

**Competitive Implications of Environmental Regulation
in the
Polyvinyl Chloride (PVC) Industry**

by Mariette T. Johnson

March 29, 1996

**The Management Institute for Environment & Business
with the support of
The United States Environmental Protection Agency**

DISCLAIMER

This report has neither been reviewed nor approved by the U.S. Environmental Protection Agency for publication as an EPA report. The contents do not necessarily reflect the views or policies of the U.S. Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

TABLE OF CONTENTS

INTRODUCTION	4
INDUSTRY STRUCTURE.....	4
Product Description	4
Product Application	5
Market Size	5
Threat of New Entrants	6
Leading Supplying Nations	6
Industry Segmentation	7
Competing Technologies	8
ENVIRONMENTAL, HEALTH AND SAFETY PRESSURES	10
Environmental Risk Analysis	10
Production	10
Usage	11
Disposal	11
Regulation.....	13
Anticipated/Potential Regulation	14
PVC Bans.....	14
Chlorine Ban	15
Nature and Focus of Regulation	15
INNOVATION IN RESPONSE TO ENVIRONMENTAL PRESSURES	16
Flexible Wrapping	16
Bottling	16
Additives.....	17
Medical Equipment.....	18
Automotive Uses.....	18
Recycling Technologies.....	18
Bio-Plastics	18
EFFECT OF ENVIRONMENTAL INNOVATION ON INDUSTRY	19
Cost Structure	19
National and World Markets	20
Country Competitiveness.....	20
Substitution Rate of Technology	21
Ripple Effect.....	22
SUMMARY	22
SOURCES.....	24
PERSONAL INTERVIEWS.....	26

INTRODUCTION

Since its early commercial production in the 1940s, vinyl (polyvinyl chloride or PVC) became increasingly inseparable from everyday life. Over the decades, vinyl was substituted in many applications for wood, glass, metal, paper and other plastics. Its greatest use was in construction piping and packaging, although vinyl was also ubiquitous in households. Consumers and industries alike depended more and more on vinyl for everyday items such as vertical blinds, contact lenses, rain gear, record albums, upholstery, shower curtains, shoe soles, cling film, mineral water bottles and a multitude of other products.

Vinyl's prevalence was not accidental, however. Its resistance to acids, alcohol, fire, alkalies and oil and its impermeability to moisture, oxygen and carbon dioxide proved incomparable in medical applications, packaging and automobile parts. The appeal of vinyl also rested in its versatility, availability, price, stability, compatibility with other materials, weight, and ability to be molded by heat.

Vinyl appeared to be an ideal material until the 1970s. Mid-decade, health and safety concerns about vinyl erupted when leading producer BF Goodrich reported to OSHA the deaths of workers exposed to high concentrations of vinyl chloride gas. Although vinyl chloride manufacturers responded to an emergency standard set by OSHA to drastically reduce worker exposure to the gas, environmental pressures against vinyl chloride persisted unmitigated through the 1990s.

Some observers predicted a shrinking market for vinyl, owing to environmental pressures. Since World War II, however, the demand for vinyl had remained high with exceptions related to two worldwide economic downturns.

This study explores the vinyl industry response to environmental pressures, including regulation, and pays particular attention to innovation and substitution as outcomes of pressures. To provide context, this study first examines the vinyl chloride product, use, industry dynamics, manufacturers, production process and the environmental pressures the industry faced.

INDUSTRY STRUCTURE

Product Description

Polyvinyl chloride is a thermoplastic made from hydrocarbons and chlorine. PVC's chlorine constitution is, in fact, what distinguishes it from other plastics. Production of PVC used an estimated 25% to 30% of the world chlorine output (*Science*, 1993 and *Environmental Building News*, 1994).

All plastics fall into the broad structural categories of thermoplastics and thermosets. *Thermoplastics* predominate since they are readily re-molded and re-formed when melted. They have a lower heat distortion point, so that they dissolve when heat and pressure or solvents are applied. In powder or granular form, these materials are used for plastic injection and molding. Thermoplastics are more versatile than thermosets because they are less rigid. Their structure of intertwined, but not interjoined, hydrocarbon chains render them relatively weak and energy-sensitive. As such, they are more readily manipulated and thus applicable to a broader range of applications. (Grandilli, 1981)

At room temperature, the vinyl chloride monomer is colorless, has an ether-like odor, and is a highly flammable gas. PVCs are also highly durable and resistant to chemicals, corrosion, water, weather, and heat.

Thermosets are harder, more brittle, more heat-resistant, and stronger than thermoplastics. These properties are a result of the joined chains of hydrocarbons that comprise thermosets. (Grandilli)

Product Application

PVC had a wide variety of applications in both commercial and consumer sectors. The main PVC markets were building/construction (60%), packaging (6%), consumer products and electrical/electronic applications (5%). (See Exhibit A). This market breakdown was relatively uniform in major PVC world markets.

In the principal PVC market, construction, the material was used for pipes, wire and cable coverings, gutters, window frames, doors, walls, panelling and flooring. (Chemical Manufacturers Association and Grandilli, 1981).

Flexible PVC wrappings were used in a number of industries, including food and drink, building, consumer goods and engineering. In these applications, vinyl was in the form of clear film, lamination film, bubble film, and stretch and shrink film.

Medical applications constituted a tiny market for PVC products (3%). Hospitals used PVC for disposable products (e.g, blood bags, tubing, surgical gloves).

Since vinyl, like all plastics, has relatively low strength, vinyl was used in non-structural auto applications, such as radiator grills, door handles, trays, screen wash bottles, fuel tanks, seats and seat housing. The automotive sector comprised 2% of the PVC market.

Consumer applications (11% of the PVC market) were numerous and included credit cards, records, toys, garden furniture, imitation leather, venetian blinds, shower curtains, appliances, folders and pens. (*Appliance Manufacturer*, 1994 and Chemical Manufacturers Association, 1995)

Market Size

Worldwide, the plastics industry generated sales of roughly \$89 billion. In 1995, US sales were an estimated \$32 billion, placing the US as the largest plastics producer in the world. (*US Industrial Outlook*, 1995) PVC production accounted for an estimated 16% of all plastics output. (*Appliance Manufacturer*, 1994) An estimated 13% of PVC produced in the US was exported out of the country.

In 1994, approximately 37 billion pounds of PVC were shipped worldwide. Europe led PVC production with an estimated 13 billion pounds, accounting for 35% of world production. (European Vinyl Association). The US produced almost as much, an estimated 11 billion lbs. Collectively, North America produced more than 30% of the world's PVC output, followed by Asia/Pacific Rim with greater than 25%. South America constituted a small world share, less than 5%. (*Chemical Week*, 1995).

Feedstock (ethylene) prices rose in the mid-1990s, and the price of PVC increased by 50% during that period. Nevertheless, US industry associations predicted an annual growth rate of 3-5%, which was closely tied to GNP rates. Industrial capacity limited growth in the mid-1990s as producers were operating beyond efficient capacity (i.e., 90-93%). Producers struggled to keep up with growth until new capacity was running in the late 1990s.

