The Economics of Phasing Out PVC

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Executive Summary

Polyvinyl chloride, also known as PVC or "vinyl," has become one of the most widely used plastics today. We encounter PVC on a daily basis in products ranging from toys, packaging, and lawn furniture to water and sewer pipes, medical equipment, and building materials.

PVC poses hazards to human health over the course of its life cycle. PVC production exposes workers and communities to vinyl chloride and other toxic substances. PVC products such as medical equipment and children's toys can leach toxic additives during their useful life. Vinyl building materials release hydrochloric acid fumes if they catch fire, and burning PVC creates byproducts including dioxin, a potent carcinogen.

The health hazards associated with the production, use, and disposal of PVC are, for the most part, avoidable. Alternatives are available across the range of PVC products. In some cases the alternatives are no more expensive than PVC; in other cases there is a small additional cost. Often there are good reasons to expect the costs of alternatives to decline over time.

Vinyl today: a look at the market

PVC sales reached 14.4 billion pounds in the US and Canada in 2002, or 46 pounds per person. Worldwide production was around 59 billion pounds, or an average of 9 pounds per person. With 5 percent of the world's population, the US and Canada consume 24 percent of the world's PVC. The principal uses of PVC in North America, in order of importance, are pipes, construction materials, consumer goods, packaging, and electrical products (such as wire and cable insulation).

Three in-depth studies have estimated the costs of phasing out PVC. The latest one, a 1997 study by Environment Canada, based on a detailed analysis of the cost of alternatives, suggests an average annual cost of $0.55 per pound. If this estimate still applied today, it would imply a total cost of $8 billion per year, or $25 per person, to phase out PVC in the US and Canada. Correction for one obviously dated assumption in that study cuts the estimate in half, to $4 billion total or $12 per person. However, there are several reasons to expect that the costs of alternatives will be still lower and will decline over time.

Factors favoring phaseout

Figures such as those from Environment Canada, based on current market prices alone, overstate the economic benefits of PVC. We explore four major economic reasons why this is the case.

- *Life-cycle costs often favor alternatives.* Some of the alternatives have higher initial purchase prices than PVC products, but are actually less expensive over the useful life of the product. Commercial flooring provides an example: among the flooring options we examined, vinyl has the lowest installed cost; but due to its shorter lifetime and higher maintenance requirements, it has the highest life-cycle cost. In such cases, rather than making a decision based on initial costs alone, purchasers can save money by comparing the full costs over the product life cycle of buying, installing, using, maintaining, and ultimately disposing of alternative products.

- *Mass production reduces costs.* Most products are cheaper when they are produced in large quantities; costs typically drop as production volumes increase. Currently the advantages of mass production favor PVC: many PVC products have achieved huge volumes, making them look cheap today. However, the alternatives to PVC could likewise grow in volume in the future, making them less expensive and more competitive than they are at present.

- *PVC products endanger their users.* The harmful effects of PVC are sometimes felt by the users of the product, as in the case of some PVC medical supplies. In case of fire, vinyl building products begin to smolder long before they burn, releasing toxic fumes of hydrochloric acid, and thereby threatening building occupants and firefighters. For this reason, the International Association of Firefighters supports efforts to reduce PVC use.

Related hazards could occur with PVC-insulated wiring, which was once standard for use in airplanes. There is no proof that PVC insulation has ever caused a plane crash, but some investigators have suggested that there are grounds for concern about older planes that are still flying with PVC-insulated wires.

- *Environmental protection costs are routinely less than anticipated.* Academic research has shown that the actual costs of compliance with environmental standards are often lower than the predicted costs. The strict standard for workplace exposure to vinyl chloride, the raw material for PVC production, established in 1974 by the Occupational Safety and Health Administration, led to profitable innovation, not vast economic losses (as predicted by industry when the standard was proposed). A recent study of the costs of controlling chlorinated pollutants confirms the pattern of advance overestimation of environmental management costs.

Markets for alternatives

Because PVC is used in such a diverse range of products, the nature of the alternatives and the likely costs of a phaseout differ from one market to the next. However, there are affordable alternatives in every market we have examined. We discuss alternatives to PVC in selected commercial and institutional markets, including pipes, roofing, floor coverings, and medical gloves, followed by a brief look at residential siding and windows, the largest-volume vinyl building products.

- *Pipes.* Almost half of the PVC manufactured in the US and Canada is used to make pipes and tubing, a diverse category spanning several distinct end uses. For municipal water and sewer pipes, PVC competes with traditional materials including iron, concrete, and vitrified clay, as well as with polyethylene (PE), a less toxic plastic that has a growing share of the market. Sales of PE pipe (for all uses) have reached about one billion pounds annually, compared to 6.5 billion pounds of PVC pipe. PE and traditional pipe materials perform better than PVC in cold climates and under high pressure; in addition, PE pipe is virtually leak-free. Factors like these are often decisive; many municipalities and water companies make decisions based on the desired physical properties of pipes rather than the differences in material prices.

Inside buildings, PVC has become common for electrical conduits and particularly for the "drain/waste/vent" pipes that carry water and waste away. Due to concerns about fire hazards, some building codes limit the use of plastic pipe in multi-story buildings; even where it is allowed, the additional requirements for fireproofing offset much of the apparent cost advantage of PVC pipe.

A case study in Austin, Texas, found that using copper, cast iron, and polyethylene plumbing rather than PVC throughout a large new building increased plumbing costs by 15 percent over all. Costs for small-diameter pipes of several varieties show modest cost differences; PVC has the lowest installed cost in some but not all applications.

- *Roofing.* In roofing, PVC competes primarily with two less toxic synthetic materials, ethylene propylene diene monomer (EPDM) and thermoplastic elastomer polyolefin (TPO), in the market for single-ply (single-layer), low-slope roofs. EPDM is by far the market leader among the three, and PVC is third in sales volume, slightly behind TPO. Advantages claimed for PVC, particularly the fact that it is available in white and therefore provides good reflectivity in hot weather, are equally available with alternative materials. PVC roofing also has a shorter lifetime than most alternatives and presents special technical problems, such as cracking and loss of flexibility under some circumstances.

An analysis of construction costs in Austin, Texas shows that both of the alternatives have lower installed costs than PVC. This is true for a range of membrane thicknesses and modes of installation. These cost relationships are echoed by data from Chicago and western Massachusetts, supporting the view that the differences are not specific to one region or climate.

- *Flooring.* For commercial and institutional flooring, PVC competes with a variety of materials, ranging from natural cork and traditional linoleum to economical synthetic rubber products, and new non-chlorinated polymers that match the look of vinyl. While vinyl flooring has the lowest first cost among the 12 flooring products we examined, its relatively short lifetime and high maintenance requirements outweigh this advantage; it is the most expensive option on a life-cycle basis. An analysis by the US Navy of two flooring options for high-traffic areas on its ships reached the same conclusion: on a life-cycle basis vinyl was far more expensive than Stratica, a durable new polymer. "Green building" efforts have often used linoleum floors as a natural, non-toxic alternative to vinyl, as seen in our case studies; linoleum and other materials provide viable alternatives to vinyl flooring under many circumstances.

- *Gloves.* A variety of disposable medical supplies can be made from PVC. We examine the case of medical gloves. Latex, which for a long time was the standard material of choice for medical examination and surgical gloves, has come to pose a serious health hazard with rising rates of latex allergies. In this context, health care institutions must move to alternative glove materials; PVC and nitrile are the principal candidates. While PVC gloves are cheaper than nitrile gloves, their lower price is counterbalanced by their lower durability. One study found PVC gloves to have a 30% failure rate under simulated use conditions, compared to 2% for both latex and nitrile. Correction for the failure rate offsets one-third of the apparent cost advantage of PVC over nitrile gloves, based on prices quoted to us by a leading distributor. Kaiser Permanente, the nation's largest not-for-profit health care organization, concluded from its internal review that nitrile gloves were cost-competitive with PVC due to their greater durability, and bought 43 million pairs of nitrile gloves.

- *Siding and windows.* Vinyl is now the most common siding material for low- and moderate-priced housing. However, wood shingles or clapboard also offer viable siding alternatives, as do fiber cement and simulated stucco. Disadvantages to vinyl siding include poor resistance to temperature, vulnerability to water damage, and chemical hazards when it burns or smolders. Despite claims that vinyl is "maintenance free," vinyl can fade with time, can require painting, and can warp. Fiber cement, a relatively new product, is more durable than vinyl and almost as low-maintenance; moreover, fiber cement does not warp or burn.

Alternatives to PVC windows include wood, fiberglass, and aluminum windows. Problems with vinyl windows include sensitivity to high and low temperatures, possible brittleness, and health hazards in case of fire. Vinyl windows can be energy efficient, but they can expand and contract, causing the seal of the window to break; in this case, they cannot be repaired, and must be replaced.

Employment effects of a PVC phaseout

There are 126,000 workers in PVC fabrication plants in the US; we estimate that there are no more than 9,000 workers making vinyl chloride and PVC resin. Replacing PVC with safer alternatives will change some of these jobs: from fabricating PVC products to fabricating the same products from other materials, most often other plastics; or from making vinyl chloride and PVC resin to making safer substitutes. However, the alternatives are likely to require about the same total employment as production of PVC. In some cases, the same workers who currently make PVC products will be employed making products from PVC alternatives.

Steps toward safer alternatives

Around the world and throughout the US, a variety of community, state, and national government initiatives have been undertaken to promote the use of safer alternatives to PVC. Many health care institutions have made statements on the need to reduce or eliminate PVC use. The auto industry and other major industries have taken numerous steps to incorporate alternatives to PVC into their products. In addition, countless innovative construction projects have demonstrated the practicality of reducing or eliminating PVC use. Examples discussed here include a green building initiative carried out by a volunteer group, GreenHOME, in partnership with Habitat for Humanity; the Erie Ellington Homes in the Dorchester neighborhood of Boston; the Sheraton Rittenhouse Square Hotel in Philadelphia; and innovative projects by religious communities.

Introduction

Why Worry About PVC?

Polyvinyl chloride has grown from a little-known material in the mid-twentieth century (used by the Navy for waterproofing in World War II, for example) to become one of the most widely used plastics today.[1] Thanks to low prices and aggressive marketing, polyvinyl chloride, also known as PVC or "vinyl," has become ubiquitous in our homes and communities. We encounter PVC on a daily basis in products ranging from children's toys, packaging, and lawn furniture to water and sewer pipes, medical equipment, and building materials.

Unfortunately, PVC poses severe hazards to human health over the course of its life cycle. We review these hazards only briefly here, as other sources present them in detail.[2]

PVC production: Vinyl chloride, the building block from which PVC resin is made, is a classified by the National Toxicology Program as "known to be a human carcinogen," and has been similarly classified as a human carcinogen by other US and international agencies.[3] PVC production exposes workers and communities to vinyl chloride,[4] and many studies have documented links between working in vinyl chloride production facilities and increased likelihood of developing diseases including angiosarcoma of the liver, a rare form of liver cancer.[5] The large numbers of workers in PVC manufacturing facilities, where vinyl chloride exposure is generally lower than in vinyl chloride and PVC resin production, also have an increased likelihood of developing angiosarcoma of the liver.[6] Vinyl chloride and PVC exposure are also associated with certain non-cancer disorders.[7]

PVC use: For most applications, PVC resins are mixed with additives such as stabilizers, plasticizers, and fillers.[8] These additives can leach out of, or volatilize from, a PVC product during the product's useful life. For example, exposure to plasticizers can occur when they volatilize from PVC products, such as building materials; when they leach out of medical equipment during use, exposing patients; and when they leach from soft plastic toys.[9] Phthalates, which are used as plasticizers, may pose hazards to development and reproduction,[10] and have been implicated in the development of respiratory problems in children.[11] Stabilizers that are used in PVC and can leach out of PVC products include lead and other heavy metals.

PVC disposal and accidental burning: When vinyl building materials catch fire—or even smolder, before igniting—they release acutely toxic fumes such as hydrochloric acid.[12] At the end of its life, PVC releases toxic substances into the environment when it is burned in an incinerator or rural trash barrel, and can leach toxic stabilizers and plasticizers when it is buried in a landfill. Dioxins, which threaten human health at extraordinarily low concentrations, are released when PVC is burned, either intentionally or accidentally.[13]

In the face of these and related concerns, vinyl advocates argue that the material offers not only low prices but also amazing convenience. PVC promises to provide "maintenance-free" building exteriors, easily installed pipes and plumbing, low-cost coverings for floors and walls, and all manner of molded or flexible plastic objects. It is widely believed that giving up PVC would impose a painful burden on the economy.

Our principal finding is that this belief is untrue; PVC does *not* offer enormous economic advantages over all other materials. Alternatives providing equal or better performance are available for almost every use of PVC. In some cases, the costs of the alternative materials are already comparable to PVC when costs are measured over the useful life of the product. In other cases, the alternatives are slightly more expensive at present, but are likely to come down in cost as their market share expands. The continued use of PVC offers small short-term gains in some areas, and none at all in others.

In this report, we explore the economics of phasing out PVC. We begin by looking at the uses of PVC today and reviewing past studies of the costs of alternatives to PVC. We then offer four principles for analysis of the alternatives, all of them challenging the economic arguments for continued use of PVC:

- Alternatives that have higher purchase prices, or higher installed costs, than PVC may still be cheaper on a full-cost accounting or life-cycle cost basis.
- Alternatives that look expensive when produced in small batches today will become cheaper when they are mass-produced.
- The unique health and environmental damages caused by PVC can endanger the users of a product, as in the case of medical supplies.

- Academic studies have shown that the costs of environmental protection are routinely overestimated in advance, and decline rapidly after implementation.

We apply these principles in a discussion of alternatives to PVC in major markets, including detailed discussion of pipes, roofing, floor coverings, and medical gloves, and a summary description of the siding and windows markets. Following the analysis of these markets, we examine the expected employment effects of a PVC phaseout and then turn to the steps that have already been taken toward alternatives.

Vinyl Today: A Look at the Market

Sales of PVC grew rapidly in the 1990s, reaching 14.4 billion pounds in the US and Canada in 2002.[14] This is equivalent to 46 pounds for every person in the two countries. PVC sales are much lower in other industrial countries: 31 pounds per person in Western Europe, and 25 pounds per person in Japan. Worldwide production was 59 billion pounds (or almost 27 million metric tons) in 2002, an average of 9 pounds per person. With 5 percent of the world's population, the US and Canada consume 24 percent of the world's PVC.

Data on the uses of PVC in the US and Canada for 1994, 1999, 2002, and forecasts for 2007, are shown in Table 1. The 2002 figures are also shown graphically in Figure 1. The principal uses of PVC, in order of importance, are pipes, construction materials, consumer goods, packaging, and electrical products such as wire and cable. Pipes, siding, windows, doors, and profiles (gutters, fences, decks, etc.) together account for more than two-thirds of PVC use, and are also the fastest-growing categories. Many other uses of PVC are growing more slowly, and a few actually declined in the recent economic slowdown. Industry projections for 2007 assume that the recession will end and growth will resume, although at a slower pace than in the 1990s.

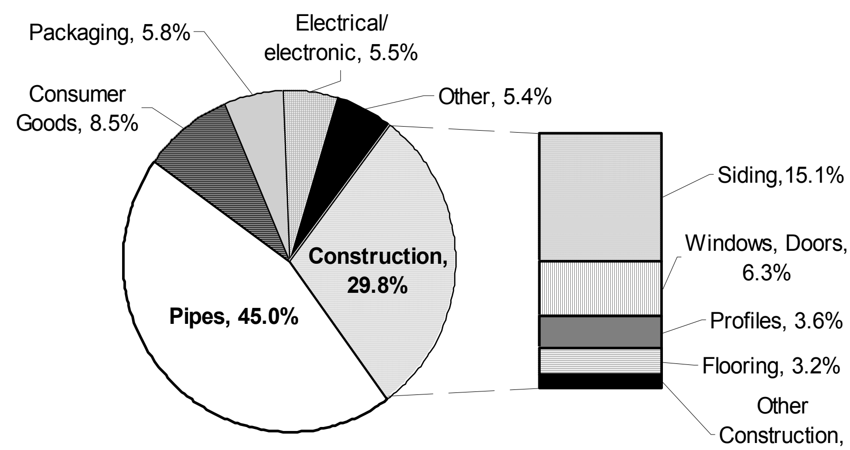
Table 1: PVC Consumption in US and Canada, 1994-2007

End Uses	Consumption (millions of pounds)				Annual growth rates		
	1994	1999	2002	2007 est	94-99	99-02	02-07
Pipes, Tubing, Fittings	4,875	6,685	6,494	7,350	7%	-1%	3%
Construction	2,790	3,990	4,293	5,413	7%	2%	5%
Siding	*1,470*	*2,175*	*2,176*	*2,710*	*8%*	*0%*	*4%*
Windows and Doors	*410*	*700*	*910*	*1,225*	*11%*	*9%*	*6%*
Profiles	*225*	*400*	*525*	*775*	*12%*	*9%*	*8%*
Flooring	*440*	*485*	*457*	*455*	*2%*	*-2%*	*0%*
Roofing	*115*	*100*	*100*	*113*	*-3%*	*0%*	*2%*
Other Construction	*130*	*130*	*125*	*135*	*0%*	*-1%*	*2%*
Consumer Goods	915	1,225	1,225	1,225	6%	0%	0%
Packaging	820	885	839	935	2%	-2%	2%
Electrical / Electronic	540	870	800	905	10%	-3%	2%
Transportation	265	310	280	310	3%	-3%	2%
Home Furnishings	185	240	240	240	5%	0%	0%
Other and Inventory	337	128	259	325			
Total	**10,727**	**14,333**	**14,430**	**16,703**	**6.0%**	**0.2%**	**3.0%**

"Other and inventory" includes medical supplies (200 million pounds in 2002), coatings and adhesives (100 million pounds), and inventory changes for the industry as a whole, which can be positive or negative, and vary widely from year to year.

Source: SRI Consulting (Menlo Park, CA), CEH (Chemical Economics Handbook) Marketing Research Report: Polyvinyl Chloride (PVC) Resins (September, 2003).

Figure 1: Uses of PVC, 2002



Source: Table 1

Costs of Replacing PVC: Three Studies

Three detailed studies, all published in the mid-1990s, have estimated the costs of phasing out PVC.

- The US-Canada International Joint Commission (IJC) for the Great Lakes examined the cost of phasing out PVC as part of its 1993 "Strategy for Virtual Elimination of Persistent Toxic Substances."[15] The report was done for the IJC by a Canadian consulting firm, Hickling Corporation. In 1994, Hickling submitted an expanded and revised version of its study.[16]
- In response to the IJC, the Chlorine Institute asked Charles River Associates (CRA), a US consulting firm, to study the economic benefits of chlorine and related chemicals, including an analysis of PVC.[17]
- In 1997, Environment Canada published a study of options for replacing chlorine-based products, including a detailed look at alternatives to PVC.[18]

These are the most extensive and comprehensive studies on the subject, although by now they are somewhat dated. Moreover, as we will explain, their cost estimates fail to incorporate several important factors that favor the adoption of alternatives. All three found PVC to be only modestly cheaper than the alternatives.

Each of the studies examined many specific uses of PVC, comparing the prices for PVC products to their PVC-free alternatives. Environment Canada created two sets of price comparisons: a low case looking at the least expensive available alternatives, and a high case based on higher-priced alternative products that were in use in Canada.

Table 2 compares the results of the studies. For each study it shows the cost increase that would result from switching to PVC-free alternatives, expressed in dollars per pound of PVC (updated to 2002 prices). Cost estimates are shown separately for pipes and for all other products. Since pipes represent about half of all PVC use, the pipe and non-pipe figures in Table 2 are averaged to obtain a rough estimate of the total cost of replacing PVC.

Table 2: Cost of Replacing PVC

US dollars per pound of PVC (2002 prices)

	CRA (industry)	Hickling (for IJC)	Environment Canada Low	Environment Canada High
Pipes	$1.43	$1.03	$0.15	$0.33
All other uses	$0.87	$1.10	$0.94	$3.84
Average	$1.15	$1.07	$0.55	$2.08

Average is the unweighted average of pipes and "all other uses" estimates
Hickling data excludes windows

Table 2 shows a remarkable degree of agreement between the two earlier studies. With one minor adjustment to the Hickling data (incorporated in Table 2), the CRA and Hickling studies yield nearly identical average costs of replacing PVC—$1.07 to $1.15 per pound.[19] The Environment Canada low case had an average cost of about half this much, due to its much lower estimate for pipe costs. For the non-pipe uses of PVC, there is fairly close agreement between CRA, Hickling, and the Environment Canada low case ($0.87 to $1.10 per pound).

The Environment Canada study, the most recent of the three, examined 14 product categories that accounted for about 90 percent of PVC use in Canada. In most categories, the study compared costs for PVC products, a common lower-priced alternative, and a common higher-priced alternative (not necessarily the highest or lowest prices on the market). Published in 1997, the study is based on prices and conditions in Canada and construction costs for the Toronto area in 1993. Nine of the 14 product categories were in the areas of pipes and construction materials, as shown in Table 3.

Table 3: Alternatives to PVC in Pipes and Construction

Source: Environment Canada, 1997

End use	Alternative materials		Cost per pound of PVC replaced (US $)	
	Low cost	High cost	Low cost	High cost
Municipal water pipe	HDPE	Ductile iron	$0.26	$0.38
Municipal sewer pipe	HDPE	Concrete		
Drainage pipe, culverts	HDPE	Concrete	($0.05)	$0.25
Drain/waste/vent plumbing	ABS	ABS/Copper		
Industrial pipe, conduits	------------ HDPE -------------			
Siding	Aluminum	Clay brick	$0.38	$6.02
Windows	Wood	Aluminum	($0.82)	$0.38
Flooring	Polyolefin	Ceramic tile/carpet	$13.54	$17.07
Wire and cable	----- Polyethylenes, other plastics -----		$3.00	$3.00

1993 Canadian prices converted to US dollars and adjusted for US inflation through 2002.

Separate low- and high-cost alternatives were not estimated for industrial pipe or for wire and cable.

Alternative materials reflect those in use in Canada in 1993, except polyolefin flooring (a polyethylene/polypropylene combination). This product was introduced in Germany in 1996; Environment Canada's low-cost flooring alternative uses the German price.

For pipes, the low-cost alternative to PVC was in each case another plastic, usually high-density polyethylene (HDPE). Traditional pipe materials such as iron, concrete, and copper provided slightly higher-cost alternatives. However, as shown in Table 3, the estimated price per pound of PVC replaced was small for all pipe applications and was actually negative (meaning the alternatives cost less than PVC) for low-cost drain and industrial applications.

The story is more complex for construction materials, where the available options are more diverse and are changing more rapidly than with pipes. For example, Environment Canada's low-cost siding alternative, aluminum siding, has all but disappeared from the market today. (Newer alternatives will be discussed below.) Flooring was the area with by far the highest cost; although it represented only 3 percent of all PVC use in Canada in 1993, it accounted for over half of the cost of the entire low-cost PVC replacement scenario. New flooring products have continued to appear, and some of the best alternatives today were not available at the time of the study.

