PVC: Turning Complex Problems into Multiple Opportunities

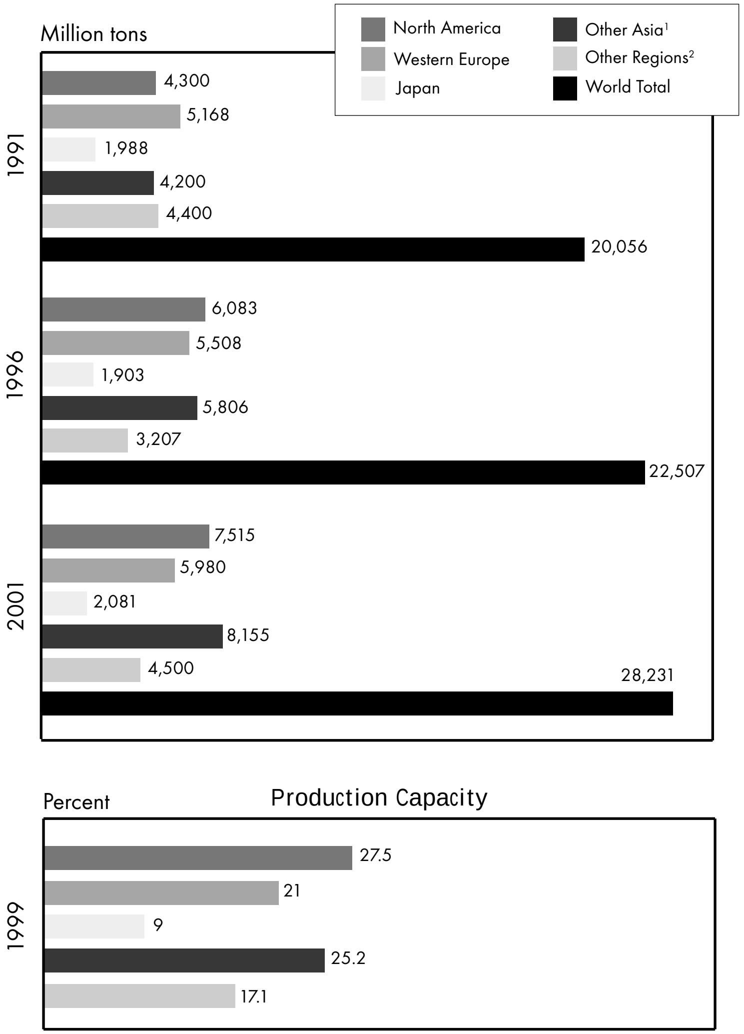
In terms of production volume, PVC, or polyvinylchloride, is the second most common plastic in the world after polyethylene. But in terms of its spectrum of applications, PVC is second to none. Polyethylene is used primarily in medical devices, packaging, electrical insulation, flooring, and some auto components. PVC is put to all these uses as well, and countless others. Currently about 60 percent of PVC production is destined for the construction industry, where it is used for everything from water pipes to siding. Most of the remaining 40 percent is in consumer goods: your phone cord, the dashboard of your car, your credit cards and shower curtain, even the wrap on your sandwich—if you're looking at plastic, there's a good chance that you're looking at PVC.[82]

First manufactured in 1936, PVC is now being produced at the rate of 22 to 30 million tons per year. (See Figure 6.) Overall, production is accelerating: in the early 1990s, it was growing at the rate of about 2 percent per year; in the first half of this decade, the annual rate of production will likely be more than twice as fast. By 2005, global PVC demand is projected to reach 33 million tons. Quite simply, PVC is now one of the most common synthetic materials in the world. There are few if any major economic activities that it does not touch in one way or another.[83]

Nearly half of the near-term growth in production is expected to occur in Asia, where the industry has prospered despite the 1997-1998 economic crisis. PVC production in Japan, South Korea, and Taiwan increased 21 percent between 1995 and 1999. China's imports of PVC jumped 360

FIGURE 6

PVC Consumption by Region, 1991–2001 (estimated); and PVC Production Capacity, Regional Percentages, 1999



[1] "Other Asia" includes China, Hong Kong, India, Indonesia, Malaysia, Philippines, Singapore, South Korea, Taiwan, and Thailand.

