against integrated battery and electronic appliances manufacturers. Manufacturers of electronic appliances seemed to be against it.[21]

14. Reuter 1993a; Exchange rate Yen/$105

15. Eisenstodt 1993, 42.

16. Moffett 1992.

17. Economist 1992.

18. Reuter 1993.

19. Home Furnishings Newspaper 1992, 89.

20. Silberg 1993, 60.

21. Silberg 1993, 60.

To summarize, with regards to the product there was a general tendency towards longevity as a result of the extreme increase in high-drain portable electrical equipment as well as a tendency towards environmentally friendly batteries as a result of regulatory and consumer pressure.[22]

Substitutes

Next to the more fundamental question of whether or not use of electrical mains instead of batteries was a more sensible ecological solution, the battery market itself contained products that could be regarded as substitutes. Another possible substitute to batteries was solar power. There were, for instance, solar powered pocket calculators.

Production Process

The production process of batteries was fairly similar regardless of the specific battery type. With regard to standard cells, zinc ingots were melted down as the first stage of the battery-making process. The molten metal was cooled by water, then ran through a stamping machine. Calots, or blanks the size of an overweight florin. were punched out. and the remaining metal was returned to the furnace. Next was the mixing plant, where manganese ore was grounded down in a giant chemistry set to act as the electrolyte. It was mixed with other chemicals to a black powder in a mixing process that was often remotely controlled by computer. Next the zinc calots were stamped into hollow tubes. In a further step the batteries finally came together. The outer casing was filled with a separator paper, a bottom washer, the chemical mix as well as a carbon rod. Finally, a bitumen and a plastic seal were poured on top. Each battery was tested automatically, then left for five days to settle, and tested again.[23]

Entry or Exit Barriers

An important entry barrier to the battery market was the ability to serve the total battery needs of retail partners and consumers. In particular the Japanese leaders in the rechargeable field had difficulties penetrating the world market without an alliance with a company that had a large distribution network, as there still was considerable education of the consumer to be done. This was exemplified by the entry

22. Key note 1991, 1.

23. Bowen 1993.

of Sanyo, together with Matsushita market leader of NiCads, into the American market: In order to gain access to the U.S. market, Sanyo was required to form a joint marketing agreement for a new brand of battery products carrying a “dual mark” product logo with General Electric.[24]

Another entry barrier, in this case primarily for European and American producers, was the tendency of manufacturers of portable appliances to use non-standard battery sizes to seize the after-sale market. This barrier prompted the American producer Duracell to push for the standardization of NiMH power packs.[25]

Buyers

Buyer Description

Since dry cell batteries were needed for diverse applications, there was no single most important purchasing criterium, other than price. Other purchasing criteria were power, longevity, ease of use, and to a lesser extent environmental friendliness and brand recognition.

Standard zinc carbon and alkaline primary batteries were primarily bought for comparably “simple” uses such as flashlights. The remaining comparably expensive non-rechargeable batteries (non-rechargeable lithium and button cells) were used for more advanced appliances where high power and low weight as well as longevity were of utmost importance, such as in cameras and hearing-aids. The still more expensive rechargeable batteries (NiCads. NiMHs and rechargeable lithium cells) were bought for even more technologically advanced appliances such as portable telephones, microcomputers or hand-held power tools.

Forty percent of batteries were bought for portable or audio uses, 21% for toys and games, 17 % for flashlights, 12 % for cameras and 10% for miscellaneous reasons .[26]

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24. Newswire 1993.

25 Silberg 1993, 60.

26. Home Furnishings Newspaper 1992, 3.

Distribution Channels

As battery purchases often arose as a result of "distress" demand, there was a high level of sales through convenience stores such as tobacco stores, news agents and gas stations, which offered extended opening hours and convenient locations (Table 5). Electrical retailers sold many batteries with new equipment, but had not been able to penetrate the aftersale market. Supermarkets and grocers sold just under 30% of total sales.[27] This distribution pattern varied from battery type to battery type. While supermarkets and grocers tended to sell a larger section of the standard battery sector, electrical retailers were particularly strong in the alkaline sector.[28]

Switching Costs

In the primary battery market (non-rechargeable), switching costs were low because battery sizes and voltages had been standardized since 1926, allowing an easy exchange of batteries from different manufacturers.[29] However, with regard to the secondary battery market, there were some potentially high switching costs. Producers of portable devices tried carefully to uphold these costs by designing equipment that only facilitated their own batteries, allowing them to capture the aftermarket.

Environmental Regulation

Environmental Risks

Mercury and cadmium used in varying contents in almost all dry cell batteries with the exception of zinc air and primary and secondary lithium cells, posed a great threat to the environment when disposed, as their casing began to leak after some period of time. If these batteries were incinerated, the situation became even worse, as it was very expensive to filter the incinerator's air output to accommodate ever-growing battery numbers. Figure 2 lists the greatest environmental risks in production, use and disposal per battery type.

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27. Key note 1991, 5.
28. Key note 1991, 5.
29. Dreyfuss 1984, 103.

The greatest environmental threats resulted from mercuric oxide button cells and non-recycled NiCad secondary cells, since these contained the most hazardous waste by weight. In the early 1990s, mercuric oxide button cells experienced decreasing sales and had been announced by manufacturers to be taken off the market by the mid-1990s due to rising costs of disposal and recycling combined with better alternatives.[30] In total, the mercury from dry cell batteries accounted for a sizeable proportion of the mercury content in household waste not incinerated, approximately 9 tons in 1991. This amount was expected to decrease as a result of decreasing sales of mercuric oxide cells.[31]

German dry cell battery producers accounted for approximately 33% of the total cadmium consumption in Germany.[32]

Current Environmental Regulation

Battery manufacturers were subject to a range of environmental regulations. The most important "regulation" in Germany, however, was not a law, but a voluntary agreement between the German Ministry of the Environment and German battery producers and importers signed in 1988. It required them to reduce the mercury content of batteries and to start recycling programs. Specific legislation was to be passed in Germany in the summer of 1994. It had been necessitated by a 1991 E.C. directive that required E.C. member countries to enact legislation forcing reduced mercury contents and regulating recycling programs. Figure 3 summarizes the most important contents of these regulations.

The voluntary agreement of 1988 between German battery producers, importers and retailers, and the Ministry of the Environment indisputably put pressure on the industry with regard to the "greening" of the batteries. The fact that batteries containing hazardous wastes were to be recycled and had to carry a label saying so, meant that the consumer had the chance to distinguish "clean" (no recycling label) from

30. Baumann / Muth 1993, 28; Taylor 1993.

31. They were the fifth highest cause of mercury in non-incinerated waste surpassed only by normal household waste (60 tons), Alkaline-chlorine-electrolytes (47 tons), fossil fuel power plants (21 tons) and dentists (10 tons). Source: Baumann / Muth 1993, 111/112.

32. Figures for 1989, Source: Rauhut (n.d.), 6 cited in Hiller 1992, 1; Similar figures in Baumann / Muth 1993, 114.

hazardous (recycling label) batteries.[33] However, accompanying information programs to educate the general public were poor, resulting in fairly low recycling rates. This forced the German Ministry of the Environment to plan specific legislation that would assure adherence to the stricter standards set by the E.C. directive enacted in 1991. The E.C. directive had originally been pushed primarily by German authorities to reduce unfair market conditions for German producers that resulted from the previous voluntary German agreement. In 1994 German battery producers were, together with their European competitors, fighting heavily against both the introduction of recycling for all batteries, which in their eyes was unnecessary and economically not feasible, and the introduction of a levy on batteries.[34]

The regulation with regards to informing the public was unclear and rather diffuse both in the E.C. directive as well as in the voluntary agreement. Clear and specific public education programs, however, were a prerequisite for high battery return rates. The general public needed to be informed well to be able to distinguish those batteries that were to be recycled from those not to be recycled in order to avoid high sorting costs before recycling. By 1994, six years after the voluntary agreement had been signed, it became obvious that low public awareness had led to low battery return rates and high sorting costs, hence, posing the greatest problem. This resulted in German legislators pushing for the recycling of all batteries as well as levies on some battery types.

Technologically there seemed to be no feasible way to reduce the cadmium content of NiCad batteries which could reach some 20 % Thus, regulation regarding NiCads was limited to recycling and disclosure requirements. With the arrival of feasible and environmentally sound alternatives to NiCads (NiMH, lithium ion), it could be hypothesized that in the long run NiCads would simply be forbidden or made unattractive by requiring extraordinarily high levies on them in the E.C.

The E.C. directive also included the possibility, but not the requirement, to impose a levy on batteries to help pay for recycling or to charge a deposit on sales of batteries in order to encourage consumers to

33. German Ministry of the Environment 1992, 2.

34. See discussion of logic behind recycling and levy below.

Figure 2

Environmental Regulation: The German Battery Industry			
Regulation Battery Type	**E.C. Directive**	**German Voluntary Agreement**	**Proposed German Regulation**
All Batteries In General	Prohibit appliances with non-removable batteries as from January 1, 1994, Develop programs to reduce hazardous waste, Organize recycling programs, Inform public; Revise above programs regularly to accommodate technical progress	Prefer batteries without hazardous waste In production, development. Industry to finance research to reach goal to reduce mercury content in alkalines to 0.1% by 1990, <0.1% by 1993	Collect and recycle all dry cell batteries
Zinc Carbon Batteries		Reduce mercury content from 0.01% to 0%	
Alkaline Manganese Batteries	Mercury content <0.025% as from January 1 1993 Separate collection and disposal	Reduce mercury content from 0.35% to <0.15% by end of 1988, Collect and recycle if mercury content>O.1% (paid by producer)	Mercury content <0.25%
Button Cells (Mercuric Oxides, Silver Oxides, Zinc Air)	Separate collection and disposal if more than 25mg mercury Dlsclose hazardous waste content	Collect and recycle (paid by producer)	&close if more than 25mg mercury
Lithium Batteries	No specific regulation	No specific regulation	No specific regulation
Nickel Cadmium Batteries	Separate collectIon and disposal if cadmium content >O.025%	Collect and recycle (paid by producer)	Dlsclose if more than 0.025% cadmium
Nickel Metal Hydride Batteries	No specific regulation	No specific regulation	No specific regulation
Lithium Ion Batteries	No specific regulation	No specific regulation	No specific regulation

The E.C. directive was passed on March 18, 1991 and came into effect on January 1, 1993. Directive was to be taken up by national law by September 18. 1992.
Voluntary agreement was between German Ministry of the Environment and Industry and Retailers in Germany from September 9, 1988.
Percentages concern content by weight.

return them for recycling when used.[35] Until the early 1990s these measures had been successfully fought

35. E.C. directive 1991, paragraph 7.

against by producers and importers, who accused them to be an unnecessary regulation of trade, although both Swiss and German legislators were thinking about such solutions. If recycling rates could not be increased in Germany, such measures were expected to be taken by the Ministry of the Environment in order to increase battery return rates.

Other regulations concerning the dry cell battery market, but not directed at it included:

* Legislation covering waste in general ("Abfallgesetz" of September 18, 1990), which set out the priorities in the handling of waste in general. Similar to legislation in the E.C., this law gave priority to waste reduction in general over its utilization or recycling, which in turn had priority over disposal. Recycling was to be carried out if technically possible, if it could "reasonably" be expected. and if a market for resulting goods or energy existed or could be created. These measures were to be paid for by the party that was obliged to dispose of the good by law. In the case of the battery industry this was the manufacturer who had voluntarily agreed to take on this obligation; .[36]

* Legislation regulating the ways of disposal per type of waste ("Technische Anleitung Abfall" of April 1, 1991). According to this regulation, NiCads and batteries containing mercury had to be disposed of in expensive underground landfills. Other dry cells could be disposed of in less costly hazardous waste landfills;[37]

* Legislation regulating which chemicals were to be considered as hazardous waste ("Abfall-bestimmungs-Verordnung" of October 1, 1990);

* Legislation regulating which goods had to be recycled in accordance with the "Abfallgesetz" ("Reststoffbestimmungs-Verordnung" of October 1, 1990); and

* Legislation regulating emissions by incinerators ("Verordnung uber Verbrennungsanlagen fur Abfalle und ahnliche brennbare Stoffe - 17. BlmSchV" of December 1, 1990). This regulation set emission limits. For cadmium these were 0.02 mg/Nm^3, 11% O_2. and for mercury 0.05 mg/Nm^3, 11% O_2.