Imports were expected to increase in the developing world, particularly the Republic of China and the Pacific Rim, as construction and demand for consumer goods were on the rise. (*Chemical Week*, 1995)

Threat of New Entrants

The barriers to entry in the PVC industry were high, owing to the cyclical nature of the petrochemical business and the high expense of constructing and retrofitting petrochemical plants. Hence, competitive threat was less from companies entering PVC or vinyl chloride monomer (VCM) - the precursor to PVC - manufacturing than from substitution. Growth in the plastics industry had been achieved by substituting "traditional" products such as steel and paper with innovative plastics technology. In much the same way, PVC stood to lose ground to newer materials and different types of plastics.

Substitution of PVC proved difficult, however, especially in the principal construction market. Plastics were preferred in many building applications owing to their relatively low cost versus other materials, their handling ease, light weight, durability, resistance to rotting, peeling, cracking and color-fading in all temperatures. (Grandilli, 1981) PVC was particularly invulnerable in wire and cable insulation, as PVC's insulating property was unequaled.

In packaging, customer demand for perfumes, cosmetics, toiletries and household products in PVC containers were on the rise, as consumers recognized the quality and innovative design possible with vinyl. PVC was believed to be superior in performance in meat and fish packaging, as it increased the shelf-life of these products. Health concerns with respect to plastic wrapping and the potential for the migration of plasticizers, however, afforded opportunity for PVC substitution in this market segment. Difficulty recycling PVC bottles also helped create a market for vinyl substitutes.

Some opportunity for substitution also existed in the medical equipment segment. There, the issue of plasticizer migration had graver importance.

Leading Supplying Nations

United States

In the U.S., the largest PVC producers, each holding more than 10% of the US market, were Formosa Plastics, The Geon Company, Georgia Gulf, and Vista Chemical. Other major producers were Borden Chemicals and Plastics, CertainTeed, Goodyear, Keysor-Century, Occidental Chemical, Shintech, Union Carbide, Vygen and Westlake PVC Corp. The following profiles are representative of the top U.S. producers of PVC.

The Geon Company, headquartered in Avon Lake, Ohio had 1994 sales exceeding \$1.2 billion as a leading US producer of PVC resins and compounds. Geon operated 13 manufacturing plants in the US, Canada and Australia. Principally, Geon marketed its products for construction-related applications and consumer durable goods. Owing to the strong competitive forces evidenced in the industry structure, US producers have relatively similar market share. In the US, PVC was expected to increase its share of the chlorine market to comprise 37%-45% by 2005. (*Chemical Week*, 1995)

Georgia Gulf Corporation, with headquarters in Atlanta, Georgia, posted net sales of over \$955 million in 1994. Of that total, 26% was in the plastics and fibers market and 17% was in the solvents and chemicals market. Georgia Gulf operated 5 manufacturing facilities in the US in 1995, mainly in the Southeast.

Vista Chemical Company, headquartered in Houston, Texas, was an integrated producer of commodity and specialty chemicals, with over 1,450 employees worldwide. The company operated 4 PVC and compounding plants, with three new units positioned for start-up. Capacity at one plant was expected to increase by 30%. Vista is a wholly owned subsidiary of RWE-DEA, a major German company with oil and natural gas interests.

Europe

In Europe, the principal PVC manufacturers were ICI, BP Chemicals, Shell Chemicals, Exxon Chemicals, EVC (EniChem/ICI), Elf Atochem and Norsk Hydro. (Key Note, 1990) The European vinyl market experienced relatively strong growth (14%, up 7% from 1994), despite strong environmental pressure against vinyl.

Asia

Japanese manufacturers of PVC, totalling 13, were substantially concentrated, with nearly half vertically integrated (i.e., also manufacturing vinyl chloride monomer). Four companies exclusively manufactured vinyl chloride monomer. In 1994, total PVC sales in Japan were 300 billion yen, constituting 10% of the world market. The rest of Asia commanded 23% of the world PVC market share.

In Japan, leading PVC manufacturers were Shin-Etsu Chemical Co., Ltd., Kaneka Corporation, Tosoh Corporation and Mitsubishi Chemical Corporation (Japan PVC Association). Elsewhere in Asia, principal PVC producers were Formosa Plastics (Taiwan), LG Chemical (South Korea), and Hanwha Chemical (South Korea).

Rest of the World

Beyond Western Europe, growth in the chemicals industry was taking place in the Middle and Far East, South America and Eastern Europe. Collectively, these regions accounted for less than 10% of worldwide PVC production.

Industry Segmentation

The industry was comprised of six main sectors:

- Chlor-alkali companies that manufacture the chlorine for PVC
- Chemical companies that use chlorine to produce ethylene dichloride (EDC) and vinyl chloride monomer (VCM or vinyl chloride) used in PVC production
- Plastics manufacturers that polymerize VCM into PVC polymer
- Companies that supply additives
- Plastics companies that mix PVC and additives
- Product companies that manufacture end-use PVC products

Upstream production was highly concentrated, whereby 13 chlorine manufacturers, 27 vinyl chloride manufacturers, and 27 PVC manufacturers competed in the US. In contrast, downstream producers were highly fragmented. Hundreds of compounders and over 2,000 OEMs (original equipment manufacturers) competed in the US and Canada.

Competing Technologies

Traditional Chlorine Production

In the first stage of PVC production, chlorine gas is produced. The predominant method of making chlorine gas is the electrolysis of salt (sodium chloride). (See Exhibit 1) Chlorine manufacturing is a critical component of the PVC product. By weight, the PVC resin is more than half chlorine (56%).

Monomer Production

In the second stage of PVC production, the vinyl chloride monomer (VCM) is made. The petrochemical ethylene, the most common hydrocarbon feedstock, is used in VCM production. Ethylene is made by cracking ethane (C_2H_4 , derived from natural gas) in a reactor at 800 degrees C. (Grandilli, 1981 and *Environmental Building News*, 1994).

Ethylene and chlorine are then combined to make 1,2-dichloroethane (EDC), which is in turn synthesized into the vinyl chlorine monomer (C_2H_3Cl).

Polymer Production

VCM is transformed into PVC through the process of polymerization. In this process, VCMs are chained together in long, intertwined ropes or polymers. (Grandilli, 1981)

Polymers are large molecules composed of chains of repeating molecules held together by a chemical bond. (Portney, 1990) Polymerization is achieved by various processes, the most common of which is suspension. In this process, the catalysts methyl cellulose and organic peroxides are stirred into VCM. The compound must be continuously and vigorously stirred and cooled for six to eight hours. Through polymerization, VCM becomes poly vinyl chloride resin in the form of stable powder. (Vinyl Institute, undated)

Additives

Plasticizers, stabilizers, elastomers, fungicides, lubricants, fillers, modifiers, anti-static compounds, optical brighteners, impact modifiers, heavy metals (lead, cadmium, tin, barium, zinc), antioxidants and pigments are added to the resin to create usable material. (*Appliance Manufacturer*, 1994) For example, to make PVC softer, more flexible and more stable, plasticizers were added by mixing the resin with oils such as tricresyl phosphate and dioctyl phthalate or with polymeric plasticizers (e.g, sebacic acid polyester). As softeners, tritolyphosphate or tricresylphosphate) and bis (2-ethyl-hexyl)- phthalate are added. Heavy metals are also be added to make PVC hard or to give it color.