Over all, the added costs of non-vinyl construction materials were modest: according to Environment Canada, the use of non-PVC alternatives for all four applications—siding, windows, flooring, and wire and cable—would have increased the cost of new residential construction by 0.4 percent in the low case, or 2.4 percent in the high case.

If these estimates applied today, what would they imply for the costs of phasing out PVC? As mentioned above, PVC consumption in 2002 was about 14.4 billion pounds for the US and Canada as a whole, or 46 pounds per person. The Environment Canada low case, the most recent and detailed cost analysis, suggests an average cost increase of $0.55 per pound from switching to alternatives (see Table 2). If this figure still applied, the total cost for replacing all PVC use would be about $8 billion a year for the US and Canada as a whole, or $25 per person.

While it is based on the best available published figures, this calculation has limited applicability today. Recall that over half of Environment Canada's total cost of alternatives came from a very high estimate for the cost of replacing vinyl flooring. As we will see, better alternatives are available today, with life-cycle costs lower than vinyl flooring. Remove the inflated flooring cost, and Environment Canada's estimate shrinks to less than $4 billion total, or $12 per person. And this is not the only factor tending to lower the cost of alternatives. In the section that follows, we examine several reasons why the cost of a phaseout will probably be even lower than suggested by current prices.

Factors Favoring Phaseout

Although the Environment Canada-based estimates of the costs of a phaseout are still too high, it is worth noting that they are not enormous compared to the North American economy. Affordable housing would not suddenly become unaffordable if, as Environment Canada estimated, replacing the leading uses of vinyl were to raise new residential construction costs by 0.4 percent (and this figure included the inflated flooring cost). Even $8 billion is less than 0.1 percent of the gross domestic product of the US and Canada; with the correction for flooring, the revised $4 billion cost is $12 per capita, less than 0.05 percent of our collective incomes. A loss of this amount, spread across the entire economy, would not cause a noticeable average change in our lifestyles and consumption levels.

Moreover, the estimated cost differences, as described above, overstate the economic benefits of PVC. There are four economic arguments for elimination of PVC, despite its modest cost advantage in some settings at current prices.

Life-Cycle Costs Often Favor Alternatives

Some of the alternatives have higher initial purchase prices than PVC products, but are actually less expensive over the useful life of the product. The three studies described above compared purchase prices, or in some cases installed costs, of PVC and alternatives. Such comparisons may give a misleading impression about the total cost of owning, using, and caring for the products in question.

The total cost over a product's life cycle is the cost that ultimately matters to the user. For example, paper plates are much cheaper than ceramic dinner plates, but households, restaurants, and institutional food services often conclude that it is cheaper in the long run to buy, wash, and reuse ceramic plates, rather than continually buying and discarding paper plates.

The concept of life-cycle costs is no more complicated than this familiar example. Rather than making a decision based on initial costs alone, it is important to compare the full costs, over a period of time, of buying, installing, using, maintaining, and ultimately disposing of alternative products. If a ceramic plate is used daily and is expected to last for a year, then the correct comparison would be the cost of 1 purchase, 365 washings, and 1 disposal versus the cost of buying and disposing of 365 paper plates.[20] As in this case, a more expensive initial purchase may be cheaper in the long run if it lasts longer and/or requires less maintenance or fewer repairs.

For some building materials, such as flooring, maintenance and repair costs can be the largest costs of the product life cycle. In such cases, the lowest-maintenance product is often the cheapest on a life-cycle basis, regardless of whether it has the lowest purchase price. As we will see in a later section, vinyl is the cheapest option for commercial and institutional flooring on a first-cost basis but the most expensive option on a life-cycle basis. When life-cycle costs are taken into account, vinyl flooring loses out to higher-priced but longer-lasting and more easily maintained alternatives.

The discussion of life-cycle costs should not be confused with academic studies known as "life-cycle analyses" (LCAs). A life-cycle cost comparison looks at the costs to the user of a product from purchase through disposal. Life-cycle analysis, on the other hand, attempts to account for all the environmental impacts of a given product, from production through use and disposal. Depending on the data categories that are included, LCAs may provide useful environmental information, but they are not a substitute for a life-cycle cost comparison. Note that life-cycle costs do not directly depend on the environmental impacts included in a LCA; rather, life-cycle costs reflect durability and ease of maintenance, as well as initial costs.

Surprisingly, some LCAs have given PVC relatively good ratings. However, these LCAs often omit the highly toxic and carcinogenic emissions that are the most serious problems associated with PVC.[21] LCAs that include toxic emissions do identify PVC as an undesirable material. The Tellus Institute Packaging Study, an early LCA that evaluated common packaging materials primarily on the basis of life-cycle toxicity, found that PVC was 10 to 12 times worse than other common plastics (which include some of the leading alternatives to PVC). If the Tellus study had used the Vinyl Institute's own estimates of emissions, published at about the same time, instead of the best available public data sources, it would have found that PVC was "only" four times as bad as other plastics.[22]

Mass Production Reduces Costs

Mass production makes everything cheaper. Many PVC products have been produced in huge volumes, making them look cheap today; the production of PVC alternatives could just as easily grow in volume in the future, making them less expensive and more competitive than they are at present. There are two related effects at work here, known as "economies of scale" and "learning curves."

Economies of scale refer to the fact that production costs per unit are often lower when goods are produced in larger batches. There are several reasons why it is cheaper for a big factory to produce large amounts of a single product, compared to smaller plants producing lesser quantities of the same good. Some processes are physically more efficient when performed on a larger scale; a bigger boiler or furnace simply costs less to operate, per unit of heat output, than a small one. In general, a larger scale of production means that more machinery, automation, and standardized procedures can be applied. A company that sells a few hundred plastic objects of a particular shape each year may have workers make them almost by hand, using only basic tools and equipment. A company that sells a few million a year will invest in molding and stamping machines, assembly lines, etc., allowing much faster, labor-saving, lower-cost production.

Learning curves describe the common pattern in which costs decline over time as an industry gains experience with a production process. This is often combined with economies of scale—as industry gains experience, factories also tend to get bigger—but learning curves are possible even if factory sizes do not change. Whenever a new process is introduced, it takes a while to debug it; hence the common, informal advice to avoid version 1.0 of any new software package. Much the same is true for manufacturing. Over time, the bugs are worked out, shortcuts and process improvements are developed, and maintenance procedures and schedules are improved. As a result, costs go down. This phenomenon was first documented in the aircraft industry in the 1930s and has been observed in industries ranging from shipbuilding to wind turbines and photovoltaic cells.[23] A common estimate is that when an industry's cumulative production (the total from the beginning of the industry to the present) doubles, the cost per unit drops by 10 percent to 30 percent. In one classic example, a study found that the Ford Model T dropped in price by 15 percent for every doubling of cumulative production from 1909 to 1923.[24]

The combined effects of economies of scale and learning curves can be seen in the evolution of many consumer electronics products. Cell phones, CD players, DVD players, digital cameras, flat screen computer monitors, and numerous other products started out as expensive and esoteric luxuries and then dropped rapidly in price as the market expanded.

At a certain point, the fact that some people are using a new product means that other people will begin to use it too. For example, if many people have begun to use a new computer program, other people will adopt it simply in order to have a system compatible with that of their colleagues. Conversely, it might be inconvenient to be the only person in a city with an unusual car model, because repairs would be expensive and parts would be hard to find. Thus, for a new technology, the fact that some people have already adopted it eventually becomes a strong argument for further adoptions. By pushing up demand, this pattern creates a snowballing effect that lowers prices and tends to "lock in" the advantage of the product that currently leads the market.[25]

Thus, when a product sells for a relatively low price and is used widely, we cannot assume that it is used widely simply *because* it is cheap. It may, instead, be cheap because it is used widely.

PVC has benefited from mass production in many markets. PVC products have been used for decades, have achieved large sales volume, and thus are mass-produced at low cost. The learning curve effect appears to have been particularly steep for PVC, with every doubling of production associated with a 30 percent to 40 percent drop in price in the 1950s and 1960s.[26] A history of the industry describes a steady stream of process innovations and improvements in production technology in these early years, along with rapid increases in the size of the newest and most efficient plants; these factors undoubtedly drove the price downward.[27]

Many of the less toxic alternatives are not yet firmly established in the market; they do not currently enjoy economies of scale and learning curve advantages comparable to those enjoyed by PVC. In some cases, less toxic alternatives that were once popular may have benefited from economies of scale in the past but have been pushed aside by vinyl and are now produced in relatively small quantities. Linoleum flooring and aluminum siding are examples of this pattern. Analyses of the long-run costs of a PVC-free future should look beyond the current price of alternative products to their (likely lower) future price as they become widely adopted and mass-produced.

PVC Products Can Be Dangerous to Users

Often the harmful effects of PVC emerge during the intended use of the product. For example, flexible PVC products used in health care, such as IV bags and tubes, contain phthalates—plasticizers that can leach out of the products during use, posing hazards to patients.[28] The US Food and Drug Administration has issued an advisory, for example, recommending measures to reduce patients' exposure to the phthalate Di(2-ethylhexyl)phthalate (DEHP) in medical devices.[29] Phthalates are also used in some flexible PVC toys, including toys that young children are likely to put in their mouths. In 1999, the European Commission adopted an emergency ban on certain phthalate-containing PVC toys and other products, such as teething rings, intended for children to put in their mouths. This ban has been renewed repeatedly, pending development of permanent regulations. Some, though not all, US manufacturers have voluntarily stopped production of PVC toys containing phthalates.[30] (The US Consumer Product Safety Commission has denied petitions to ban PVC in toys for young children or to issue an advisory about hazards associated with these toys.[31])

Additional problems occur when PVC is exposed, intentionally or otherwise, to heat. In case of fire, vinyl building products release large quantities of hydrochloric acid, and smaller quantities of many other toxins, threatening building occupants and neighbors as well as firefighters. For this reason, some firefighter associations are working to educate the public about the hazards of PVC and are supporting municipal and state level policies to reduce PVC use. The International Association of Fire Fighters points out that 165 people died in the Beverly Hills Supper Club Fire of 1977, and 85 people in the MGM Grand Hotel Fire in Las Vegas in 1980—almost all of whom, according to the firefighters, were killed by inhalation of toxic fumes and gases, not by heat, flames, or carbon dioxide. A likely culprit is the hydrochloric acid created by the decomposition of PVC used in wiring and other building materials.[32] Medical researchers have found elevated levels of long-term respiratory and other health problems in firefighters who put out fires involving large quantities of PVC and have identified hydrochloric acid—acting alone or in combination with carbon monoxide and soot—as the probable cause of the damages.[33]

PVC is often advertised as "fire resistant," meaning that a fairly high temperature is required to start it burning. However, PVC starts to smolder and release toxic fumes such as hydrochloric acid at a lower temperature, long before it ignites. If PVC is gradually warmed, more than half of its weight is given off as fumes before it gets hot enough to burst into flames.[34] The hydrochloric acid released by burning PVC is potentially lethal to people caught in a burning building; other products of PVC combustion, such as dioxin, exert their health effects more slowly and are spread across a larger population.

Related hazards occur with PVC-insulated wiring, which was once standard for use in airplanes. There is no proof that PVC insulation has ever caused a plane crash, but some investigators have suggested that there are grounds for concern about older planes that still contain PVC-insulated wires. Full-sized modern airplanes contain 100 or more *miles* of wiring. The insulation on this wiring is critical to air safety: defects in the insulation could allow short circuits and sparks, potentially setting off a fire or explosion. A possible example is ValuJet Flight 592, a DC-9 that crashed in 1996, killing all 110 people on board. Although the flight crew reported an electrical power failure moments before the aircraft crashed, many reports instead focused on the possibility that oxygen tanks on board caused the crash. *Aviation Today* said in a special report on this and another accident,

> The ValuJet Flight 592 accident aircraft was rigged with a type of wire insulation, PVC, that will not pass the FAA's current flame test.… Among PVC wire's unacceptable properties, its burning insulation creates copious amounts of smoke, and the insulation can turn to hydrochloric acid when exposed to moisture. It is found on all DC-9s built through 1975. In addition, the vast majority of 727s…were built with PVC wire. According to an anonymous telephone call to investigators from a self-described company maintenance technician three days after the ValuJet crash, the accident aircraft "was continually having electrical problems...circuit breakers and wiring were shorting out..."[35]

Use of PVC wiring is now prohibited on new planes, since PVC insulation failed Federal Aviation Administration (FAA) flammability tests in 1972.[36]

But as *Aviation Today* noted, many older airplanes that are still flying contain PVC-coated wiring; the FAA never banned its use.[37] The US Air Force discontinued installation of PVC in 1977, although replacing all of the existing wiring at once was too expensive; the schedule for gradual replacement of wiring in some Air Force planes stretches out until 2015.[38] Meanwhile, the potential hazards of older planes continue: there have been at least nine instances of in-flight electrical fires in DC-9 aircraft since 1983, three of which occurred after the ValuJet crash.[39]

In these and similar cases, PVC is an inferior product precisely because of its health and environmental hazards, for those who use it as well as those who make it.

Environmental Protection Costs Less Than Anticipated

The costs of environmental protection are often overestimated in advance. One of the classic examples of this trend actually occurred in PVC production. A strict standard for workplace exposure to vinyl chloride (the raw material from which PVC is made) was established in 1974 by the Occupational Safety and Health Administration (OSHA), following recognition of the likely carcinogenicity of vinyl chloride. Consultants to OSHA estimated the costs of reducing vinyl chloride exposure at around $1 billion; industry estimates were even higher. Actual costs turned out to be around a quarter of OSHA's estimate, since industry quickly developed new, cost-effective technologies to comply with the regulation.[40]

Similar patterns have been found for many environmental standards. One study found that compliance costs for environmental regulations were overestimated in advance in 11 out of 12 cases. Another study found that advance cost estimates for environmental compliance turned out to be more than 25 percent too high in 14 out of 28 cases, while they were more than 25 percent too low in only 3 of the 28 cases.[41] A review of this literature for Environment Canada and the Ontario Ministry of Energy, Science and Technology, focusing specifically on the costs of controlling chlorinated substances, confirmed that overestimation of regulatory costs is more common than underestimation. Among the cases where it found serious overestimation of US regulatory costs were the advance predictions of compliance costs for the Montreal Protocol on ozone-depleting substances and the bans on the toxic pesticides DDT and chlordane/heptachlor.[42]

There are at least three reasons for this repeatedly lighter-than-expected burden. First, economies of scale and learning curve effects are usually not built into prospective cost estimates, but often arise in the production of pollution control devices and cleaner alternative materials. Second, as with vinyl chloride, regulation may stimulate innovation and lead to the introduction of new, more efficient technologies. Finally, overestimation of costs may at times be a bargaining tactic for industry in arguing against environmental protection.

While many of the analyses cited here refer to regulations, often involving traditional end-of-pipe pollution controls, exactly the same factors are at work in the case of clean production alternatives: economies of scale and learning curves will be important, industry will develop new technologies to ease the transition, and the costs of the transition to clean production may be exaggerated in advance for rhetorical or bargaining purposes.

The best-known claims of extraordinary costs imposed by environmental policy do not stand up to careful examination; they turn out to be based on a series of errors and misinterpretations.[43] This has important implications for employment and other economic impacts. Despite rhetorical claims to the contrary, environmental protection has almost never caused noticeable numbers of job losses.[44] Moreover, the critics often forget that environmental initiatives create jobs, many of them skilled blue-collar jobs. The phaseout of PVC is a case in point; the alternatives to PVC are guaranteed to require the efforts of industrial and construction workers. The possible employment implications of a PVC phaseout are examined in a later section of this report.

Markets for Alternatives

Because the uses of PVC are so diverse, the alternatives are likewise varied. The next five sections look at specific markets for PVC, exploring the available alternatives, the different properties that make alternatives more or less attractive, and the costs of replacing PVC with safer products. The first three markets involve products used in commercial and institutional construction: pipes, roofing, and flooring.[45] The fourth examines medical supplies, particularly gloves. Finally, we take a brief look at the fast-growing residential construction uses of vinyl in siding and windows.

Alternatives to PVC, I: Pipes [46]

Much of the PVC used is invisible to most of us; it is usually buried underground—or under the sink or behind the walls. But visible or not, modern life involves a lot of pipes. Some estimates suggest that municipal water and sewer systems will acquire $8 billion of pipes annually for the next 20 years. In addition, large quantities of pipes will be installed to meet residential, commercial, industrial, and agricultural needs. Many of these pipes will be made of PVC, providing by far the most important market for vinyl. Pipes and pipe fittings make up almost half of PVC use, as seen in Table 1.

PVC pipes have been in use for at least 30 years and have become standard in some applications, such as the "drain/waste/vent" (DWV) tubing that carries wastewater away from kitchens and bathrooms. They have also gained a large share of the market for small-diameter municipal water and sewer pipes and for electrical conduits. According to industry estimates, on a lineal basis PVC accounts for more than 70 percent of all water and sewer pipes now being installed in the US.[47]

PVC pipes are competing both with traditional pipe materials—copper, iron, concrete, and vitrified clay—and with polyethylene (PE) and other plastic pipes. Among other plastics, acrylonitrile butadiene styrene (ABS) is sometimes used for drain pipes; however, PE is by far the most important plastic pipe material after PVC. The different pipe materials have contrasting strengths and weaknesses.[48]

- The traditional materials are heavier and, for large-diameter pipes, may be harder to install and repair. However, they are strong under extremes of pressure and temperature. Copper plumbing remains the standard for hot and cold water in most buildings. Iron water and sewer pipes may corrode in acidic soil; they are sometimes coated with tar to combat corrosion.
- PVC is lightweight and lower priced than some alternatives and requires less skill to install and repair. However, PVC is weaker under high pressure and becomes brittle at below-freezing temperatures. For hot water pipes, a more expensive, modified form, chlorinated PVC (CPVC), must be used.
- PE pipes offer a lightweight alternative with greater strength under pressure, as well as stronger, more leak-proof joints and the ability to withstand temperatures well below freezing. For hot water pipes, a more expensive, modified form, cross-linked polyethylene (XLPE, marketed as PEX), must be used.

In view of its emerging role as an alternative to PVC pipes, we begin with an examination of the PE pipe industry. We then discuss the two major market segments: municipal water and sewer pipes and plumbing within buildings, including a detailed look at a recently constructed building that specified PVC-free plumbing. We conclude with price comparisons for several common plumbing jobs with and without PVC.

Polyethylene Pipe[49]

PE pipes are one of the most important alternatives to PVC. PE is the only other leading material to approach PVC in both weight and ease of installation; while some equipment is needed to install PE pipes, small-scale pipe-welding machines are becoming available for homeowner or small contractor use. Moreover, PE has important advantages over PVC, such as greater strength under pressure and under low temperatures, and lower rates of leaks and breakage. Production of polyethylene, although not pollution-free, is far less toxic than production of PVC; most of the toxic effects of the PVC life cycle involve chlorinated emissions, and PE does not contain chlorine.

PEX (cross-linked polyethylene) is suitable for hot and cold water and, because of its flexibility, can easily be bent around corners without a coupling or fitting, reducing labor time and the potential for leaks and system failures that tend to occur at joints in fittings. Because of its inherent flexibility, it has high tolerance for expansion and contraction, thus making it burst resistant.

Sales of PE pipe in the US and Canada, as estimated by the Plastics Pipe Institute, have grown rapidly, doubling in just a few years in the late 1990s.[50] PE pipe sales for 2000 and 2001 are shown in Table 4. The total reached 1.4 billion pounds in 2000, before dropping back to a little over 1.0 billion pounds as the economy slumped in 2001. For comparison, PVC pipe sales are around 6.5 billion pounds a year, as shown in Table 1.

Small declines in PE pipe sales occurred in many areas in 2001, reflecting the economic slowdown and reduced pace of construction. The largest decline occurred in conduits, which represented one-third of all PE pipe sold in 2000. PE conduits were widely used in the “dot-com” economy with its many cable and conduit needs; this market suffered an abrupt downturn beginning in 2001.

Substantial quantities of PE pipe are used in areas that do not compete with PVC, such as gas distribution and oil and gas production. Water and sewer pipes, which are areas of direct competition between the two plastics, are among the top uses for PVC, but represent only a fraction of the PE pipe market.

Some companies produce both PE and PVC pipe, giving them an additional motive to avoid competition between rival plastics. For example, J-M Manufacturing, the world’s largest PVC pipe manufacturer, recently acquired Quail, an Arkansas-based manufacturer of PE piping. J-M acknowledges an increased demand for PE, attributable in part to the appeal of leak-free joints as well as contractors’ increased familiarity and ability to work with the material.[51] They also are projecting increased market demand for PE in the water/sewer markets, in addition to the strong hold that PE currently has in the gas market.

Table 4: Markets for Polyethylene Pipe

	millions of pounds sold in US and Canada	
	2000	2001
Uses competing with PVC		
Water pipes		
Potable water up to 3"	77	75
Potable water 4" and above	65	58
Irrigation and agriculture	38	37
Sewers and drains	42	46
Conduits	500	193
Industrial and mining	178	174
Landfills	11	14
Crosslinked (PEX) pipe	20	32
Subtotal, competing with PVC	**931**	**629**
Other uses		
Gas distribution	236	210
Oil and gas production	180	180
Other	33	39
Export	36	15
Subtotal, other uses	**485**	**444**
Total	**1416**	**1073**

Source: Plastics Pipe Institute, "2001 Statistics: North American Shipments of Polyethylene & Crosslinked Polyethylene Pipe, Tube & Conduit"

PE pipe is newer to the market and hence less familiar to plumbers, contractors, and municipal public works departments, than PVC and traditional pipe materials. The American Water Works Association first gave its approval for the use of small-diameter PE water pipes in 1978, and for larger diameters only in 1990. PE plumbing has also been approved by the National Sanitation Foundation.

Reluctance to embrace new materials, including CPVC, PEX, and PE, especially in large commercial projects, results in part from memories of the failure of an earlier “new” pipe material, polybutylene (PB). Introduced in the late 1970s, PB pipe quickly gained a reputation for frequent leaks. However, it continued to be sold through the 1980s and early 1990s because its ease of installation allowed savings of hundreds of dollars per home. A class action suit against Shell, the largest manufacturer of PB pipe, *Cox v. Shell*, was settled in 1995 for $950 million, one of the largest settlements in US history.[52] Today, numerous companies offer PB pipe removal services.

Water and Sewer Pipes

PVC has been very successful in the market for small-diameter municipal water and sewer pipes. Some observers claim that PVC pipe installation minimizes municipal labor and equipment costs and also minimizes the length of time that streets are blocked for pipe installation. For larger diameter main pipes, where strength under pressure is of great concern, the traditional materials have retained a substantial share of the market, and PE is a stronger contender than PVC. Strength under extreme temperatures is more important in northern areas where the ground often freezes; accordingly, PVC has made greater inroads in southern, frost-free parts of the country.