Focus of Regulation

Battery regulation was aimed primarily at the producer. Even recycling laws were aimed at the battery industry itself, since battery manufacturers were required to facilitate the recycling programs. Neither

36. Baumann / Muth 1993, 6.

37. Baumann / Muth 1993, 7.

the actual battery production process, nor battery use was regulated since there were no apparent dangers in these fields. Battery disposal was the main focus of regulation. The E.C. directive's goal was to sensibly reduce the level of hazardous waste disposal in whatever way technically feasible. Informing the public and setting up recycling schemes were part of such solutions.

Type of Regulation

Most of the regulations governing batteries were performance standards or outright command-and-control measures. There were regulations forbidding appliances from which batteries could not be removed easily, standards which regulated the level of cadmium and mercury emissions from incinerators, and limits on mercury and cadmium contents.

Other types of regulations included disclosure requirements in order to enable effective recycling programs and voluntary agreements like the agreement to reduce mercury in primary batteries and to recycle mercuric oxide cells and NiCads between German producers and importers and the German Ministry of the Environment. There were also some market-type regulations such as the E.C. directive's inclusion of the possibility to enact the imposition of a levy on batteries to help pay for recycling or to charge a deposit on sales of batteries.[38]

Industry/Government Interaction

It was interesting to observe the evolution of the regulation setting process in the battery industry. In 1988, German producers and importers signed a voluntary agreement, burdening them with substantial investments into "greening" their products and setting up collection schemes. The reason for the industry to do so was that the hope to get around the necessity to recycle all primary batteries containing mercury.[39] In addition, the argument might have been to act early, so as to have clear planning possibilities and later reap first-mover advantages.

38. E.C. directive 1991, paragraph 7.

39. See discussion below.

Undoubtedly the German industry had managed to reduce the level of mercury level in household waste dramatically by research and development activities. Up to the early 1990s recycling programs had not been successful, with the effect that the E.C. directive's goals were not being met in Germany by means of the voluntary agreement. In the eyes of some officials at the German Ministry of the Environment, this had been the result of the producers' and importers' efforts to try to impose the responsibility of sorting the batteries onto the general public. This did not work. The average consumer was not able to separate hazardous from non-hazardous batteries.[40] The German legislators in effect had no other choice than to impose tougher rules - recycling of all batteries, which meant there was no necessity of sorting for the consumer. Also, a levy seemed likely, at least in the long run. The apparent strategy of the producers to get around further regulation with the help of the voluntary agreement had in effect not worked out.

40. Bundesumweltamt: Genest. Personal communication to the author

COMPETITION

Germany

Competitiveness Overview

Germany was the fourth largest exporter of dry cells in the early 1990s after Belgium, USA, and Japan. In 1991, the German export share in the dry cell battery market was approximately 8% of world exports (Table l-3). At the same time, Germany was the world's second largest importer with a share of 8% of world battery imports. This resulted in Germany having the third largest negative trade balance with regard to batteries, after the Netherlands and Hong Kong (Table l-3).

In 1992, the German dry cell battery market amounted to approximately $790 million,[41] compared to the $4.2 billion market in Japan.[42] It was interesting to note the difference in the segmentation of these markets. Secondary cells were much less significant in the German than in the Japanese market, accounting for only 33% of the German markets' value in 1992,[43] compared to a very high 66% in Japan.[44]

Leading Firms

The German battery industry employed approximately 12,000 employees and had revenues of approximately $1.2 billion per year in the early 1990s.[45] German battery production was dominated by Varta, the leading German battery maker, which employed some 9,000 people. Varta produced a complete range of batteries (Table 4).

41. Author's own estimate.

42. Economist 1993.

43. 87.8 % primary by weight, which approximates to 66% by value. Source: Baumann/ Muth 1993, 5.

41. Economist 1993. See Tables 1 and 2 in the appendix.

45. Baumann / Muth 1993, 4. Exchange rate DM/$1.70.

Distinctive Strategies or Features in Country

The German dry cell battery industry was not distinguished by its inventiveness. In the 1970s and 1980s, the rapid developments in the rechargeable battery market pushed mainly by appliances producers' need for smaller and more powerful batteries had been largely missed by German producers. Another reason for this fact was the buyer segmentation (see above). Towards the end of the 1980s however, the largest producer, Varta, engaged in major research and development activities to avoid losing out from this largest growing segment of the market, especially of the NiMH and lithium ion types. It also formed a joint venture for the development of rechargeables with Toshiba and Duracell, none of whom were market leaders in this sector of the market.

It thus appeared as if Germany's battery producers were more or less waiting for the best technical development in the field and only then reacting to the market. This strategy was financed by profits in other business segments - Varta was a whole range producer of batteries and earned most of its revenue in the wet cell automotive sector. Its results were shrinking German market shares in the dry cell market and an uncompetitive position in the growing rechargeable battery market, a segment where Japanese producers had become world leading.

Japan

Competitiveness Overview

Japan's export share in dry batteries had fallen from 17% in 1987 to around 13% in 1991, possibly as a result of trying to improve their world market position by establishing production plants outside of Japan (Table l-3). Japan was the world's third largest exporting country.

Japanese dry cell battery imports were very small, accounting to only 1.9% of world imports in 1991. This left Japan with a huge trade surplus of more than $250 million in 1991 (Table l-3).[46] The Japanese dry cell battery market totalled US $4.2 billion in the early 199Os, of which approximately 66% were secondary cells.

46. United Nations, International Trade Statistics Yearbook, vol. II, var. ed.

Leading Firms

The Japanese battery industry was dominated by a small number of firms. Sanyo and Matsushita together commanded 80% of the Japanese NiCad sector[47] and Sanyo, Matsushita and Toshiba were the strongest contenders for the growing NiMH segment. Other producers included Sony Energytec, Hitachi Maxell and Furukawa Battery.

Distinctive Strategies or Features in Japan

Japanese producers concentrated mainly on the secondary dry cell market, which was driven by sophisticated demand from world-leading Japanese producers of electric and electronic appliances. By the early 1990s it had become more and more apparent that this had been a very wise choice, since mounting worldwide "greening" pressure had made rechargeable cells very attractive to consumers. With NiMH and the even more advanced rechargeable lithium cells, rechargeable products that were environmentally friendly had been developed. These were widely expected to experience dramatic growth rates throughout the 1990s to the detriment of primary cells.

The United States

Competitiveness Overview

The U.S. was the world's second largest exporter of dry cell batteries after Belgium (whose battery industry was dominated by American firms). The American export share in the dry cell battery market had increased from 8.68% in 1987 to more than 14% of world exports in 1991 (Table l-3). This increase was the result of the growing strength of the two leading U.S. battery makers, Duracell and Ralston Purina. At the same time, the U.S. import share had decreased to just above 8% of world imports in 1991, giving the U.S. a large trade surplus in the dry cell battery market.

The U.S. battery industry changed dramatically during the mid-1980s. From being a large net importer of batteries in 1987, the U.S. had become the third largest net exporter, preceded only by Belgium and

47. Moffett 1992.

Japan. As in Germany, but unlike the case in Japan, secondary cells represented a rather small share of the American market and accounted for only 25% of domestic battery sales in the early 1990s.[48]

Leading Firms

The U.S. battery market amounted to some $3 billion per year in the early 1990s,[49] of which approximately two thirds or $2 billion were sales of alkaline batteries.[50] The market for rechargeable cells amounted to $650 million in the early 1990s and was expected to grow to $1 billion by 1995.[51]

The largest producer in the U.S. was Ralston Purina. Though at root a pet food company, Ralston had become the biggest battery-maker in 1985, after it acquired U.S. Eveready from Union Carbide. In 1992, it also acquired U.K. Eveready from Hanson.[52] Ralston Purina, in addition to its strong base in standard life primary cells, had two alkaline battery factories in France and in Switzerland.[53]

The other large American producer was Duracell, the world leader in the alkaline sector of the market, which in the early 1990s was still growing, although in principal substitutable by rechargeable batteries, In the early 199Os, the combined domestic market share of Ralston Purina and Duracell was approximately 80%. However, it was seriously threatened by the growing share of rechargeable batteries. a sector that was dominated by Japanese producers.[54]

Other important American producers included Rayovac, producing primarily button cells, with a domestic market share of 10% and Kodak, producing primarily lithium cells, with a share of 7% .[55]

48. Author’s own estimate.
49. Rudd and Tait 1992, 1.
50. Liesse 1993.
51. Gale Research 1993, 4.
52. Cowe 1992. 13.
53. Bowen 1993a.
54. Author’s own estimate.
55. Thomson Financial Networks 1992.

EFFECTS OF REGULATION ON COMPETITIVE ADVANTAGE

Reduction of Mercury Content in Primary Batteries

Regulation-induced innovation had a strong impact on the battery industry's competitiveness - both positive and negative. One area of innovation that was particularly affected was the reduction of mercury content in batteries. As a result of their voluntary agreement to reduce the mercury content in primary batteries, German producers had invested heavily into research and development and associated production process changes of alternative technologies. German producers, namely Varta, the only primary battery producer in Germany, were thought to have invested $26.5 million into reducing the mercury level in zinc carbon and alkaline batteries, representing some 257% of the European total of $106 million.[56] This amount was the result of research and development, changes in the production process, plus extensive field tests to appraise the technical feasibility of the reformulated batteries. Mercury, which had been used in nearly all batteries to lessen the internal generation of explosive gas, had been reduced by the introduction of zinc of a higher concentration.[57]

The reason why this investment had seemed attractive at the time was the fact that batteries containing little or no mercury could be disposed of together with normal household waste, rather than having to be recycled or collected and then disposed of in specialized and expensive landfills -- the cost of which according to German legislation the battery industry was to bear. The cost of battery reformulation thus promised to be offset by reduced costs of disposal, which had been expected to amount to approximately $600 per ton.[58] However, as mentioned, the promise did not materialize since the zinc used in batteries was later also declared a hazardous waste by German legislation because it included traces of cadmium. Thus mercury free batteries could still be disposed of only in specialized landfills.