Additives were present in various proportions ranging from 5% of the PVC formulation to as much as 50%. (Norsk Hydro, 1992)

Final Production

PVC is melted into end-products through the process of extrusion, injection and molding. Most commonly, rigid and semi-rigid plastic containers were made by injection or blow-molding.

PVC is a physical mixture, as opposed to a new chemical compound. This distinction is important to understand since the components of physical mixtures are capable of migrating into other materials if compatibility is greater. (Norsk Hydro, 1992).

Innovative Chlorine Production

A more energy-efficient method of chlorine production was advanced that produced higher-value by-products (Environmental Building News, p. 9). It involved the use of FM21 membrane cells. The membrane process involves an organic membrane, such as a fluorinated polymer, to take apart the products of electrolysis. (Norsk Hydro, 1992). Cell membrane technology accounted for a minor portion of chlorine production although it was increasing in usage.

Innovative Final Production

Die-mounted water jet technology (to cool rigid PVC such as window frames internally), and multi-strand die systems (to improve speed on the production line), were developed. (*Modern Plastics*, 1994)

PVC production was made more efficient by the adoption of the lower-energy consumption process of efficient drying.

In recognition of the issue of PVC component migration, producers designed formulations for particular contact applications.

Innovative Additives

Industry players anticipated legislation against heavy metal-based additives and thus substituted mineral-based additives. Wire and cable producers resisted this shift, as substitutes in this application did not perform up to standards.

ENVIRONMENTAL, HEALTH AND SAFETY PRESSURES

Environmental Risk Analysis

Although all plastics have come under fire for environmental reasons, vinyl chloride was attacked more severely on the basis of its chlorine content. Some studies revealed that the formation of polychlorinated dibenzodioxins (dioxins) and polychlorinated dibenzofurans (furans), occurred throughout the lifecycle of PVC, although this belief was disputed by industry players. All agreed, however, that dioxins were formed in incineration or accidental combustion of PVC-containing products. (Great Lakes United)

Dioxins were known to be "ultrahazardous" in their ability to illicit development disorders, to suppress immune function, to increase cancer risk, to disrupt endocrine systems, producing estrogen-mimicking effects detrimental to reproductive systems, to accumulate in the fatty tissues of humans and animals, and to be highly persistent in the environment (i.e., they do not readily degrade.) (*Plastics World*, 1994,

Science, 1993 and *C&EN*, 1993) To place dioxin toxicity in perspective, the substances were believed to be 10,000 times more toxic than cyanide.

The EPA's Dioxin Reassessment, first published in 1994, increased the scope of concern about dioxins and framed the controversy between environmentalists and industry about the causes and effects of dioxin. The study instigated a series of studies in Europe about the hazards of chlorine and PVC.

The following segments profile the environmental concerns throughout the lifecycle of PVC.

Production

Environmental groups were concerned with PVC beginning with its production stage and the initial transportation of explosive materials involved in the process, as well as the creation of toxic wastes. In chlorine production, chlorine, mercury and hydrogen were released in the amalgam process. The diaphragm process released chlorine, hydrogen and asbestos fibers, which presented a workplace hazard. In addition to these airborne pollutants, liquid and solid wastes were also formed. Inorganic contaminants such as calcium, magnesium and iron compounds created from brine purification formed a wet sludge deposited into landfills. The amalgam chlorine process produced mercury-contaminated water. (See Exhibit 2)

In the thermal cracking of natural gases that leads to vinyl chloride, the principal pollutants generated were carbon dioxide, nitrogen oxide, carbon monoxide, ethylene, and propylene. Methane and other pollutants are generated. Low molecular weight pollutants were generally sold as raw materials for other processes, such as solvent manufacture. Higher molecular weight by-products were able to be incinerated to generate energy and produce hydrogen chloride. (Norsk Hydro, 1992)

The most likely emissions from a PVC manufacturing plant were VCM and PVC dust released into the atmosphere or contaminating waste water. Waste water containing heavy amounts of fine PVC particles often ended up in landfills. PVC plants were also documented to release fugitive emissions of volatile organic compounds (VOCs) from tanks, valves, incinerator stacks and pipe connections. (Norsk Hydro, 1992).

Acid gas emissions and VOCs caused a host of environmental effects. Emissions of acid gases were known to result in acid rain, acidifying lakes and soil and negatively impacting ecosystems. VOCs contributed to the creation of toxic ground-level ozone.

Usage

PVC was believed by environmentalists to be toxic in usage. The primary culprit was believed to be plasticizers, suspected carcinogens, which migrated from PVC-containing materials into the air (from PVC flooring), into food and drink (from PVC packaging) or into IV solution, blood, fats and some drugs (from IV bags, blood bags or other medical equipment). (Business Wire, 1992) Of most concern was the plasticizer DEHP (diethylhexyl phthalate) which was most prevalent in PVC. (See Exhibit 3)

Although it did not address the issue of plasticizers, a report released by the UK government's Ministry of Agriculture Fisheries & Food concluded that dioxin levels in food packaging posed no health threat to humans. (Vinyl Institute, undated)

The use of products containing vinyl chloride was the subject of health considerations as early as the

1970s. It was known then that plastic packaging containing vinyl chloride could leach into food, beverages and consumer products. (Doniger, 1978)

The issue of carcinogenicity erupted in 1973 when BF Goodrich (now The Geon Company) revealed to OSHA that several workers exposed to high dosages of vinyl chloride died from a rare liver cancer, angiosarcoma. Within several years after the dangers of vinyl chloride were exposed, emissions had been reduced by more than 90%.

The International Agency for Research on Cancer pinpointed vinyl chloride as a human and animal carcinogen. According to the Agency for Toxic Substances and Disease Registry of the US Public Health Service, increases in cancer of the liver, lung and brain, as well as other diseases (e.g., acroosteolysis, causing bone tuft degeneration; scleroderma; Reynaud's phenomenon) were attributable to occupational exposure to vinyl chloride. Skin, eye, mucous membrane and respiratory tract irritations were also said to result from acute exposure to the chemical, as was nausea, staggering gait, euphoria, anesthesia, headache, and reduction of visual and auditory response. Central nervous system malformations were also documented near PVC production facilities. (Rosenman, 1989)

Although heavy-metal based additives were no longer used in materials in contact with food or medical products, lead was still commonly used in European water pipes in the early 1990s; similarly, tin stabilizers were used for the same purpose in the US. (Norsk Hydro, 1992).

