

# **The Economic Benefits of Polyvinyl Chloride in the United States and Canada**

PREPARED FOR:

**Chlorine Chemistry Division of the  
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and  
The Vinyl Institute**

**By**

**Whitfield & Associates**



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## The Economic Benefits of Polyvinyl Chloride in the United States and Canada

Polyvinyl chloride (PVC) is a versatile thermoplastic material that is used in the production of hundreds of products that consumers encounter in everyday life and many more that are encountered less frequently but are nevertheless very important in construction, electronics, healthcare, and other applications. It finds widespread use in these applications because of its low cost and desirable physical and mechanical properties. It is fabricated efficiently into a very wide range of both rigid and flexible products. PVC also has inherent flame resistance. Substitutes for PVC materials may be available, but often the alternative materials and processes are not as efficient or substitution costs are high.

PVC is used in an enormous variety of applications and competes with a diverse range of substitute materials. For example, PVC pipe holds a commanding share in large diameter pressure water and sanitary sewer pipe because of its low initial cost, ease of installation, long and reliable service life, and its low replacement and repair cost. Ductile iron and concrete are the major substitutes in these applications, and while the cost per foot of pipe may be comparable to PVC, installation costs are higher, particularly for concrete, since many more pipe joints are required. Replacement and repair costs are much higher for concrete than for PVC pipe as well. Additional costs are imposed by the loss of water due to main breaks and pumping costs may be higher for these substitute materials.

The net cost to consumers in the United States and Canada for the substitution of alternative materials for the PVC-based products that they currently use would be almost \$17.7 billion dollars per year. In addition to these costs, we estimate that consumers would be forced to pay additional costs because producers of the substitute materials would need \$5.6 billion in new investment to manufacture the incremental volume of substitute material, and incur the associated \$2.8 billion per year in capital recovery charges. The avoidance of these costs is part of the benefit that PVC brings to consumers. Thus, the total direct and indirect benefits of access to PVC to consumers in the United States and Canada amount to over \$20 billion per year.

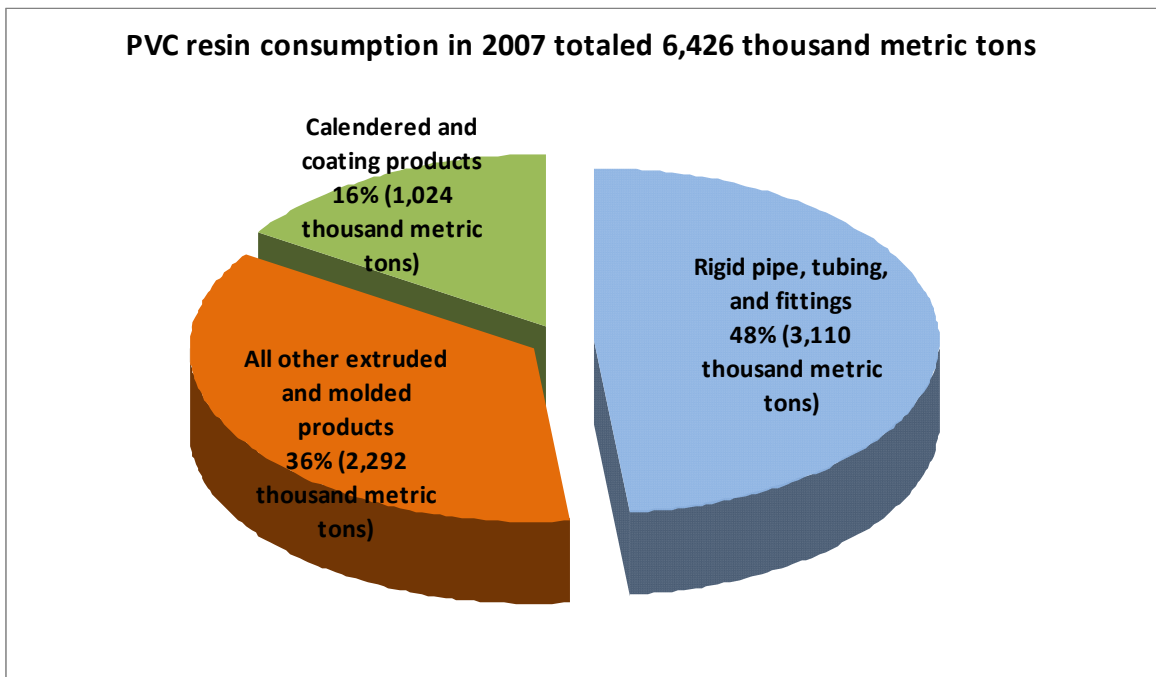
### I. Introduction

Polyvinyl chloride (also called vinyl or simply PVC) is a versatile thermoplastic material that is used in the production of hundreds of products that consumers encounter in everyday life and many more that are encountered less frequently but are nevertheless very important in construction, electronics, healthcare, and other applications. It finds widespread use in these applications because of its low cost and desirable physical and mechanical properties. It is fabricated efficiently into a very wide range of both rigid and flexible products. PVC also has