[2] "Other Regions" includes Africa, Eastern Europe, Latin America, Middle East, and Oceania. *Source: See endnote 83.*

percent between 1994 and 1999—a trend that is likely to continue. The primary driver of Asian demand is the construction industry, especially in the region's major cities, such as Beijing, Bangkok, and Manila.[84]

PVC manufacturers are already well placed to serve this market. About 150 companies in 50 different countries currently produce the material, but the largest manufacturers are in Asia. The biggest of all is Japan's Shin-Etsu Chemical Company; Formosa Plastics of Taiwan is the world's number two producer. Manufacturers in South Korea, the United States, and Europe round out the world's top 10 PVC manufacturers, which together accounted for more than 40 percent of global capacity in 1997.[85]

The world's current cumulative burden of PVC probably comes to about 400 million tons. Around 250 million tons of this quantity is most likely in use; the remainder is piling up in landfills, feeding incinerators and backyard fires, or clogging up the recycling stream.[86]

PVC is certainly persistent but it's not a POP. In its pure form, PVC resin appears to be biologically inert. There is no evidence that it bioaccumulates or that it is mobile in the environment, for instance by being susceptible to long range atmospheric transport. But in the full context of its lifecycle, PVC presents a very different picture. Every stage of that lifecycle—from manufacture, to use, to disposal—creates dangerous chemicals, including some of the most notorious POPs.[87]

PVC is the only major commercial plastic that contains chlorine. The other major plastics are almost entirely petroleum-based, but PVC has a chlorine content of up to 45 percent by weight. The high chlorine content can give PVC an economic advantage over other plastics: it helps insulate PVC prices from oil market fluctuations. But chlorine is also PVC's biggest ecological liability.[88]

Chlorine is introduced into the PVC lifecycle at the beginning of the manufacturing process. Basically, it takes three steps to produce PVC resin, and the first of these combines ethylene gas with either elemental chlorine or hydrogen chloride to produce ethylene dichloride, or EDC.

Because of its role in PVC manufacturing, more EDC is produced than most other organic synthetics. In 1997, global manufacturing capacity for this material stood at 33.5 million tons, a total that is expected to increase in the next few years. EDC is not persistent, so it isn't a POP. It is, however, extremely dangerous. According to the hazard ranking system of the U.S.-based NGO Environmental Defense, it ranks among the top 10 percent of all synthetics, in terms of its capacity to damage ecological and human health. It's a known carcinogen and a suspected nerve poison. It may cause birth defects, and damage the sex organs, heart, lungs, liver, kidneys, and skin.[89]

For each ton of EDC produced, about 4 kilograms of byproducts are created. About half of this material consists of "light ends"—that is, substances that are more volatile than EDC. These are typically reprocessed into the solvent perchloroethylene. The remaining byproducts are tar-like "heavy ends," which are simply waste and may end up in the air, water, soil, and potentially, in wildlife and people. Many persistent toxics have been identified among these byproducts, including several of the "dirty dozen" POPs: dioxins and furans, PCBs, and HCB. In 1994, the British manufacturer ICI Chemical and Polymers Limited concluded in an internal memo that it was nearly impossible to avoid creating dioxins and furans during the manufacture of EDC.[90]

Some of these "dirty dozen" compounds may occur at substantial levels. In 1995, for example, Greenpeace scientists examined the wastes from a Vulcan Materials EDC facility in the U.S. state of Louisiana, and concluded that the plant's discharges were "among the most dioxin-contaminated wastes ever discovered." At a Dow Chemical plant also in Louisiana, industry chemists found that PCBs accounted for 0.03 percent of the plant's EDC heavy end wastes. That may not sound like much, but if it's a typical level of contamination, then the world's PVC manufacturers may be producing several tons of PCBs unintentionally per year.[91]

The second step in the PVC recipe calls for heating the EDC in the absence of oxygen. This process converts the EDC to vinyl chloride monomer, or VCM. Like its precursor, VCM isn't a POP but it is dangerous. It's a carcinogen and a nerve poison. It has also been linked to liver damage, suppression of the immune system, and testicular abnormalities. VCM production also generates a substantial quantity of byproducts—by weight, byproducts account for about 3 percent of the results of VCM synthesis. Given current global rates of VCM production, several hundred thousand tons of these byproducts are generated every year. Nobody knows what exactly is in these materials, but they are likely to be contaminated by dioxins and furans. In 1998, scientists studying VCM byproducts at a fairly up-to-date Russian facility found them heavily contaminated with dioxins and furans.[92]