Not everyone, however, has opted for PVC. In recent years, some municipal water and sewer systems have chosen PE instead of PVC. Performance issues, not cost, appear to drive the decision. The Indianapolis Water Company (IWC) has switched to PE because it reduces leaks at the joints and bends in the pipes and because a new installation technique (which works only with PE) minimizes excavation and disruption. IWC has now installed more than 30 miles of PE pipe of diameters larger than 20 inches.[53]

IWC is a subsidiary of United Water Company, a large private company that operates privatized water systems in many areas. United Water affiliates in New Jersey and New York also choose to avoid PVC in order to minimize leaks, since they operate in congested urban areas where it is expensive and difficult to excavate and repair underground pipes. Local building codes and conditions require very strong pipes, and United Water uses iron and cement pipes in New York and New Jersey; PVC is not durable enough for use under these conditions. However, United Water does use some PVC in Florida, where there is less concern about damage to pipes due to frost. [54]

California communities that have switched to PE or other non-PVC pipes for some applications include the Contra Costa Public Works Department, which uses PE pipes for storm drains; they view PE as superior to concrete or metal pipe on the basis of its low weight, ease of installation, low cost, and reduced level of leaks at the joints. The Los Angeles Department of Water and Power has used PE pipes to replace old water mains after major breaks, because it is the material that minimizes leaks.

PE pipe producers have described additional case studies of adoption of PE pipe for water distribution systems in Palermo, Italy, and in Toronto, as well as in smaller communities throughout the US.[55] In these cases, PE was selected for characteristics including resistance to earthquakes and freezing, minimal damage to sensitive environments (the flexibility of PE allows less invasive drilling techniques for laying pipe), and the long-term integrity of its heat-fused joints.

Municipal agencies and decision-makers rarely view the price of the pipes themselves as the most important factor in choosing water and sewer pipes. A representative of the Boston Water and Sewer Commission emphasized this point, stating that it costs so much to dig up the streets and install the pipes that the price of the pipe itself is irrelevant to the city's decision. Boston uses the pipe material that the agency considers appropriate to each job: ductile iron for water mains; copper for house services; ductile iron or reinforced concrete for large diameter sewer pipes; and PVC for small diameter sewer pipes. PVC was chosen for the smaller sewer pipes on the basis of its light weight and ease of connection.[56]

PVC has also been adopted for other low-pressure, low-temperature-stress applications such as irrigation pipes, culverts, drain pipes, and some industrial pipes. However, high-pressure applications, such as gas pipelines, cannot use PVC; instead, PE pipe has a major share of these markets.

If hydrogen becomes an important fuel in the future, as the Bush administration and others have sometimes suggested, a system of non-PVC pipes will be needed to transport it: hydrogen can diffuse out through the walls of PVC pipes, due to the porous molecular structure of the PVC polymer. (PE, although not as porous as PVC, apparently is also unsuitable for hydrogen pipelines.)[57]

In short, despite PVC's continuing strength in this major market, there are other materials that play an important role, and numerous municipal customers who have decided to rely on alternatives to PVC for some or all of their pipe needs.

PVC Plumbing and Conduits: Pro and Con

Different considerations arise in plumbing, as well as conduits for wire and cable, within buildings. For do-it-yourself plumbing, sections of small-diameter PVC pipe, manufactured in 10-foot or 20-foot lengths, are easy to cut to the desired length and join together with pipe cement (although some pipe cement products used in home plumbing are themselves toxic[58]). However, when plumbing is installed by skilled workers, PVC loses this advantage: it requires more joints, and time must be spent waiting for cemented joints to dry before testing and using the pipes, in contrast to alternatives with fewer, but stronger, welded joints.

For electrical conduits, PVC competes with steel; steel is more expensive and harder to bend and install, but is often required by building codes for its much greater fire resistance. PVC is of course more flammable than steel, but it is also less flammable than other plastics. For conduits where fire resistance is less of a concern, such as optical fiber and computer network cables, PE has been widely adopted.

Outstanding concerns regarding fire hazards have driven building codes in some areas, such as the city of Chicago, to exclude all plastic piping, including PVC and CPVC, from all commercial building applications. Chicago also prohibits plastic pipe in all residential structures three stories and above. New York State has similar legislation, banning plastic pipe, including PVC, from all commercial buildings and from residential buildings over six stories in height, at least through 2004. Industry critics attack such measures as make-work regulations that needlessly drive up construction costs in order to protect union jobs. Unions defend them as safety measures, citing the health hazards of PVC fires.[59]

Both the Chicago and the New York State standards apply to all plastic pipes, not just PVC. Some supporters of these standards have argued that all plastic pipes are flammable and will ignite at lower temperatures than other building materials. This remains a controversial view; many critics have rejected the idea that the use of plastic pipes affects the risk of fire.[60]

Even where PVC pipe is allowed by building codes, concerns about fire prevention may raise its effective cost. Based on experience in the design of an eight-story residential assisted living facility in Cambridge, Massachusetts, engineering consultant John Rattenbury concludes that the cost advantage of PVC over cast iron plumbing is largely illusory. Although the price per foot for sanitary and storm drains appears to be at least three times as high for cast iron pipes as for PVC, the building code requires firestopping protection every time PVC passes through a wall, plus thermal expansion joints on PVC pipes. Iron is completely fireproof and has a much lower coefficient of thermal expansion, so the requirements are much less taxing for iron pipes.

These and other difficulties make installation in a multi-story building far more expensive with PVC, offsetting most of the apparent cost advantage. In addition, Rattenbury observes that cast iron drain pipes are much quieter.[61]

Case Study: Building Without PVC Pipes[62]

Although PVC has become conventional for some plumbing uses, large commercial and residential buildings can be built with no PVC pipes. There are examples of such buildings around the country. In some cases PVC must be avoided due to building codes, as in Chicago and New York; in other cases the choice of PVC-free plumbing is due to the growing interest in "green building" design in general and the desire to minimize PVC use in particular.

One such building is the Austin Resource Center for the Homeless in Austin, Texas. (It is far from the only example, even in Texas: the University of Texas-Houston School of Nursing building made almost identical choices about pipes.) This project, located in downtown Austin, is a 26,820 gross square foot building with a construction budget of $4.7 million. For this project, copper was specified as the domestic water piping, and cast iron was used in all other interior pipe applications, with polyethylene used for irrigation pipe. According to the plumbing contractor, MJ Mechanical, these pipe choices resulted in an estimated 15 percent total increase in the costs of plumbing materials and labor.

- The decision to choose copper over PVC for domestic water arose independently of the project goal; in general, copper is a common choice for domestic water pipes. Copper provides long-term reliability and familiarity, which are important for both owners and the trades.[63] The PVC option for hot water pipes would require CPVC (chlorinated polyvinyl chloride), formulated to withstand higher temperatures than standard PVC. (At this point, CPVC is still considered a new market entry, with only a 10 to 15 year track record in the US. For experienced installers, copper can be installed in about the same time as PVC; industry handbooks estimate that it costs 10 percent more to install CPVC than to install copper.)
- For sanitary, waste, and vent pipes, cast iron was used instead of PVC even though PVC has become the standard material for these applications. The cast iron cost 15 percent more than PVC for materials, and did not change labor costs.
- To water the grounds, the project specifications called for flexible polyethylene pipe housed in

steel sleeves. The specification of the steel sleeves was based on concerns that the PE pipe could become brittle and thus require additional protection. This boosts both the material and labor costs of this system; installation labor expenses are estimated to run about three times the cost of installing PVC irrigation pipe without a sleeve. However, some pipe experts believe that such sleeves are unnecessary on PE pipes and would describe this as a case where misconceptions about materials led to more costly choices.[64]

Plumbing Price Comparisons

To conclude our discussion of pipes, we look at the costs of PVC and alternatives for several categories of plumbing. Table 5 shows the retail purchase price for two varieties of small-diameter pipes: ¾-inch pipes made of materials not suited for hot water, and ½-inch pipes that are able to carry hot water. Note that PVC and PE are fairly close in price for ¾-inch pipe, as are CPVC and PEX for ½-inch hot/cold water pipe. Only copper is distinctly more expensive among the alternatives shown in Table 5.

Table 5: Retail Plumbing Prices

Category	Material	Price per foot
¾-inch pipe	PVC	$0.14
	PE	$0.16
½-inch hot/cold water pipe	CPVC	$0.29
	PEX	$0.34
	hard copper	$0.58
	soft copper	$0.67

PVC is Schedule 40; copper is Type L. Prices are for various lengths (10 - 100 feet), converted to price per foot.

Prices are from Home Depot and Lowe's on line, and from an Austin, Texas, plumbing supply store, as of September 2003.

The small differences in material price between PVC and PE plumbing, seen in Table 5, are rarely decisive for the total cost of a plumbing job. Tables 6 and 7 present installation costs for ¾-inch plumbing, based on a standard database that is widely used in the industry for estimating job costs. Table 6 presents the costs for pipe installation alone, showing that installation of PE-aluminum, or PEX-aluminum, pipe is cheaper than CPVC. Labor costs are much greater than material costs and vary more widely between the two jobs: differing labor costs account for almost all of the difference in total cost between CPVC and the PE options.

Table 6: Installation Costs, ¾-inch Plumbing - Pipe Only

	(amount per lineal foot)			
	Labor Hours	Labor Cost	Material Cost	Total Cost
CPVC	0.055	$1.51	$0.55	$2.06
Cross linked PE-aluminum	0.030	$0.83	$0.60	$1.43
PE-aluminum	0.030	$0.83	$0.47	$1.30

CPVC has solvent welded joints; both PE-aluminum pipes have crimped joints.
Source: 2003 National Plumbing & HVAC Estimator

Table 7 presents an expanded estimate of installation costs, including the hangers and tees required by plumbing codes as well as the pipe itself. Note that the two tables refer to different categories of pipe: Table 6 refers to hot/cold water pipe, whereas Table 7 does not. In the latter case, the comparison shows that PVC is somewhat cheaper than copper, again almost entirely due to differences in labor requirements.

Table 7: Installation Costs, ¾-inch Plumbing - Complete Installation

	(amount per lineal foot)			
	Labor Hours	Labor Cost	Material Cost	Total Cost
Copper	0.116	$3.20	$0.76	$3.97
PVC	0.091	$2.52	$0.72	$3.24

Complete installation includes hangers and tees, as required by code.
Copper is Type L, with brazed joints, installed horizontally.
PVC is Schedule 40 with solvent-weld joints, installed horizontally.
Source: 2003 National Plumbing & HVAC Estimator

For small-diameter plumbing, the price comparisons do not tell a story of large advantage in either direction: retail prices are similar for PVC and other plumbing materials (Table 5); installation cost estimates favor the alternatives in some cases (Table 6) and PVC in others (Table 7). It seems safe to conclude that there are feasible, affordable alternatives for PVC-free plumbing.

Alternatives to PVC, II: Roofing

Roofing is a $30 billion-a-year industry that installs new and replacement roofs made from a wide range of materials.[65] Although multi-ply (multi-layer) roofs can be applied on any building, it is increasingly common to use single-ply roofing membranes, particularly in low-slope applications for commercial buildings. To provide for a range of different uses, single-ply roofing membrane manufacturers produce an extensive selection of membranes with varying levels of thickness and reinforcement.

There are three major single-ply roofing membrane materials for low-slope roofs: ethylene propylene diene monomer (EPDM), thermoplastic elastomer polyolefin (TPO), and PVC. (In steep-slope roofs, PVC has a market share of less than 0.5 percent.) The installed cost for any of the three is often cheaper than for other styles of roofing. As shown in Table 8, EPDM is clearly the market leader; the combination of EPDM, TPO, and PVC roofs together accounts for more than one-third of low-slope roofing sales. (Additional single-ply materials, included in "all other," amount to another 2 percent of sales.) Among single-ply roofing choices, the alternatives are often lower-priced than vinyl, as explained below.

Table 8: Low-slope roofing sales, 2002

EPDM	23.7 %
Bitumen	22.4
Asphalt - built-up	16.6
Asphalt shingles	7.4
TPO	5.8
Metal	5.6
PVC	4.8
All other	13.7
Total	**100.0**

Low-slope roofs are those with a slope of less than 14 degrees.

Figures are weighted averages of new roofs (29%) and re-roofing (71%), reflecting the relative proportion of sales.

Source: Beverly Siegel, "An Industry Overview," *Professional Roofing Magazine* (April, 2003).

Life-Cycle Roofing Costs

For roofing, as for other construction products, what matters for cost-effectiveness is the total life-cycle cost of a product, rather than just its initial installed cost. On the Tufts University campus, for instance, there are dozens of buildings that periodically require re-roofing. According to a general contractor that frequently works for the university, Tufts formerly used EPDM, but has now switched to built-up asphalt for low-slope roofs. Although the multi-layer asphalt roof costs almost twice as much per square foot as EPDM, Tufts has decided that the multi-layer roof is better suited to its requirements and reduces maintenance costs. PVC is not a viable option for the university, in the contractor's view, since it would cost even more per square foot than asphalt, due to the time-consuming installation process. In addition, it would not last as long and would tend to develop cracks and leaks.[66]

As this example suggests, the expected lifetime of a roof is crucial to its life-cycle costs. PVC does poorly by this standard. A study of the lifetimes of almost 24,000 low-slope roofs found that PVC had the shortest average life among the roofing types in the study (Figure 2). Thus, even if PVC and another roofing material had identical installed costs, PVC would have a higher cost per year of expected lifetime.[67]

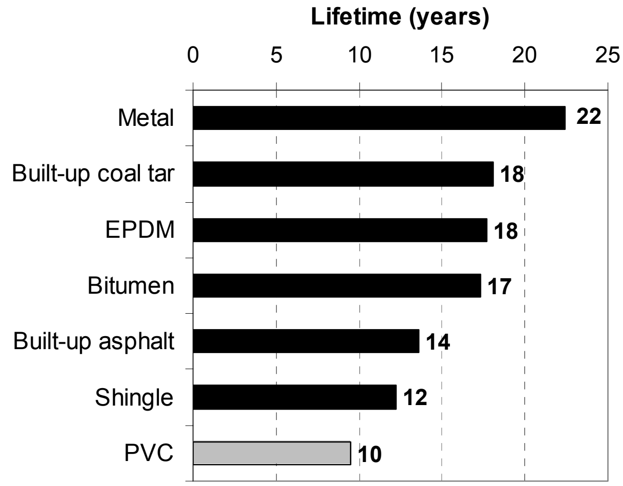
Characteristics of Roofing Materials

As in other uses, the choice between PVC and rival roofing materials depends on the physical characteristics of the materials as well as the price differentials. Single-ply roofing systems are popular because of their comparatively low cost and ease of installation. Within the single-ply category, the leading materials are often seen as differing in reflectivity, energy efficiency, durability and flexibility, among other properties. In this section we discuss differences among PVC, EPDM, and TPO.

Reflectivity

The vinyl industry advertises the fact that white vinyl roofs reflect sunlight and thereby lower building temperatures, increasing the energy efficiency of a building when air conditioning is in use. This benefit has been recognized by EPA's Energy Star program, which identifies proven energy-conserving technologies. Until TPO was introduced, PVC was the only white, single-ply membrane roofing material available.

Figure 2: Average Life of Roofs



Source: Kenneth G. Schneider Jr. and Anne S. Keenan, "A Documented Historical Performance of Roofing Assemblies in the United States 1975-1996," *Proceedings of the Fourth International Symposium on Roofing Technology* (September, 1997).

Today, however, there are other options for white roofs. TPO, a relatively new polymer, is available in white, tan, or gray. It was first introduced in 1991 in Europe and has since made the jump to the North American market, where it is gaining market share. EPDM, an inexpensive synthetic rubber product, is naturally black; however, it can be made white through coating or painting with a titanium dioxide layer. The New Orleans Superdome, for example, has a white EPDM roof.

During hot weather, roofing color is an important factor affecting energy efficiency. While the significance of white roofs is unquestioned for many parts of the country, there is an ongoing debate about the impact of roof color in northern climates. Buildings in northern climates often experience more heating than cooling days; some experts argue that this makes a solar-absorptive or darker colored roof preferable. Opponents of this view argue that white roofing reduces energy *costs* even in northern latitudes because cooling is a more expensive process than heating, due to its reliance on electricity rather than oil or natural gas. In addition, some roofs in northern climates are snow covered during much of the cold season, making the color of roofing materials less important during the winter.[68] Ongoing research on roof reflectivity at Oak Ridge National Laboratory will address this question; in a preliminary discussion of the research, the lead investigator suggested that roof color might have little overall effect on building energy costs in northern climates.[69]

Durability and Flexibility

The three single-ply materials differ in durability and flexibility, with PVC generally lagging behind both of the other options.

Advantages of TPO membranes compared with PVC include superior flexibility in cold weather—allowing easier installation in cold climates[70]—and retention of flexibility throughout the life span of the material. EPDM offers similar advantages—the ability to withstanding a broad range of temperatures, resist weathering, and stretch and conform to unusual shapes. It has excellent UV radiation, ozone, and weathering resistance. In the past, a key disadvantage of EPDM was that its seams were less effective than those of either PVC or TPO under similar installation conditions. According to individuals working in the roofing industry, this problem has been eliminated with the advent of new seaming techniques using tape.

As in other vinyl products, additives such as plasticizers must be present in PVC roofing membranes in order for them to withstand frequent traffic and maintain flexibility. Gradual migration of plasticizers out of PVC roofing materials can lead to seam failure and structural damage, which were problematic when PVC was first introduced to the roofing market. Stabilizers are now added to the PVC to slow migration of the plasticizers, increasing the life span of the PVC membrane, but this does not entirely eliminate the problem.

The shorter lifetime of PVC roofs, as shown in Figure 2, results in part from their tendency to become brittle and crack. This effect was highlighted in research by the US Army's Construction Engineering Research Laboratory (CERL). Launching a long-term investigation into PVC membrane roofing, a 1981 CERL report noted anecdotal evidence of PVC roof failures in both Switzerland and the United States, and said, "The two most serious PVC membrane problems are embrittlement from loss of plasticizer or from exposure to ultraviolet rays and excessive shrinkage."[71] A 1997 paper, reporting on CERL's ten-year field study of three PVC roofs at military installations, found that the performance of two of the roofs was "generally satisfactory," whereas "problems related to shattering and splitting" occurred at the third.[72] The paper offered a detailed technical comparison of samples of the three roofs, noting some evidence that the roof that shattered may have lost more plasticizer than the ones that remained intact.

Methods of installation

The installed cost of a roof depends on the method of installation as well as the choice of material. There are three primary ways to install single-ply roofing systems: fully adhered, mechanically fastened, and ballasted. TPO, EPDM, and PVC can each be installed in any of these three ways.

A *fully adhered* roofing system uses the most expensive and labor-intensive method of installation. During installation of a fully adhered roofing system, insulation boards are placed first and fastened to an underlayment. This is a high performance system used in situations where leaks cannot be tolerated even temporarily, or where the roofing system may be exposed to high winds. Seams can also be heat-welded in a fully adhered roofing system.

A *mechanically fastened* roofing system is essentially a quicker, somewhat less thorough and less expensive variant on the fully adhered system. Insulation boards are tacked down (though the fasteners are spaced farther apart than in a fully adhered system) and the seams can be heat-welded together. In a mechanically fastened system, the membrane sheets are fastened to the substrate at certain intervals, depending on specifications.

A *ballasted roofing system* has the simplest installation process. Insulation is loose laid, and gravel is layered on top of the single-ply membrane, holding the system in place. This causes the roof to take on a grayish color (mitigating solar heat gain somewhat when a black membrane is used). In areas where river-washed gravel is readily available, this is the least expensive installation process.

Costs of single-ply roofing systems[73]

To examine the prices of single-ply roofing systems, we have collected data for several roofing options from one location, Austin, Texas, and compared them to costs for specific projects in three other locations. The data demonstrate that PVC has the highest installed cost of the three major single-ply roofing materials. On a cost per year basis, PVC's disadvantage is likely even greater due to its shorter expected lifetime, as documented above.

Energy Star initiatives have increased the use of white roofing membranes in Texas. Many localities, including Austin, offer rebates for increased insulation or use of white reflective membrane. In these areas, PVC maintains its market share in part because it is slightly easier to heat weld in warm climates. In addition, TPO is relatively new to the roofing membrane industry and thus introduces reliability concerns, making some institutions reluctant to switch to TPO. EPDM is less popular in Austin, despite its low cost, due to the interest in white roofs for energy conservation.

Table 9 compares the costs (including material and installation labor) of EPDM, TPO, and PVC roofing options for commercial roofs in the Austin area. Figure 3 presents the same data graphically for 45 mm roofing membranes. As these figures show, the cheapest roofing option considered here is ballasted EPDM, while fully adhered TPO and PVC have the highest costs.

The range of variation among these costs is not enormous and will not necessarily be decisive in every decision-making process. The highest price shown in the table is less than 150 percent of the lowest price. However, it is clear that TPO is less expensive than PVC in all cases, for all methods of installation and for both membrane thicknesses. Ballasted EPDM roofs, despite their comparative energy inefficiency, have lower installed costs than any of the alternatives.

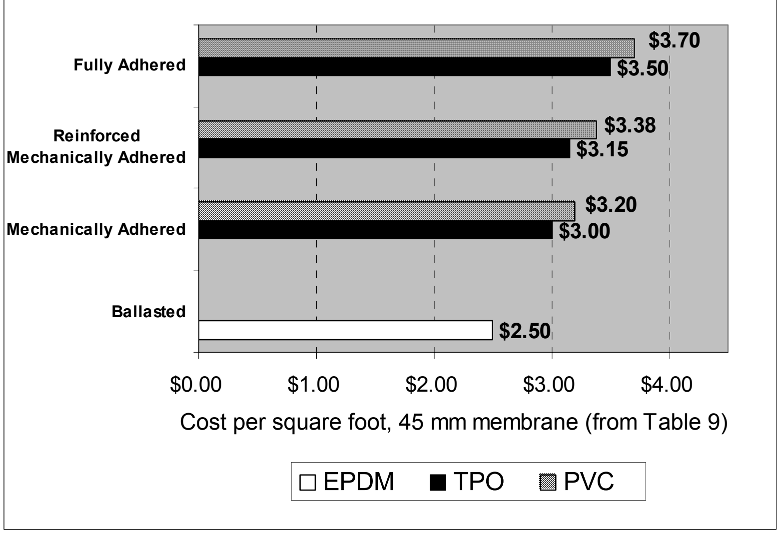
Table 9: Installed Costs of Roofing in Austin

(costs per square foot for materials and labor)

	Ballasted	Mechanically Adhered		Reinforced Mechanically Adhered		Fully Adhered	
Thickness	EPDM	TPO	PVC	TPO	PVC	TPO	PVC
45 mm	$2.50	$3.00	$3.20	$3.15	$3.38	$3.50	$3.70
60 mm		$3.15	$3.38	$3.30	$3.53		

Source: Fifth Wall Roofing (http://www.fifthwallroofing.com/)

Figure 3: Roofing Installation Costs in Austin



Similar costs and conclusions can be observed elsewhere. For instance, a recent project in Chicago installed 140,000 square feet of roofing on a commercial building.[74] The total project cost was $400,000 for materials and labor. Thus, the installed cost was $2.86 per square foot, similar to costs observed in Austin. The material selected was TPO.