Contrary to expectations, the removal of mercury from primary batteries had not reduced the cost of raw materials, since the mercury had been replaced by cleaner, and therefore more expensive, zinc, while the

56. German Battery Producer's Association: Kiehne, Director. Personal communication to the author.

57. Europile 1991, 4.

58. Baumann / Muth 1993. 107.

production process itself had remained more or less the same.[59] It could not be determined, whether the, reduction of mercury levels in alkaline batteries had affected their production costs. As mercury was removed from primary batteries, the production process became safer since no more carcinogenic materials had to be handled. This resulted in a reduced liability exposure, which could not be quantified There was a curious by-product to the battery industry's efforts to develop environmentally friendly batteries. By concentrating on new product launches and marketing activities in the "green" battery sector, producers had encouraged consumers to think of batteries as potentially harmful products.[60]

Recharging of Primary Batteries

One of the most surprising developments in the battery industry was the 1992 announcement of the rechargeable alkaline battery. Rayovac, an American producer, introduced such a battery called "renewal" that was based on a technology developed by the inventor of the alkaline battery himself, Professor Kordesch at Battery Technologies of Canada.[61] Rayovac's new batteries could be recharged up to 25 times, but cost only twice as much as conventional alkaline cells. In addition, they had a much smaller self-discharge rate than conventional secondary cells (only 0.2% per month compared with up to 2% per day). Low self-discharge rates were important for two reasons. On one hand, they allowed secondary cells to be utilized in flash-lights and the like. On the other hand, rechargeable cells could be sold fully charged, which was valued by customers.[62]

Even more surprising was an announcement made in 1994 by a researcher of the renowned Eidgenossische Technische Hochschule (Technical University) in Zurich, Switzerland. Standard alkaline batteries could also be recharged several times. Manufacturers had always contended that alkalines could not be recharged, and would explode if attempted to be recharged. In fact, this was explicitly stated on all alkaline batteries sold in Germany. Provided that certain safety precautions were undertaken, standard alkaline batteries could be recharged in rechargers used for NiCads at least up to 10 times without

59. C. Emmerich: Braun, Marketing Director. Personal communication to the author.

60. Key Note 1991, 10.

61. Silberg 1993, 60.

62. Zinniker 1993. 2.

additional cost.[63] They had to be recharged before the batteries were completely empty (best results if recharged at 70% full) and over-recharging was dangerous, because it caused the batteries to burst, releasing its alkaline electrolyte into the recharger. The battery industries' claims, that recharging standard alkaline batteries would cause them to explode, were simply not true.[64] The alkaline battery suddenly threatened to be a low cost competitor for NiCad and NiMH batteries.

Interestingly, this technology was not new. It had been known since the first introduction of alkaline batteries, that in principle they could be recharged.[65] Even standard zinc carbon batteries were theoretically rechargeable, although no tests of its economic and technological feasibility were known. Rechargeable alkaline batteries and the recharging of standard alkaline batteries were still fairly new developments in 1994. surrounded with much uncertainty as to their feasibility. If successful, they would be a great bonus to the environment, since recharging a battery 10 times amounted to a waste reduction of 90 % , at considerably lower cost. However, they also promised to pose a tremendous dilemma to the battery industry, which would have to decide how to maintain its profitability in the face of falling sales of batteries that suddenly lasted 10 times longer. The beneficiary of rechargeable alkalines were likely to be the environment, the consumer, and the manufacturer of the recharging instrument. The battery producers, however, were only likely to lose.

It was unclear whether these innovations were spurred by strict environmental regulation or simple economic reasons. It should be noted however, that environmentally conscientious consumers and strict legislators had shook up an otherwise slow industry.[66] This had spurred a lot of innovations, of which the rechargeable alkaline cells was just one.

63. Zinniker 1993, 1.

64. Zinniker 1993, 3-4.

65. Linden 1993. Cited in Zinniker 1993, 1.

66. Economist 1993.

Levies on Rechargeable Nickel Cadmium Batteries

NiCad batteries were under strong pressure from regulators, because they contained large amounts of cadmium, a very toxic metal. By 1994, it was still impossible to reduce the Nicad battery's cadmium content. Thus, manufacturers and regulators focused their efforts on the recycling of NiCads.

As was mentioned before, the E.C. directive included the possibility to enact the imposition of a levy or sales deposit on batteries to help pay for their collection and recycling.[67] Such measures had until 1994 been successfully fought against by producers and importers who accused them to be an unnecessary trade restriction. In 1994, however, German as well as Swiss legislators were thinking about such a solution to help increase the consistently poor return rates on NiCads, causing the battery industry to rally against it with the following arguments:

* "Disadvantage" for producers of those batteries covered by the regulations since prices of their batteries would rise in comparison to possible alternative batteries;

* Risk of misuse was high, at least as long as other European countries did not enact similar legislation, since batteries for which no levy had been paid could be returned in countries with levy-systems to collect the levy. Origin labelling that would prevent this kind of "battery tourism" was accused of being too expensive; and

* A levy would be effective only after several years, since rechargeable batteries last up to seven years. (The long life-span was disputed by others.)

Since it was undisputed that a levy was some sort of burden for the producers and importers concerned, it was being negotiated whether the levy would only be enacted if recycling rates did not rise (i.e. if the prime objective of the levy could not be reached solely by better informing the public). If enacted, the NiCad levy would provide a strong incentive to the development of environmentally sounder alternatives, such as rechargeable alkalines, NiMH or rechargeable lithium cells (see below). Swiss regulators for example had suggested a levy of $1.33 on each NiCad cell, which would make competing batteries more attractive to consumers by this amount.[68]

67. E.C. directive (1991), paragraph 7.

68. Swiss Ministry of the Environment: Studer. Personal communication to the author. Exchange rate Sfr/$l.50.

Nickel-Metal-Hydride Rechargeable Batteries

Nickel-Metal-Hydride rechargeables were a fairly recent development. On first sight it seemed that the extreme growth rate of the rechargeable market had been spurred by environmental considerations, since the recharging of cells containing hazardous wastes was preferable to the disposal of huge amounts of primary cells. But, in reality, this growth had been caused primarily by the growth of the electronic appliances market, such as portable telephones. Since its producers where primarily based in Japan, the secondary dry cell sector was also dominated by this country.

The newest marketable development in the rechargeable field, the NiMH cell, had been developed in response to environmental concerns since the NiCad battery, which it was intended to substitute, had come under increasing environmental pressure all over the world. In the mid-1990s their price was still twice that of NiCad batteries and their self-discharge rate was reported to be twice as high as that of conventional NiCad rechargeable batteries. However, these disadvantages were offset by a 60% higher energy density which should give them an advantage in the portable field - some analysts predicted their growth rate would be three times as high as that of NiCad rechargeable batteries.[69] resulting in a share of more than 25% of the rechargeable market by the mid-1990s.[70] Also, the voltage was the same for either battery, meaning products built to accommodate NiCad batteries could still accommodate NiMH cells.

In terms of cost per unit of storage, NiMH batteries were as expensive to produce as the NiCad batteries they were intended to replace. With the realization of experience curve effects in large production volumes, it was reasonable to expect NiMH production costs to fall in the future. Given their double energy density, they were to initially sell for roughly twice the price of NiCads, not even factoring the price premium its customer might be willing to pay for the additional utility he derived from a

69. Silberg 1993, 60.

70. Moffett 1992.

comparably lighter and longer lasting battery.[71] The cost of converting from NiCad to NiMH production could not be determined, but one manufacturer reported to have spent some $2 million within two years.[72]

Battery Recycling

Since manufacturers were required to facilitate battery disposal or its recycling in Germany, much development work had focused on this area. Provided the content of batteries could not be made environmentally safe to begin with, recycling seemed to be the soundest solution, for it offered a chance to safely extract and either reuse or dispose of the hazardous materials a battery contained. Recycling of batteries had a long tradition in Germany, as wet cell batteries had been recycled for more than 100 years .[73]

According to the German battery industry, a number of prerequisites had to be met in order to make battery recycling of both primary and secondary batteries successful:

- A sufficiently high collection rate for recyclable batteries (given in principle, but exact levels highly disputed);
- Availability of recycling technology;
- Reusability of battery contents (given for mercury, silver, and cadmium); and
- Economic feasibility (given for mercury, if in sufficiently large concentrations, for silver. and to a lesser extent for cadmium, but not for zinc according to producers).[74]

Sufficiently high return rates (prerequisite 1) was the subject of much debate. Whereas producers claimed that the voluntary agreement requiring producers and retailers to take back batteries containing high levels of mercury and NiCads had lead to return rates of approximately 50% for NiCads and approximately 70% for mercuric oxides in the early 1990s, there were other sources which contended that the return

71. Economist 1992.

72. C. Emmerich: Braun. Marketing Director. Personal communication to the author. Exchange rate DM/$1.70.

73. Kiehne 1990, 1.

74. Hiller 1990, pp. 6.

rates were much lower (35% and 28% respectively).[75] These low rates had lead to the necessity of stricter regulation in Germany to comply with the E.C. directives' goals as was described above.

In the early 1990s several different recycling technologies were available (prerequisite 2). In principle one could recycle mixtures of all batteries in a single process, or separate batteries first at a cost of about $580 per ton and then recycle them individually.[76] The first method was employed in Switzerland by a company called Recytech at a cost of approximately $3,200 per ton.[77] Once sorted, NiCad rechargeables were recycled in a French plant in Snam, at a cost of approximately $2,900 per ton.[78] Button cells, once sorted, were recycled by the German company NQR for $7,650 per ton.[79] These costs did not include storage and shipping.

Reusability of raw materials contained in batteries (prerequisite 3) was given for mercury, silver and cadmium. Other chemicals were of no further value in the early 1990s and had to be disposed of in landfills (cost of disposal of non-reusable recycling products are included in costs of recycling above).

The last prerequisite was the most debated one. Its requirement would be fulfilled (i.e. a win-win situation realized) if the price of the recycled constituent was lower than the price on the prime market. Whether or not this was the case could not be determined.

To a great extent the economic feasibility was a function of the recycling rate. The prerequisite for a high recycling rate was strict disclosure requirements making separate collection of batteries possible. An alternative that was not favored by producers was the simple recycling of all batteries. In addition, to get wide participation rates, the general public had to be well informed. If recycling rates could be

75. Baumann / Muth 1993, 91.

76. Baumann / Muth 1993, 107.

77. Recytech, Amman: Marketing Director. Personal communication to the author. Exchange rate Sfr/$l.50

78. Baumann / Muth 1993, 107. Exchange rate DM/$1.70.

79. NQR: Personal communication to the author. Exchange rate DM/$1.70

increased it could be hypothesized that a viable recycling market would develop (in 1994 there were only a few recyclers) with the likely result of reduced recycling costs.

Taking the high costs of disposal or recycling into consideration, the reduced disposal costs of mercury free primary batteries thus represented a substantial offset to the initial cost of removing the mercury from batteries. The cost of disposing mercury free batteries in landfills was substantially lower than having to recycle batteries containing mercury.[80] Taking into consideration the above mentioned sorting and additional storage and shipping costs, this amounted to approximately $3,000 per ton.[81]

In addition, a possible offset in general terms was to be seen in reduced disposal costs if recycling of all batteries as proposed by German regulators could be waived by increasing return rates of environmentally hazardous batteries. If these return rates could be increased, the German legislature would have no reason to propose such regulation. This amounted to approximately $1,500 per ton.[82]

Indirect Effects in Pollution Control Industries

An industry that was indirectly affected by regulations concerning primary dry cell batteries was the incinerator industry. Since the permitted level of mercury and cadmium emissions had consistently decreased, high investments in filtering the incinerators' emissions were necessary. Estimates of some experts totalled such investments at $2 million with additional annual operating costs of about $150,000.[83] Taxpayers would bear the cost. Through the removal of mercury from primary cells these costs could be saved.

In addition, the development of alternative technologies was spurred by growing concern over mercury emissions from incinerators. An incinerator in Lee County, Florida, used a carbon injection system on

80. See discussion of removal of mercury from primary batteries above.

81. Author's own estimate ($588 sorting + $588 storage and shipping + $2,500 cheapest recycling - $600 disposal cost = $3,076).

82. Cost of recycling at only available recycler of all batteries in Switzerland minus approximate average disposal cost in mid 1990s ($1000 per ton).