Disposal

Landfilling

Several of the characteristics that made vinyl versatile (i.e., non-corrosivity, stability, resistance to UV degradation) created environmental problems in the final stages of the PVC lifecycle. Although PVC's invulnerability to the corrosive environment of landfills allowed it to be used as landfill liners, it also released additives damaging to groundwater. Over time, heavy metals and other additives were broken down by microbial activity or corrosive liquids. Vinyl remnants with higher resistance to degradation remained in the landfill as "fluff." (See Exhibit 4)

Landfill space was also a problem, particularly in Europe.

Lastly, landfilled solid waste contributed to the development of the powerful greenhouse gas methane.

Recycling

As plastics assumed greater relevance in daily life, reducing plastics in landfills became a higher priority. Overall, plastics accounted for 20% of the solid waste stream by volume, of which vinyl constituted .5% in 1993, according to industry estimates. PVC contaminated the plastic waste stream because it was difficult to separate PVC from polyethylene terephthalate (PET), as they were virtually indistinguishable.

Many viewed PVC recycling as prohibitively expensive and thus recycling was extremely limited (.2% of all post-consumer PVC in 1992). (*Municipal Solid Waste*, 1993) Consequently, the fraction of PVC production that was recycled was "down-cycled" (i.e., recycled into a lower-grade product such as carpet backing or floor mats which are less valuable than commodities the vinyl originated from).

An estimated 150 million PVC bottles were successfully recycled in 1993 and some predicted this figure to double by 1997. (*Modern Plastics*, 1993) Industry players maintained that tremendous potential

existed for recycled vinyl. Recycling volume in 1995, however, remained constrained by key challenges: economically viable collection, transportation, separation and sorting as well as developed end-markets for all kinds of vinyl.

Incineration

When burned accidentally or intentionally, PVC produced hazardous wastes. Incineration of vinyl released hydrogen chloride gas, a toxin contributing to acid rain, as well as heavy metals. Any heavy metal residues trapped in filters had to be disposed of as a hazardous waste. Although scrubbing systems existed to separate about 99% of hydrogen chloride produced by the incineration of vinyl and other chlorine-containing products, no method was 100% effective. EPA research estimated that 95% of all known sources of dioxins emissions were from medical and municipal waste incineration. (*BNA National Environment Daily*, 1995)

PVC formulations containing flame retardant metal and molybdenum oxides increased fire toxicity. The release of noxious fumes from PVC in burning buildings and subways heightened public concern over the real threat of PVC-linked accidental fire.

Swedish and Danish studies have revealed that PVC accounted for an estimated 30-70% of chlorine content found in incinerators. The majority of chlorine existed as hydrogen chloride gas which had to be removed from flu gases. A lesser degree of chlorine was in heavy metal chlorides from such discarded items as batteries and electronic components. In minute quantity, chlorine was present in dioxins and furans found in flu gases.

To some degree, the economic and environmental costs of incineration were able to be offset by energy recovery, of which 70-75% of energy was estimated to be recoverable. The municipal solid waste incinerator in Brussels, for example, produced 5% of the city's electricity in 1990.

Regulation

United States

The plastics industry, like all other chemicals industries, was subject to air, water, hazardous waste, and worker safety regulation.

In the late 1970s, health hazards associated with prolonged worker exposure to vinyl chloride monomer prompted Occupational and Safety Health Administration (OSHA) and Environmental Protection Agency (EPA) regulation of the vinyl industry. As a result, the industry installed controls that reduced emissions by 99%. (Vinyl Institute, undated)

The Food and Drug Administration (FDA) banned the use of PVC food containers in the mid-1970s owing to evidence that vinyl chloride monomer in the packaging migrates into fatty and alcohol-based foods. (Great Lakes United) Industry modifications to PVC processing reduced migration of the monomer and lessened risk of cancer; this led to a reversal of this law in 1986.

In the 1980s, concern erupted over the use of plasticizers in cling film products despite little scientific research on the effect of plasticizer migration. Potential health risks were incurred with the use of plasticizers in PVC sheeting, specifically dioctyl adipate (DOA) and di-2-ethyl-hexyl adipate (DEHA or DOP).

Even though a 1987 scientific report maintained that plasticizer migration was not a real threat to human health, other researchers believed otherwise. In 1990 EC plastics directive III/3142/89 for overwrapping meat and produce limited plasticizer migration.

Europe

In late 1994, the European Commission legislated a recycling target of 15% for the plastics industry. During the same period, the European Environment Ministers adopted a directive for higher dioxin emissions standards. The European Union (EU) drafted a proposal to set more stringent standards for the incineration of municipal waste, which was expected to raise the cost of removing, treating and disposing of dioxin-related residue in incinerators.

An EU program focusing on pollution-related diseases (such as developmental disorders, fertility, cancer) was to be proposed in 1995, potentially impacting chlorine use and the PVC industry.

National legislation in Europe also impacted PVC. The German Ministry of Land Development published technical guidelines in 1993 requesting that PVC stabilizers not include lead and cadmium. In Denmark, the "can ban" legislation, upheld by the European Court of Justice in the absence of a common EU ruling, prevented the use of plastics, including PVC, in beverage containers. Finland enacted an eco-tax in June 1994 on all bottles, according to their recyclability.

At the same time, industry pressures resulting from the difficulty in finding suitable PVC alternatives for certain applications led an attack against a proposal to the Swedish Parliament to phase out plasticized PVC by 2000. (*Modern Plastics*, 1995) In addition, although it was disputed, the German Federal Government Commission endorsed the use of PVC in building uses after a two and a half year study of PVC. (*Plastics News*, 1994). In late 1994, Belgium redrafted its proposed legislation to tax mineral water bottles made of PVC but not of other plastics so that PVC would not be disfavored. (*Chemical Week*, 1994)

Anticipated/Potential Regulation

United States

By 1996, EPA was slated to finalize legislation controlling air emissions of the more than 2,200 medical waste incinerators (MWI). EPA proposed legislation to require any incinerator, regardless of its size, to meet Clean Air Act standards. This move was prompted when EPA was sued for not enforcing the federal standards on MWI that were imposed on 150 municipal incinerators. Although a multitude of state and local mandates on air control existed, they were not as stringent as federal legislation. (American Hospital Association, interview, 1995)

Although the EPA previously proposed to regulate emissions from secondary lead smelters in 1994 and had previously classified PVC scrap as hazardous waste, in April of 1995, the agency proposed to remove emission limits on lead smelters. EPA research indicated that the amount of PVC found in lead-acid battery scrap had declined 90%. The proposal would have required 23 smelters to install maximum available control technology to reduce air pollution by 2,200 tons per year. (*BNA National Environment Daily*, 1995).

Europe

Initially in 1993, the German Ministry of the Environment proposed an ordinance avoiding and recycling waste from end-of-life vehicles which would directly affect PVC used in the automotive sector.