In this case, the choice of TPO was driven primarily by the fact that the TPO installed price was 5 percent lower than that of PVC (which is consistent with the Austin data in Table 9). Labor estimates were equivalent for PVC and TPO; the difference in installed price reflected differences in material costs. Given similar performance characteristics and warranties between PVC and TPO, the contractor indicated that this was a relatively simple decision in which the deciding factor was materials price.

Somewhat higher costs, but the same general conclusion—PVC is the more expensive choice—can be found in recent experience in western Massachusetts. Two similar school buildings, in the towns of Longmeadow and Chicopee, recently replaced roofs of about 120,000 square feet. The one that specified vinyl paid $916,000, while the one that did not specify a material paid $679,000 for a TPO roof.[75] The difference in cost between these two roofs—roughly $7.60 versus $5.70 per square foot—reflects not only material prices but also differences in labor costs.

Alternatives to PVC, III: Flooring [76]

Flooring manufacturers sold 7.9 billion square feet of hard floors in 2002, with a wholesale value of $7.1 billion. Vinyl accounted for 3.6 billion square feet, and $1.84 billion of these totals—45 percent by area and 26 percent by value. Roughly two-thirds of vinyl flooring is installed in residential buildings and one-third in commercial and institutional buildings.[77]

PVC primarily competes with other resilient flooring materials—a category that includes all major floor surfaces except wood, ceramic tile, and carpet. Resilient flooring options range from natural cork and traditional linoleum through synthetic rubber products and new non-chlorinated polymers. Vinyl flooring is advertised as a uniquely affordable, durable, and easily maintained product. However, while vinyl generally minimizes initial costs of purchase and installation, it is not usually the longest-lasting choice, nor the easiest or cheapest to maintain. Its higher maintenance costs can actually make it one the most expensive flooring options on a life-cycle basis.

Our analysis starts with a description of the leading options for resilient flooring, then compares the life-cycle costs of these options, and concludes with case studies of decisions between vinyl and linoleum flooring in three cities.

Resilient Flooring Options

Vinyl

Vinyl flooring materials contain varying amounts of plasticizers, stabilizers, and fillers. Plasticizers make the naturally rigid PVC pliable. However, the vinyl can become brittle as the plasticizer separates from the polymer over time; stabilizers are used to slow this separation. A filler compound, generally pulverized limestone, is present in vinyl composite tiles (VCT); some VCT products contain as little as 13 percent vinyl by weight.[78]

Health concerns associated with use of vinyl flooring include possible adverse effects on respiratory health during ordinary use as well as toxic emissions in case of fire. For example, a 1999 study in Norway found an association between use of PVC flooring in homes and increased likelihood of bronchial obstruction in young children.[79] In case of fire, vinyl flooring can give rise to hydrochloric acid fumes, dioxin emissions, and other toxic substances (see earlier discussion of fire risks).

These health concerns, as well as life-cycle cost calculations, have prompted interest in alternatives to vinyl flooring. A number of resilient flooring alternatives are available, with varying characteristics and advantages.

Cork

Cork is harvested from the cork oak tree (*Querus suber*), found mainly in Portugal, Spain, and North Africa. The trees live to be 300 to 400 years old; once they are 50 years old, they can be harvested every nine to ten years—a process that involves careful removal of only the outer layer of the bark, allowing the tree to survive. Due to the infrequency of the harvest and its expense, all harvested material, including the cork dust, is used. Some cork tiles also have a recycled rubber backing.

After the manufacturing process, cork tiles are either left unfinished or finished with a wax or polyurethane topcoat. The most durable option, and the one best suited to commercial applications, is the polyurethane topcoat; refinishing with polyurethane is required only every three to four years.

Cork can be extraordinarily long lasting; some cork floors that were installed in the early twentieth century are still in use. Examples include the US Department of Commerce Building in Washington, D.C., and St. Mary's of the Lake Chapel near Chicago.[80]

Linoleum

A classic of decades past, natural linoleum floor covering is made from renewable materials: linseed oil, pine or other rosin, ground cork dust, wood flour, mineral fillers, and pigments. Linoleum products, available in both sheet and tile, have a natural jute or polyethylene backing depending on the manufacturer. Due to its material composition, linoleum is inherently anti-static and anti-bacterial.

Of the raw materials that compose linoleum, environmental concerns have been raised about volatile organic compound (VOC) emissions associated with linseed oil. However, according to a test performed by the California Department of Health Services, the average VOC emissions level for linoleum falls toward the low end of the range of emissions by vinyl products and by carpets: 170 micrograms of VOCs per square meter per hour for linoleum, compared to 80 to 600 for various carpets and 120 to 2300 for a range of vinyl products. Stratica (discussed below) had emissions of less than 10, which is below the level the test could detect.[81]

Linoleum was once manufactured widely in the United States; however, as demand began to fall in the 1950s, the industry declined here, with the last US plant closing in 1975. Today, natural linoleum is still produced in Europe; an estimated $20 to $25 million worth of linoleum is imported into the United States annually.[82] The product's image has prospered, even if the industry producing it did not: in building supply stores such as Home Depot, "linoleum" now refers to a different product, namely vinyl floor coverings designed to look like traditional linoleum.

Non-vinyl Polymer Flooring: Stratica[83]

Stratica is a proprietary resilient floor covering material manufactured by Amtico in both European and US plants. Its topcoat, DuPont's Surlyn, was originally developed as an outer surface for golf balls. Surlyn is heat-fused to the Stratica base and is responsible for the floor covering's durability and low maintenance requirements. It is the resilient floor material most similar to vinyl flooring in appearance, with a high-gloss (yet low-maintenance) surface.

Stratica is a low-VOC material that is non-allergenic and mildew and odor resistant. Introduced to the United States market in 1997, Stratica boasts a 100 percent recovery rate for its post-industrial waste. Post-consumer Stratica waste can be recycled into backing for more Stratica flooring; however, facilities do not yet exist for this process in the United States.

Rubber

Rubber floor covering, available in both tiles and sheets, can be made from natural rubber, from recycled automobile and truck tires, or from synthetic rubber compounds including styrene butadiene rubber (SBR), ethylene propylene diene monomer (EPDM), nitrile, or the proprietary Nora rubber.

Health and environmental concerns vary widely with the composition of the rubber floor material. General concerns have been raised about VOC emissions and the overall impact on indoor air quality, particularly for products made from recycled tires and/or styrene. Carbon black dust, emitted by some rubber products, also raises concerns about indoor air quality. The manufacturing process for SBR products creates potential worker health hazards.[84]

Rubber is also suitable for use under a wider range of conditions than some alternatives; both cork and linoleum tend to swell when exposed to consistent moisture. Rubber flooring has the advantage of requiring very little maintenance.

Life-Cycle Costs

Data gathered from floor specialists and distributors in three cities--Austin, Washington, and Chicago--reflect the cost of materials and installation, as well as regular maintenance requirements and estimated costs for common maintenance functions for heavily used commercial and institutional floor space.[85] Costs for leading resilient flooring materials over a 20-year life cycle are shown in Table 10.

Table 10 shows the initial costs, expected life span, annual maintenance costs, and 20-year life-cycle costs of selected brands in five categories of flooring materials: vinyl, cork, linoleum, non-chlorinated polymer (Stratica), and rubber. All costs are presented on a per square foot basis. The table demonstrates the substantial importance of maintenance costs.

Initial material and installation costs are as low as $2.65 per square foot for vinyl tile and range from $5.50 to $11.70 for other materials. Based on initial material and installation costs alone, an institution could spend as little as about $2,700 to install 1000 square feet of vinyl composite tile (VCT), or two to four times that amount for a higher-end floor. Thousands of dollars of initial savings are apparently available by choosing vinyl tile—the high-end rubber floor shown in this table (Flexco-Radial, last line of Table 10) would cost $9,000 more than vinyl tile for a 1000 square foot installation.

However, flooring installation represents a very small part of total cost when expressed in terms of cost per year of use. Far more important is the annual maintenance cost; the data in Table 10 show that for heavy-traffic areas maintenance costs account for at least 98 percent of the life-cycle cost for each flooring material.[86] The high-end rubber floor has the lowest maintenance costs per square foot, and therefore the lowest life-cycle costs over all. Over 20 years, it would save more than $500 per square foot, compared to the "low cost" vinyl tile. Cork, the second-most expensive product in Table 10 in terms of first cost, is the second cheapest on a life-cycle basis due to its low maintenance costs and long lifetime. Stratica is also a bargain compared to vinyl; linoleum is cheaper than vinyl on a life-cycle basis, although more expensive than several of the other alternatives. In short, the initial cost savings from vinyl are counterbalanced by high costs over the life cycle of the flooring.

Table 10: Life cycle costs of flooring (per square foot)

Material	Brand - type	Initial cost: material and installation	Expected life span (years)	Initial cost per year of life span	Maintenance cost per year	Total cost over 20 years
		A	*B*	*C = A / B*	*D*	*E = (C + D) * 20*
Vinyl	Armstrong - Solid Vinyl	$9.70	25	$0.39	$52.00	$1,048
	Armstrong - VCT	$2.65	15	$0.18	$52.00	$1,044
Cork	Dodge - Regupol	$7.25	40	$0.18	$25.70	$518
	Expanko	$10.30	30	$0.34	$25.70	$521
Linoleum	Armstrong	$6.30	25	$0.25	$40.00	$805
	Forbo - Sheet	$5.50	35	$0.16	$33.30	$669
	Forbo - Tile	$6.42	25	$0.26	$33.30	$671
Non-chlorinated polymer	Amtico - Stratica	$6.75	40	$0.17	$32.00	$643
Rubber	Dodge - Regupol-Econights	$6.50	30	$0.22	$40.00	$804
	Dodge - Regupol-Ecostone	$7.75	30	$0.26	$40.00	$805
	Expanko - Treadmaster	$7.50	30	$0.25	$32.00	$645
	Flexco - Radial I, II	$11.70	35	$0.33	$24.00	$487

Source: Center for Maximum Potential Building Systems (Austin, Texas), based on communications received in September 2003 from Terry Bessire, Intertech Flooring (Austin); Kim Pexton, Jim G. Davis Construction Corporation, and Lesa Green, Turner Construction Company (Washington, D.C.); and Gail Bothwick, Farr Associates (Chicago).

A similar conclusion emerges from a US Navy assessment of decking materials for its ships.[87] In that assessment the Navy tested Stratica in high-traffic areas (such as food service areas) on ten ships, covering a total of 37,800 square feet. Due to the heavy use, the estimates of the lifetimes were shorter, 10 years for Stratica versus 5 for vinyl tile; the Navy also found that Stratica required about one-third as much labor for maintenance. The maintenance costs were by far the dominant factor, as shown by the Navy's analysis of costs over a ten-year span, summarized in Table 11. The Navy estimates that the maintenance costs per square foot per year (one-tenth of the ten-year maintenance and repair figures shown in Table 11) are about $20 for Stratica and $59 for vinyl, compared to $32 for Stratica and $52 for vinyl reported in Table 10.

The high maintenance costs shown in Tables 10 and 11 may be interpreted as worst-case estimates, appropriate for the heaviest-use areas. For example, the Navy's food service areas on major ships are presumably very high-traffic areas, with hundreds of sailors moving through them several times a day. In contrast, many offices, stores, and institutions experience much lower traffic and likely have correspondingly lower floor maintenance costs.

Table 11: Life-cycle costs of Stratica vs. vinyl

($/sq. ft. over 10 years)	Stratica	Vinyl tile
Purchase and installation	$7.00	$6.25
Repair	$4.00	$6.50
Maintenance labor	$192.24	$587.78
Total	$203.24	$600.53

Source: "Implementation Assessment for Maintenance Free Decking," memorandum prepared for the Under Secretary of the US Navy by the Commander, Naval Supply Systems Command (January 14, 2000).

However, the key conclusion to be drawn from Tables 10 and 11—vinyl tile is more expensive than other flooring options on a life-cycle basis, due to its high maintenance costs—would remain true even if maintenance costs were substantially lower. Recalculation of Table 10, assuming 1 percent of the reported maintenance costs for each material, would still find both vinyl tile options to be more expensive over 20 years than any of the alternatives. Even at this reduced level, maintenance costs would still represent more than half of the life-cycle costs for 10 of the 12 options in Table 10. Similarly, recalculation of Table 11 assuming 1 percent of the Navy's repair and maintenance costs would still find Stratica to be cheaper than vinyl over 10 years.

The Maintenance Costs Puzzle

The conclusion that vinyl flooring has higher life-cycle costs than the alternatives rests on two facts shown in the tables above. First, the lower-cost vinyl option, VCT, has the shortest lifetime of any of the materials shown in Table 10; its installed cost *per year of life span* is actually higher than for some of the alternatives (see column C in Table 10). Second, the maintenance cost per square foot is higher for vinyl than for any of the alternatives.

It may seem surprising that vinyl floors have higher maintenance requirements than the alternatives in commercial and institutional settings. In contrast, sales of vinyl flooring to residential customers rely on the claim that vinyl is the "maintenance free" choice. There are several likely explanations for the differing evaluations of maintenance needs. Virtually any commercial or institutional flooring gets heavier use than most residential floors; for this reason, residential and commercial vinyl flooring are somewhat different in material composition, leading to different maintenance requirements.[88] In addition, there are often higher standards for glossy appearance of floors in nonresidential areas, despite the heavier traffic. (See the Austin case study, below, for more on high-gloss standards.)

Because standard maintenance regimens for vinyl flooring represent significant expenses, some commercial vinyl flooring products are starting to offer lower-maintenance options: for example, urethane wear finishes that reduce the frequency of strip and wax cycles, or new commercial finish products that require only annual application and eliminate the need for stripping. Product developments of this kind could lead to reduced maintenance costs in the future.[89] The data in Table 10 reflect price comparisons as of 2003, based on actual industry data in several regional markets. In addition, changes in the maintenance protocols for other flooring products could affect their maintenance costs as well. Forbo, a major vendor, promotes dry maintenance of its linoleum flooring; this is a source of significant maintenance-related savings when linoleum is used rather than vinyl. In contrast, Armstrong, another leading vendor, recommends the use of higher-cost polish and wet maintenance methods for linoleum in order to produce a gloss finish similar to that of vinyl. The company contends that this method has performance benefits as well, although Armstrong's warranty is not affected by the cleaning regimen adopted.[90]

Case Studies: Vinyl versus Linoleum

The choice among rival materials for resilient flooring is debated in countless design projects, involving a mixture of economic, engineering, and environmental considerations. To look more closely at the prospects for alternative materials, we examined specific design decisions in buildings in Austin, Washington, and Chicago—all of which involved the choice between linoleum and vinyl. The results were mixed: some found linoleum to be comparable to vinyl in performance and lower in maintenance costs, as well as preferable on environmental grounds; others faulted the performance of linoleum, or were unable to resist the lower installed cost of vinyl.

Austin, Texas [91]

The University of Texas at Austin has used a variety of flooring material for student residence halls: linoleum flooring (both sheet and tile), vinyl sheet, and VCT flooring. Three university floor areas in two buildings have used linoleum and vinyl products from the same supplier, Forbo.

One building has a sheet vinyl floor installed in the ground floor lobby, and linoleum tile in the second floor lobby. An older dormitory has linoleum sheet flooring. In the first building, the university is generally satisfied with the linoleum tile, but notes that it does not achieve the sheen of the vinyl product on the first floor. That vinyl floor is the university's favorite in terms of maintenance and appearance.

In the building with the linoleum sheet installation, the lack of sheen is also a concern; there is a sense that the linoleum doesn't respond as well as the sheet vinyl to spray buff maintenance between reapplications of new polish. This older building is subject to periodic water leaks and the linoleum has bubbled as a result of water exposure. The lack of moisture resistance appears to be the linoleum's main vulnerability. Leaks at building doorways, window leaks, and water fountains have created several urgent repair situations. A similar pattern of problems has not appeared with vinyl products.

Each of the three installations is nine to ten years old. The university's perception is that the vinyl sheet product has been the easiest to maintain, had the least problems, and upheld its appearance the best. Because these facilities are used 24 hours a day, every day, application of new polish only occurs during shut-down periods between semesters. Spray-buffing is relied on for standard, frequent maintenance between reapplications of polish.

In general, people expressed a surprising degree of concern about the lack of a gloss finish on linoleum flooring. An adjustment in expectations might be expected as part of a market transformation process, so that individuals come to understand that a floor does not need to be glossy in order to be clean. Some of the savings available from the use of linoleum disappear if the maintenance protocols required for vinyl are used, unnecessarily, in order to achieve the same level of gloss found with vinyl flooring. It may be important to train maintenance crews in the differences between vinyl and linoleum products. Without such training, in a building where both types of flooring are present, maintenance staff may default to known maintenance procedures, which have been developed for vinyl.

Washington, DC [92]

We examined two recent projects in Washington. In one federal building, the Government Services Administration (GSA) selected linoleum to cover approximately 3,000 square feet instead of VCT. Installed costs for VCT were estimated at $1.50 per square foot (even lower than the cost shown in Table 10); thus it was about $5.00 per square foot cheaper than linoleum. Nonetheless, linoleum was chosen for two reasons: first, a rapidly renewable and environment friendly product would complement the Leadership in Energy and Environmental Design (LEED) program for green building design; second, linoleum was projected to cost less to maintain over the life of the product than VCT. Project managers also took into account the fact that the wear characteristics of linoleum are about the same as VCT.

In another project, a major architectural design firm used linoleum for a 40,000 square foot renovation in its Washington office. The differential in installed cost per square foot was again about $5.00 per square foot. The designers were well versed in environmental sustainability issues and felt strongly about using environment friendly surfaces in the space. They typically recommend linoleum in lieu of VCT in all of their projects.

Chicago, Illinois [93]

The Interfaith Single Room Occupancy (SRO) project, under construction in Chicago in 2003, aims to provide permanent housing for 63 single, homeless women and six families. One environmental goal of the building design was to choose materials with low VOC emissions. At the same time, the project had a tight budget. Both of these factors influenced flooring choices.

As a nonprofit enterprise constructing a residential building, the Interfaith SRO project faced different, and lower, costs than commercial buildings; maintenance requirements, in particular, are lower, since many parts of the building will experience much less traffic than an office or other business establishment. However, the general pattern was the same: vinyl flooring had a lower first cost, while linoleum had lower maintenance costs and a lower overall life-cycle cost.

Project managers originally intended to use linoleum because of its ease of maintenance as well as its low VOC emissions. Vinyl, with its more complex maintenance requirements and potential to aggravate respiratory problems, was not their preferred option. However, the higher first cost of linoleum installation was a burden for the project's limited finances. In the course of research for this project, a supply of unused vinyl flooring was found in a closed factory. As the flooring was headed to the landfill, using the material was thought to be a more environmentally sustainable option; and the installed price of the product was unusually low given the circumstances—less than half the price of ordinary VCT.

Ultimately, project managers settled on a compromise in which the resident's apartments and townhouses, accounting for half the floor space in the project, would have the bargain-priced vinyl flooring and all public spaces would have linoleum. The vinyl product that was available would not have been suitable for high traffic areas, such as hallways and recreation areas, where the linoleum was placed.

Lessons from Case Studies

Our case studies, selected from recent experience with environmentally conscious ("green building") initiatives, show that the case for alternatives to vinyl is not yet as widely accepted in flooring as, for instance, in roofing. Characteristics favoring vinyl flooring include the ease of maintaining a traditional high-gloss appearance and the appeal of low installed costs for severely budget-constrained buyers.

However, our analysis suggests a number of additional considerations that could tip the balance toward the alternatives. The low installed cost of vinyl is often misleading; on a life-cycle cost basis, other products are often cheaper. There is a wide range of alternative materials, no one of which is right for every application; one possible inference from the case studies is that some green building efforts may have overemphasized linoleum at the expense of other alternatives. Cork provides an equally natural, renewable flooring with a very long lifetime and low maintenance costs; rubber offers water resistance and the lowest life-cycle costs in some circumstances; and Stratica combines a vinyl-like, high-gloss appearance with minimal maintenance and lower life-cycle costs than vinyl. Despite some environmental concerns of their own, each of these alternatives avoids the toxic emissions associated with the PVC life cycle.

Alternatives to PVC, IV: Medical Supplies and Gloves

Medical supplies account for less than 3 percent of total PVC use.[94] Nonetheless, PVC medical products have significant and troubling implications from a public health perspective, due to leaching of plasticizers from medical equipment as well as the hazard of dioxin formation when medical waste is incinerated. [95]

The bulk of PVC use in disposable medical devices occurs in three types of products: gloves, bags, and tubing. Each of these categories has multiple sub-categories with distinct requirements. For example, the broad category of bags includes IV bags, which may hold medications, nutritional fluids, or saline solutions; total parenteral nutrition bags, which are used to feed patients intravenously when they cannot eat; and a variety of bags used to store blood, including bags for whole blood and bags for individual blood components such as red blood cells or platelets. Multiple alternatives to PVC exist in each area; bags can be made from materials including nylon, ethylene vinyl acetate (EVA), polyethylene (PE), polypropylene (PP), and polyolefins. Tubes can be made from materials including silicone, polyurethane, and rubber.[96]

For the most part, the raw materials available for manufacture of PVC-free bags and tubes are somewhat more expensive than PVC on a per pound basis. Partially counterbalancing this greater materials cost, some alternatives are inherently stronger than PVC, requiring less raw material for a similar product or providing greater durability. In manufacturing PVC-free bags, for example, manufacturers can partially offset the higher materials cost through downgauging (using a thinner sheet of the alternative product) and eliminating extra materials (PVC bags must be wrapped in an extra bag to prevent volatilization of plasticizers and resulting loss of flexibility before use; non-PVC bags do not require this overwrap).

For example, leaching problems arise with some types of tubing. Like other pliable PVC products, PVC medical tubing—which includes products ranging from IV tubes to parenteral nutrition systems to enteral feeding tubes—derives its flexibility from the addition of plasticizers. These plasticizers leach out of the PVC tubing to varying extents, depending on how they are being used. One recent study found that after 24 hours inside an infant's stomach, PVC feeding tubes had lost half their plasticizer content.[97] In cases where the tubing is inside the patient's body, the leaching of plasticizers not only introduces a toxic substance directly into the patient's body, it also decreases the flexibility of the tubing over time. The health effects of plasticizers in children's bodies may be subtle or delayed, making them difficult to track, but if a feeding tube becomes brittle and unusable, this effect is readily observed. Alternatives such as silicon are substituted for PVC for longer term uses.

Costs, Institutions, and Medical Purchasing

There is wide variation from one product category to the next in the availability and prices of non-PVC gloves, bags, and tubing. In some cases, non-PVC alternatives are currently available on the market at competitive prices. For example, cost-competitive alternatives are available for IV bags, platelet and fresh frozen plasma bags, and oxygen masks.[98] In other cases, non-PVC alternatives cost more than PVC devices but also present clear performance advantages, such as greater durability.