83. Weber 1993, 1.

smokestacks, in which mercury attached to the carbon and was removed. The Lee County facility was the first in the U.S. to use this cheaper technology.[84]

International Effects

In a few instances, German manufacturers were able to transfer their German experience to foreign markets. Its pioneering development of low mercury-content batteries, for example, arguably gave Varta a first mover advantage. However, Varta was unable to translate this advantage into a market share increase.[85] Nevertheless it allowed Varta to use the experience gained in the German market to convey an environmentally concerned image in other markets. Varta had been the first brand to develop the concept of the green battery in the U.K., introducing a mercury-free zinc carbon formulation in January 1989. Its lead in this sector was partly due to the more environmentally-conscious German market, which had already taken to the idea, and also presaged moves by the European Community to regulate the level of mercury and other noxious materials in dry cell batteries subsequently. A number of other competitors rapidly jumped onto the green bandwagon -- Kodak, Philips, and Panasonic were selling mercury-reduced cells in the U.K. within a few months -- but Varta was said to have gained a significant advantage within the British market from this move.[86]

84. Weber 1993, 1.

85. Get-man Battery Producer's Association: Kiehne, Director. Personal communication to the author.

86. Key Note 1991, 4.

APPENDIX

Table 1

Dry Cell Batteries
World Export Share Development

	1987	1989	1991
Belgium	13.7%	15.0%	15.2%
United States	8.7%	11.7%	14.5%
Japan	17.1%	16.3%	13.1%
Hong Kong	4.3%	7.3%	7.8%
Germany	8.6%	8.3%	7.6%
U.K.	8.9%	5.5%	6.1%
China	2.8%	4.6%	5.6%
Netherlands	5.4%	5.1%	4.7%
Singapore	4.1%	4.5%	4.2%
Switzerland	5.3%	4.8%	3.9%
Other	21.3%	17.1%	17.3%
TOTAL	$1,475,512	$1,780,995	$2,454,445

Note: Amounts in $1,000
Source: United Nations. International Trade Statistics Yearbook, vol. II, var. ed.

Table 2

Dry Cell Batteries World Import Share Development			
	1987	1989	1991
Hong Kong	4.9%	6.4%	9.0%
Germany	8.2%	7.2%	8.5%
United States	15.4%	10.7%	8.1%
Netherlands	6.3%	8.7%	7.4%
U.K.	7.9%	7.4%	6.8%
Belgium	4.3%	4.3%	4.8%
Singapore	1.8%	2.4%	2.7%
Japan	0.7%	1.5%	2.1%
Switzerland	2.4%	2.1%	1.9%
China	0.2%	0.4%	0.7%
Other	48.2%	48.9%	48.1%
TOTAL	$1,538,611	$1,885,543	$2,469,695

Note: Amounts in $1,000
Source: United Nations. International Trade Statistics Yearbook, vol. II, var. ed.

Table 3

Dry Cell Batteries
World Trade Balance Development

	1987	1989	1991
Belgium	136,844	185,518	254,295
United States	-109,127	6,152	155,756
Japan	240,459	261,837	269,723
Hong Kong	-11,588	9,910	-30,458
Germany	667	11,724	-21,726
U.K.	10,146	-42,731	-17,958
China	39,008	75,210	120,528
Netherlands	-16,939	-73,730	-67,654
Singapore	33,179	34,185	37,992
Switzerland	41,325	46,69 1	47,998

Note: Exports-Imports, amounts in $1,000, historical prices.
Source: United Nations. International Trade Statistics Yearbook, vol. II, var. ed.

Table 4

Leading German Dry Cell Batteries Producers

Company	Sales	Exports	Employees	Year Founded	Comments
Varta AG, Hagen	Dry Cells: DM868 million (1992)	55%	14,000, of which 6,000 in dry cells world wide, 1,500 in dry cells Germany	1888	Produces a complete range of batteries, including automotive batteries
C. Emmerich, Frankfurt	8- 10 million cells	Low	Approximately 400	1946	Specializes in NiCads and NiMh
Sonnenschein Lithium, Budingen	DM22 million	64 %	Approximately 100	1910	Subsidiary of a small producer of a automotive and wet gel batteries; specializes in lithium cells

Source: Author’s own research.

Table 5

Sales of Dry Cell Batteries by Outlet in the U.K. (By Value)		
	1988	1990
Supermarkets and Grocers	28%	29%
Variety Stores	18%	17%
Confectionery-, Tobacco- and News-Sellers	10%	12%
Electrical Retailers	9%	8%
Chemists	8%	8%
Hardware and Do-It-Yourself Stores	5%	6%
Other	22%	20%
TOTAL	100.0%	100%
Source: Key Note 1991, 5.		

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COMPETITIVE IMPLICATIONS OF ENVIRONMENTAL REGULATION IN

THE PRINTING INK INDUSTRY

This case study was prepared by Claas van der Linde, Hochschule St. Gallen. The research was conducted in collaboration with the Management Institute for Environment and Business (MEB) and the U.S. Environmental Protection Agency. Copyright 1994 by MEB. The author gratefully acknowledges the assistance provided by Michael Brockhaus.

THE PRINTING INK INDUSTRY
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EXECUTIVE SUMMARY

Most innovation in the printing ink industry occurred due to environmental pressures coupled with economic concerns. Printing inks were produced for use with printing machines, which, by a variety of different technologies, applied them in liquid form to some substance, usually paper, where they dried, Most printing inks consisted of two parts: A mix of pigments and resins which constituted the final print on the paper, and a liquid carrier that was used to transport the pigments to the paper, after which it was to dry by evaporation or oxidization.

Both parts, pigments and liquid, posed a series of threats to the environment which resulted in worldwide environmental regulation and corresponding innovation by printing ink manufacturers. In order to facilitate print saturation and deep gloss, the pigments used to contain toxic metals that could result in serious environmental problems during the printed matter's recycling or after its final disposal. Likewise, the liquids used as carrier fluids posed a number of problems. In order to facilitate quick drying of the ink, many of them usually contained volatile organic compounds (VOCs), which quickly evaporated after the ink had been applied; but were a threat to the environment, because they caused the formation of ozone in the air.

One environmental problem that was successfully solved during the mid-1980s was the danger associated with toxic metals in ink formulations, which contaminated the ink sludges resulting from paper recycling. Their removal and replacement with non-toxic substances had resulted in an improvement to the environment and had removed substantial regulatory pressure, but at the price of slightly higher raw material costs.

By the late 1980s and early 1990s legislation on the permitted level of volatile organic emissions was tightened in many countries. In order to comply with these regulations, the printing ink industry developed a number of alternatives, some of which had not only environmental but also economical advantages. A first area of innovation, and one that took place primarily in the United States, had been the replacement of mineral oils in inks with vegetable oils, particularly soy oils.

The major environmental advantage of soy inks was their low VOC content (O-4 % compared to 25%-40 % with conventional petroleum-based inks). This reduced their VOC-emissions significantly and lowered worker exposure to toxic chemicals. However there was a big question mark behind soy-based inks since soy-oils were suitable primarily for printing processes where the ink dried by being absorbed by the paper and not by evaporation. Printing processes that relied on drying by evaporation - and most VOC-emissions occurred during evaporation - were not suitable for soy-based inks or were very difficult to adapt.

The discussion about soy-based inks was characterized by widely differing declarations made by Americans and Europeans. In the U.S., the use of soy oil was supported by the domestic soy industry. Their soy oils had become a political issue and thus factors such as their environmental compatibility and the intensity and clarity of colors they produced were stressed. Contrasting this view, European critics stated the limited use of soy oils for cold set inks and associated problems in de-inking. They also asserted that soy-based inks were only cost competitive in the segment of colored inks, since black soy inks could cost up to twice as much as conventional petroleum-based inks. Therefore, European manufacturers did not adopt soy-based inks, but continued to innovate in highly refined petroleum oil which they maintained was environmentally friendly and offered better commercial viability at the same time.

Another area of innovation was in ultraviolet (UV) printing inks where the drying process was carried out by UV radiation instead of heat from a heat setting oven. UV-cured inks did not result in any harmful emissions, facilitated instantaneous drying, and gave a high gloss. They were particularly suitable for printing on plastic and cardboard materials. Although they were more expensive, UV-cured inks required only 50% the energy that was needed for printing with conventional inks. They also resulted in a substantial improvement in printing speed due to the faster drying process. These advantages had resulted in UV-cured inks being the fasted growing market segment in the early 1990s.

Beginning already in the late 1970s research and development began to be focused on the development of water-based inks. Initially these efforts had been spurred by cost considerations, because the oil crisis had resulted in substantial price increases for mineral oil inks. In the 1980s, when solvents contained

Figure 1

Technical Processes in Printing: An Overview

The most important printing techniques used in the 1990s were lithography, gravure, flexography, and screen printing. During centuries they all had been derived form letterpress.

Letterpress was a process invented by Gutenberg for the world's first printing press he had developed in Germany some six centuries ago. The letter's image area was raised above the non-printing area and was inked by rollers and pressed into contact with the paper. Letterpress ink dried slowly through oxidation only, except in newspaper production where dried by absorption by the paper and could be accelerated by the application of heat.

Lithography used a flat printing plate with an image area that was receptive to ink and non-printing areas that were wetted by water and chemicals to repel ink. Litho printing was dominant in many applications as it was more economical than letterpress. The inking system, however, was fairly complex. Specially formulated heat setting inks to facilitate instant evaporation were used on lithographic web offset presses. Newspapers printed on lithographic machinery did not need heat driers as the ink was absorbed by the paper.

In the *gravure method* the image was recessed into a plate surface and the depth of the cut and the number of ink cells determined the quantity of ink that was transferred to the paper. Different thicknesses of ink were applied to give a range of tones. Gravure was very popular for printing magazine, brochure and directory printing, because as the cylinder plates had a long life and achieved fast print speeds on a variety of surfaces. Digital controls and laser and electron beam engraving were replacing hand engraving of plates. Large and small establishments used gravure as the method of printing as it gave consistently high quality in high or low production volumes.

Flexographic printing, which was derived from the rotary letterpress printing process, was a rapidly growing technique that had become one of the main methods for printing on packaging materials such as plastic, film, polyethylene bags, corrugated containers, as well as newspapers. It used photopolymer plates and fast drying inks or ultraviolet (UV) cured pastes. The advantage of flexographic printing was that it was accurate, fast, economical and gave good print quality.

Screen printing used a porous stencil through which ink was squeezed onto the underlying substrate that could be of any material, i.e. paper, metal, plastic, textiles, etc. The mesh through which the ink was squeezed ranged from fine to coarse and could be made of fabric or metal gauze, which determined the thickness of ink that was deposited on the material. Screen printing was very versatile as almost any type of ink could be used and color could be applied without restriction. Its limiting factor was the relatively slow rate of production. However, new types of equipment were being introduced to improve the rate of output.

in mineral oil inks became the focus of environmental regulation, the research efforts into water-based inks were increased, since without any doubt water was the safest solvent. Water-based printing inks initially presented several problems. They resulted in higher printing costs, because their formulation was more complex and they required more heat to dry. Initially, they also resulted in a loss of gloss and a tendency of the paper to be warped or distorted by the water. However, these problems were subsequently solved. By 1993 new resins had been developed that overcame most of the problems associated with water-based inks such as lower printing speeds, higher heating costs, and degraded paper quality. Another important innovation had been new waterborne flexographic inks for use in food packaging, allowing the use of the flexographic printing method with its distinct cost advantage over conventional printing methods in this environmentally sensitive application.

Fundamental changes were also occurring with respect to the use of alcohol in the printing process, which might ultimately lead to waterless printing without the need for a fountain solution containing VOCs. Fountain solutions were used in offset printing to render non-image areas unreceptive to the ink. They were water-based and contained a dampening aid whose role it was to reduce the water's surface tension. Traditionally, the most effective dampening aid had been isopropyl alcohol (IPA), a VOC that evaporated quickly, and thus facilitated short ink drying times and high printing speeds. However, as VOCs they were also subject to stringent environmental regulation. A further disadvantage was that they were dangerous substances, because they were skin irritants and could explode. To address these problems, manufacturers innovated in two directions: The first had been to reduce the percentage of IPAs in the fountain solution without adversely affecting its performance. A second, more promising direction had been the development of an alcohol-free, non-VOC substitute that allowed to bring emissions down to zero, maintained the fountain solution's performance, and reduced dampening costs by 30% to 50%.