PVC Bans

Plastics were under threat of ban once their use became commonplace. Numerous bills limiting plastics, including PVC, were advanced throughout the US. (*Plastics World*, 1990) New Jersey cities passed packaging ordinances banning plastic packaging, including PVC in retail food establishments. (Local Solutions to Global Pollution, 1991)

Throughout Europe, municipal PVC phase-outs in the 1990s impacted subway system construction, underground use of PVC piping and hospital applications. More than half a dozen Austrian states and towns including Vienna, Innsbruck and Salzburg strongly discouraged the use of PVC in construction. Although these phase-outs were not directives or explicit bans of PVC, the aforementioned Austrian jurisdictions withheld subsidies for projects using PVC.

Similarly, the Swedish Food Manufacturers group voluntarily agreed to phase out PVC food packaging in 1990. The same year, the Government of Switzerland banned PVC in mineral water bottles, beer and soft drink packaging. In June 1991, the Government of Denmark and the Danish Plastics Federation voluntarily agreed to phase out the use of PVC in packaging, construction and medical equipment. The agreement also strove to significantly increase PVC recycling by 2000. In 1993, the Swedish National Assembly adopted the Eco-Cycle Proposition, which supported the development of alternative plastics and which stated that PVC should be avoided as it was particularly burdensome on the environment. In 1994, the Danish Environment Ministry planned to publish a handbook of "green" PVC purchasing guidelines, potentially discriminating against PVC. (European Council of Vinyl Manufacturers, 1994)

A multitude of Northern European companies took a stance against PVC. IKEA of Sweden is one notable example. In September of 1993, driven by senior management, IKEA discontinued the use of PVC where alternatives existed. The company vowed that by September 1996, it would phase out PVC entirely (with the exception of electric lamp cords, for which it proved difficult to find a suitable replacement).

In Germany, Sony-Europe instituted an internal packaging policy to replace PVC with polyethylene (PE), polystyrene (PS) and polyethylene terephthalate (PET). Likewise, Bayer replaced PVC packaging with polypropylene (PP) in 1991. AEG announced that it would no longer use PVC in its electronics and appliances (e.g., vacuums, ovens). Siemens also moved to make PVC-free coatings for cables. BMW specified its preference for PVC alternatives for dashboards, trim and wire coating owing to European plastics recycling legislation. (*Chemical Week*, 1995)

Danish supermarket chain IRMA A/S eliminated PVC products and Denmark's largest retail chain, Matas, substituted other products for 75% of PVC-containing goods.

Several Austrian retailers, such as SPAR, Bene (an office equipment supplier) and Gowi (a toy producer) moved away from PVC.

In the UK, on the other hand, companies such as Boots and Marks & Spencer declared their acceptance of PVC.

Chlorine Ban

There was some discussion in the early 1990s of banning the entire class of organochlorides, including PVC products. The American Public Health Association, for example, stated in 1993 that organochlorines should be treated as a class and phased-out, with the exception of chemicals proved to be safe or essential. The International Joint Commission on the Great Lakes agreed with these conclusions in 1992 and 1994, recommending that chlorine and chlorine-containing compounds used as industrial feedstocks be reduced or eliminated. (*US Industrial Outlook*, 1995) Similarly, the European-based Paris Commission on the Northeast Atlantic and the Barcelona Convention on the Mediterranean Sea agreed that discharges of persistent bioaccumulative chemicals, including organochlorines, be eliminated. In opposition, industry supporters pointed to an industry-commissioned study by Charles River Associates which assessed the negative economic impact of an organochlorine ban.

Nature and Focus of Regulation

Toxic control statutes, including those addressing vinyl chloride, were enacted incrementally over a period of many years. This fragmented approach, which did not address environmental, health and safety issues in the context of the entire life cycle of vinyl chloride, subjected the industry to the overlapping and sometimes conflicting requirements of separate laws. (Doniger, 1978) Industry anticipated economic demise as a result of initial regulation of the industry in the 1970s. As noted earlier, however, industry growth was undampened. And, in the 1990s the cost of complying with regulation was said to cost up to 30% of capital expenditures, yet the industry continued to expand.

INNOVATION IN RESPONSE TO ENVIRONMENTAL PRESSURES

The prevalence, cost, performance and versatility of PVC made substitution unlikely to occur rapidly or easily. Substitution occurred most readily in short-life uses of the material and where environmental and health concerns were highest (i.e., packaging and medical equipment). Also, alternatives were more available in non-durable products and market pressure to replace PVC in products with short lifespans was stronger. (Great Lakes United)

Some manufacturers were pressured to move away from PVC in order to accommodate recycling demand. Recycling of PVC was difficult, as additives in PVC and PVC-composites are commonly used.

Innovation was less apt to occur in the primary PVC market (i.e., construction) given the strong performance characteristics of PVC and lower level of environmental and health risks associated with 50-year lived products in minimal contact with people.

Although many minor PVC markets (e.g., credit cards) affected by environmental pressures experienced substitution, the following sectors address the more important innovations that were taking place.

Flexible Wrapping

The cling film industry is illustrative of the potent impact of public health concern on PVC-based products. Manufacturers of plasticized PVC stretch films that had not already done so developed low-migration PVC films to comply with the 1987 EC directive.

In 1989, UK-based Lin Pac introduced a low-migration film for the food industry. The UK's Borden also introduced a low-migration film called Fresh-Cling LM, suitable for all

applications and microwave use.

By 1992, di-2-ethylhexyl phthalate (DOP), still being produced at a rate of 300 million lbs./yr., showed no prospects for significant growth.

The concern about plasticizers also led to the use of ethylene vinyl acetate copolymers, known as EVA copolymers (they do not contain plasticizers) for clear film, lamination film, bubble film, stretch and shrink film.

Bottling

In response to concern regarding plastics in landfills, Premier Waters designed crushable polyethylene terephthalate (PET) bottles for leading mineral water marketers Evian Eau Minerale Naturelle and Vittel of France. Evian's parent Danone invested over \$60 million in 1994 and 1995 to create a new bottle design with PET. Historically, PVC had been used in mineral water bottling. Although Evian was a market leader with 21% market share in France, the new design was anticipated to help Evian recover from a 1994 market share erosion.

In new packaging, large manufacturers were reluctant to use PVC. PET began to supplant PVC in cosmetic bottles that were stretch blow molded. (*Modern Plastics*, 1994)

UK-based ICI's Melinar group designed PET to allow the plastic to be refilled and reused. Melinar supplied plastics for soft drink franchises in Europe through Wellstar. Over a five year period, bottles could be reused up to 20 times and then recycled into filling for clothing and toys.

Additives

Non-toxic alternatives to heavy metals (e.g., lead, arsenic, chromium and cadmium) used in colorants and stabilizers for PVC were developed in response to EPA classification of PVC scrap as hazardous waste. Suppliers began to produce barium-zinc, calcium-zinc, magnesium-zinc and calcium-aluminum zinc, which display similar performance characteristics in certain applications. Among the first innovations heavily tested was a calcium-zinc thermal stabilizer. For vinyl food packaging, the compound performed well, but for PVC pipe and other rigid vinyls, customers were unsatisfied with the thermal stability of calcium-zinc. US additives maker Akcros marketed its series called Interlite, consisting of calcium, magnesium, and zinc in place of heavy metals.