The full cost implications of choosing a given material involve a range of factors, including performance and durability of the product. In addition, supply and demand interactions affect costs over time. Demand for products made from safer materials can provide the impetus for manufacturers to invest in new equipment to launch production.

The evolving institutional structure of American medicine makes it difficult to analyze the markets for individual medical supplies. Health care institutions increasingly purchase medical devices via group purchasing organizations (GPOs). Through GPOs, health care institutions are often able to place large orders and receive substantial discounts through bundling of purchases. A vendor may supply many products, for use at many locations, under a single agreement with a GPO.

Due to the size and market power of the institutions involved, the prices actually paid for medical devices are affected by the volume in which they are purchased. The price of an order of surgical gloves or IV bags, for example, is often negotiated as part of a larger package that includes many other medical supplies. The negotiated price may depend on the total volume of the supplies of all types bought by the GPO. Therefore, prices for the same good offered by different vendors, or paid by different purchasers, may not be strictly comparable to each other.

Still, it is possible to make some broad comparisons on the basis of advertised prices. In the remainder of this section, we focus on the factors that influence choice of materials for medical gloves in particular. We look at variations in prices of gloves intended for use in medical settings, using the prices quoted to us by a vendor—which may be higher than the price that would be negotiated by a major GPO.

Gloves in Medical Settings

Disposable gloves are used in medical settings to prevent disease transmission and as a barrier to chemicals and chemotherapy drugs. Materials used in high volume for examination gloves, which are the focus of our discussion here, include latex, PVC, and acrylonitrile (also known as nitrile). Other glove materials include neoprene, another chlorinated plastic; Elastrin, a proprietary elastomer; and polyurethane. Surgical gloves may be made from materials including latex or nitrile; PVC is not approved by the FDA for use in surgical gloves because it is not considered strong enough for the conditions of surgery.

In many hospitals, gloves are also used by food service workers to prevent direct contact between their hands and the food they prepare. For food service settings, polyethylene gloves offer a low-cost, effective option. These gloves do not need to be of medical quality since they are not acting as protection against bloodborne pathogens.

Latex allergies and the need for alternatives

Latex, made from natural rubber, was the material of choice in medical settings for many years. However, with rising frequency of glove use in health care in the late 1980s and 1990s, large numbers of health care workers and others developed allergies to latex.[99] The mildest symptoms of latex allergy can be similar to hay fever; more severe reactions include hives, asthma, and dangerous swelling of the face, mouth, and airway. At its most severe, latex allergies can produce anaphylactic shock, a severe and frequently fatal reaction that can involve swelling of the throat and a sudden decline in blood pressure. Thus, it has become imperative that health care institutions identify alternatives to latex gloves in order to protect their workers, patients, and visitors.[100]

In the context of increasing problems with latex allergies, many health care institutions are now looking at the relative merits of vinyl and nitrile gloves. While these alternatives are less acutely toxic than latex to health care providers and patients, there is no entirely non-toxic glove material on the market. As we have seen, the manufacture and disposal of PVC products is associated with the production and release of toxic and persistent chemicals. Acrylonitrile can also pose health hazards as a pollutant at hazardous waste sites where it has been discarded and in air, soil, and water near industrial facilities where it is produced, although acrylonitrile breaks down relatively rapidly and does not bioaccumulate.[101]

Most latex and many nitrile gloves contain accelerators—chemicals added to facilitate the manufacturing process and ensure that gloves are strong and resilient. Some health care workers exposed to accelerators in gloves can develop allergic contact dermatitis, a form of skin irritation producing itching and blistering lesions similar to those associated with a poison ivy reaction.[102] Some companies now provide accelerator-free nitrile gloves. While accelerator allergies can be a serious problem, they are not on the order of latex allergies, because they do not produce a systemic reaction and are not as widespread.

Performance evaluation

Glove performance can be judged in terms of multiple characteristics, including durability, barrier quality, and tactile properties. Barrier quality is the ability of a glove to prevent transmission of pathogens carried in blood or other fluids and is linked to over-all durability. Tactile properties refer to the extent to which the glove allows normal sensation in the hand.

Gloves can be subjected to a variety of tests to gauge their reliability as a barrier to disease transmission. Some of these tests are required by the US Food and Drug Administration (FDA); others are voluntary. Testing requirements depend on the intended use of the product; for example, gloves for use with chemotherapeutic agents are in the highest class and require more rigorous testing than examination or surgical gloves.[103]

Most tests that assess the durability and barrier quality of medical exam gloves are best suited to detecting gross manufacturing problems. Often, the gloves are simply filled with water and tested for leaks. More sensitive tests have also been developed in which the glove material is placed in contact with a fluid containing a virus, and the material is tested for permeability to the virus. For example, the ASTM F 1671 test looks at the ability of the glove material to protect against blood-borne pathogens, such as viruses.[104] FDA does not require manufacturers to test glove effectiveness in preventing movement of viruses across the glove material, but some manufacturers carry out this test voluntarily. Other tests are available to measure the ability of gloves to protect against chemicals used in medicine, such as chemotherapy drugs.

A recent study compared barrier integrity of latex, nitrile, and PVC gloves.[105] The study looked at barrier integrity of each glove type both in "static" conditions, in which the glove was simply removed from the box and tested, and in conditions of activity, in which the glove was manipulated to simulate actual use in health care. The gloves were subjected only to the test for water leaking; more sensitive tests were not attempted.

The researchers found dramatic differences in the gloves' barrier integrity after manipulations simulating the kinds of activity for which gloves are commonly used, such as connecting and disconnecting a syringe or wrapping, taping, and unwrapping a blunt object.

The researchers tested four brands each of vinyl and latex gloves, and two brands of nitrile gloves. They found that for all nitrile and latex gloves tested, the failure rate ranged from 0 to 5 percent. For vinyl gloves, there was greater variation among brands; three brands had failure rates from 1 percent to 3 percent when used directly out of the box, while the fourth had a 12 percent out-of-box failure rate. The highest failure rates appeared in vinyl gloves tested after simulated use; these had failure rates ranging from 12 percent to 61 percent.[106] Table 12 shows the average failure rates observed by the researchers for each material, both for gloves tested directly out of the box without manipulation and for gloves tested after manipulations simulating normal use.

The study notes that PVC has relatively poor barrier qualities due to its molecular structure; even when plasticizers are added, "vinyl still lacks the ability to stretch when stressed or snagged, and readily fractures, tears, or separates at the molecular level resulting in barrier loss."[107] The authors conclude that nitrile and latex gloves are significantly more resistant than vinyl to breaking down or leaking during use.

Table 12: Average failure rates of vinyl, nitrile, and latex gloves

	Out of box	Simulated use
Vinyl	4.8%	29.8%
Nitrile	3.0%	2.0%
Latex	2.0%	1.8%

Source: Rego and Roley 1999
Vinyl glove examples include both standard vinyl and "stretch" vinyl.

In the case of latex, pores in the material sometimes allow visible leakage; medical staff may find patients' blood on their hands after wearing apparently intact gloves. The Sustainable Hospitals Project at University of Massachusetts-Lowell has even received anecdotal reports of hospital practitioners in an emergency department who routinely put on a double layer of latex gloves to avoid this problem.[108]

Durability and total utilization cost

The superior barrier qualities and durability of nitrile mean that the difference in cost, relative to performance, is not as great as it appears from the unit prices listed here. A 1999 analysis by Kaiser Permanente, the nation's largest not-for-profit health care organization, found that on a total utilization cost basis, nitrile gloves were cost competitive with the alternatives, due to their greater durability.[109] On the basis of this analysis, Kaiser Permanente decided to switch to nitrile, purchasing 43 million nitrile gloves.[110]

The data used in Kaiser Permanente's cost analysis are not available. As noted above, health care institutions generally purchase medical supplies, including gloves, through large contracts that include multiple types of equipment and supplies. Negotiated prices for these contracts may depend on an institution's total volume of purchases and are generally lower than publicly available "list prices." (In general, anyone purchasing 43 million items might expect to get the lowest possible price per item; other medical institutions are likely to make smaller, but still substantial, glove purchases.) Nonetheless, it is possible to gain some insight into price differences by comparing publicly available list prices. Actual prices paid by health care institutions are likely to be lower than these list prices.

Medical gloves come in a wide variety of sizes and specifications. Glove characteristics that may vary from one product to another include glove length, the diameter of the wrist opening, the thickness of the material, hand orientation (right and left hand gloves produced separately, or ambidextrous gloves), durability, and the level of quality testing that has been applied to the product.

Table 13 shows the prices of vinyl, latex, and nitrile medical exam gloves available through the distributor Fisher Scientific. The gloves used for this example are sold under the distributor's name, as a Fisher brand product, and are among the distributor's most commonly sold varieties. (They are, however, manufactured by three different companies.) The three examples examined here were identified by Fisher Scientific sales staff as being broadly comparable to one another. All are size large, powder free, medical exam grade gloves. According to the sales staff, powdered gloves would cost less for each material, but the ratio among the prices would be approximately the same.[111]

The quality standards that the gloves meet are not identical; in several respects, the standards are lower for vinyl. For example, the percentage of leaks allowed is higher for the vinyl gloves than for the latex or nitrile gloves.[112] The minimum standards for strength and elongation of examination gloves are also lower for vinyl gloves than for latex and nitrile gloves.[113]

Based on the prices available directly from Fisher Scientific, when gloves are purchased in cases of 10 boxes (1000 gloves) each, nitrile gloves cost twice as much as vinyl gloves.[114] The bulk discount available for cases of 1000 gloves is the maximum bulk discount offered to us by Fisher, so these prices per glove would apply for larger orders as well.

If gloves never failed (or all types failed at the same rate), and equal numbers were used for a task regardless of the choice of material, then the prices in column B would describe the relative costs of different gloves. In particular, using nitrile gloves would cost twice as much as using PVC gloves.

However, because of durability differences among glove materials, it makes more sense to consider the average cost per *glove use*. Thus we build in a "durability factor" to reflect the average measured failure rate for each glove type, using the "simulated use" failure rates from Table 12. With this approach, we make the assumption that in every instance in which a glove fails the user discards it and puts on a new glove. In other words, we assume that vinyl gloves will be discarded and replaced due to failure in 30 percent of all uses, while nitrile and latex will be discarded and replaced due to failure only 2 percent of the time. This assumption is an approximation for the more complicated reality, in which some glove failures go undetected while in other cases, health care professionals may wear a double layer of gloves due to concerns about the gloves leaking or breaking.

As Table 13 shows, building in this durability factor decreases the cost difference between vinyl and nitrile from about seven cents per glove to less than five cents per glove use. Thus, the differential is reduced by about a third through the incorporation of the durability factor.

Table 13: Durability and Glove Prices

Material	Price per case of 1000	Price per glove	Average failure rate	Durability factor	Price per glove use
	A	*B = A/1000*	*C*	*D = 1/(1-C)*	*E = B*D*
Vinyl	$66.96	$0.067	29.8%	1.42	$0.095
Nitrile	$140.47	$0.140	2.0%	1.02	$0.143
Latex	$154.71	$0.155	1.8%	1.02	$0.157

Prices from Fischer Scientific sales staff.
Average failure rate is for simulated use conditions, from Table 12.

Anecdotally, there are other advantages to switching to nitrile as well. For example, the Sustainable Hospitals Project has been in contact with hospitals that found certain important, though nonquantified, practical benefits associated with switching to nitrile across the board and eliminating all other glove materials. One hospital that previously stocked over 80 different glove types and brands was able to switch to fewer than ten when the hospital began purchasing only nitrile gloves; in addition, the hospital no longer had to make special arrangements for susceptible staff to avoid latex. The switch also eliminated the need to educate staff about which glove types were safe for varied uses and settings.[115]

Glove costs in context

How much of a difference glove prices make to a health care institution's overall budget depends on how many gloves are consumed per patient and how much the institution spends per patient as a whole. The federal *National Hospital Indicators Survey* provides overview statistics on expenditures and revenues at community (non-teaching) hospitals in the US. These hospitals were estimated to spend $1,318 per patient day for inpatient care, and $265 per outpatient visit.[116]

These total cost figures can be used to put glove costs in context. For example, if five pairs of gloves (ten individual gloves) are used per patient-day, switching from PVC to nitrile gloves would increase glove costs per patient-day from slightly under a dollar a day to slightly under $1.50 a day, a difference of about 48 cents in total expenditures per patient-day, or an increase of less than 0.04 percent of total expenditures per inpatient patient-day. If ten pairs of gloves (twenty individual gloves) are required per patient-day, the switch would increase costs by about one dollar, or less than one-twelfth of a percent (less than 0.08 percent) of expenditures per patient-day. The costs discussed here, of course, do not include any calculation of the costs of illnesses that could be transmitted due to glove failures.

Alternatives to PVC, V: Siding and Windows

The fastest-growing uses of PVC, and the largest after pipes, are vinyl siding and windows. As seen in Table 1, early in this report, siding and windows experienced double-digit annual growth rates throughout the 1990s and now represent about 20 percent of all PVC use in the US and Canada. Here we examine these areas briefly; our discussion of siding relies heavily on the August 2003 *Consumer Reports* survey*,* which offered a comprehensive review of the available alternatives. Our discussion of windows draws on a number of construction industry sources.

Siding[117]

Vinyl is now the most common siding material for low- and moderate-priced housing, but it is not the only product on the market. Wood shingles or clapboard also offer viable siding alternatives, as do fiber cement and simulated stucco. Aluminum, an important alternative in the past, has all but vanished from the market and is not discussed here.

Vinyl

Vinyl siding is available in a variety of colors, thicknesses, and qualities. Installation is easy, and vendors tout vinyl as "maintenance free." Vinyl is known for its ability to mimic other looks such as wood. It is often said to be resistant to water damage; it is also impervious to insects.

Unfortunately, vinyl siding can warp if it gets too hot. It is also sensitive to cold temperatures, which can cause it to chip or crack and become brittle, and it expands and contracts with temperature changes. Many home improvement sources contest the common claim that vinyl is not damaged by water; it is often acknowledged that when cleaning or painting vinyl, a homeowner must, much as with wood siding, be careful to remove all mildew prior to adding a coat of paint. Vinyl presents the additional problem that it can burn or smolder, threatening the health and safety of people in or near a burning house, as well as the health and safety of firefighters.

Vinyl generally fades with time, although some higher end sidings now include UV protection to limit the amount of fading that can occur. Once the color has faded, it may need to be painted, requiring specific paints and processes to ensure the desired look. After the vinyl has been painted, it will need to be repainted in time, although the frequency depends on the quality of paint used—high-quality paint can last up to ten years, whereas lower-quality paint may last only four years. According to Electrospec Home Inspection Services notes, because of the heat absorption of vinyl, a homeowner needs to be careful not to paint the vinyl a color any darker than the original color.[118]

Wood

Wood siding is also easy to install, although not as easy as vinyl. It has the added value of being the preferred look for housing: vinyl and fiber cement siding both seek to emulate the appearance of wood siding. Wood can be purchased finished or left natural, and it is impact resistant, even in cold temperatures.

Wood siding, though, can warp, twist, or be damaged by water if not properly maintained. It is also vulnerable to insect damage and burns readily. In order to maintain wood siding properly it does need to be painted or stained repeatedly, although how frequently this is required depends on the quality of the paint used and on the climate.

Fiber cement

Fiber cement is a newer alternative to wood and vinyl siding and is made primarily from a combination of cement, sand, and cellulose fibers. According to Georgia-Pacific, it is installed much like wood, although carbide or diamond head blades or shears, which are stronger than ordinary sawblades, are suggested in order to preserve the blades. (According to architect Bruce Hampton, some contractors "carry the cost of a saw with each new job" for large scale projects, because the dust damages the saw over time.)

The look created by fiber cement can vary from rough sawn cedar to stucco, depending on its embossing. Fiber cement is available in a number of forms, such as planks or octagon shaped shingles, and can be purchased already primed and painted. It does not warp or twist, is impact resistant, and is impervious to insects. Unlike vinyl siding, it does not expand and contract, nor does it burn or smolder in a fire.

Fiber cement does need to be painted, but it requires painting less frequently than wood siding: Georgia-Pacific notes that some third parties guarantee their coatings for twenty years. However, although fiber cement itself does not burn, products applied to it may. It may also be damaged by water freezing and thawing. The material data sheet for Hardiplank, a brand of fiber cement, warns that the product contains silica. Inhaling silica dust during manufacturing or construction work can cause silicosis, a devastating lung disease. This is a potentially controllable problem; but unless the silica dust *is* controlled, fiber cement production and installation present health hazards to the workers who make and install it.

Simulated stucco

Simulated stucco is a relatively new product on the market, offering a very distinct appearance. Sometimes called Exterior Insulation Finish Systems (EIFS), it uses a polymer-based outer coating that contains plastic resin, which makes it softer and more flexible than cement-based stucco, over a cement board sheathing.[119] If it is not applied properly, the material may trap moisture and allow the growth of mold, problems which have sparked a number of lawsuits. If improperly applied, simulated stucco cannot be fixed; it must instead be replaced, possibly along with the wood structural components behind the EIFS barrier.[120] Although it is impervious to insects, it can crack, requiring it to be refinished, and it can burn.

Costs

The cost of each of these products varies, depending on the quality of the siding. *Consumer Reports* compared the material costs and estimated lifetimes of high- and low-quality siding of each of the alternatives, as shown in Table 14. Some anecdotal reports suggest a shorter life span for vinyl,[121] but we use the *Consumer Reports* estimates for all materials for the sake of consistency. A simple additional calculation, shown in the last two columns of Table 14, demonstrates that the material cost per year is lowest for fiber cement among lower-quality siding options, and for wood among the higher-quality options. (This is not a complete life-cycle cost calculation, since it does not include installation and maintenance costs.)

Windows

As in the case of siding, vinyl has become widely used for windows in low- and moderate-priced construction, but it is not the only option on the market. Alternatives to vinyl windows include wood, fiberglass, and aluminum windows. There are also options for repairing old wood windows to improve their energy efficiency. Energy efficiency is a major concern influencing the choice of new or replacement windows.

Vinyl

The benefits and drawbacks of vinyl windows are similar to those of vinyl siding. Vinyl windows do not rot, but they are sensitive to both hot and cold temperatures, can become brittle, and can incur dents. Often sold as “maintenance free,” vinyl windows raise some of the same issues discussed in connection with maintenance of vinyl siding. In addition, the fiberglass industry (i.e., the supplier of a competing product) notes that of all window materials, vinyl has the greatest rate of thermal expansion, which can cause the seal of the window to break early. If this does occur, vinyl windows cannot be fixed and must instead be replaced.[122]

Fiberglass

Fiberglass is a newer product in windows, and many contractors and suppliers have little experience with it. According to the fiberglass industry, fiberglass is an extremely strong material: three times stronger than wood or wood composite and eight times

Table 14: Siding Material Costs and Lifetimes

	Cost per square foot		Estimated lifetime (years)		Cost per 100 sq ft per year	
	Low	High	Low	High	Low	High
Vinyl	$0.45	$1.95	25	50	$1.80	$3.90
Wood	$0.67	$3.46	10	100	$6.70	**$3.46**
Fiber cement	$0.84	$2.55	50	50	**$1.68**	$5.10
Simulated stucco	$1.77	$2.39	20	30	$8.85	$7.97

Source: Cost per square foot and estimated lifetime from “Vinyl Siding: More Uniform Plastic,” *Consumer Reports* (August, 2003), pp.23-25. High-quality vinyl and fiber cement lifetimes were reported as "50+" years. Cost per 100 square feet per year is our calculation from *Consumer Reports* data. Boldface indicates lowest cost in each column.

stronger than vinyl. It does not rust, rot, warp, corrode, crack, or dent. It has the lowest thermal expansion rate of all of the window types, guaranteeing a tight seal. Fiberglass windows are often Energy Star products. They come in standard colors, can have a wood veneer, can be painted to match any color scheme, and can be repainted.[123] Both fiberglass and chemicals often used with fiberglass also pose hazards to human health.[124]

Wood

Wood windows are traditional, and, as with siding, wood creates the look that alternatives imitate. Wood windows can be repaired and maintained so that they are as energy efficient as vinyl windows.[125] Wood is also an easier material to work with for custom window fits. The drawbacks of wood windows are identical to wood siding: they require painting, may rot, warp, become insect infested, condense, or be damaged by moisture.[126] They can also burn. Although wood windows do not expand at the rate that vinyl does, they do expand quite a bit more than fiberglass or even aluminum.[127]

Many wood frames that are replaced by vinyl could have easily been repaired and, with weather stripping, can become as energy efficient as vinyl windows. Repairing wood windows may be a better alternative to retain the historical character of a building and to cut down on waste.[128] For historic renovation, repairing wood windows or replacing them with new wood windows is often the only option.

Aluminum

Aluminum windows are often used to comply with building codes for three-story and higher residential and commercial buildings.[129] Aluminum is a strong, durable material that does not rust and does not normally require paint, although there are some reports that the factory finish may wear off after about 20 years, making painting necessary at that point. Although aluminum has slightly higher thermal expansion than fiberglass, it has less than the other window products, ensuring a stronger and longer-lasting seal.[130] However, thermal breaks must be added to aluminum windows to make them energy efficient.

Costs

Window costs vary widely based on size, style, and quality; few vendors offer precisely comparable windows made of the full range of materials. One California vendor quoted prices, as of late 2003, for a 6x4 foot window, of $190 in aluminum, $225 in vinyl, $250 in fiberglass, and $300 in wood.[131] As with siding or other products, differences in installation cost, maintenance and repair cost, and lifetime could be more important than these differences in purchase price.

Employment Impacts of a PVC Phaseout

Replacing PVC with safer alternatives will change some jobs: from fabricating PVC products to fabricating the same products from other materials, often other plastics; or from making vinyl chloride monomer and PVC resin to making safer substitutes (again, often other plastics). In many cases, the same workers who currently make PVC products are likely to be employed making similar products from PVC alternatives.

More generally, the money that is now spent on PVC products, the uses of those products, and the jobs created by production and use of PVC will not disappear from the economy in the transition to alternative materials. The skills that are needed to make many products out of PVC will still be needed to make the same products out of something else; there is no evidence that the substitutes would require less labor or that resources spent on clean alternatives create fewer jobs than resources spent on PVC.

Size of the Industry

It is surprisingly difficult to determine the total number of workers who are employed in making PVC and PVC products. Industry sources report that there are 126,000 workers in PVC fabrication plants; in addition, as explained below, we estimate from the limited available data that there are 9,000 or fewer workers making vinyl chloride monomer (VCM) and PVC resin.

The 1997 Economic Census, the source of the latest available detailed government data on employment by industry, reports that some 826,000 workers were employed in plastic product manufacturing of all types. However, most of that total is not broken down by type of plastic or product.[132] Industry sources report even larger totals: according to the Society for the Plastics Industry, there were 1.5 million workers in the plastics industry and another 850,000 employed in upstream industries that supplied the plastics industry in 2001.[133] These figures refer to the plastics industry as a whole; most plastics industry workers are not involved with PVC.