Another way to eliminate VOC emissions in offset printing was to substitute the fountain solution as a whole and print waterless, a relatively new technology that required no alcohol or any other form of costly and environmentally hazardous dampening system in the pressroom. With certain applications, waterless printing could thus result in substantial cost savings. The technology's future prospects were very promising: According to industry experts, at least 10% of web-offset printing was expected to be performed waterless by 1996.

Another area of innovation had been the cleaning agents used for removing inks from printing presses and production equipment. Due to their high VOC-content they were subject to strict regulation. A possible substitute had been developed in 1992 in the U.S. It was more expensive than conventional, VOC-based cleaning agents, but this disadvantage was partly offset by its advantages in terms of easier application, reduced health hazards, and eliminated risk of explosion.

As a result of the huge number of different printing ink ingredients and the variety of different processes where inks were used, printing inks were enormously complex products. This made it very difficult for legislators to set sensible regulations, and created the potential for costly and useless requirements. A good example for such a mistake was the German Bundes-Immissionsschutzgesetz under which coldset printing processes were subject to an approval procedure concerning air emissions to get an operating license, despite the fact that coldset printing could not even result in any air emissions because coldset inks dried by absorption in the paper and not by evaporation.

INDUSTRY STRUCTURE

ln the 199Os, the commercial environment for ink manufacturers was influenced not only by environmental laws and regulations, but also by the influence of technical changes and by a recession which had severely impacted the printing industry. This had intensified problems for ink manufacturers as well as many of their customers, some of whom, having invested heavily in new printing presses during the boom years of the 1980s, were in serious financial difftculties because of slack demand.

The introduction of new printing materials required completely new approaches. Reformulations of printing inks had become necessary to comply with all the technical and environmental changes. Ink manufacturers had to take into account the effect of national and international laws on their customers, as well as the increasing emphasis on the recycling of every printed matter. Printing inks had to be made easily removable during recycling and the solvents used during printing had to be recoverable.[1]

Product

Product Description

Printing inks were used for printing with printing machines. Modem printing inks were derived from the original, century-old formulations, which had been a mixture of soot and burnt oils mixed with resins and gums from natural sources such as trees, resulting in a typically black drawing ink.

Printing inks were to be distinguished from writing inks which were very fluid and contained virtually no pigments as these would clog a pen’s nib. Ball point pens also did not use printing inks, using instead a thick, dyed, nonaqueous paste that dried almost immediately on contact with the paper. Printing inks were highly complicated chemical compounds consisting of a variety of pigments. During several dispersion processes these compounds were made into specially formulated varnishes in order to suit particular methods of printing.

I. ICC Key Note Market Reports 1992, 6.

Typical varnishes were made from resins dissolved in petroleum spirits, alcohol, or linseed oils, which had been thickened by high temperature heating. Ink containing carbon black was used by newspapers as it rapidly soaked into the upper layer of the paper and, unlike many other printing inks, did not require additional drying agents.

Every printing process had its own requirements for inks and the choice of which ink to use depended on a variety of factors such as the nature of the substrate to be printed on, type of application, drying speed, the need for color, and the type of printing process itself. Colored inks, which were essentially based on a mix of yellow, magenta (red) and cyan (blue), were used extensively by the printing industry for illustrative and decorative work. Black, called a non-color. was the standard for most remaining inks,

Ink formulations were designed to ensure the ink adhered to a wide variety of surfaces such as paper, board, glass, metal, plastic, wood, or textiles. The various printing techniques could only work with particular types of ink which ranged from fluids to pastes. There were also many different inks for different types of equipment. Plasticizers were added to give flexibility to the ink and adhesives were added to bind the ink to the substrate, such as paper, plastic or others. Wetting agents and waxes were used to make the ink resistant to abrasion. Catalysts were added to facilitate quicker drying. Alternatively, solvents were added which evaporated on contact with the substrate, or water emulsions which were heat dried when employed, or other drying methods such as ultraviolet radiation were used.[2]

Substitutes

Despite a fairly large number of actual and potential substitutes, printing inks as well as printing in general did not face any serious substitution threats. The long expected negative impact of electronic media such as electronic mail, voice mail, data on compact disc, and so on did affect the printing industry, but not to the extend which had often been predicted.[3]

2. ICC Key Note Market Reports 1992,4.

3. Commission of the European Communities, 1991/92. 8-24.

Likewise, laser and ink jet printing was gaining rapidly in popularity as the cost of equipment fell and reliability improved. However, these techniques were not considered to be suitable for high volume applications where conventional printing remained paramount. There niche was in business areas where high quality repetitive printing was required in relatively short production runs.[4]

Production Process

Similar to paint manufacturers, printing ink manufacturers were primarily formulators. They determined the optimal combination of at least 1,500 different raw materials which satisfied the user's printing needs and supplied that formulation to their customers. The manufacturing process aimed at providing a uniform mix and sizing of component materials and basically consisted of four steps. First was a premixing step where pigments, adhesives and solvents were combined to produce a paste of homogeneous composition. In a dispersion process the pigment particle size was then reduced. The material was subsequently thinned with additional solvents, oils and resins and then, in a final step, once again dispersed.[5]

Economies of Scale

Given the large variety of different formulations and an extreme customer orientated small-batch production process, economies of scale were modest. However, in an industry where R&D constituted a main source of competitive advantage, larger companies which could fund these activities were sometimes said to be favored over small firms.[6]

Entry or Exit Barriers

There were two important entry barriers in the printing ink industry: Strong supplier-customer relationships which often had been developed over generations. The other entry barrier was the manufacturer's know-how concerning the large variety of printing ink formulations mentioned before.

4. ICC Key Note Market Reports 1992, pp. 3.
5. Huber-Gmppe 1989, pp. 7.
6. ICC Key Note Market Reports 1992, 3.

As in the allied printing and publishing industry, a main exit barrier was constituted by the highly specialized fixed assets.

Buyers

Buyer Description

Virtually every industry was a customer for printing inks, but the main sectors of demand were from the publishing, printing, and packaging industries.

The publishing industry - newspapers, books, and magazines - represented a huge market for the specialist printers in this activity. In recent years newspaper printing had been transformed by the adoption of electronic technologies at every stage of the process from the origination of text and pictures to the final product.

Commercial printing covered a multitude of industries such as the production of directories and catalogues, financial, legal and business forms, timetables, advertising material, or reference manuals, which were fundamental to commercial life. Commercial printing represented a large market for the printing ink industry and many of the companies involved had specialized in this segment.

The packaging industry was another major customer for printers. It was the most resilient to recessions. The food and drink industries used a wide variety of packaging materials such as paper, cardboard, plastic, metal, glass, and wood. The ink had to adhere to, and be consistently legible on all these materials even in the most extreme conditions. Inks and varnishes were as varied as the packaging materials, some were aqueous based, some contained alcohols, and, for volume printing on plastic surfaces, solvent-containing inks were used. Particular care was taken over wrappings and inks used with certain types of food, because of the fear of possible contamination.

Distribution Channels

The main distribution channel for printing was directly by the company itself. Beyond that there were few print ink wholesalers. The main reasons for direct distribution were the necessary close relationships between the ink manufacturer and the printer due to research and delivery requirements, risks associated with storing inks, and the high transportation costs.[7]

Bargaining Power

printing ink manufacturers generally had low bargaining power. Thus, many of the newly developed environmentally friendly inks of the early 1990s were initially more expensive than conventional inks, but were not able to fetch higher prices in the market.

Suppliers

The primary suppliers to the printing ink industry were producers of synthetic chemicals. Multinational chemical and petrochemical firms such as BASF, Hoechst, Bayer, Ciba-Geigy, Sandoz, ICI, and Dow Chemical were important suppliers to the industry throughout the world. More recently, because of the more intensive use of biodegradable ingredients such as soy oil, producers of the underlying agricultural products had become critical suppliers as well.

Environmental Regulation

Environmental Risks

The printing ink industry impacted on a number of environmental media throughout all major steps of its extended value chain, beginning with raw material and suppliers to production and usage until the final disposal of the printed matter. There was strong pressure on printers to use less polluting water-based inks or inks with higher solid content. These inks, which were considered to be the most environmentally friendly, were becoming increasingly accessible to a wider range of printing processes.

The major environmental impact regarding printing inks were volatile organic compounds (VOCs). In the presence of heat and sunlight, VOCs reacted with nitrogen oxides in a photo-chemical reaction and formed ozone, a contaminant of the air. VOCs were contained in solvents in the ink and were released during production as well as during application (i.e. during the printing process itself). VOCs presented the largest problem during the printing process, where solvents evaporated when the print dried. This

7. Commission of the European Communities, 1991/92, 8- 18

was less of a concern during the production process, because most producers of print inks had already

Figure 2

Environmental Impacts: Printing Inks				
Stage / **Media**	**Suppliers** Petrochemical Industry	**Production** Printing Ink Industry	**Usage** Printing Industry	**Final Disposal of Printed Matter**
Waste			Waste inks	Toxic waste (solved in the mid-1980s by eliminating toxic heavy metals from pigments)
Soil	Storage of raw materials	Storage of inks		
Water	Storage of raw materials	Storage of inks. <u>cleaning of production machinery</u>	<u>Cleaning of presses with water</u>	
Air	Storage of raw materials	Evaporation of solvents during production process; Cleaning of production machinery with solvent-based solutions	Evaporation of solvents and alcohol during the printing process; Cleaning of presses with solvent-based solutions	
normal typeface: small impact		<u>underlined: medium impact</u>		**bold: large impact**

adopted closed-loop systems, which allowed them to recapture part (or most) of their VOC emissions

Another source of VOCs in the printing process was the dampening aids used in fountain solutions. Fountain solutions were used in lithographic offset printing, where they were applied to the lithographic plate to render non-image areas unreceptive to ink. Traditionally, some 15% to 20% of a fountain solution consisted of VOCs. The amount of VOC emissions depended to a considerable extent on the degree of finishing: the more finishing, the larger the environmental problem since more solvents were required.[8]

VOCs also posed a problem during cleaning of printing ink production equipment as well as during cleaning of the printing press itself which was usually done with solvent-based detergents.

8. Association for the Promotion of Research in the Graphic Arts Industry (UGRA) 1992, pp. 2.

Another environmental issue was the disposal of waste ink, many types of which were classified as toxic waste. In many countries, the regulations for disposal of waste inks had become so strict that they had prompted ink manufacturers and printers to attempt optimizing the recovery of used inks.

Yet another environmental issue was energy efficiency. The production of mineral oil-based raw materials in the petrochemical industry used more energy than the production of renewable raw materials.

An additional potential risk - especially for suppliers - was the storage and transport of fluid ingredients such as solvents. Many fluids were flammable and in the case of an accident were potential threats to the air, soil, and water.[9]

Printing inks could also pose environmental problems when it came to recycling printed matter. In this case the type of ink played an important role: Not all inks had the same de-inking characteristics, which determined the output quality of recycled paper as well as the energy usage for processing.

Unlike the case until the early 1980s and because of the elimination of toxic metals such as cadmium and lead from pigments during the mid-1980s, the final disposal of printed matter was no longer a problem. They could easily be disposed of in landfills or burned.

Focus and Type of Regulation

Environmental regulations concerning the printing ink industry varied widely throughout the world. Whereas European, Japanese and American producers faced very strict regulations and standards, many companies based in Asia - primarily Korea and Malaysia - were not yet confronted with any legal restrictions.