In the final stage of PVC synthesis, the VCM is liquified under pressure and then mixed with a chemical solution that causes the VCM molecules to link together into long chains, or polymers. The result is PVC, in the form of a fine, white powder. The process creates substantial waste, because of the spent mixture, but—as far as is known—no POPs are emitted at this stage.[93]

Unfortunately, raw PVC is practically useless, because the chlorine makes it brittle and prone to degrade rapidly when exposed to ultraviolet light. With other polymers, such problems can be dealt with by modifying their carbon chains, but with PVC, that approach doesn't work. Instead, various other chemicals must be added to the resin to give it the necessary durability and flexibility. These additives are not chemically bonded to the resin, so they may migrate to the surface of the material and leak into the surrounding environment. (Think of the smell of a new shower curtain: your nose is detecting the "out-gassing" of plastic additives.) As additives migrate out, PVC becomes brittle again, limiting its usefulness.[94]

Several different types of PVC additives are a health concern; heavy metals, for example, are sometimes used as stabilizers. But in terms of the quantities used, the most important additives are plasticizers, compounds that confer flexibility. Some 90 percent of plasticizers belong to a group of 25 compounds called phthalates, and some of the most common phthalates are POPs or POP-like compounds.[95]

Very roughly, global phthalate production appears to be in the range of 5.5 million tons a year. Because of their role in PVC production, phthalates are ubiquitous in both manufactured products and the environment. "It has become very difficult to analyze any soil or water sample without detecting phthalate esters," writes U.S. EPA scientist Robert Menzer, in a toxicology textbook. Phthalates have even been found in a species of deep sea jellyfish that lives 1,000 meters below the surface of the North Atlantic. Some experts argue that even supposedly pure laboratory materials may be contaminated with phthalates, making it difficult to establish baseline levels of exposure.[96]

In both wildlife and laboratory animals, phthalates have been linked to a range of reproductive health effects, including reduced fertility, miscarriage, birth defects, abnormal sperm counts, and testicular damage, as well as to liver and kidney cancer. As early as the 1970s, scientists had found that chicken embryos died when subjected to a 0.4 percent solution of one of the most common phthalates, diethylhexylphthalate (DEHP). That's a very high concentration by the standards of modern toxicology, but human blood stored in vinyl bags can reach this level in a day or two.[97]

Far more troubling are the low-dose effects of several phthalates. For example, EPA testing on laboratory animals has shown that *in utero* exposure to DEHP can deform the male sex organs and cause other types of "demasculinization," at levels far below those of previous toxicological concern. The same is true of another common phthalate, dibutyl phthalate.[98]

In humans, no "safe" level of exposure to phthalates has been determined, but numerous studies show that people are probably being contaminated by substantial quantities of these substances. For example, hospital patients receiving intravenous infusions have been shown to be at risk of exposure to DEHP, which can leach directly out of intravenous tubes and into the patients' bloodstreams. Recently, scientists at the U.S. Centers for Disease Control and Prevention have detected phthalates in urine from women of child-bearing age, at levels that cause fetal abnormalities in laboratory animals. And various studies have shown that children who chew on PVC toys—such as pacifiers and teething rings—absorb phthalates into their bodies.[99]

Phthalates can leach out of intravenous tubes and into patients' bloodstreams.