Experimentation in the 1990s replacing heavy-metal based heat stabilizers with unsaturated natural oils with epoxy groups formed at the double bonds proved successful in both reducing metal content and lowering costs. Epoxidized soy bean, sunflower and linseed oil did not release hazardous compounds into the environment when incinerated and were less costly than metals. (Norsk Hydro, 1992).

Medical Equipment

Hospitals proved to be particularly concerned with the health impacts of medical products, including PVC products. Additionally, pending environmental regulation of hospital incinerators, which tended to be smaller-scale, lower-budget (and hence ill-equipped with scrubbers) also poised hospitals to be more receptive to PVC substitutes.

McGaw Inc., headquartered in Irvine, CA responded to the prevailing sensitivity to health and

environmental considerations in 1990 by developing non-PVC intravenous bags named EXCEL. The IV bags were non-toxic, environmentally safe and biologically inert, and thus did not produce toxic gases when incinerated. The product also alleviated concerns about PVC-related plasticizer migration. Plasticizer migration was more apt to occur in medical applications of PVC, as the 120 degree F heat required for steam sterilization fostered migration. (Business Wire, 1992)

Cyrovac, spinoff of \$1.4 billion (1994) Grace Packaging, developed a polyolefin film which passed tests for use in numerous medical applications such as IV and blood bags.

Rhone-Poulenc Agriculture created a water-soluble, heat-sensitive bag of PVA (poly vinyl alcohol) film for medical applications. (American Hospital Association, 1995)

Automotive Uses

In general, the automotive industry embraced the use of plastics and other lightweight materials in the interest of fuel efficiency. In fact, the Partnership for a New Generation of Vehicles (PNGV), which included the Big Three and the US federal government, was formed in 1994 and emphasized plastic composites in automotive design.

Although it had been preferred for auto interiors, manufacturers were shifting away from PVC as a result of environmental concerns about recyclability and incineration. (*Modern Plastics*, 1994) Some manufacturers went farther; BMW and Mercedes announced their intentions in the early 1990s to create automobiles without any PVC.

Geon, Parma Plastics, Hematite, and Philip Environmental Inc. formed an alliance to recycle PVC in automotive scrap. Reclaimed PVC is recycled at the USCAR auto disassembly plant in Highland Park, MI and used to create new automotive parts. (CANCORP Plus)

Dow Chemical developed a metallocene-based polyolefin technology which it anticipated to replace 20% of flexible PVC. Polyolefins had similar characteristics to PVCs but did not allow for the migration of plasticizers into materials. The driver of this technology according to Dow was a "lab invention" rather than a search for an alternative plastic. The product's growth was expected to be stymied by "relatively high prices, limited capacity, and the need for market and technical development," at least in the short term. (*Modern Plastics*, 1994) The clarity and elasticity of the product, as well as low-temperature impact, offered good performance in many niche applications.

Recycling Technologies

PET recyclers' unwillingness to accept vinyl and growing concern about vinyl in the waste stream prompted the development of recycling technologies. The Center for Plastics Recycling Research at Rutgers University and National Recovery Technologies, Inc. of Nashville, Tennessee were among those involved in designed systems such as electromagnetic detection of chlorine-containing plastics (e.g., vinyl). X-ray fluorescence was also applied to the identification and sorting of vinyl. Composites, however, remained difficult to sort.

One recycler in North Carolina was recovering vinyl siding at a rate of 1.92 million lbs. annually, grinding vinyl into pellets on-site. In Europe, a joint venture of PVC manufacturers ICI and EniChemi recycled PET and PVC bottles, converting the material into powder or granules.

Tokyo-based TOA Electronics Ltd. also designed an automatic infrared sorting technique to identify resin

in waste. The molecular identity of a resin was revealed through spectrometry using short-range infrared waves of 1-2 micrometers.

Bio-Plastics

In response to the search for alternatives to plastics recycling and incineration, a half-dozen manufacturers in the US and Japan began developing innovative plastics based on polylactic acid (PLA) polymers or polyglycolides around 1990. Unlike their predecessors in the late 1980s, these thermoplastic "bio-plastics" were truly biodegradable. Since bio-plastics were derived from microbially fermented corn and other agricultural products in the case of PLA and from plant cellulose in the latter, they were entirely compostable and ultimately reverted to carbon dioxide and water. (*Plastics Technology*, 1995) Bio-plastics did not degrade in the absence of microbes and could also be chemically reconverted to lactic acid and repolymerized for re-use. Despite its degradability, PLA applications were not restricted to short-term uses. Degradability could be varied considerably.

Although bio-plastics were pre-commercial in 1995, in trials with customers, PLA's performance mimicked that of flexible PVC and other plastics. PLA was viewed as a logical substitute for blow molded and injected molded utensils and bottles, extruded film and packaging sheet for lids, trays and other containers. Specific attributes responsible for the superior performance were proprietary, but included such features as being more stretchy and having higher impact resistance.

In 1995, Cargill had an operating capacity of 8-12 million/year and intended to open a commercial plant capable of 100-300 million lbs./yr. by 1998. The joint venture of DuPont Co. and ConAgra, Inc. (Newport, Delaware-based Ecochem) and the Chronopol Co., a spinoff from Adolph Coors Co. also teamed up in a 50/50 joint venture called Ecopol L.L.C. Their objective was to market the PLA technology they had been developing since 1990 for engineering applications. Japanese firms Dainippon Ink & Chemicals, Inc., Mitsui Toatsu Chemicals, Inc. and Shimadzu Corp. were planning pilot plants in 1995 for their PLA technologies.

EFFECT OF ENVIRONMENTAL INNOVATION ON INDUSTRY

Cost Structure

PVC markets achieved sustained growth for decades in large part because of PVC's relatively low cost. High prices for wood, glass and other types of plastics accounted in part for PVC's staying power. Process innovation, however, such as die-mounted water jet technology that cooled profiles internally, and multi-strand die systems that improved line speeds also suggested a continued market for PVC. (*Modern Plastics*, 1994)

Compared to PVC, alternatives were generally premium-priced. New-generation polyolefin resins, however, had the potential to meet or outperform PVC in cost. This was especially so in flexible plastics markets.

Bio-plastics in 1995 were higher-priced than their PVC counterparts, but the cost of producing bio-plastics was expected to be lower than PVC production in the long run. In 1995, the price of PVC feedstock ethylene was \$.15/lb. versus \$.10 for bio-plastic feedstock corn sugar. According to bio-plastic developers, the two materials were comparable in terms of usage rates (i.e., 1 lb. of ethylene or 1 lb. of corn sugar produced 1 lb. of plastic). (Chronopol interview)

Bio-plastic technology had been in use for absorbable surgical sutures and bone screws, but had been

cost-prohibitive for other applications at \$500 to \$2000/lb. Minneapolis-based Cargill planned to price PLA at \$3-5/lb. initially and \$1/lb. later in commercial production using newer technology.