Most current or proposed regulations in the early 1990s were performance standards or command and control instructions which focused on air-pollution (Germany's Bundes-Immissionsschutzgesetz, the E.C. 's VOC-Directive, US Clean Air Act Amendments). In addition, there were also a few instances of

9. Association for the Promotion of Research in the Graphic Arts Industry (UGRA) 1992, pp. 2.

Figure 3

Environmental Impacts: Printing Inks				
Stage / **Media**	**Suppliers** Petrochemical Industry	**Production** Printing ink Industry	**Usage** Printing Industry	**Final Disposal of Printed Matter**
Waste			**Waste inks**	Toxic waste (solved in the mid-1980s by eliminating toxic heavy metals from pigments)
Soil	Storage of raw materials	Storage of inks		
Water	Storage of raw materials	Storage of inks. cleaning of production machinery	Cleaning of presses with water	
Air	Storage of raw materials	Evaporation of solvents during production process Cleaning of production machinery with solvent-based solutions	**Evaporation of solvents and alcohol during the printing process; Cleaning of presses with solvent-based solutions**	
normal typeface: small impact		underlined: medium impact		**bold: large impact**

voluntary or "gentleman's agreements:" In 1985, for instance, the Swiss printing ink industry agreed with the Ministry of the Environment to reduce solvent usage by 20% .[10]

10. Egger and Stall 1992, 43.

COMPETITION

In 1991, the United States of America was by far the largest producer of printing ink in the world, producing nearly 900,000 tons which represented some 45% of the world's production. The U.S. was followed by Europe with a 1991 production volume of over 600,000 tons and Japan with about 400,000 tons. The remaining 100,000 tons was accounted for by Australia, East Europe and some Asian states.

Germany

Competitiveness Overview

In 1992, the European Community accounted for nearly 90% of the total production of printing inks in Europe. Among its member countries, Germany was by far the largest printing ink manufacturer with a total production of over 250,000 tons representing an European production share of 40% and a world production share of 12.6%.[11] Other important European manufacturers of printing ink were the UK, France and Italy which together held a production share of almost 40%. The remaining 20% was split among the Netherlands, Belgium, Spain, and others.

Since the industry was primarily orientated towards the domestic market, its export quota was only 28 % , far below the German industry average. With DM464 million, the German printing ink industry had one of the largest positive trade balances in Europe.[12]

Leading Firms

The leading German printing ink manufacturer was thought to be Kast-Ehninger of Stuttgart. Kast was a subsidiary of BASF of Ludwigshafen, the second largest printing ink producer in the world, and held a European market share of approximately 15%. The second largest German firm was the Huber-Gruppe of Munich with a 9% European market share, followed by Gebr. Schmidt of Frankfurt with 8% and Siegwerk Druckfarben of Siegburg with 8% .[13]

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11. Commission of the European Communities, 1993, 6-20.
12. CEPE, European Confederation of Paint, Printing Ink and Artists' Colours Manufacturers Associations, 1993
13. Verband der deutschen Druckfarbenindustrie, Frankfurt, 1994.

Another leading firm was Hartmann Druckfarben, which was based in Frankfurt. This $81 million/year ink maker had been acquired in 1986 by Japan's Dainippon Ink and Chemicals (DIC), the world's largest producer of printing inks. Hartmann had previously been a subsidiary of BASF. West German antitrust law had obligated its divestiture after BASF's acquisition of the American ink and automotive coatings maker Inmont, which boosted BASF's German printing ink market share to more than 50% .[14]

In 1990 Sun Chemical (a division of Dainippon Ink and Chemicals) had signed a letter of intent with the East German Druck- und Lederfarbenfabriken Halle to set up a joint venture to produce printing ink for East Germany and other Eastern European markets using Sun's technology. Sun had been the first U.S.-based printing ink manufacturer to enter into such an agreement.[15]

Distinctive Environmental Regulation in Country

The most important law in Germany regulating VOC-emissions was the Bundes-Immissionsschutzgesetz, Bimschg (Federal In-mission Control Act) of 1974. Implementation of this law was required by the states according to recommendations in the Technische Anleitung (TA) Luft, a set of technical instructions on how to control air quality.' In strict legal terms, the TA Luft was only binding to administrative authorities. However, indirectly, it also had a binding effect on the printing and printing ink industries because of the approval procedures it contained.

The TA Luft was amended and updated several times, with major changes occurring in 1986 and 1991. Until 1991, its primary impact on the printing ink industry had been the requirement to receive formal approval for plants using more than 250kg solvents per hour. Manufacturers who exceeded this limit were allowed to demonstrate equivalent reductions at other facilities, providing them with flexibility as to where to reduce emissions most economically. The 1991 amendments to the TA Luft increased the stringency of requirements for printing processes, putting limits on air emissions of $0.50 g/m^3$.

14. "Dainippon Buys a European Printing Inks Maker." Chemical Week July 23, 1986, 7.
15. "Sun Ink Venture in East Germany." Chemical Week May 16, 1990, 48.

German printing ink manufacturers were also subject to the United Nations European Commission for Europe (ECE) protocol for reductions of VOCs which aimed at a 30% reduction in VOC-emission by the year 2000.

By 1994, there was still no directive from the European Community concerning VOC emissions besides the ECE protocol. All European Community directives were based on article 130s of the European Community Treaty, thus requiring each individual member country to devise its own method of implementing the directive. Industry representatives sometimes feared that this might lead to vastly different laws, followed by significant market distortions.[16]

The most important planned directive concerning the printing ink industry was the directive on "The Limitation of The Emissions of Organic Compounds. " This draft included the obligation to install a solvent-management plan and set emissions limits for VOCs. Most relevant was its Annex IV which set specific VOC emissions limits for printing ink manufacturers.

The draft directive also defined a maximum of 5% organic solvent content for water-based printing inks. The European printing ink manufacturers association criticized this limit, contending that the aim should not be to eliminate the solvents, but rather to retain them as complete as possible in the inks.

The second directive on "Integrated Pollution Prevention and Control" was expected to affect the printing ink industry in two ways. By establishing cut-off limits for the most polluting substances for water, soil and air it was expected to lead to increased research into environmentally friendly water-less inks. It was also expected to lead to the increased use of closed-loop solvent recovery systems, because it required an integrated environmental protection approach to prevent polluters from shifting emissions from one media into another. Increased adoption of closed-loop solvent recovery system, in turn, was expected to lead to further development of monosolvent inks which were necessary prerequisites for solvent-recovery systems to be economically feasible.

16. "Developments of Printing Ink in the 1990s." Ink & Print 1993, 18.

A further feature of the directive on integrated pollution control was that it contained provisions for exempting manufacturers from certain requirements, if they committed to setting up an emission plan with fixed targets.

The United States

Competitiveness Overview

With a world production share of 42% and annual sales of $3 billion in 1992, the United States was the world's largest manufacturer of printing inks.[17] U. S . printing ink manufacturers were oriented towards their domestic market even more than their European counterparts. 98% of the American production of printing inks was geared towards the domestic market and only 2% was exported.[18]

Leading Firms

The largest U.S. producer of printing inks was Sun Chemical of Fort Lee, New Jersey. It had been acquired in 1987 by Japan's Dainippon Inc.,[19] an acquisition which had made Dainippon the largest printing ink and graphic arts supply company in the world.[20]

Flint Ink of Detroit, a privately held company, was North America's second-largest producer of printing ink, and the world's largest producer of newspaper ink. Flint Ink also produced chemical pigments for the printing industry. In 1991, Flint Ink had $510 million in sales.

Other leading U.S. manufacturers of printing ink were JM Huber of Edison, New Jersey, the Sakata Group of Elk Grove Village. Illinois, Superior Printing Ink of New York City, and U.S. Printing Ink of New Jersey.[21]

17. Commission of the European Communities, 1993, 6-20.
18. "Flint Ink's Future Was Printed in Soybeans." Data Courier August 31, 1992, vol. 8, no. 35, sec. 1, 3
19. ICC Key Note Market Reports 1993, 19.
20. ICC Key Note Market Reports 1993, 19.
21. "Flint Ink's Future Was Printed in Soybeans." Data Courier August 31, 1992, vol. 8, no. 35, sec. 1, 3.

Distinctive Environmental Regulation in the United States

In the U.S., VOC emissions from printing inks were regulated since the passage of the Clean Air Act Amendments of 1977, which set standards for acceptable levels of ambient ozone. Similar to Germany's TA Luft, the law required the U.S. Environmental Protection Agency (EPA) to provide Control Technique Guidelines (CTGs). CTGs were guidance documents issued to the states to help in developing regulations on air pollutant emissions and recommended specific, reasonably available control technologies. Once finalized and issued, states in ozone non-attainment areas had 12 months tune to adopt the CTG's recommendations as regulations. CTGs only set minimum requirements and states and local agencies were free to issue stricter rules.[22]

CTGs contained so-called control strategies for efficient emissions reduction that affected three areas of the printing industry: ink manufacturing operations, controls for fabric printing operations, and controls for web offset printing operations. Most control strategies focused on add-on controls, process modifications. or reformulation or substitution of materials.

The American printing ink .industry was also subject to the 1990 Clean Air Act Amendments, which among others, specified

* permitting requirements for installations,
* annual emission fees,
* restrictions on 189 hazardous air pollutants and categories, as well as
* control requirements for VOC sources.[23]

There was also regulation concerning the waste ink problem. It included the Resource Conservation and Recovery Act of 1976 (RCRA), which defined solvents, solvent-containing inks, and other toxic materials as hazardous waste, and the Comprehensive Environmental Response Compensation and Liability Act of

22. "Sheetfeds Set for Eco-Cleanup." Graphic Arts Monthly March, 1992, vol. 64, no. 3, 56.

23. "Printing Industry Works on Air Pollution Control. " Pittsburgh Business Times & Journal January 28, 1991, vol. 10, no. 25, 3.

1980 (CERCLA), commonly known as the Superfund law, which was intended to facilitate the cleaning up of hazardous waste sites and, where possible, to impose liability for cleanup on responsible parties.[24]

24. "Waste Ink: The Burden was Shifting." Graphic Arts Monthly January, 1991, vol. 63, no. 1, 116.

EFFECTS OF REGULATION ON COMPETITIVE ADVANTAGE

Product Effects in the Printing Ink Industry

Due to new environmental laws and scientific results, the list of chemicals that was not approved for use in inks because of health or environment concerns was much longer than the list of chemicals that was approved. This limitation increased the challenge that ink manufacturers faced: To devise formulations that met all technical requirements and were environmentally safe. Ink research in the 1980s had solved for the most part problems such as toxic metal contamination and flammability. More difficult was the reduction or elimination of VOCs and the problem of proper post-production waste ink disposal in accordance with regulations.[25]

Although the printing ink industry had come a long way in making inks and coatings more environmentally friendly, users and the public at large still continued to have many misconceptions about how safe they were to use and dispose of. Because many of the ingredients that went into inks were derived from petrochemicals, they tended to be immediately suspect. But while they might be considered hazardous and had to be handled in certain ways, they were not necessarily toxic.

By 1994, almost no inks contained lead or other toxic metal compounds anymore. Surplus inks, however, were still disposed of in approved landfills or, preferably, used as fuel in cement kilns or similar incinerating programs.[26]

To address environmental problems manufacturers had developed a number of different inks. The most frequently discussed alternatives to conventional petroleum-based inks were soy-based-, UV-cured, and water-based inks.

25. “R&D Choices: Printing Inks.” Graphic Arts Monthly April 1992, vol. 64, no. 4, 94.

26. “Inks Aren’t the Problem: The Ink Industry had Come a Long Way Toward Eco-Responsibility.” Folio: The Magazine for Magazine Management April 1, 1992, vol. 2 1, no. 4, 101.