Turning specifically to PVC and related activities, another industry group, the Alliance for Responsible Use of Chlorine Chemistry (ARCC), claims that there are 482,000 workers in chlorine-related jobs. This total includes 180,000 employees of dry cleaning establishments, most of whom use perchloroethylene, a chlorinated dry cleaning fluid.[134] Aside from dry cleaning, the core of the ARCC employment data consists of two categories: 126,000 workers at PVC fabricating plants, and 170,000 workers at chlorine-producing and chlorine-using chemical plants.

Note that the chlorine-producing and chlorine-using plants (which are combined in the ARCC employment figures) are not all involved in the PVC life cycle. Some of the plants are large, multi-product chemical industry facilities with significant numbers of workers making products unrelated to PVC or chlorine. Among the chlorine-using plants, there are enterprises making other products such as pesticides, paper mill chemicals, solvents and dry cleaning fluid. Plants involved in the PVC life cycle are a small fraction of the chlorine-producing and chlorine-using category recorded by ARCC. Our best guess, explained below, is that no more than about 9,000 workers, and possibly fewer, are employed in production of vinyl chloride monomer (VCM) and PVC resin.

The data for the US as a whole and for the eleven states identified by ARCC as the industry leaders are shown in Table 15. The PVC fabricating plants are smaller and pay less, with a national average of 54 workers per plant and payroll of $27,000 per worker. The chlorine-producing and chlorine-using plants are larger and pay more, averaging 376 workers per plant with a payroll of more than $45,000 per worker.

Yet another industry source, the *Chemical Economics Handbook*, periodically publishes in-depth reports on vinyl chloride monomer (VCM) and PVC resin production. The latest available reports appeared in December 2000 for VCM, and September 2003 for PVC.[135] In 2000 there were 12 VCM plants in the US, with the capacity to produce 17.4 billion pounds of VCM, as shown in Table 16. Seven of the facilities, accounting for more than half the capacity, were located jointly with PVC plants owned by the same company.

As of mid-2003, ten companies produced PVC resin in the US at twenty locations, as shown in Table 17, for a total capacity of 15.8 billion pounds. Three other plants were idled by the recession, with an additional capacity of 1.2 billion pounds.

Table 15: Industry Estimates of Chlorine-Related and PVC Fabricator Employment

	PVC Fabricators			Chlorine-Producing and Using Plants (*not all PVC-related*)			
	Number of Facilities	Employment	Payroll (millions of dollars)	Chlorine-Producing Plants	Chlorine-Using Plants	Employment	Payroll (millions of dollars)
California	238	12,679	$342	0	26	6,024	$266
Florida	91	5,599	$151	0	3	212	$10
Illinois	123	4,251	$115	0	22	7,495	$334
Louisiana	6	575	$16	9	22	11,650	$538
Michigan	123	3,751	$101	0	16	17,632	$798
New Jersey	120	7,127	$192	0	47	17,387	$771
New York	119	4,723	$128	3	20	7,154	$325
Ohio	210	12,138	$328	2	18	3,877	$175
Pennsylvania	127	6,864	$185	0	16	3,552	$156
Tennessee	54	3,503	$95	1	12	15,038	$703
Texas	112	9,048	$244	6	42	27,268	$1,262
All other states	1,009	55,457	$1,497	27	160	52,605	$2,374
US Total	**2,332**	**125,715**	**$3,394**	**48**	**404**	**169,894**	**$7,712**

Data refer to an unspecified recent (current) year.

Source: Alliance for the Responsible Use of Chlorine Chemistry (ARCC), http://www.chlorallies.org/employ.html (viewed October, 2003).

Employment at these plants is not consistently reported in any published source. Through website searches and telephone inquiries we were able to obtain employment data for 14 of the 20 facilities, as shown in Table 17. These data vary in definition from one plant to another. In at least one case, an important category of contractor employees was not included. In some other cases, including the two largest employment entries in Table 17 (the workers at the Formosa and OxyVinyls Texas facilities), the data include other workers as well as those making PVC resin.

Since many facilities produce more than one product, it is hard to avoid uncertainties in the delineation of PVC employment. Nonetheless, using the figures in Table 17 in the absence of better data, the plants where we have employment data average 2.82 million pounds of PVC capacity per worker. If this ratio applied to the other plants as well, total employment in the plants that make PVC resin would be about 5,600. Our guess is that this is, if anything, a high estimate, although we are unable to produce a better figure. [136]

Table 16: VCM Production Facilities, 2000

Company	*Plant location*	*Capacity (million lbs)*	*PVC at same location?*
Borden	Geismar, LA	1,000	Yes
Dow	Oyster Creek, TX	2,030	
Dow	Plaquemine, LA	1,500	
Formosa	Baton Rouge, LA	1,475	Yes
Formosa	Point Comfort, TX	880	Yes
Georgia Gulf	Lake Charles, LA	1,000	
Georgia Gulf	Plaquemine, LA	1,600	Yes
Oxymar	Ingleside, TX	2,100	
OxyVinyls LP	Deer Park, TX	1,200	Yes
OxyVinyls LP	La Porte, TX	2,450	Yes
PHH Monomers	Lake Charles, LA	1,150	
Westlake Monomers	Calvert City, KY	1,050	Yes
Total capacity		**17,435**	

Source: SRI Consulting (Menlo Park, CA), *Chemical Economics Handbook: Vinyl Chloride Monomer* (December, 2000)

Table 17: PVC Production Facilities, 2003

Company	*Plant location*	*Capacity (million lbs)*	*Employment (if available)*
CertainTeed	Lake Charles, LA	475	80
Colorite	Burlington, NJ	120	145
Dow Chemical	Texas City, TX	140	
Formosa	Baton Rouge, LA	990	505
Formosa	Delaware City, DE	144	115
Formosa	Iliopolis, IL	320	
Formosa	Point Comfort, TX	1,365	2000
Georgia Gulf	Aberdeen, MS	1,050	174
Georgia Gulf	Oklahoma City, OK	500	50
Georgia Gulf	Plaquemine, LA	1,250	
Occidental	Pottstown, PA	220	310
OxyVinyls LP	Deer Park, TX	555	} 656 *
OxyVinyls LP	Pasadena, TX	2,050	
OxyVinyls LP	Louisville, KY	585	77
OxyVinyls LP	Pedricktown, NJ	360	50
PolyOne	Henry, IL	125	
PolyOne	Pedricktown, NJ	130	
Shintech	Freeport, TX	3,300	200
Shintech	Plaquemine, LA	1,300	
Westlake PVC	Calvert City, KY	800	75
Total		**15,779**	**4,437**

* includes VCM and PVC employment at both OxyVinyl Texas locations.

Source: SRI Consulting (Menlo Park, CA), CEH (Chemical Economics Handbook) Marketing Research Report: Polyvinyl Chloride (PVC) Resins (September, 2003).

We do not have separate employment data for VCM production; in cases of joint production at the same location, some VCM employment may be included in our PVC resin employment estimate. The Environment Canada study of chlorine-related industries (discussed early in this report in connection with the costs of alternatives) identifies one Canadian plant where 200 workers were producing VCM, with production of at least 4.71 million pounds per worker. If this ratio applied to US VCM production today, there would be about 3,700 workers making VCM at the 12 facilities shown in Table 16 (some of whom have already been included in our estimate of PVC resin workers). Again, this is, if anything, too high an estimate.[137]

Our estimates are therefore 5,600 or fewer workers producing PVC resin, and 3,700 or fewer workers making VCM, with an uncertain amount of double-counting between the two categories. In sum, the number of workers producing VCM and PVC resin is roughly 9,000 or less. These workers are only a small fraction of the much larger number of employees in chlorine-producing and chlorine-using plants in Table 15. In addition, as shown in Table 15, there are roughly 126,000 workers at PVC fabrication plants. That is, most of the workers employed in PVC-related industries are fabricators, not VCM/PVC production workers.

Effects on PVC Workers

A complete PVC phaseout will not happen overnight. But, over a period of years, it will change the jobs that are performed in our economy. Many workers will find themselves doing the same job with different materials; for example, the same products may be fabricated at the same plants, but out of different plastics. As the momentum builds for a PVC phaseout, the owners of fabrication plants will seek actively to keep up with the changing market.

In many cases, plants with the capacity to manufacture PVC products have the capacity to manufacture alternative products as well, although different equipment may be required. For example, the PVC Container Company manufactures plastic bottles from both PVC and polyethylene terephthalate (PET). According to a company representative, PVC and PET bottles are made with different equipment, but are manufactured at the same facility.[138] In other cases, PVC products distributed within the US are fabricated overseas. For example, the medical gloves discussed in the section on medical supplies, above, are all manufactured in Asia. Omni International gloves are manufactured in countries including China, Malaysia, and Thailand; High Five gloves are manufactured in either China or Taiwan; and Kimberly Clark gloves are manufactured in Thailand.[139] Thus, switching among the glove types we have discussed here would apparently have no employment consequences within the US. We did not investigate the effect on employment in the producing countries; we did learn that gloves produced for Kimberly Clark are manufactured at a single plant, which has a separate production area for each glove material and employs different equipment for each type.

In the case of large PVC products, such as pipes, equipment requirements may differ for production using alternative materials. However, many companies produce or use a diversified set of plastics, so ceasing sales of PVC products would likely lead to a shift within the company, not putting the company go out of business. As mentioned above, for example, J-M Manufacturing has recently diversified to begin producing PE in addition to PVC pipe. Another interesting example is Westlake Chemical Corporation, a vertically integrated company that produces both VCM and PVC while also producing alternatives, including polyethylene. Westlake's fabricated products include both PVC and polyethylene pipe, among other products.[140] In a similar vein, CertainTeed Corporation produces a variety of PVC products, but also produces fiber cement siding, one of the promising alternatives to vinyl siding.[141] While the employment practices of such companies will vary from case to case, corporate diversification creates the possibility of retaining and reassigning workers when PVC is phased out.

Workers who make VCM and PVC resin would not necessarily be out of work if PVC is phased out: in many cases PVC will be replaced by other petrochemical products, such as non-chlorinated plastics or synthetic rubber, which may be made by the same companies or in the same communities that now make VCM and PVC. Thus there will be new jobs to be filled making the alternative materials, which current VCM and PVC workers could well perform.

At the same time, it is possible that some workers will not find jobs making the alternatives. Even if the old jobs are replaced with new ones, the labor market does not automatically move the displaced workers into the new positions. The threat of some job turnover is not unique to the question of chemical phaseouts; rather, it occurs with any large-scale policy shift.

The changes that would result from a PVC phaseout are not large relative to the ongoing turnover of employment in the US economy. Jobs are constantly being eliminated, and other jobs created, in enormous numbers. In the 12-month period from August 2002 through July 2003, when total US employment decreased by 170,000 jobs, there were actually 48,150,000 new hires and 48,320,000 separations (quits, retirements, layoffs, and firings).[142] In manufacturing alone, which was particularly hard hit in the same period, losing just over a million jobs, there were 4,000,000 new hires and 5,020,000 separations. That is, in addition to the net loss of a million manufacturing jobs, there was turnover of another four million jobs—an average turnover of 11,000 manufacturing jobs per day, every day of the year. If every job in VCM and PVC resin production were replaced by a different job producing substitute materials in a different plant, this would amount to less than one day's average turnover of US manufacturing employment.

Nonetheless, the replacement of jobs in VCM and PVC production with jobs in other industries could impose a real burden on the affected workers (just as employment turnover of all sorts frequently does). If substitute materials are produced at the same or nearby locations, the displaced workers could be offered employment in the plants making the new materials; but this may not solve the entire problem. Providing protection and support for workers who lose their jobs is an inescapable problem of public policy, both for the small numbers who may be affected by health and environmental policies such as a PVC phaseout and for the much larger numbers who are affected by business-oriented "free trade" schemes, budget cutbacks, management errors, marketing failures, and other ongoing sources of turmoil in the market economy. One interesting and ambitious policy option for displaced workers, the Just Transition blueprint developed by a coalition of labor and environmental leaders, sounds utopian in the US political context, but is actually more modest than similar programs that exist in Europe today.[143]

Steps Toward Alternatives

Many steps have already been taken in the direction of reducing and ultimately eliminating the use of PVC. In this final section we examine three areas where movement away from PVC can already be seen: public policy initiatives in the US and around the world; industry initiatives, including those by auto companies and other leading manufacturers; and a small sampling of the numerous “green building” initiatives in the US. In the first two areas, we rely heavily on an extensive review published by Greenpeace.

Policy Initiatives to Phase out PVC [144]

Here we provide a brief overview of forward-looking policies, initiatives, and strategies that have been adopted by communities, governments, and professional organizations concerned about the health and environmental hazards associated with PVC production, use, and disposal. These efforts include laws, policy statements, strategic plans, and other government initiatives.

US State and Municipal Policies

A number of municipal governments in the US have adopted policies on PVC products. For example, Rahway, New Jersey, prohibits the use of PVC or polystyrene in retail food establishments, requiring the use of degradable packaging. Lake in the Hills, an Illinois town, has banned the use of PVC pipes in construction, due to a variety of practical and safety-related concerns, including worker exposure to glues and solvents during installation. In California, the city of Oakland and Marin County have passed resolutions encouraging the use of PVC-free materials and the use of PVC alternatives in health care institutions, with a long-term goal of phasing out PVC products from health care entirely. Glen Cove, New York, has banned PVC use in eating utensils or food containers in all city food retailers.

A number of states and municipalities have adopted policies on dioxin emissions, some of which include specific references to PVC. San Francisco, Oakland, and Berkeley, California have adopted resolutions to eliminate dioxin, including PVC use reduction as part of a broader strategy. The Rhode Island Department of Environmental Management has adopted a regulation to reduce PVC materials in the waste stream by 50 percent by 2003. New Hampshire has adopted a policy to cut dioxin emissions; the policy specifically discusses use, disposal, and labeling of PVC. Boston has recently adopted a dioxin reduction purchasing resolution that could lead to a reduction in use of PVC products.

Canada

Canada has banned PVC in food packaging and has initiated a public awareness campaign to urge parents not to purchase such toys for small children. British Columbia has made a commitment to the long-term goal of encouraging hospitals to replace PVC with safer materials. The Toronto city government places restrictions on the disposal of PVC products.

US Health Care Organizations

A number of US health care institutions and professional societies of health care providers have adopted resolutions encouraging the elimination of PVC and other products that are important contributors to dioxin formation. The American Public Health Association (APHA) has adopted resolutions to phase out dioxin contributors in medical waste, including PVC products. The Chicago Medical Society, the California Medical Association, and the Minnesota Medical Association have adopted resolutions to investigate PVC alternatives as a means to reduce dioxin emissions from medical waste. The American Nurses’ Association and the American Medical Women’s Association recommend the reduction of dioxin emissions from medical waste. The member hospitals of the Maine Hospital Association have all committed to continuously reducing the use and disposal of PVC plastic, prioritizing disposable health care and office products as a first step.

The annual CleanMed conference brings together researchers, product vendors, health care purchasers, and others to exchange information on safer health care technologies and to promote the development of healthy markets in these products.[145]

Europe

Sweden was the first country to propose general restrictions on the use of PVC in 1995; restrictions have been enforced since 1999, and the country is working toward discontinuing all PVC uses.

Denmark created a policy in 1996 urging the phaseout of PVC use after the failure of a 1991 voluntary PVC recycling program. One local community in Denmark has restricted the sale of PVC and latex toys and has committed to the reduction of PVC use in hospitals and other institutions. Denmark's Grenaa Hospital has been a world leader in the elimination of PVC, having started a program to replace PVC with safer alternatives as early as 1988. Germany has banned the disposal of PVC in landfills as of 2005, is minimizing the incineration of PVC, and is encouraging the phaseout of PVC products that cannot easily be recycled. Since 1986 at least 274 communities in Germany have enacted restrictions against PVC. The government of the Netherlands has created a policy that requires the use of alternative products for those that have no feasible recycling or reuse system.

Spain's government created a goal in 1995 of reducing PVC packaging by 20 percent by 2000. A number of cities in Spain have developed restrictions on the use of particular PVC products. In addition, 62 cities in Spain have signed on to a "PVC free" agenda, which declares that they will phase out all PVC food packaging and discontinue use of PVC construction materials in government and governmentally funded buildings. In Austria, a number of regional governments have initiated policies that restrict the use of PVC. The capital of Luxembourg recommends that no new PVC piping shall be put in the sewage systems. In Norway, the capital city, Oslo, decided in 1991 to phase out use of PVC in all public buildings. A number of local governments in the United Kingdom have adopted policies to avoid use of PVC windows, and the community of Newhaven has adopted a policy to become entirely PVC free, unless PVC alternatives cannot be procured at a reasonable cost. The Czech Republic has adopted policies to ban the use of PVC food packaging after 2008.

In addition to the policies developed by countries and municipalities, public transportation and utility systems in many countries require the use of PVC-free materials. Public subway and rail systems in Austria, Germany, Spain, and the UK all prohibit the use of PVC cables. The German railways go one step further and avoid the use of any PVC materials. Additionally, water, sewer, and gas companies in the UK are also not using PVC pipes in new or replacement projects.

A number of regulatory initiatives have focused on PVC toys, due to the threat of harm to children if they suck or chew on soft plastic toys. Certain PVC toys and other PVC products for small children have been banned in the European Union as a whole since 1999. Bans on the use of PVC for soft toys have been adopted in many European countries, as well as in other countries including Argentina, Mexico, the Philippines, Tunisia, and the Fiji Islands.

Asia/Pacific

Japan passed a law requiring manufacturers to recycle all packaging material by 2000 in order to reduce dioxin emissions; in response, many manufacturers have switched to non-PVC packaging. Japan has also adopted a policy that limits the use of PVC sheathing in cables used in all governmental and public buildings. An ordinance was also amended to restrict the use of PVC containing toxic additives in cooking utensils and baby toys. Many cities in Japan have adopted, although not necessarily implemented, bans either on all PVC products or on particular PVC products. Singapore has legislated that PVC coated cables are hazardous waste and therefore bans their import under the Basel Convention on Hazardous Waste.

Industry Initiatives [146]

Recognizing the health and environmental reasons to reduce PVC use, and the feasibility of alternatives, many industries—including some very big ones—have begun to shift away from PVC.

Automobiles. A number of car manufacturers have made strong commitments to reducing the use of PVC in their products, often citing environmental, health, and engineering reasons. European manufacturers have taken many steps in this direction. For example, Peugeot in France is reducing PVC use in the interior and exterior of its cars as a way to prevent recycling problems. A number of German car manufacturers have sharply reduced PVC use. Daimler-Benz stopped using PVC in underbody coating and in the interior of all cars as of 1995 and planned to ultimately phase out all PVC use. Opel, the European subsidiary of General Motors, and Mercedes Benz also do not use PVC in car interiors. BMW has adopted material specifications that express a preference for dashboard, trim, and wire coating materials other than PVC, and offers PVC-free dashboards.

Japanese car manufacturers have also taken concrete steps toward reducing PVC use. For example, Daihatsu Motor Company has established a PVC reduction policy, reducing PVC use in instrument panel padding, roof linings, side moldings, side window linings, the soundproofing component of dashboards, and door trim. The company is investigating ways to reduce PVC use further in side windows, roof fabric, floor undercoating, and wire harness coating. Hino Motors is considering PVC alternatives in truck and bus interiors, exteriors, and wiring systems. Honda made a commitment to replacing PVC interiors by 2003. Mitsubishi is working to substitute PVC in instrument panels and door trim surfaces and already is using alternatives for roof linings and sheet materials. Nissan began using alternatives to PVC in cables in 1997 and is using PVC alternatives for instrument panels, door trim, and side guard moldings and harnesses. Suzuki Motor Corporations is increasing its use of substitutes for PVC, and Toyota has developed PVC alternatives for car interiors and bumpers.

In the US, the world's largest auto manufacturers have also committed to reducing PVC use. General Motors eliminated PVC from its interiors in 1999. The 2000 Pontiac Bonneville used a PVC-free material for the full instrument panel for the first time in North America. Ford has set the target of eliminating the use of PVC by the model year 2006 for all of its plants worldwide and is instructing its suppliers to design vehicles using more recycled content and plastics that are easy to recycle. A number of US auto suppliers have begun their own initiatives to remove PVC and have started by removing it from interior panels, instrument panels, integrating skin, substrate, reinforcing beams, and batteries.

Food Packaging and Water Bottles. The use of PVC in food packaging has been the source of considerable concern in Europe. PVC food packaging is no longer used in Austria, due to measures taken by Austrian supermarket chains in the early 1990s. Carlsberg Italia, the Italian unit of the Danish beer company, has discontinued its use of PVC caps. A number of water bottling companies in Europe have also stopped using PVC in their bottles, including Nestlé brands, Spa, and Evian. In Spain, thirty-six water bottling companies including Danone and Perrier are phasing out PVC.

In Brazil, the agricultural food manufacturer Cargill no longer uses PVC bottles for its Liza soybean oil brand. In Japan, Nihon Suisan Kaisha has converted to PVC-free packaging for its sausages, and Kagome Company has converted to PVC-free packaging for all household products.

In the US, Federated Group, Borden Cremora Non-Dairy Creamers, and Eagle Family Foods have converted to PVC-free packaging for their creamers; Dean Foods is replacing its milk containers with PVC-free packaging; VegiWash has eliminated the use of PVC in its fruit and vegetable wash bottles; and Planters has eliminated its use of PVC bottles for peanut oil.

Hospital Initiatives. Grenaa Central hospital in Denmark has phased out 95 percent of its PVC use. The Glanzing pediatric clinic in the Wilhelminen Hospital in Vienna became the first Neonatal unit in the world to announce in 2003 that it will cease to use PVC products for invasive uses, although some products for non-invasive uses do not yet have a PVC alternative.[147] Glanzing has also introduced PVC-free products in construction, as well as for overshoes, gloves, bed mattresses, and aprons.