National and World Markets

Growth

New end-user markets for vinyl were under development, including fencing and sea walls, with an estimated potential growth of 1 billion pounds a year. (*Modern Plastics*, 1994) Developing regions presented strong opportunities for PVC growth. Demand for PVC was on the rise in the Republic of China and the Pacific Rim (*Chemical Week*, 1994). Asia (apart from Japan), Eastern Europe and Mexico were predicted to account for 8-12% annual growth in PVCs through 2000 to meet demands for infrastructure upgrading and improved distribution and packaging systems.

Nevertheless, it was predicted that environmental concerns would allow PVC substitutes to leapfrog PVC where construction and other potential uses for PVC were beginning to take off. Since recycling of plastics had become of critical interest, the success of vinyl recycling programs would in part determine vinyl's survivability vs. innovations.

Recycling

In the 1990s, the vinyl industry expended considerable effort to improve recycling technologies, responding to the pressure in the US and Europe from processors that recycled all plastic material.

Nearly all post-use vinyl ended up in landfills, including construction and demolition debris and the demand for recycled vinyl exceeded supply. In 1995, 0.1% of all vinyl produced was recycled. Of the estimated 15,000 communities engaged in recycling, 25% accepted vinyl in 1994.

Country Competitiveness

United States

Long recognized as the lowest-cost PVC producers given abundant ethylene feedstock supplies and the strong dollar, US manufacturers' international competitiveness became more vulnerable with the weakening of the dollar and the rise in ethylene prices experienced in the mid-1990s.

Nonetheless, a number of PVC production facilities in the US anticipated sustained growth, evidenced in their expansion plans. Shintech Inc. was expected to complete a 540 million-pound capacity addition by the end of 1995. Likewise, Vista Chemical was slated to increase capacity by 300 million pounds. Occidental Chemical Corporation planned to expand a facility by 120 million pounds. Over the following two years, CertainTeed Corporation planned to increase production by 150 million pounds, Georgia Gulf Corporation was expected to expand capacity by 200 million pounds and Formosa Plastics Corporation was scheduled to raise production by an undisclosed amount.

Innovators were experiencing growth in their niche markets. Owen Healthcare entered into a supplier agreement with McGaw for \$50 million over 5 years. Owen president Carl E. Isgren found McGaw's

EXCEL bag to be the only environmentally-friendly product of its kind marketed. (Business Wire, 1991)

Europe

The move by French mineral water bottles away from PVC to PET was predicted to cause a 100,000 metric ton per year decline in PVC usage. Fewer PVC manufacturers reported plans for expansion compared to the US.

PVC substitutes, meanwhile, were taking hold in niche markets. Kabi Pharmacia AB of Stockholm, a leading supplier of IV products in Europe, obtained licensing rights for McGaw's EXCEL IV containers, and expected to generate \$10 million in revenues in the first 5 years of European sales. "Responsiveness to environmental issues is especially important in the European market," according to Lars Lingegren, president of Kabi. "EXCEL IV bags can be incinerated without damaging the environment." (Business Wire, 1991) McGaw's chairman and CEO James M. Sweeney noted that the agreement demonstrated the shift away from PVC containers in IV treatment. McGaw invested over \$40 million in creating new products that are less damaging to the environment and to patients. Sweeney stated that the new IV product was a key factor in the company's increase in market share. "Health care providers are under intense public scrutiny. They want to make purchasing decisions that are consistent with their health care mission."

Asia

In Asia, PVC manufacturers such as Tokuyama Sekisui Company of Japan anticipated a 200 million pound PVC expansion in 1995.

Japanese bio-plastic companies such as Mitsui Toatsu produced PLA to address the lack of landfill space. Japanese firms perceived target commodity markets for PLA outside the US, in Europe and Asia. In Japan, customers were willing to pay more, government support existed, and public relations benefit was perceived in using PLA. According to one manufacturer, US customers were unwilling to pay a premium for bio-plastics, and unless regulation ensued, the US market was unpromising.

Substitution Rate of Technology

Vinyl industry observers contended that less than 6% of the total PVC market would be affected by substitution in coming years. Applications for "giant" rigid PVC in waste, sewer and drain-vent piping, appliance control panels, window, siding, and other exterior profiles, and business machine housings were thought to be relatively invulnerable to replacement. (*Modern Plastics*, 1994)

In the smaller PVC markets, replacement in the order of 50% or more by the end of the century was expected to take place in rigid food containers, blister pack or packaging sheet, water distribution pipe, flexible flooring, food wrap, IV medical bags, tubing, dashboard skins, and wire and cable coverings.

The replacement of PVC bottling with crushable PET plastic, affected 12% of the French PVC market (*Chemical Week*, January, 1995) In water bottling, PET had a 45% share vs. PVC with 33%, glass 15% and other (mainly can) 7%. (Key Note, 1995)

Concern over plasticizers in flexible wrapping moved the industry away from conventional PVC film to alternatives such as cellulose and high-density polyethylene (HDPE), resulting in a temporary growth of 10% per annum in HDPE. In some instances, plasticizer plants, such as BASF's Carney, NJ plant with 240 million lb./yr. capacity and 175 million lb./yr. of phthalic anhydride (the main phthalate raw material) were shut down. Total plasticizer demand declined as the trend toward PVC substitutes continued. No new markets for flexible film had been uncovered in a decade. Tightening supply of phthalic anhydride (PA), the principal raw material for the phthalates used in plasticizers. (*Modern Plastics*, 1992)

In medical applications, the penetration of PVC alternatives was remained small. The market for IV bags was estimated at approximately \$30 million in the US, heavily controlled by Baxter (55% market share). Abbott Laboratories captured approximately 35% of the market, while McGaw held 10%. Cyrovac, maker of non-PVC medical products, had a smaller share of the market.

Ripple Effect

The range of environmental concerns about PVC, from dioxin to recycling, elicited R&D efforts in a new generation of plastics, bio-plastics. Regulation and the threat of regulation was also seen as driving the development of alternatives.

One of the most promising innovations seemed to be the bio-plastics developed by several US and Japanese firms. This new generation of plastics had the potential to eventually wrestle significant share from flexible PVC, polyethylene and other plastics markets. (*Plastics Technology*, 1995)

SUMMARY

U.S. environmental regulation launched against the vinyl chloride industry in the 1970s, which was anticipated to wield devastating economic consequences, did not impede growth and profitability. Instead, it instigated changes in production processes and product quality, rendering the industry more viable under the scrutiny it endured in the next two decades. Although the industry experienced a few downturns attributable to global economic conditions, through the mid-1990s, the growth rate of the vinyl industry outpaced the oft-used predictor of PVC industry growth, the GNP.