There is also growing evidence of actual injury. Swedish researchers recently reported that male workers in PVC plants have a risk of developing seminoma (a form of testicular cancer) that is six times that of the general population. The increased risk appears to be linked to DEHP, which can promote tumors by disrupting the endocrine system. (No increase in risk was found among workers manufacturing other types of plastics.) Another recent study found DEHP present at seven times the normal level in a group of Puerto Rican girls, aged 6 months to 2 years, who were showing premature breast development. A 1999 study in Oslo, Norway concluded that young children may absorb phthalates from vinyl floor covering; children in homes with such coverings had an 89 percent greater chance of developing bronchial obstruction and symptoms of asthma than did children living in homes with PVC-free floor coverings.[100]

At the end of its useful life, PVC is once again a source of POPs. PVC waste is already substantial and it's expected to grow considerably in the coming years. In the European Union alone, PVC waste is expected to jump 76 percent over the next two decades, from 4.1 million tons in 1999 to 7.2 million tons by 2020. There are at present three standard disposal options: incineration, dumping the material in landfills (the usual procedure for construction wastes), and more recently, recycling. None of these is a satisfactory long-term solution.[101]

Recycling might seem like the best approach, but recycling PVC is problematic due to its high additive and chlorine content. At recycling centers, incoming plastics are sorted, then crushed and pulverized. When a load with some PVC in it is treated this way, the various PVC formulations lose their chemical distinctiveness and contaminate any other plastics in the batch. The resulting bits of plastic may be uniform in size, but they are extremely varied in terms of additive content. (Another reprocessing strategy is to heat the materials, which breaks them down chemically into plastic monomers, oil-like compounds, and hydrochloric acid.)[102]

In essence, reprocessed PVC is downgraded. Such material can be used for products with very low performance standards, such as railroad ties, highway sound barriers, marine bulkheads, and construction "lumber" inside walls that are not load-bearing. It is estimated that two-thirds of current PVC demand could in theory be met with recycled PVC. But according to the Association of Postconsumer Plastic Recyclers (a U.S. plastic trade association), there are few markets for downgraded PVC. Even if there were viable markets, there is still the contamination factor. As one APPR board member put it, "the whole plastics recycling industry would run more smoothly if PVC was not part of the post-consumer waste packaging stream."[103]

Given the relatively low costs of landfilling and of virgin PVC, the current economics do not favor recycling. Recycling any plastic requires costly, labor-intensive sorting of enormous amounts of material. In New York City, for example, scores of workers manually separate plastic items from a *daily* stream of 2,000 tons of metals, glass, plastic, paper, and other materials. By volume, about 60 percent of post-consumer waste is mixed plastics but very little of that is PVC. The containers that consumers toss into their recycling bins are primarily high density polyethylene and polyethylene terephthalate. (In 1998, these materials accounted for 94 percent of all plastic bottles collected in the United States.) In the United States and Canada, just 0.1 percent of post-consumer PVC is now recycled. In the European Union, the figure stands at 3 percent. Since the early 1990s, waste PVC is increasingly being shipped to China, India, or Africa for "reprocessing," where it is usually either just burned or buried.[104]

Worldwide, most PVC wastes are sent to landfills. In most European countries, for example, this share is between 50 and 90 percent. (Only Denmark reports less than 30 percent.) Yet PVC is only a tiny fraction of the total volume of municipal solid waste. In Europe, just 2.5 percent of total landfilled municipal waste is PVC. In Japan, the share is 12.2 percent. The share of chlorine that PVC contributes, however, is quite high: it accounts for up to 66 percent of chlorine in the household solid waste stream.[105]

Unregulated dumps are still common in much of the world, a condition that allows phthalates and other PVC additives to contaminate groundwater and air. Even in Europe, it wasn't until 1994 that leachate control systems were required for landfills. Open air dumps are most susceptible to leaching: about one-third of the phthalates will leak into the environment under aerobic conditions. And if the PVC is buried, it typically outlasts any collection system intended to prevent leaching. Even where state-of-the-art bottom liners and drainage pipes exist, the system is usually only guaranteed for about 80 years. Since rigid PVC does not have a half-life of any "relevant rate," in the words of an EU-commissioned study, its presence in the environment will continue long after the official life of a dump.[106]

As far as POPs are concerned, incineration is the worst waste disposal strategy of all. Yet a large portion of PVC-laden waste is simply burned. Given the material's chlorine content, that is a virtual guarantee of significant dioxin emissions. Worldwide, incineration of medical and municipal wastes, both of which usually include a substantial burden of PVC accounts for 69 percent of known dioxin and furan releases into the atmosphere—some 7,000 kilograms a year. (This figure is only a partial estimate, since it includes emissions for only the 15 countries that responded to a 1999 UNEP survey on the subject.)[107]