In the US, Universal Health Services, the third largest hospital management company, and Tenet Healthcare Corporation, the second largest for-profit health care company, are actively looking to replace PVC medical supplies. Four medical supply purchasing organizations—Broadlane, Consorta Inc, Premier Inc, and Novation—have all committed to reducing the procurement of PVC products and have urged their members to do the same.[148]

The shift to PVC-free medical care products is facilitated by new technological developments. For example, the Japanese company Terumo has begun manufacturing PVC-free dialyzing fluid bags made from polypropylene and has developed a new polypropylene material for continuous ambulatory peritoneal dialysis; McGraw Inc supplies PVC-free IV bags in the US; and Saint-Gobain Performance Plastics has recently developed an alternative to PVC for medical tubing.[149]

Shoes. Nike began to phase out PVC in its products in 2001, and currently advertises several PVC-free footwear models. Nike's website showcases several PVC-free shoe brands, which are labeled with Nike's new environmentally sound logo.[150] Other manufacturers, including Adidas, Asics, and Puma, are also in the process of phasing out PVC in shoes.[151]

Electronics. Sony states in its 2003 *Corporate Social Responsibility Report* that the company is working to reduce PVC in all its products by the end of 2005.[152] Sony now has PVC-free headphone cords, speaker boxes, and disk drives on the market.[153] Recently, Sony released two products in the Tokyo market that replace PVC with the corn-based polymer polylactic acid (PLA): a DVD player and AIBO, a robotic pet.[154] Toshiba is currently working to phase out the use of halogenated compounds, including PVC, from its circuit boards.[155]

Furniture. The Swedish furniture retailer IKEA, well-known across Europe and the United States, started phasing out PVC use in September of 1992. To date IKEA has eliminated PVC from all furniture, and plans to phase out PVC in its lamp wiring by 2006.[156]

Retailing. Marks and Spencer, one of the largest retailers in Great Britain, pledged in 2001 to phase out the use of PVC in its products, focusing initially on food packaging.[157]

Innovative Construction Projects

There has been an explosion of interest in environmentally sound construction in the US in recent years. A wealth of information on green building initiatives, including many case studies of individual building projects, is available through the US Green Buildings Council. Initiatives showcased by the council address a range of environmental and health concerns, including energy efficiency, environmentally sound management of wastes, and creating buildings with good indoor air quality. [158]

The Healthy Building Network (HBN) provides a clearinghouse of information and contacts on PVC-free and other environmentally preferable building practices. HBN has also collected case studies of building initiatives that have used safe construction materials, including a number of health care institutions that have undertaken green building projects. To cite just one example, Beth Israel Medical Center in New York City completed a set of interior renovations in 2000. Among other steps to ensure environmental safety and protect indoor air quality, Beth Israel excluded PVC from its construction and furniture specifications.[159]

In this section, we highlight just a few of the growing number of innovative construction projects in which special efforts have been made to choose materials that are safe for human health and the environment, while keeping costs low. All of the examples discussed here have reduced or eliminated the use of PVC.

GreenHOME, a volunteer group, partnered with the Washington, DC chapter of Habitat for Humanity to design and build a low-income home that is energy efficient and built from materials that are safe for human health and the environment.[160] The purpose of the project was to demonstrate that green building is not only an option for luxury homes; it is equally possible for home builders on a budget. After exhaustive research on materials, the group constructed a home whose total cost was $75,000.

The GreenHOME house is not 100 percent free of vinyl, but the use of vinyl was kept to a minimum. The windows of the house are vinyl-clad wood and cost $264 each. The siding is Hardiplank (a fiber cement product), purchased at $0.55 per linear foot, for a total cost of $2,534. For flooring, the project used salvaged wood floors for living room areas and natural linoleum for the kitchen. The total cost of flooring was $4,221. For roofing, the material of choice was 100 percent recycled aluminum shingles, at a cost of $1,464.

Another good model of green building on a budget is the **Erie Ellington Homes** project in Dorchester, Massachusetts.[161] Developed by the Codman Square Neighborhood Development Corporation with technical assistance provided by the Hickory Consortium (Bruce Hampton, AIA, architect), this project includes fifty high-energy-efficiency housing units. The builders used fiber cement clapboards instead of vinyl and high-quality recycled content aluminum clad wood windows instead of vinyl clad windows.

One goal of the project was to provide safe homes for children and adults with asthma, by avoiding building materials that are associated with air quality problems. Although not definitive, early results suggest that the project has had some success in this regard; interviews with new residents have shown that symptoms were noticeably reduced in 8 out of 18 asthma sufferers.

To save money, the project used vinyl composite tile in some public areas, such as common halls and stairs; these were selected as areas in which outgassing of phthalates would be least likely to affect occupants. For some other areas the project used alternative flooring products, including linoleum.

Both the Erie Ellington project and the GreenHOME project used Hardiplank, a durable fiber cement siding product that requires very infrequent painting. The GreenHOME project estimates that the Hardiplank siding will require painting "every 15 to 20 years, compared to every 5 to 10 years for wood siding in the Washington, DC climate."[162] Managers of both projects seem to have been relatively satisfied with Hardiplank. The principal disadvantage of the material for the GreenHOME project, which relied largely on volunteer labor, is that Hardiplank is somewhat more difficult for volunteers to work with than vinyl. The project report notes that cutting the planks created large amounts of dust, so that volunteers had to wear filtration masks. Dust would have been reduced if the project had used special tools for cutting the Hardiplank, but these tools were out of the price range of the project. In addition, because it is more dense than wood, the Hardiplank siding was more difficult to nail into place than wood siding would have been. The GreenHOME project report concludes that overall, "these problems were minor and acceptable."[163]

The **Sheraton Rittenhouse Square Hotel** in Philadelphia advertises itself as an "environmentally smart hotel."[164] The hotel has wallpaper with a water-based finish instead of vinyl wall coverings. Carpeting in the hotel does not have a PVC base. For flooring in non-carpeted areas, the hotel has used natural linoleum instead of vinyl tile. The hotel plumbing includes no PVC pipe.

Barry Dimson, co-owner of the hotel, has made the economic case for building environmentally sound hotels in a series of articles. He argues that up-front costs for building an environmentally sound hotel, using safe building materials, are not significantly different from the cost of building a "traditional" hotel, where air quality may be poor due to mold and off gassing from PVC and other building materials. Dimson notes that an estimated 20 percent of total project cost in the construction of a new hotel is land acquisition, and around 55 percent is "the 'hard' cost of construction, with 'soft' costs such as carrying charges and design fees comprising the remaining 25 percent." If half of the "hard cost" of construction is dedicated to excavation, foundations, and superstructure, then just half the construction cost is dedicated to "the building's 'skin,' mechanical equipment, [and] building materials." This 27.5 percent is the portion that is affected by green building considerations. Thus, argues Dimson, "even if [green building materials] cost 10 percent more up front, 10 percent of 27.5 percent represents a premium of [just] 2.75 percent over the total cost."[165]

Green building was prioritized in construction of a new building for **Adat Shalom**, a synagogue in Bethesda, Maryland.[166] Among other choices, the community chose to use cork instead of vinyl flooring wherever possible. Since finishing construction of the new building, members of Adat Shalom have been working with others to spread knowledge of best practices for green buildings in religious communities. The "Building in Good Faith" initiative, launched by filmmaker Judith Helfand and religious leaders, asks faith-based institutions to reduce their purchasing and use of toxic building materials, particularly those made from PVC.[167]

Conclusion

PVC has become universal, used in every area of modern life. It is said to be cheap, convenient, safe, and maintenance free. Our review of the evidence finds that the advantages of PVC are often overstated—it is a little cheaper than the alternatives in some areas, but no bargain at all in others. Our analysis offers four categories of responses to the economic argument for PVC:

- It is not always cheaper on a life-cycle cost basis, as in flooring.
- The alternatives will become cheaper over time, due to economies of scale and learning curve effects.
- The use of PVC products often poses health and safety hazards, as in medical supplies.
- The costs of environmental protection and improvement are routinely overstated in advance.

In our look at specific markets, we found that less toxic alternatives are successfully competing with PVC in many pipe applications, in single-ply roofing, in flooring on a life-cycle cost basis, and in medical supplies due to growing concerns about the health hazards of PVC. In siding and windows, among the fastest-growing vinyl markets of recent years, promising new alternatives have appeared.

The employment effects of a transition to alternative materials may be modest. PVC will be replaced by other materials that also require labor; workers will still be needed to make the substitute products. In some cases, the same factories and workers may fabricate the same products from new materials.

There are policy initiatives at every level, internationally and within the US, calling for reduction and restriction of PVC use. Major industries are beginning to substitute less toxic materials for PVC throughout their product lines. The rapidly growing “green building” movement has created numerous successful examples of the use of safer alternatives materials; the few examples described here are only a sample of the encouraging diversity of approaches emerging in the construction industry today.

Our review of PVC uses and alternatives makes it clear that a PVC phaseout is achievable and affordable. The alternatives are increasingly well known and well developed, and in many cases are already cost-competitive with PVC. It is realistic and practical to build health and environmental considerations into materials choice for municipal infrastructure, commercial and residential building, medical supplies, and consumer products. The cost impacts of substitution will be modest, and will grow smaller over time.

Endnotes

[1] For an overview of PVC's history, see Peter H. Spitz, *Petrochemicals: The Rise of an Industry* (New York: John Wiley and Sons, 1988).
[2] For an overview of current information and references on health hazards associated with PVC production, use, and disposal, see the affidavit of Judith Schreiber, PhD, Senior Public Health Scientist, New York State Office of the Attorney General, provided to the Supreme Court of the State of New York, In the Matter of the Application of Resilient Floor Covering Institute and Tarkett, Inc, vs. New York State Department of Environmental Conservation, Index Number 6721-02, May 9, 2003, available at http://www.healthybuilding.net/documents/Affidavit-of-Judith-Schreiber-Ph-D.pdf, viewed December 2003. Our review draws on the summary provided by Schreiber and references therein. Also see Joe Thornton, *Pandora's Poison: Chlorine, Health, and a New Environmental Strategy* (Cambridge, MA: MIT Press, 2000).
[3] US Department of Health and Human Services, Public Health Service, National Toxicology Program, *Report on Carcinogens, Tenth Edition* (December 2002), available at http://ehp.niehs.nih.gov/roc/toc10.html, viewed November 2003. Also see US Environmental Protection Agency, "Vinyl Chloride Hazard Summary" (2002) and International Agency for Research on Cancer International Agency for Research on Cancer, "Overall evaluations of carcinogenicity: An updating of IARC monographs, Volumes 1 to 42," *IARC Monographs on the Evaluation of Carcinogenic Risks to Humans, Supplement 7,* (Lyon, France: IARC, 1987), pp. 373-376, cited in Schreiber 2003.
[4] On routes of human exposure to vinyl chloride, see Agency for Toxic Substances and Disease Registry, *Toxicological Profile for Vinyl Chloride* (September 1997, CAS # 75-01-4), p. 153ff, available at http://www.atsdr.cdc.gov/toxprofiles/tp20.html, viewed December 2003.
[5] See, for example, ATSDR, 1997, pages 54 to 60; Lewis, 1999; and MMWR,1997 for reviews; and, Maltoni et al., 1981; Maltoni and Lodi, 1981; Maltoni, 1974; Pirastu et al., 1990; Wagoner, 1983; and Wu et al., 1989). Recent follow-up of the mortality and cancer incidence among European and Taiwanese workers employed in the vinyl chloride industry have confirmed these findings (Ward et al., 2001; Wong et al., 2002)." (Schreiber 2003)
[6] See C. Maltoni, "Two Cases of Liver Angiosarcoma among PVC Extruders of an Italian Factory Producing PVC Bags and Other Containers," *American Journal of Industrial Medicine* 5: 297-302 (1984); J. Kielhorn, "Vinyl Chloride: Still a Cause for Concern," *Environmental Health Perspectives* 108:7 (2000); and R. H. Wong, "An increased mortality ratio for liver cancer among polyvinyl chloride workers in Taiwan," *Occupational and Environmental Medicine* 59 (2002), 405-409, all cited in Schreiber 2003.
[7] See Schreiber 2003, points 17 and 18.
[8] On use and health effects of PVC additives, see Schreiber 2003, points 21-25. On use of plasticizers in medical equipment, also see Joel Tickner, "The Use of Di-2-Ethylhexyl Phthalate in PVC Medical Devices: Exposure, Toxicity, and Alternatives," (University of Massachusetts Lowell: Lowell Center for Sustainable Production, no date).
[9] See our later sections on flooring and on medical supplies for additional discussion of plasticizer exposure through these routes.
[10] See National Toxicology Program and Center for the Evaluation of Risks to Human Reproduction, *NTP-CERHR Expert Panel Report on Di(2-ethylhexyl) phthalate* (NTP-CERHR-DEHP-00) (October 2000), available at http://cerhr.niehs.nih.gov/news/phthalates/DEHP-final.pdf, viewed December 2003.
[11] See Jouri J. K. Jaakola et al., "Interior Surface Materials in the Home and the Development of Bronchial Obstruction in Young Children in Oslo, Norway," *American Journal of Public Health* 89:2 (February 1999), 188-192.
[12] See Schreiber 2003, point 35. Also see Robert F. Dyer and Victor H. Esch, "Polyvinyl Chloride Toxicity in Fires: Hydrogen Chloride Toxicity in Fire Fighters," *Journal of the American Medical Association* 235 no. 4 (1976), pp.393-397; Jeffrey S. Markowitz, Elane M. Gutterman, Sharon Schwartz, Bruce Link, and Sheila M. Gorman, "Acute Health Effects Among Firefighters Exposed to a Polyvinyl Chloride (PVC) Fire," *American Journal of Epidemiology* 129 no. 5 (1989), pp.1023-1031.
[13] See Thornton 2000, especially pp. 271, 276, and 316-319, and references therein. Also see Schreiber 2003, point 30.
[14] All figures in this paragraph are calculated from Eric Linak with Kazuo Yagi, "Polyvinyl Chloride (PVC) Resins," Chemical Economics Handbook Marketing Research Report (Menlo Park, CA: SRI International, September, 2003).

[15] International Joint Commission, "A Strategy for Virtual Elimination of Persistent Toxic Substances" (Windsor, Ontario, 1993).
[16] Hickling Corporation, "Economic Instruments for the Virtual Elimination of Persistent Toxic Substances in the Great Lakes Basin," report to International Joint Commission (Windsor, Ontario, 1994).
[17] Charles River Associates, Inc., "Assessment of the Economic Benefits of Chlor-Alkali Chemicals to the United States and Canadian Economy" (Boston, 1993).
[18] Environment Canada, "A Technical and Socio-Economic Comparison of Options to Products Derived from the Chlor-Alkali Industry" (1997).
[19] The adjustment is that Table 2 omits Hickling's data on windows; Hickling estimated that implausibly large savings were available from replacing PVC windows with aluminum windows. Thus our adjustment increased the Hickling cost estimate for replacing PVC.
[20] These are purely hypothetical numbers for illustrative purposes, not real data. In reality, of course, ceramic plates often last much more than a year, increasing their attractiveness relative to paper plates.
[21] LCAs frequently emphasize energy use, carbon dioxide emissions, and criteria pollutants, since these categories are often better documented than toxic emissions. For a comparative analysis of recent LCA studies of PVC, highlighting their differences in data coverage, see Eric Copius Peereboom, Rene Kleijn, Saul Lemkowitz, and Sven Lundie, "Influence of Inventory Data Sets on Life-Cycle Assessment Results: A Case Study on PVC," *Journal of Industrial Ecology* 2 no. 3 (1999), pp.109-130.
[22] *Tellus Institute Packaging Study* (Boston: Tellus Institute, 1992). For a brief overview of this massive study, see Frank Ackerman, *Why Do We Recycle? Markets, Values, and Public Policy* (Washington DC: Island Press, 1997), Chapter 5.
[23] For detailed formulae used to calculate learning curve effects, see the "Learning Curve Calculator," available at http://www.jsc.nasa.gov/bu2/learn.html (viewed February, 2003). On the economic theory of learning curves, see, for example, A. Michael Spence, "Investment Strategy and Growth in a New Market," *The Bell Journal of Economics* 10 no. 1 (Spring, 1979), pp. 1-19; Steven Klepper and Elizabeth Graddy, "The Evolution of New Industries and the Determinants of Market Structure," *The RAND Journal of Economics* 21 no. 1 (Spring, 1990), pp. 27-44; and Pankaj Ghemawat and A. Michael Spence, "Learning Curve Spillovers and Market Performance," *Quarterly Journal of Economics* 100 Supplement (1985), pp. 839-852.
[24] In that period, cumulative production of the Model T went from less than 20,000 to about 7 million cars, doubling more than eight times. W. J. Abernathy and K.Wayne, "Limits of the Learning Curve," *Harvard Business Review* 52 no. 5 (1974), pp.109-119.
[25] Brian W. Arthur, an economist at the Santa Fe Institute, has argued that many of society's important economic and technological choices are "path dependent." A technology that, perhaps accidentally, gains a slight lead early in its history may be able to solidify that lead by gaining market share and lowering prices, "locking out" other technologies that may be equally or more efficient if adopted on a large scale. The Windows operating system, the standard videocassette format, the dominant nuclear reactor design, and the gasoline-powered automobile engine, for example, all started with only small leads over equally (or more) attractive rival technologies; all have come to be "locked in" and dominate their markets through the path-dependent process that Arthur describes. See Brian W. Arthur, *Increasing Returns and Path Dependence in the Economy* (Ann Arbor: University of Michigan Press, 1994).
[26] Our calculation from the graph in Peter H. Spitz, *Petrochemicals: The Rise of an Industry* (New York: John Wiley and Sons, 1988), p.415. Spitz presents separate graphs of cumulative production vs. price for PVC and copolymers, for value added by polymerizer, and for vinyl chloride monomer. In these three graphs, a doubling of cumulative production is associated with price declines of 34 percent, 31 percent, and 40 percent, respectively.
[27] Spitz (1988), pp.390-417.
[28] See Joel Tickner (no date).
[29] US Food and Drug Administration, "FDA Public Health Notification: PVC Devices Containing the Plasticizer DEHP," (July 12, 2002), available at http://www.fda.gov/cdrh/safety/dehp.html (viewed September, 2003).
[30] For a survey of toy manufacturers' actions on PVC toys, see the Greenpeace Toy Report Card, available at http://greenpeaceusa.org/bin/view.fpl/7434/article/287.html (viewed November, 2003).
[31] See US Consumer Product Safety Commission, "Re: Petition Requesting Ban of Use of Polyvinyl Chloride (PVC) in Products Intended for Children Five Years of Age and Under," letter to National Environmental Trust and other groups (February 26, 2003), available at http://www.cpsc.gov/LIBRARY/FOIA/FOIA03/petition/Ageunder.pdf (viewed November, 2003).
[32] "Hazardous Materials: Polyvinyl Chloride," International Association of Fire Fighters, AFL-CIO, CLC (Washington DC, 1995). For a detailed literature review of health impacts of PVC, including combustion impacts,

see the affidavit of Judith Schreiber before the Supreme Court of the State of New York in the matter of *Resilient Floor Covering Institute v. New York State Department of Environmental Conservation* (2003), available at http://www.healthybuilding.net/pvc/NYS_vinyl_affidavit_js.pdf (viewed September, 2003).
[33] Robert F. Dyer and Victor H. Esch, "Polyvinyl Chloride Toxicity in Fires: Hydrogen Chloride Toxicity in Fire Fighters," *Journal of the American Medical Association* 235 no. 4 (1976), pp.393-397; Jeffrey S. Markowitz, Elane M. Gutterman, Sharon Schwartz, Bruce Link, and Sheila M. Gorman, "Acute Health Effects Among Firefighters Exposed to a Polyvinyl Chloride (PVC) Fire," *American Journal of Epidemiology* 129 no. 5 (1989), pp.1023-1031.
[34] Dyer and Esch (1976).
[35] "Expanded Inspections Needed To Assess Wiring Woes, Experts Say," *Aviation Today* special report (May 25, 1998), available at http://www.aviationtoday.com/reports/wiring7.htm (viewed October, 2003).
[36] Edward Block, airplane wiring expert and former Pentagon consultant, personal email correspondence, available at http://www.geocities.com/Eureka/Concourse/7349/wire.html (viewed October, 2003).
[37] Project on Government Oversight, "Fact Sheet on Aircraft Wiring Problems" (2000), available at http://www.pogo.org/p/contracts/ca-021102-wiring.html (viewed October, 2003).
[38] Darren Huese, "Tinker tackles aging wiring systems," Oklahoma City Air Logistics Center Public Affairs, available at http://www.afmc.wpafb.af.mil/HQ-AFMC/PA/news/archive/2001/jan/Tinkerwiring.htm (viewed October, 2003).
[39] *Aviation Today* special report (May 25, 1998).
[40] US Congress, Office of Technology Assessment (OTA), *Gauging Control Technology and Regulatory Impacts in Occupational Safety and Health* OTA-ENV-635 (Washington, DC: US Government Printing Office, September 1995), p.89.
[41] Hart Hodges, "Falling Prices: Cost of Complying With Environmental Regulations Almost Always Less Than Advertised," Economic Policy Institute (1997) (http://epinet.org); Winston Harrington, Richard D. Morgenstern, and Peter Nelson, "On the Accuracy of Regulatory Cost Estimates," *Journal of Policy Analysis and Management* 19 no. 2 (Spring 2000), pp.297-322.
[42] Cheminfo Services, *A Retrospective Evaluation of Control Measures for Chlorinated Substances (Case Studies of Ex-Ante/Ex-Post Socioeconomic Effects)*, report to Environment Canada and Ontario Ministry of Energy, Science and Technology (March, 2000).
[43] See Lisa Heinzerling, "Regulatory Costs of Mythic Proportions," *Yale Law Journal* 107 no. 7 (May, 1998), pp.1981-2070; Lisa Heinzerling and Frank Ackerman, "The Humbugs of the Anti-Regulatory Movement," *Cornell Law Review* 87 no. 2 (January, 2002), pp.648-670.
[44] See Frank Ackerman and Rachel Massey, "Prospering With Precaution" (2002), available at http://www.ase.tufts.edu/gdae/policy_research/PrecautionAHTAug02.pdf; and Eban Goodstein, *The Trade-Off Myth: Fact and Fiction about Jobs and the Environment* (Washington, DC: Island Press, 1999).
[45] These three sections were prepared with the assistance of Gail Vittori of the Center for Maximum Potential Building Systems in Austin, Texas. For comprehensive listings of alternatives to vinyl flooring and other construction materials, see the website of the Healthy Building Network, at http://www.healthybuilding.net/pvc/alternatives.html (viewed November, 2003).
[46] Thanks to Jamie Harvie of the Institute for a Sustainable Future in Duluth, Minnesota for reviewing and commenting in detail on material presented here.
[47] Keith Christman, Vinyl Institute, "Vinyl Use in Building and Construction," Vinyl Material Council Newsletter (May, 2003), available at http://www.aamanet.org/pdf_files/Council_News_pdfs/VMC_Newsletter_May_03.pdf.
[48] Qualitative information on pipe materials is drawn from sources including Environment Canada 1997 and Jamie Harvie with Tom Lent, "PVC-Free Pipe Purchasers' Report," http://www.healthybuilding.net/pvc/pipes_report.html (viewed December, 2003).
[49] This section relies heavily on the Plastics Pipe Institute (PPI) website, http://plasticpipe.org, and on personal communication from Rich Gottwald, president of PPI, September-October 2002.
[50] Plastics Pipe Institute, "2001 Statistics: North American Shipments of Polyethylene & Crosslinked Polyethylene Pipe, Tube & Conduit".
[51] Daniel O'Connor, J-M Manufacturing, personal communication (September 2003).
[52] See http:// www.usinspect.com/PBPlumbing/PBBackground.asp.
[53] See "Project Profiles: Indianapolis Water Company's Successful Transition to HDPE Pipe Marks Turning Point for Industry," available at http://www.isco-pipe.com/isco/project_profiles/indy_water_01.asp, viewed November 2003.

