The Economics of Phasing Out PVC

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December 2003

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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.

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 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 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.

- 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).

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: Low cost	Alternative materials: High cost	Cost per pound of PVC replaced (US $): Low cost	Cost per pound of PVC replaced (US $): 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

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]

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]

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

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 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

	Labor Hours	Labor Cost	Material Cost	Total Cost
	(amount per lineal foot)			
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.

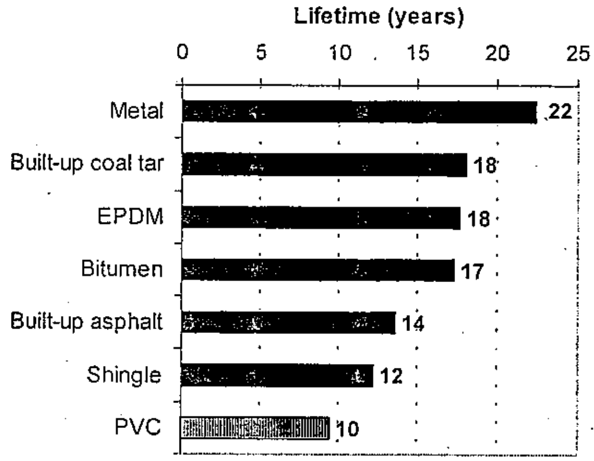
Table 7: Installation Costs, ¾-inch Plumbing - Complete Installation

	Labor Hours	Labor Cost	Material Cost	Total Cost
	(amount per lineal foot)			
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.

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

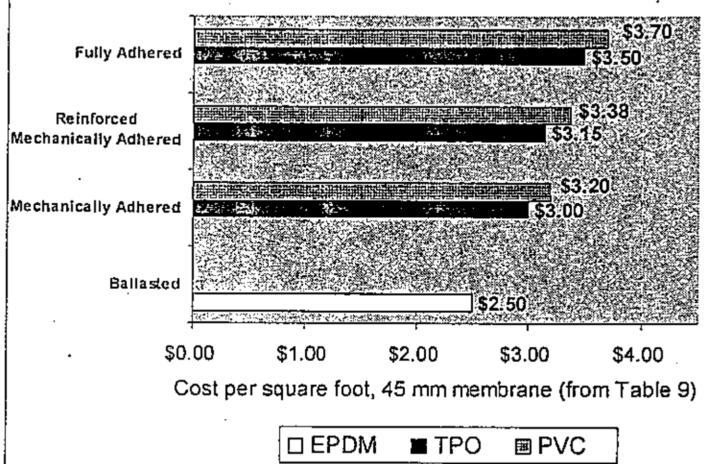
Table 9: Installed Costs of Roofing in Austin

(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.

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, 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 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 materials offers a potentially promising alternative to PVC.

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

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.

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.

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.

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) 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]

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, 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

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.

[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).

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.

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.pgr.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).

[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.