Japan currently reports the highest level of dioxin emissions in the world. The Japanese government is now trying to contain dioxin releases from more than 3,800 highly polluting municipal incinerators. (In contrast, the United States has fewer than 200 such facilities in operation.) But Japan is not the only country facing a dioxin crisis from incineration: on a per capita basis, the emissions rate for the Netherlands is almost as high and the rate for Belgium is more than double. Many countries have only recently begun to monitor emissions, and have yet to attempt to control them. Reflecting on the public health implications of this practice, a California nurse recently remarked, “I came to the chilling realization that the trash I throw away on my unit is actually causing people to get the cancer and reproductive problems which I’m then treating.”[108]

New evidence suggests that an enormous quantity of dioxin is being produced by the unregulated burning of household waste in open pits or in barrels in the backyard. The high emissions result from a large proportion of PVC in the waste and low burning temperatures. The first dioxin assessment conducted by the Commission for Environmental Cooperation of the North American Free Trade Agreement found that half of Mexico’s emissions may come from the burning of household waste. In the United States, a recent study showed that three dozen households that burned their trash outdoors emitted as much in the way of dioxins and furans as a “properly operated waste incinerator serving up to 120,000 households.” These findings have troubling implications for rural areas, especially in developing countries, where a great deal of waste is burned in the open. Such concerns led the Philippines to ban all waste incineration in 1999.[109]

There is, however, a point of controversy here. Some researchers have pointed out that there is no clear relationship between the dioxin and furan emissions coming out of an incinerator and the chlorine content of the waste going into it. This is because many other factors influence the production of dioxins: the temperature of the burn, the oxygen level, the availability of surfaces on which dioxin formation can occur, and so on. It is also true that many apparently

innocuous substances may sometimes produce dioxins when burned—wood, for instance, or table salt. But while there is a continuum of sorts, there are nevertheless huge differences of degree. According to tests conducted by the German EPA in 1991, PVC combustion produces dioxins in ash in the range of 7.5 to 662 ppt (parts per trillion), while the results for paper, wood, or cotton containing inorganic chloride were below the detection limit of 0.1 ppt. Removing PVC from the incinerator waste stream won’t end dioxin production, but it will certainly result in a substantial reduction.[110]

Soybean oil makes a better plasticizer than phthalates.

Faced with such risks, a growing number of policy makers and consumers are looking to change the role of PVC in their lives. What they are finding is that alternatives are currently available for almost every application of PVC. In 1997, for example, a consulting firm hired by the Canadian government produced a cost-benefit analysis for 90 percent of Canada’s PVC uses, including pipes, siding, window frames, wire and cables, flooring, and various applications in flexible materials. (See Table 4.) Since construction accounts for 60 percent of PVC use, building codes may provide an especially important point of leverage: as it becomes economically feasible to do so, requiring materials other than PVC for new projects could give substitution efforts an enormous boost.[111]

The substitute materials themselves vary widely. Some are a direct throwback to an earlier era, such as wooden window frames. Others are high-tech modifications of familiar materials, such as the new biopolymers that are being produced from common crops. In general, the challenge will be to move away from the current, minimize-the-up-front-cost response to our material needs, and to adopt a more sophisticated approach, which seeks to minimize the *total* cost, both economic and environmental.

One potentially useful strategy is to alter the composition of PVC itself. For example, there is a group of compounds derived from various vegetable oils that can be used

TABLE 4

Alternatives to Major Construction Uses of PVC, According to a 1997 Canadian Study

Application	Alternatives (primary first) *(secondary in italics)*	Change in Cost if Alternatives Were Used	Change in Cost of the Application's Total Sales
		(1997 Canadian dollars)[1]	(percent)
Pipes	HDPE or ABS plastic	+44 million	+2
	Ductile iron, concrete, or copper/cast iron	*+96 million*	*+5*
Siding	Aluminum	+80 million	+10
Window frames	Wood	–118 million	–10
	Aluminum	*+55 million*	*+5.3*
Cable insulation	Polyethylene plastic	+181 million	+11
Flooring	Polyolefin plastic	+338 million	+11
	Ceramic tile and alternative carpeting	*+426 million*	*+14*

[1] Canadian dollars were not converted to U.S. dollars because of substantial exchange rate variation ($1 Cdn was $0.74 U.S. in January 1997 but $0.66 in October 2000).