[54] Information on pipe materials used by United Water in New York and New Jersey was provided by Ron Seligmuller, Purchasing Department, United Water, personal communication, August 2002.
[55] Steve D. Sandstrum, "Case Studies in High Density Polyethylene (HDPE) Water Distribution Systems," presentation to American Water Works Association Annual Conference (2003), available at http://www.plasticpipe.org/pdf/pubs/case/THUR2-6.pdf. Sandstrum is a manager at BP Solvay Polyethylene North America.
[56] Boston Water and Sewer Commission, personal communication (July 2003).
[57] Robert Socolow, editor, "Fuels Decarbonization and Carbon Sequestration: Report of a Workshop", Princeton University Center for Energy and Environmental Studies Report No. 302, September 1997, pp.35-36 (http://mae.princeton.edu/people/faculty/socolow/R302webfinal.pdf, viewed December 2003).
[58] Two PVC cement products reviewed by the Center for Maximum Potential Building Systems (CMPBS) had relatively high volatile organic compounds (VOC) levels of 600 g/l and 760 g/l. According to CMPBS, many PVC cement products are made from tetrahydrofuran (THF) and cyclohexane; manufacturers of THF recommend varying exposure limits, in one case as low as 25 parts per million for an 8- and 12-hour time-weighted average; and individuals with preexisting diseases of the lungs or liver may have increased susceptibility.
[59] "Safety And Health Activists, Environmentalists And Unions Win Ban on Plastic Pipe in New York State," *NYCOSH Update on Safety and Health* (January 14, 2002), available at http://www.nycosh.org/Update12_Jan-Mar_2002.html.
[60] For example, Joseph Zicherman of the consulting firm Fire Cause Analysis concludes a detailed review of flammability concerns involving plastic pipes by saying, "if proper installation detailing is observed, plastic piping installations present no greater fire risk than other types of piping materials available on the market today." See Joseph Zicherman, "Plastic Pipe and Fire Safety," available at http://www.ppfahome.org/pdf/safety.pdf.
[61] John Rattenbury, "Cast Iron vs. PVC: How Much Would You Pay for Quieter Pipes?," *PM Engineer Magazine* (August, 2000).
[62] Thanks to Gail Vittori and Monica Brown of the Center for Maximum Potential Building Systems in Austin, Texas, for the Austin case study and plumbing price comparisons.
[63] See, for example, http://BuildersWebsource.com, which compares copper and CPVC plumbing, concluding that if installed properly, "copper plumbing can last the life of the structure with little maintenance and overall long-term life-cycle savings."
[64] Jamie Harvie, P.E., personal communication (October, 2003).
[65] Total US roofing industry sales, including repairs and maintenance, were $30.2 billion in 2001: Olicia Hinojosa and Karen Kane, "A Measure of the Industry," *Professional Roofing* (April, 2002).
[66] Kevin Aylwin, Payton Construction, personal communication (May, 2003). Tufts building personnel referred us to Payton Construction for answers to questions about the university's roofing choices.
[67] Figure 2 shows a relatively low lifetime for built-up asphalt roofs, although Tufts University selected this roofing type in part for its longevity. The resolution of the apparent paradox is that the data in Figure 2 are averages including roofs with different numbers of plies. Roofs with more plies, such as those at Tufts, will have longer lives.
[68] Ray Corbin, "Urban Heat Islands," *Roofing Contractor* (October, 2001).
[69] Comments by Dr. William Miller, as described in David Roodvoets, "SPRI," *Roofing Contractor* (May, 2003 supplement). "SPRI" refers to the Single-Ply Roofing Institute.
[70] Northcoast Commercial Roofing Systems representative, personal communication.
[71] Myer J. Rosenfeld, "An Evaluation of Polyvinyl Chloride (PVC) Single-Ply Membrane Roofing Systems," US Army Corps of Engineers Technical Report M-284 (March, 1981), available at http://www.rci-mercury.com.
[72] David M. Bailey, Stuart D. Foltz, Walter J. Rossiter Jr., and James A. Lechner, "Performance of Polyvinyl Chloride (PVC) Roofing: Results of a Ten-Year Field Study," *Proceedings of the Fourth International Symposium on Roofing Technology* (September, 1997), available at http://www.rci-mercury.com.
[73] The source for the Austin case study is Todd Hewitt, an associate of Fifth Wall Roofing (http://www.fifthwallroofing.com/), an Austin Green Building Program roofing contractor; information provided to Center for Maximum Potential Building Systems.
[74] Information on the Chicago project was supplied by the Center for Maximum Potential Building Systems.
[75] Public summaries of open bidding for roof replacement at the Longmeadow High School, Longmeadow, MA (December, 2001), and for the Bellamy Middle School, Chicopee, MA (March, 2002); copies on file with authors.
[76] The source for this section, unless otherwise noted, is research done by the Center for Maximum Potential Building Systems (CMPBS).
[77] *Floor Covering Weekly*, "Statistical Report 2002."

[78] Terry Bessire of Intertech Flooring, Austin, TX, personal communication.
[79] Jouri J. K. Jaakola et al., "Interior Surface Materials in the Home and the Development of Bronchial Obstruction in Young Children in Oslo, Norway," *American Journal of Public Health* 89:2 (February 1999), 188-192.
[80] These are described at www.expanko.com.
[81] California Department of Health Services, Indoor Air 96..
[82] DCHA Green Materials Guide, page 1, CMPBS (September, 2002).
[83] See www.stratica.com for more information.
[84] The Occupational Health and Safety Administration notes that "A major ingredient used in manufacturing synthetic rubber and resin, 1,3-butadiene, has been found to cause cancer in laboratory rodents." See http://www.osha.gov/dts/hib/hib_data/hib19840411.html.
[85] Data were provided by Terry Bessire, Intertech Flooring (Austin, TX), Kim Pexton, Jim G. Davis Construction Corporation, Lesa Green, Turner Construction Company (Washington, DC) personal communication (September, 2003), and Gail Bothwick, Farr Associates (Chicago, IL) personal communication (September, 2003) to Center for Maximum Potential Building Systems.
[86] That is, referring to the column headings in Table 10, the ratio [D / (C+D)] > 0.98 for every material shown.
[87] "Implementation Assessment for Maintenance Free Decking," memorandum prepared for the Under Secretary of the Navy by the Commander, Naval Supply Systems Command (January 14, 2000).
[88] For example, according to information gathered by the Center for Maximum Potential Building Systems, Armstrong's residential flooring is coated with a factory urethane finish, which cannot be buffed, whereas Armstrong recommends a wax finish for commercial flooring.
[89] For example, GlossTek 100, manufactured by Windsor Industries (www.windsorind.com, viewed November 2003), does not require stripping; the company's promotional literature claims up to 43-45% savings in floor maintenance costs.
[90] See www.floorexpert.com. Search for Technique No. 19: Linoleum-Wet vs. Dry Maintenance (November, 2001).
[91] Information for this case study was provided by Terry Bessire of Intertech Flooring (Austin, TX) as related by Rick Early, Asst Director of UT/Austin's Division of Housing & Food Service, to Center for Maximum Potential Building Systems (CMPBS).
[92] Information for this case study was provided by Kim Pexton of Jim G. Davis Construction Corporation, personal communication (2003).
[93] Information for this case study was provided by Gail Borthwick of Farr Associates, personal communication (September 2, 2003).
[94] The "other" category in Table 1, which includes medical supplies, represents about 2 percent of PVC use; however, it also includes inventory changes, which could be negative, making the size of medical supplies ambiguous. Earlier versions of the same data source reported "other" uses, including medical supplies, without inventory changes, making it clear that medical uses of PVC were less than 3 percent of the total.
[95] In 2002 the US Food and Drug Administration (FDA) issued an advisory recommending that health care institutions work to reduce patients' exposure to the widely used plasticizer DEHP due to concerns about its effects on the developing male reproductive system. See US Food and Drug Administration, "FDA Public Health Notification: PVC Devices Containing the Plasticizer DEHP," (July 12, 2002), available at http://www.fda.gov/cdrh/safety/dehp.html (viewed September, 2003). On incineration of PVC medical waste and formation of dioxins and other persistent pollutants in medical incinerators, see Thornton 2000, pp. 268, 278-9, 283ff, and 317.
[96] Health Care Without Harm, "Alternatives to Polyvinyl Chloride (PVC) and Di-2-Ethylhexyl Phthalate (DEHP) Medical Devices," In *Going Green: A Resource Kit for Pollution Prevention in Health Care* (October 15, 2001 version), available at http://www.noharm.org.
[97] Rossi 2000, rev. 2001, citing Landstingsförbundet (Federation of Swedish County Councils), *PVC in the Swedish Healthcare System: Current Applications and New Alternatives* (Stockholm: Landstingsförbundet, 2001).
[98] Mark Rossi, *Neonatal Exposure to DEHP and Opportunities for Prevention* (Falls Church, VA: Health Care Without Harm, October 2000, revised June 2001).
[99] Albert Rego and Lorraine Roley, "In-use Barrier Integrity of Gloves: Latex and Nitrile Superior to Vinyl," *American Journal of Infection Control* 27 no. 5 (October, 1999). The Universal Precautions published by the Centers for Disease Control in 1987 emphasized the need for health care workers to treat all patients as potentially infected with HIV or other blood-borne diseases and to use gloves and other protective gear accordingly. See Centers for Disease Control, "Recommendations for prevention of HIV transmission in health-care settings,"

Morbidity and Mortality Weekly Report 36 supplement no. 2S (1987), available at http://www.cdc.gov/mmwr/preview/mmwrhtml/00023587.htm.

[100] For overviews of the concerns associated with use of latex medical supplies and proposals for eliminating latex hazards in health care institutions see Philip B. Kellett, "Latex Allergy: A Review," *Journal of Emergency Nursing* 23 (1997), pp.27-36; also see Kristi K. Miller and Page Weed, "The Latex Allergy Triage or Admission Tool: an Algorithm to Identify which Patients would Benefit from 'Latex Safe' Precautions," *Journal of Emergency Nursing* 24 (1998), pp.145-52. As many as 70 percent of anaphylactic reactions in children who have been anesthetized for surgery are thought to be caused by latex allergy; see F. Porri et al., "Association between Latex Sensitization and Repeated Latex Exposure in Children," *Anesthesiology* 86 no. 3 (March, 1997), pp.599-602. On the economic rationale for protecting health care workers by creating a latex-safe environment, see V.L. Phillips et al., "Health Care Worker Disability Due to Latex Allergy and Asthma: a Cost Analysis," *American Journal of Public Health* 89 no. 7 (July, 1999), pp.1024-1028. In an examination of three health care facilities of different sizes, this study finds that institutions are likely to benefit financially by creating a latex-safe environment, thus avoiding the high costs of illness and disability that can result from latex allergy.

[101] For toxicity and exposure information on acrylonitrile, see Agency for Toxic Substances and Disease Registry (ATSDR), "ToxFAQs for Acrylonitrile," CAS # 107-13-1 (July, 1999), available at http://www.atsdr.cdc.gov/tfacts125.html (viewed July, 2003).

[102] See US Department of Labor Occupational Safety and Health Administration, "Technical Information Bulletin: Potential for Allergy to Natural Rubber Latex Gloves and other Natural Rubber Products," (April 12, 1999), available at http://www.osha.gov/dts/tib/tib_data/tib19990412.html.

[103] Food and Drug Administration, "Guidance for Industry and FDA—Medical Glove Guidance Manual" (July 30, 1999), available at http://www.fda.gov/cdrh/manual/glovmanl.pdf (viewed October 22, 2003).

[104] Information on this test is from Sustainable Hospitals Project, "Selecting Medical Gloves," fact sheet available at http://www.sustainablehospitals.org/HTMLSrc/IP_Latex_GloveFacts.html (viewed October, 2003).

[105] Rego and Roley (1999).

[106] Notably, the brand with the highest out-of-box failure rate is not the same as the brand with the highest failure rate after use. Thus, the high average failure rates cannot be attributed to a localized problem in a single brand.

[107] Rego and Roley (1999).

[108] Catherine Galligan, Sustainable Hospitals Project, University of Massachusetts Lowell, personal communication.

[109] Kathy Gerwig, Director, Environmental Stewardship and National Environmental Health and Safety, Kaiser Permanente, personal communication (November, 2002).

[110] Anonymous, "EPP Success Story: Kaiser Permanente," *Environmentally Preferable Purchasing News for Health Care Organizations* 2 no. 3 (May, 2000).

[111] Fisher Scientific sales staff, personal communication (July, 2003). Bulk prices were obtained using an existing Tufts University account number on file with Fisher Scientific. The gloves on which we gathered information were provided to Fisher Scientific by manufacturers High Five, Kimberly Clark, and Omni.

[112] According to manufacturer information, the Accepted Quality Level (AQL) for leaks is 2.5 for vinyl gloves, meaning that up to 2.5 percent of the gloves may leak, whereas the AQL for the vinyl and nitrile gloves is 1.5.

[113] See Kimberly-Clark, "All FAQs: Medical Gloves—Testing—Barrier," available at http://www.kchealthcare.com/LrnFAQsQandA.asp?id=891&CategoryName=Medical%20Gloves%20-%20Testing%20-%20Barrier (viewed November, 2003).

[114] For the gloves that Fisher Scientific sales staff identified as broadly comparable, the latex gloves are the most expensive option. Some sources report substantially lower prices for latex. Since we focus here on the choice between vinyl and nitrile, we have not investigated latex glove prices further.

[115] Catherine Galligan, Sustainable Hospitals Project, University of Massachusetts Lowell, personal communication.

[116] Centers for Medicare and Medicaid Services, "Table 1: Selected Community Hospital Statistics, 1999-2002," data drawn from *National Hospital Indicators Survey,* available at http://cms.hhs.gov/statistics/health-indicators/t1.asp (viewed October, 2003).

[117] This section draws heavily on "Vinyl Siding: More Uniform Plastic," *Consumer Reports* (August, 2003), pp.23-25; it is the source for this description of siding alternatives, except as noted.

[118] Electrospec Home Inspection Services, "Painting aluminum and vinyl sidings," available at http://www.allaroundthehouse.com/lib.pqr.p3.htm (viewed October 1, 2003).

[119] Stark and Stark law firm, "What is EIFS?" available at www.njeifs.com/whatiseifs.html (viewed October 8, 2003).

[120] Stark and Stark law firm, "Can EIFS be repaired?" available at www.njeifs.com/caneifsberepaired.html (viewed October 8, 2003).
[121] Bruce Hampton, Hickory Woods Consortium, personal communication.
[122] BobVilla.com, "Material and Construction Options for Windows," available at http://www.bobvila.com/ArticleLibrary/Subject/Windows/Residential/WindowMaterials.html (viewed September 25, 2003).
[123] Comfort Line Inc., "The right choice…Fiberglass!"
[124] On the carcinogenicity of fibrous glass products, see US Department of Health and Human Services, Public Health Service, National Toxicology Program, "10th Report on Carcinogens, Tenth Edition" (December 2002), available at http://ehp.niehs.nih.gov/roc/toc10.html#toc (viewed November 2003). For an overview of occupational hazards, see American Lung Association of Georgia, "Facts About Fiberglass," available at http://abrannen.home.mindspring.com/alag/fbrglass.htm (viewed September, 2003). For a history of science and policy on fiberglass, see Peter Montague, "A Carcinogen that is Everywhere," *Rachel's Environment and Health News* #444 (June 1, 1995), available at http://www.rachel.org/bulletin/index.cfm?issue_ID=681 (viewed November 2003).
[125] Cramer, Oneida, "Window Restoration," available at http://www.homeissues.com/viewarticle.cgi?article=152&category=3 (viewed September 26, 2003).
[126] BobVilla.com.
[127] Comfort Line Inc. "The right choice…Fiberglass!"
[128] See Cramer, Oneida; John Paquette, "What's Wrong with Vinyl Windows?" East Row Historic District, Newport, KY, available at http://eastrow.org/articles/vinylwindows.html (viewed October 2, 2003).
[129] Ross, Mickey, President Ross Window Corp, "New Windows Give a 'Green' Outlook," New York Association of Realty Managers, available at http://www.nyarm.com/oct00/windows.html (viewed September 26, 2003).
[130] Comfort Line Inc. "The right choice…Fiberglass!"
[131] Prices from 5 Points Sash and Doors employee, personal communication (September 26, 2003).
[132] The total employment in NAICS industry 3261, "plastics product manufacturing," was 826,615. Of these workers, 526,382, well over half, were described only as being in industry 326199, "all other plastics product manufacturing." See http://www.census.gov/epcd/ec97/us/US000_31.HTM#N326.
[133] SPI, *Size and Impact of the U.S. Plastics Industry*, as described on http://www.plasticsdatasource.org/impact.htm.
[134] http://www.chlorallies.org/employ.html (viewed October 7, 2003).The data refer to a recent but unspecified year.
[135] SRI Consulting (Menlo Park, CA), *Chemical Economics Handbook: Vinyl Chloride Monomer* (December, 2000), and *CEH Marketing Research Report: Polyvinyl Chloride (PVC) Resins* (September, 2003).
[136] It seems likely that the employment data in Table 17 err more often in the direction of including too many workers, such as those who make other products at the same plants. The one obvious case of incompleteness in the other direction, underestimating employment, seems smaller by comparison. If too many workers are counted in Table 17, then the true average productivity—pounds of PVC per worker—is higher than our estimated 2.82 million pounds per worker, and the number of workers needed to produce the entire industry output is lower than 5,600. Further support for the guess that the industry has higher productivity, and hence lower total employment, than our estimates can be found in Environment Canada's study of chlorine-related industries in Canada in 1993. That study describes three PVC resin plants, with an average capacity of 3.14 million pounds per worker. If there have been advances in productivity since 1993, the capacity per worker should now be even higher. See Environment Canada, "A Technical and Socio-Economic Comparison of Options to Products Derived from the Chlor-Alkali Industry" (1997), Chapter 9.
[137] The 200 workers were also producing a larger quantity of EDC, a VCM precursor; some of the EDC was exported, and some was used to produce VCM. Thus the workers' actual productivity was higher (and estimated US labor requirements per million pounds of VCM should be lower) than the numbers presented in the text.
[138] PVC Container Company, Eatontown, NJ, interview with sales representative (October 28, 2003).
[139] Omni International (Bedford, NH), High Five, and Kimberly Clark company representatives, personal communications (October, 2003).
[140] Information on Westlake is drawn from Westlake's website, at http://www.westlakegroup.com/index2.html (viewed November, 2003).
[141] CertainTeed website, http://www.certainteed.com (viewed November, 2003).
[142] Calculated from the Bureau of Labor Statistics, Job Openings and Labor Turnover Survey, Tables 4 and 6, available at http:www.bls.gov/jlt/ (viewed October 8, 2003).

[143] See the discussion of the Just Transition program in Frank Ackerman and Rachel Massey, "Prospering With Precaution" (2002), available at http://www.ase.tufts.edu/gdae/policy_research/PrecautionAHTAug02.pdf. On the Just Transition program, see James P. Barrett and J. Andrew Hoerner, "Clean Energy and Jobs: A Comprehensive Approach to Climate Change and Energy Policy" (Washington, DC: Economic Policy Institute, 2002).
[144] Most of the information presented in this section is drawn from Greenpeace International, "PVC-Free Future: A Review of Restrictions and PVC free Policies Worldwide, 8th Edition" (2001) and Washington Toxics Coalition, "Anti-Vinyl, -PBT and –Dioxin Resolutions Adopted Across America and Around the World" (2002).
[145] See http://www.cleanmed.org.
[146] Unless otherwise noted, all information in this section is from Greenpeace (2001).
[147] Health Care Without Harm, "Glanzing Clinic in Vienna is First PVC-Free Pediatric Unit Worldwide," Press release (June 13, 2003).
[148] "Four Top Hospital Group Purchasers to Cut Mercury, PVC," *Waste News* (November 5, 2002).
[149] Saint-Gobain Performance Plastics, "TYGON® Medical Plasticizer-Free Tubing Developed Specifically for DEHP-Plasticizer and PVC Replacement in Medical Applications" (no date).
[150] See http://www.nike.com/nikebiz/nikebiz.jhtml?page=27&cat=sustainable (viewed November, 2003). Follow the "PVC-free" link and click "close" in the first panel to see details on current PVC-free shoe brands.
[151] "Athletic shoe makers had better leave stockings and not shoes out for Santa this Christmas, suggests Greenpeace," *Pesticide & Toxic Chemical News* 30 no. 8 (Dec 17, 2001), p.28.
[152] Sony Corporation, "Sony and the Global Environment," available at http://www.sony.net/SonyInfo/Environment/environment/communication/report/2003/pdf/e_2003_05.pdf (viewed November, 2003).
[153] See promotional materials at http://www.sony.net/SonyInfo/Environment/environment/communication/advertisement/08 (viewed November, 2003).
[154] US Grains Council, "Global Update" (March 14, 2003), available at http://www.grains.org/news/global_updates/glo-03-14-03.pdf (viewed November, 2003). It is worth noting that PLA is currently manufactured by Cargill from genetically engineered corn, which itself poses environmental hazards. Plant-based polymers can be produced sustainably in principle and do not require genetic engineering for their production.
[155] See company information at http://www.toshiba.co.jp/env/english/04/index3.htm (viewed November, 2003).
[156] IKEA Press Room, "IKEA CEO speaks at a Greenpeace conference in London," (October 10, 2001), available at http://www.ikea.com/about_ikea/press_room/press_release_int.asp?pr_id=492 (viewed November, 2003).
[157] See http://www2.marksandspencer.com/thecompany/mediacentre/corporatesocialresponsibility/2001.shtml (viewed November, 2003).
[158] For case studies on green buildings, see http://www.usgbc.org/Resources/links.asp#4 (viewed November, 2003).
[159] Healthy Building Network, "Green Healthcare Construction Case Studies," available at http://www.healthybuilding.net/healthcare/Green_Healthcare_Case_Studies.pdf (viewed November, 2003).
[160] Brett Goldstein, ed., *Green and Lean: Designing and Building an Affordable, Resource-Efficient Home* (Washington, DC: Green Home, 2000).
[161] Information on Erie Ellington Homes is available at Hickory Consortium, "Erie Ellington, Dorchester, Massachusetts," available at http://www.hickoryconsortium.org/erie_ellington.htm (viewed July, 2002). Additional information was provided by Bruce Hampton, Architect, Hickory Consortium, personal communication (November, 2003).
[162] Goldstein (2000) p.29.
[163] *Ibid.*
[164] Information on the Rittenhouse Sheraton is from Barry Dimson, co-owner, personal communication (September, 2002); also see www.sheraton.com\philadelphiarittenhouse.
[165] Barry H. Dimson, "The Economics of Green Hotels," (January 23, 2002).
[166] See the Adat Shalom website at http://adatshalom.net, which is the source for this account.
[167] See http://www.myhouseisyourhouse.org/ for information on Building in Good Faith.