Environmental concerns in the 1980s and 1990s over dioxin formation, plasticizer migration, recycling, and the production of hazardous wastes associated with PVC heightened the appeal of innovative alternatives to vinyl. New regulation and bans in the 1990s also affected innovation, but the performance, versatility, cost and other characteristics of PVC precluded a significant level of substitution for other products.

In fact, measurable substitution occurred only in non-durable PVC applications in which pressures were more fierce. By 1995, as yet untested (in the commercial market) bio-plastics seemed the only innovation with strong potential to topple PVC's predominance in packaging and film. Even if bio-plastics successfully siphoned off market share from PVC in these markets, it would impact no more than 10% of the overall PVC market.

Marketplace pressures also affected a key supplier to the industry. An industry-wide switch from heavy-metal based additives to mineral-based alternatives took place as industry players feared a repeat of the asbestos and CFC scenarios.

Unequivocally, environmental pressures and regulation were not enough to unhinge PVC from its status as the material of choice in the principal construction market. PVC manufacturers saw no competitive advantage in developing alternatives to a highly versatile, lightweight, corrosive-resistant, fire-retardant, inexpensive, highly compatible material that, while challenged, saw no slack in demand.

SOURCES

"Chemicals and Allied Products" and "Plastics and Rubber", *U.S. Industrial Outlook* . U.S. Department of Commerce, 1994 and 1995.

"Chlorine's Future: Restructured but Strong," *Chemical Week*. April 26, 1994.

"Collection is the big problem facing PVC." *Plastics World*, April, 1990.

Doniger, David D. *The Law and Policy of Toxic Substances Control: A Case Study of Vinyl Chloride. Ecology Law Quarterly*, 1978.

Environmental Building News, "Should We Phase out PVC?" January/February, 1994, vol 3., no. 1.

"Environmental Profile: Facts About Chlorine, The Material Used to Make PVC", The Vinyl Institute (undated).

"Evian to Introduce Water Bottle in States," *Plastics News*, April 17, 1995, p. 63.

Ford, Tom. "PVC supporters dispute dioxin charges." *Plastics News*, June 5, 1995. P. 7

Gilgrist, Andy. "The Shape of Things to Come," *Marketing Week*, September 16, 1994, pp. 43-47.

Grandilli, Peter A., *Technician's Handbook of Plastics*, Van Nostrand Reinhold Co., New York, 1981.

Great Lakes United, "Planning for the Sunset".

Heldaas, S Storetvedt et al. "Incidence of cancer among vinyl chloride and polyvinyl chloride workers: further evidence for an association with malignant melanoma," *British Journal of Industrial Medicine*, July 8, 1988.

Hileman, Colette. "Concerns Broaden Over Chlorine and Chlorinated Hydrocarbons," *Chemical and Engineering News*, pp.10-20, April 1, 1993.

King, Roger. "Plastic bottle recycling rate rises 21%", *Plastics News*, June 5, 1995 pp. 1, 24.

Naitove, Matthew H. "Push is on to commercialize biodegradable lactide polymers," *Plastics Technology*, March, 1995, Vol. 41, No. 3, p. 15.

Neubauer, Alfred. *Chemistry Today*. Arco Publishing, New York, 1983.

Portney, Paul R. *Public Policies for Environmental Protection*. Resources for the Future, Washington, DC, 1990.

Preker, Hans. "Conquering problems with polypropylene for blisters," *Manufacturing Chemist*, May 1992, vol. 63, No 5., p. 33.

"PVC Recycling: Landfill fodder? It doesn't have to be," *Modern Plastics*, March, 1989.

"PVC/Vinyl Backgrounder." *Appliance Manufacturer*, December 1994, p. 131-132.

Rosenman, Kenneth D., M.D., et al. "Central Nervous System Malformations in Relation to Two Polyvinyl Chloride Production Facilities." *Archives of Environmental Health*. Sept./Oct., 1989, Vol 44, No 5.

"The Crusade Against Chlorine," *Science*, Vol. 261, July 9, 1993, pp. 152-154.

Tilley, Kate. "PVC may be forced to forgo Olympics." *Plastics News*, June 5, 1995, p. 1, 23.

"Vinyl Plastics and Solid Waste: Some Basic Facts," The Vinyl Institute (undated).

"Vinyl, under attack, shows its staying power", *Modern Plastics*, McGraw-Hill, November, 1994, vol 71, no 11, p. 46-51.

Wolfe, Paris. "From Sortation to Marketing, the Vinyl Loop Gets Stronger," *Recycling Today*, March 1990.

PERSONAL INTERVIEWS

Alvay, Linda. Corporate Communications, Procter & Gamble, Cincinnati, OH
American Hospital Association, Washington, DC
American Plastics Council, Washington, DC
Bevaqua, Frank. International Joint Commission on the Great Lakes Water Quality
Bureau of National Affairs (BNA) Reporter, Washington, DC
Burnett, Bob. Executive Director of the Vinyl Institute, Morristown, NJ
Cappelle, John. Occidental Chemicals, Ingleside, TX
Carroll, Bill. Chemical Manufacturers Association, Washington, DC
Chemical Engineering, New York, NY
Consumers Union, NY
Cray, Charlie. Greenpeace, Chicago, IL
Durham, Mark. Witco, Greenwich, CT
European Vinyl Manufacturers Association, Brussels, Belgium
Glass Packaging Institute, Washington, DC
Gottesman, Roy. Former Director of the Vinyl Institute
Hampson, Don. Akros, New Brunswick, NJ
Heinle, Dick. Marketing Director of Formosa Plastics, NJ
Japan PVC Association, Tokyo, Japan
Kokeyuchi, Hisao, Manager of Technical and Intellectual Property, Mitsui Toatsu, NY
Larson, Lee. Environmental Lawyer, Geon Company, Avon Lake, OH
Moeller, Mitch. Marketing Director, McGraw, Irvine, CA
National Materials Exchange Network, Spokane, WA
National Solid Waste Management Association, Washington, DC
Pappas, Chris. Marketing Director, mPE at Dow Chemical, Midland, MI
Procter & Gamble, Cincinnati, OH
RCRA Hotline, Washington, DC
Renshaw, Jim. Monsanto, St. Louis, MO
Rodgers, Tom. Chronopol, Golden, CO
Russotto, Nancy. Director, Assoc. of Plastics Manufacturers in Europe, Brussels, Belgium
Ryan, Chris. Cargill, Minneapolis, MN
Sandborg, Verie. Baxter Healthcare International, IL
Smee, Bob. National Materials Exchange Network, Spokane, WA.
Society of the Plastics Industry, Washington, DC
Svalander, John. Director, European Council of Vinyl Manufacturers, Brussels, Belgium
Solid Waste Assistance Program, Washington, DC
SWANA, Bethesda, MD
TSCA Hotline, Washington, DC
Wisner, D'Lane. Manager of Marketing, Packaging. Geon Company, Avon Lake, OH