Source: See endnote 111.

to plasticize PVC. In effect, soybean oil can substitute for phthalates. In the United States, vegetable oil plasticizers represented about 15 percent of the market for phthalates in 1996. Although they are generally more expensive than phthalates, they have several properties that phthalates lack: they confer stability, thereby eliminating the need for heavy metal stabilizers, and they do not leach out of the plastic, so they extend the life of the product.[112]

There may be other ways to make PVC safer. A Canadian company, for example, has recently designed a PVC filler from calcium hydroxide. This material is intended to prevent phthalates from leaching and to neutralize the hydrochloric acid that forms when PVC is burned. Should the filler itself prove safe, adding it to the PVC recipe could be a useful stop-gap measure, until the time that non-PVC substitutes are in place.[113]

Of course, the more effective strategy over the long-term will be to identify whole-material substitutes for PVC. It's interesting to note that as early as 1971, NASA scientists were warning against the use of PVC in aerospace because of its volatility in a vacuum and the presence of phthalates. Moreover, as a NASA engineer noted in a letter to the editors of *Chemical and Engineering News*, "substitute polymers... are available and in many cases they have far superior physical properties at a small sacrifice in immediate cost."[114]

In general, the simplest solution may be simply to turn to another conventional plastic. Fortunately, not all plastics are as bad as PVC. The most common plastic in the world, polyethylene, just happens to be the one that the international environmental group Greenpeace considers to be the least harmful of the petroleum-based plastics. Because of their simpler polymer structures, polyethylene and the closely related polypropylene require no plasticizers and need fewer additives than PVC. (Polyethylene is also much cheaper than PVC—about one-tenth the environmental cost per unit weight.)[115]

Replacing PVC with nonchlorinated plastics such as polyethylene virtually eliminates the chances of forming POPs. A new generation of polyolefins (the class of plastics to which polyethylene and polypropylene belong) is being developed that may be custom tailored to meet many of the current applications of PVC, often using the same processing equipment.[116]

Perhaps even more visionary is the interest in producing plastic resins from plants. This is actually how the original plastics were made; for example, sap from the Malaysian *Gutta percha* tree was used to make the plastic that insulated telegraph wires in the 19th century. Today such biopolymers are derived from a wide variety of plant materials—oat hulls, corn, soybeans, oil seeds, or wood. In the United States, some federal funding is now available for research on biopolymers and some large corporations are showing interest in the possibilities. In April 2000, for example, Cargill Dow announced plans to build a large factory for turning out plastic from corn. The potential of this line of development could be substantial: the crops could be grown organically and processed in a closed-loop manufacturing system with renewable energy sources, yielding a virtually nonpolluting plastic.[117]

At present, unfortunately, the possibilities for substituting biopolymers for PVC are fairly limited. Because of their fragility, the current starch-based resins are generally only suitable for short-lived items, and most PVC is used for durable applications. But as with other environmental technologies, there is reason to hope that demand will help drive innovation. Growing concerns about PVC are likely to mean substantial profits for any company that succeeds in developing biopolymers to replace it. And in the meantime, there are some important short-term opportunities—for example, replacing PVC in medical goods. Such applications have important implications for public health; the sooner PVC is phased out of products like intravenous tubing, the better.[118]

The relationship between PVC and dangerous chemicals is complicated: POPs and POP-like materials are byproducts throughout the PVC lifecycle, from manufacture, to use, to disposal. The politics of PVC is complicated as well. Any serious effort to phase it out will likely encounter opposition not just from the industry that produces it, but from at least some segments of the industries that use it in large quantities.

But there is a useful strategic lesson hidden within all this complexity: complicated processes are susceptible to change at many different points. It should be possible to develop an agenda that pursues an array of substitution strategies simultaneously, while looking for business and political opportunities to help speed the transition. Perhaps some of those strategies will turn out to be dead ends. But by developing a “complex solution” to fit a complex problem, it should be possible to reach the goal—the replacement of PVC—even though the exact means of achieving it are likely to be in flux.