Soy-Based Inks

Considerable confusion surrounded the use of soybean oil as a substitute for petroleum oil in printing inks. Letterpress and lithographic inks had traditionally been made with vegetable oils. Only after World War II, with the development of high-speed printing presses, had fast-drying petroleum-based inks become the standard. By the 1990s, however, there was, once again, a move towards printing inks that were based on vegetable oils. An initial driving force behind the development of soybean inks had been rising petroleum costs.

Responding to the energy crisis in the late 1970's, the American Newspaper Association began looking for a vegetable-oil ink, hoping that its price would be lower and more stable than that of petroleum inks. Soybeans were already domestically grown in the United States at that time, and thus the choice for a vegetable oil was a natural one. By 1986 a first soy-based newspaper ink had been developed, and one year later, in 1987, Sun Chemical's General Printing Ink Division introduced the first commercial soy-oil ink to the market. All major ink makers soon introduced similar soy inks. By the early 1990s, one-third of all U.S. newspapers were printed with soy-based inks, including half of the nation's dailies[27] and about 3% of the U.S. soy oil production was used to manufacture printing inks.[28]

In the U.S., soy-based inks soon gained in acceptance because of their environmental compatibility combined with their good performance: American printers had noted better results on older presses, an easier clean-up between runs, a greater stability on the press, and better compatibility with recycled papers. Soy-based inks did not rub off the paper as readily as petroleum-based inks, and soy-based colored inks produced intense, clear colors on the paper.[29]

On the other hand, the slow drying speed of soy-based ink was a primary source of complaints that was voiced by some printers, particularly those in sheetfed operations. The ink films applied in sheetfed

27. "Flint ink's Future Was Printed in Soybeans." Data Courier August 31, 1992, vol. 8, no. 35, sec. 1, 3.

28. "Einsatz nachwachsender Rohstoffe in Druckfarben." Farbe+Lack July 1992. vol. 98, no. 7, 509.

29. "Soy-Based Inks: US and Western European Consumption Would Double by 1995, Market Could Approach $ 800 Million." Industrial Bioprocessing November, 1991, vol. 13, no. 11, 4.

printing were generally heavier than those applied in news and forms printing, and a greater variety of substrates was used Both the thickness of the film and the inability of some substrates to allow penetration and absorption adversely affected drying times. These difficulties were even more Pronounced in high-speed heatset offset printing. Because heatset inks dried primarily by evaporation, the high boiling range and low vapor pressure of soya oil, even at minimum substitution levels, could create drying problems, requiring printers to slow down their presses or increase oven temperatures and resulting in increased fuel consumption, a rise of paper degradation, and a loss of ink g1oss.[30]

For these reasons, European manufacturers maintained that soy oils were unsuitable for heatset inks. They also asserted that soy oil was more aggressive to the production facilities and thus had an adverse effect on printing press lifetime.[31] Soy-based printing inks were also more expensive than conventional inks. Color newspaper inks made with soybean oil cost about 5% to 10% more than petroleum-based inks and black soybean inks could cost up to twice as much as petroleum inks, making them very price uncompetitive.[32]

petroleum-based inks contained 25-40% VOCs, compared to only O-4% for soy-based inks. Reduced VOC emissions and lowered worker exposure to toxic chemicals thus were the principle environmental advantages of soy inks. However, the major VOC problems occurred during the drying process in heatset printing, whereas no drying was needed in coldset printing where the ink was completely absorbed by the paper. Since soy-based inks presented major problems in heatset operations, their adoption did not really solve the VOC-problem.

Other ecological benefits that had been claimed by some soy ink proponents - better biodegradability, the creation of less toxic waste, and less hazardous de-inking sludges - were also questioned by many ink makers from Europe, as well as from the petroleum industry. These critics maintained that soy oil

30. “Soy Oil Inks.” Graphic Arts Monthly March 1992, vol. 64, no. 3, 116.

31. “Werbung fur Druckfarben mit nachwachsenden Rohstoffen?” Verband der deutschen Druckfarbenindustrie. 1994.

32. “The Media Business - A New Ingredient for Many Papers: Soybean Ink.” The New York Times March 23, 1992, Section D, 8.

was no more easily biodegraded than petroleum on paper, and that much of the toxicity of printer's waste was due to the pigments and resins used in ink formulations, regardless of the carrier. In contradiction to the American standpoint, Europeans stated that soy-based inks did not have better de-inking qualities than petroleum-based inks. Moreover, while there might be reduced VOC emissions from using soy-based inks, these were not significantly less than those emitted from inks formulated from modern saturated petroleum oils, which, according to German, E.C. and American law, were not hazardous either.[33]

Soy-based inks were appropriate for use with letter-press and lithographic presses, but not for gravure presses. Therefore, newspapers were the biggest market for soy-based inks, particularly in color printing. However, European associations noted that the use of soy-based products in the U.S. to a large extent was the result of political pressure from the domestic soy industry, as evidenced by the Vegetable Ink Printing Act, which required that 40% of all lithographic federal printing be done with vegetable inks.[34]

UV-Cured Inks

Traditionally, high-gloss clear coatings, used on the covers of books and magazines, had required various types of volatile petroleum solvents. Driven by environmental regulations, as well as by cost considerations, ink manufacturers in the early 1990s began research on ultraviolet curing alternatives. By 1993, most of the conventional inks in high-gloss clear coatings segment had been replaced by ultraviolet (UV) cured inks.

UV-cured inks consisted of specialized resins and solvents, so-called liquid acrylic monomers, and certain additives that, when subjected to high-intensity UV light, solidified. The "drying" process was thus carried out by UV radiation instead of applied heat from a heat-setting oven.[35] Since no solvents were emitted during the process, it was pollution free. Nonetheless, the process also had some negative effects

33. "Werbung fur Druckfarben mit nachwachsenden Rohstoffen. Verband der deutschen Druckfarbenindustrie. 1994.

34. "Shades of Green: Environmentally-Friendly Inks and Dyes." Chemical Marketing Reporter September 20. 1993, vol. 244, no. 12, SR14.

35. ICC Key Note Market Reports 1993, 21.

on the environment. Not only did UV-cured inks contain carcinogens,36 but de-inking was a concern with UV inks and coatings as it was difficult to break them down with conventional techniques. However, his drawback could be overcome by adopting the so-called flotation process for de-inking (see below). [37]

UV-cured inks were increasingly being used for high speed printing, where they were not only advantageous from an environmental standpoint, but also highly cost-effective. They required only half the energy used by conventional inks requiring heat set ovens which more than offset their initial price disadvantage. In terms of cost effectiveness, there were few alternatives to UV inks for high-gloss clear coatings printing .[38]

As a result, UV-cured inks were gaining in sheet-fed printing, packaging, as well as narrow and wide width flexography. With expected growth rates of 10% to 15% in the 1990s.[39] radiation reactive inks had become the new segment leader in growth. Manufacturers said that 25 years of research into their development and potential end uses was finally paying off. Economic considerations, as well as pressure form environmental regulations, had led to innovations that led to distinct competitive advantage to their developers.

Water-Based Inks

Some twenty years ago, even before the development of soy inks, water-based inks had emerged as an alternative to petroleum-based inks. Ink manufacturers began experimenting with water-based inks even before the oil crisis of the 1970s. Pressure from increasingly strict environmental regulations subsequently prompted the industry to try them as a means of eliminating petroleum solvent altogether, initially only with limited success. Substantial research work subsequently allowed to considerably

36. “The Greening of an Industry: Printers and Consultants Develop Environmentally Friendly Printing Products.‘ Folio: The Magazine for Magazine Management July 1990, vol. 19, no. 7, 29.

37. “Inks Aren’t the Problem: The Ink Industry has Come a Long Way Toward Eco-Responsibility.” Folio: the Magazine for Magazine Management April 1, 1992, vol. 21, no. 4, 101.

38. ICC Key Note Market Reports 1993, 23.

39. “Shades of Green: Environmentally-Friendly inks and Dyes.” Chemical Marketing Reporter September 20. 1993, vol. 244, no. 12, SR14.

improve the qualities of water-based ink, allowing printers to shift from solvent-containing to water-based inks wherever the required printing process allowed it.[40]

Compared to solvent-containing inks, water-based inks produced brighter colors.[41] However, the raw materials they required were more expensive than those used to make petroleum-based inks. Initially, they also required more heat to dry, did not print as well or had as much gloss, and the water tended to distort the paper causing waviness in the printed product.[42] A further disadvantage was that water-based inks were not always compatible with existing printing processes and required modifications such as additional heat drying facilities.

In the early 1990s, printing ink manufacturers succeeded in developing new resins for water-based inks to be used in high speed web printing presses. New waterborne systems were also formulated for gravure and flexographic inks to be used in food packaging. The new resins overcame most of the problems associated with water-based inks such as their lower printing speeds and high heating costs.

Since they did not contain any organic solvents, water-based inks were not only non-hazardous, but also non-flammable. However, problems associated with their de-inking initially constituted a drawback. Probably the most popularly used de-inking method was the flotation process which relied on the fact that oil-based printing inks, being less dense, floated to the top if mixed with water, where they could be collected. Because water-based inks did not contain any oils they were impossible to use with the flotation process.[43] After considerable research conducted by a group of U.S. manufacturers, this drawback was removed in 1993 by developing an additive to the flotation process that allowed newspapers that had been imprinted with water-based inks to be recycled to standard commercial levels.[44]

40. Huber-Gruppe: Dr. Reismann. Personal communication to the author.

41. “Flint Ink’s Future Was Printed in Soybeans.” Data Courier August 31, 1992, vol. 8, no. 35, sec. 1, 3.

42. “Inks Aren’t the Problem: The Ink Industry had Come a Long Way Toward J&-Responsibility.” Folio: The Magazine for Magazine Management April 1, 1992, vol. 21, no. 4, 101.

43. ‘Ink Market Segments Had Flat Year: Printing Ink Manufacturers.” Graphic Arts Monthly March, 1993, vol. 65, no. 3, 96.

44. ICC Key Note Market Reports 1993, 23.

Given higher raw material costs, the Price of water-based inks was higher than the price of conventional petroleum-based inks. In several applications this initial cost disadvantage was fortunately offset by other economic advantages. In the packaging industry, for instance, where they were used on flexible substrates including both paperer and plastic film, water-based inks had made great inroads, because the flexographic printing process that was generally employed with water-based inks was less expensive than the conventional offset process with petroleum-based inks.[45]

As a result, sales of water-based printing inks were expected to grow substantially. In the U.S., for instance, they were estimated to grow at an annual growth rate of 6.3%) reaching some 246 million pounds of ink by 1995 to represent a share of 10.3% of the 2.38 billion pounds market total.[46]

New Petroleum-Based Inks

particularly in Europe, where soy-based inks had never received the attention they had attracted in the U.S., petroleum-based inks continued to be the focus of substantial research and development efforts. By the early 1990s spurred by strict environmental regulations and customers who were demanding environmentally safe printing inks, the trend in Europe was towards the use of highly refined petroleum. These oils combined the well-known qualities of conventional petroleum-based inks with the added advantages of non-toxicity. One manufacturer even pointed out that they were edible.[47] Their non-toxicity thus provided easier storage, a safer printing process, and an improved public acceptance. In 1993, highly refined petroleum oils were more expensive than conventional oils, but industry observers expected this price differential to be at least reduced, if not eliminated, with continued innovation efforts .[48]

45 “Shades of Green: Environmentally-Friendly Inks and Dyes.” Chemical Marketing .Reporter September 20, 1993, vol. 244, no. 12, SR14.

46. Chem Systems. In: “Shades of Green: Environmentally-Friendly Inks and Dyes. ” Chemical Marketing Reporter September 20, 1993, vol. 244, no. 12, SR14.

47. A. Miiller AG: Hauser, in: “Die Sensation auf dem Drucketmarkt.” Amriswiler Zeitung March 24, 1992.

48. “Shades of Green: Environmentally-Friendly Inks and Dyes.” Chemical Marketing Reporter September 20, 1993, vol. 244, no. 12, SR14.

Production Process Effects in Printing Ink Production

In the early 1990s, printing ink manufacturers and printers in most industrialized nations were subject to newly enacted environmental laws which regulated organic solvent discharges and waste generation resulting from both printing ink production and printing ink application, i.e. the printing process itself. The laws also affected working practices concerning the exposure of employees to potentially harmful carcinogens. Strict controls and enforcement frequently made it impossible to operate from old premises which had been adapted over the years on an ad hoc basis, necessitating investments in premises as well as new processing equipment in order to comply with regulations which were certain to become even stricter in future years.

Once again, volatile organic compounds and recycling were the main environmental issues. Regulation had led to considerable change and innovation for printing ink manufacturers as well as printers themselves.

Solvent-Recovery Systems

To comply with regulations restricting the release of VOCs contained in petroleum solvents for use in heatset inks, most heatset printers employed devices on their driers that catalytically incinerated the solvents .[49] Realizing that incineration was at best a suboptimal solution involving the elimination of VOCs, which themselves represented a costly raw material, manufacturers soon began to research technologies that would allow them to not only comply with regulations, but also to re-use the VOCs. One such technology that was successfully employed by many printing ink manufacturers involved a closed loop system that recovered and then redistilled the evaporated solvents into holding tanks for subsequent re-use in printing inks. This technology could only be used for production processes involving one single kind of solvent, so-called monosolvent processes, because separating different VOCs was economically unfeasible. Frequent re-use of solvents also posed a threat of introducing contaminants to the manufacturing process which might negatively affect printing ink quality.

49. "Shades of Green: Environmentally-Friendly Inks and Dyes." Chemical Marketing Reporter September 20. 1993, vol. 244, no. 12, SR14.

There were several solvents which could be economically recycled without adversely affecting product quality, The most popular one was Toluene, a solvent that was primarily used for gravure inks. Recycling of toluene in a typical gravure production process allowed to reduce solvent input by about 20% and toxic waste by nearly 5%, for a total production cost reduction of 8%.[50] In addition, the risk of explosion was reduced and hence the cost of insurance. Closed loop VOC systems not only allowed the producer to comply with regulations and protect the environment, but also resulted in improved economic efficiency.

Cleaning Solutions

Another area where printing ink manufacturers had to confront environmental issues was machinery cleanup. To remove excess printing inks, oils, and other inputs from production equipment, manufacturers frequently employed cleaning agents which contributed to air pollution because they contained up to 100% volatile organic compounds. One method for printing ink companies to lower their VOC emissions from machinery cleaning was to better train employees on the proper use of solvents.[51]

However, by the early 1990s, an American Control Technique Guideline draft (CTG) called for cleaning agents to contain only 30% VOC, with the remaining 70% consisting of soap and water. Users initially feared that the low VOC content cleaning agents required by the CTG would lead to increased costs, slower drying times, and reduced cleaning ability. Cleaning agent producers were able to quickly innovate and develop solutions that addressed these concerns, There were also less risks associated with storing the modified cleaning agents.

A particularly innovative cleaning agent was introduced in 1992 by an American supplier in Palmer, Pennsylvania. It was composed of non-volatile compounds with properties similar to conventional volatile solvents. It did not contain water, but could be mixed with water and thus was compatible with water-

50. Kast-Ehninger/BASF Druckfarben: Hagmann. Personal communication to the author.

51. "Water, Water Everywhere. . . .But Not a Drop in the Ink." Graphic Arts Monthly November, 1991, vol. 63, no. 11, S14.

based cleaning processes. This cleaning agent did not only address the VOC problem during cleaning processes, but was said to be also very reasonably priced.[52]

Re-Use of Inks

The re-use of inks was also a concern for the printing ink industry, although the diversity of inks as well as imperfect separation processes continued to pose problems. It was impossible for printing ink manufacturers to re-feed inks stemming from de-inking processes from paper recycling into their production processes. However, printing ink manufacturers often took back unused or leftover printing inks from their customers and either re-used them or had them disposed of. Reuse of printing inks was only possible if they were pure and could be clearly identified. Given the ever increasing number of different printing inks, this had become very difficult. This fact, combined with more stringent environmental regulation concerning the final disposal of printing ink, had made manufacturers wary of accepting unused inks. Instead, they suggested ink recycling systems to their printer customers which fed waste ink back into the printing process as a more efficient solution of this problem. An example for such a system will be presented below.

Production Process Effects in Printing Ink Application

Fountain Solutions

Fountain solutions were applied to the lithographic plate to render non-image areas unreceptive to ink. Since printing inks were oil-based, the fountain solution was water-based and contained a dampening aid whose role it was to reduce the surface tension of the water. More than half of all VOCs emitted from the pressroom stemmed from isopropyl alcohol (IPA), which had been used as a dampening aid since the 1950's. In the early 199Os, anticipation of future regulations, coupled with concern for the environment and employees, prompted a number of printers to demand IPA substitutes.[53]

52. "Sheetfeds Set for Eco-Cleanup." Graphic Arts Monthly March, 1992, vol. 64, no. 3, 56.

53. "Inks Aren't the Problem: The Ink Industry had Come a Long Way Toward Eco-Responsibility." Folio: the Magazine for Magazine Management April 1, 1992, vol. 21. no. 4, 101.

Most dampening aids which were subsequently developed were also VOCs, but could be used in lesser concentrations in the fountain solution, causing less VOC emissions. Thus, while fountain solutions had previously required up to 15% IPA, now only between 1-4% of the new dampening aids were necessary.[54] There were even substitutes available that had zero VOC content: FFC International of Lancaster, Pennsylvania, a company founded by two former press operators, had introduced a zero-VOC alcohol product in 1992 .[55] The IPA substitutes not only reduced VOC emissions, but were also cost effective. Even though they cost some 5% to 10% more than IPA, they allowed an estimated average savings of 30% to 50% in overall dampening costs estimated, because so much less of them was required.

Waterless Printing Technologies

Another way to eliminate VOC emissions in offset printing was to substitute the fountain solution as a whole and print Waterless, a relatively new technology that required no alcohol or any other form of dampening system in the pressroom. This technology had been developed during the late 1980s, particularly in Japan, where the so-called Toray waterless plate in printing processes was used.[56] Because the process required no fountain or dampening solutions, its users were automatically in compliance with environmental regulation concerning water pollution and VOC-emissions.

A further advantage of the waterless printing process was that it produced much higher print quality. Waterless inks could be used in a much greater film thickness, resulting in stronger colors, higher saturation levels, and greater gloss. They also tended to be more rub- and scratch-resistant than conventional inks. With the absence of water, much less ink was absorbed into the paper; it literally stood on the surface of the page, which was the reason for the intense colors and higher gloss and saturation levels that were achieved with waterless inks. Waterless printing was particularly useful for printing on surfaces that were not compatible with water, but could also be used on many other surfaces.

54. "Sheetfeds Set for F&-Cleanup." Graphic Arts Monthly March, 1992, vol. 64, no. 3, 56.
55. "Sheetfeds Set for Em-Cleanup." Graphic Arts Monthly March, 1992, vol. 64, no. 3, 56.
56. ICC Key Note Market Report 1993, 25.

A final advantage of water-based inks was that they were said to be used more easily on recycled papers .[57]

As with any new technology this one also had its initial problems. Principally, over-heating of the plates was expected to be solved with the introduction of new inks and improved cooling system inks. Ink manufacturers such as Dai Nippon's U.S. subsidiary Sun Chemical had already invested considerably in the research and manufacture of waterless inks. Because they did not require any costly dampening systems, waterless printing could result in substantial cost savings. Therefore the future prospects for this technology were very promising: Industry experts expected that at least 10% of the web-offset segment would be waterless by 1996.[58]

Ink Recycling

Waste ink management was a complicated issue because of the confusion concerning the intent and content of many environmental regulations. It was also unclear whether the printer or the printing ink manufacturer was responsible for the disposal of waste inks stemming from the printing process. Three disposal options were commonly discussed:

* Resource recovery, a method which transformed waste inks and similar materials into a supplemental fuel;
* Incineration, in which high-temperature burning reduced inks to a safely disposable ash; and
* Stabilization, in which wastes were solidified and disposed of in approved landfills.

In each of these cases, major disadvantages lay in both the bulk of the waste material going into the waste stream, and in the general public's antipathy to the processes involved. Waste inks had commonly been disposed of by the printing ink manufacturer, and not by the printer who had generated it. Theoretically, however, it was more sensible to have the printer himself deal with the waste ink, because transportation

57. "Shades of Green: Environmentally-Friendly Inks and Dyes." Chemical Marketing Reporter September 20. 1993, vol. 244, no. 12, SR14.

58. ICC Key Note Market Report 1993, 25.

costs would be saved and some direct pressure would be exerted on the printer to minimize the amount of waste ink he generated.

Letting the printer himself deal with the waste ink was not necessarily costly. A Swiss printing firm discovered that it could actually save money by recycling into its own production process a considerable amount of the waste ink it generated.[59] Prior to its recycling program, the company had generated 3,000 kg of waste ink per year, which had been collected in cans and was returned to the ink manufacturer in a labor intensive process that also posed considerable risks to the environment in case of spillage. This motivated the firm to search for methods to re-use its waste ink. After several field trials, it finally discovered that new printing ink could contain up to 5% of waste ink without negatively affecting print quality. The only equipment needed to re-feed waste ink into the printing process was a stirring machine to mix old and new inks which cost about SFr43,000 ($30,000). The new system led to considerable savings in transportation and disposal costs which resulted in a return on investment of three years. Moreover, the environmental aim had been reached by reducing the waste amount by 90%.

59. Zollikofer AG: Stihl. Personal communication to the author.

APPENDIX

Table 1

Ingredients of Printing Inks		
Ingredients	**min %**	**max%**
Pigments	5	30
Solvents	20	70
Adhesives	15	60
Wetting agents. waxes	1	10
Source: Gebr . **Schmidt.**		

Table 2

World Production of Printing Inks			
Country or area	**1990** (1000 tons)	**1991** (1000 tons)	**1991** (%)
USA	863.7	893.1	42.8
Japan	386.1	386.9	18.54
Europe[2]	624.3	642.3	30.78
E.C.[2]	575.8	595.4	28.54
Germany	244.8	262.9	12.6
Others[2]	155.2	164.2	7.87
Total	2029.3	2086.5	100
Calculated from data provided by the Commission of the European Communities, 1990/91, 8-35; UN Statistical Year Book; Statistisches Bundesamt.			

Table 3

European Production of Printing Inks				
	Volume (1000 tons)			Value (1000 ECU)
Country	**1990**	**1991**	**1992**	**1992**
Austria	9.7	9.7	11.9	45,298
Belgium	30.9	27.0	28.2	101,590
Denmark	8.0	7.7	10.0	43,334
Finland	9.3	8.6	8.5	26,709
France	66.7	63.0	67.0	314,000
Germany	244.8	250.0	269.0	981,711
Italy	74.4	65.4	69.3	239,916
Netherlands	22.3	29.5	25.8	117,000
Norway	6.2	6.4	6.2	24,700
Portugal	3.8	3.7	--	--
Spain	31.6	21.3	22.7	78,100
Sweden	11.6	14.3	12.6	48,905
Switzerland	--	12.8	21.4	163,477
UK	92.6	119.8	132.5	573,000

Source: UN Industrial Statistic Yearbook 1991; CEPE, European Confederation of Paint, Printing Ink and Artists' Colours Manufacturers Associations.

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