inherent flame resistance. Substitutes for PVC materials may be available, but often the alternative materials and processes are not as efficient or substitution costs are high. It is the most widely consumed thermoplastic material after the polyolefins (polyethylene and polypropylene). Consumption in 2007 in the United States and Canada amounted to over 6.4 million metric tons, or almost 14.2 billion pounds.

Consumers select products that contain PVC even when lower cost substitutes are available because they offer longer lives and reduced maintenance costs or aesthetic appeal. A breakdown of consumption of PVC resin (the powdered form of pure PVC) by major end use application and a compilation of some of the many products made from PVC is presented below.

**Figure 1: Consumption of PVC Resin in the United States and Canada, 2007**



Source: Whitfield and Associates based on American Chemistry Council's Monthly Statistical Report (PIPS).

**Table 1: Some Representative Products Manufactured from PVC**

<b>CONSTRUCTION</b>	<b>AUTOMOTIVE</b>
Piping & fittings for water distribution, irrigation & sewers; grey water recycling kits; electrical conduits; siding, awnings, soffit, skirting, weather stripping, gutters & downspouts; decking & fencing; window, door frames and cladding; landfill liners & geomembranes; swimming pool liners; single-ply roofing; conveyor belts; piping used in food processing, chemical processing & other manufacturing; floor & wall coverings; coated paneling; adhesives; maintenance coatings	Interior upholstery; “soft” dashboard & arm rests; dashboard instrument components, airbag covers; body side moldings, bumper guards; windshield system components, rearview mirror housings; under-the-hood wiring; under-the-car abrasion coatings; floor mats; adhesives & sealants; boots & bellows; battery separators; audio & video components; lighting components; steering cover & transmission parts; A/C system components
<b>MEDICAL &amp; HEALTHCARE</b>	<b>ELECTRICAL AND ELECTRONICS</b>
Blood bags and tubing; cannulae; caps; catheters; connectors; cushioning products; device packages; dialysis equipment & tubing; drainage tubing; drip chambers; ear protection; goggles; inflatable splints; inhalation masks; IV containers and components; laboratory ware; masks; mouthpieces; oxygen delivery components; seals; surgical wire; jacketing; thermal blankets; urine and colostomy bags; valves and fittings	Computer housing & cabling; printed circuit board trays; power wire insulation & sheathing; communication cable jacketing; backing for power cable; electrical plugs & connectors, wall plates, connection boxes; soft keyboards; keyboard trays; coating for optical mouse pads; memory stick & USB covers/casings; LED product components; laminate for plastic security passes & “smart cards”
<b>PACKAGING</b>	<b>CONSUMER PRODUCTS AND OTHER</b>
Sterile medical packaging; tamper-proofing over-the-counter medication; shrink wrap for software, games, & household products; blister and clamshell packaging to protect toys, hardware, electronics, personal care products, & foods such as eggs and meat; bottles for household & personal care products, cooking oils & automotive lubricants; closures for bottles & jars; can coatings	Wind turbine blades; machinery parts; housings & handles for tools; garden hoses; tarpaulins; patio furniture, upholstery; appliance housings; window shades & blinds; table cloths, place mats, shower curtains; sporting goods, beach balls; vinyl leather goods; luggage, footwear, gloves, rainwear; handbags; apparel; coated paper; holiday decorations; toys

Source: Whitfield and Associates

***PVC Production***

PVC has found widespread use because of its desirable properties, low cost and versatility. It starts as a powder that is derived from salt and fossil fuel.<sup>1</sup> The ability to manipulate its characteristics through selection of the appropriate manufacturing and fabrication processes, and

<sup>1</sup> PVC’s principal raw materials are chlorine (derived from salt) and ethylene (derived mostly from natural gas).

use of appropriate additives, including plasticizers for flexible products, is unmatched by any other thermoplastic material.

Some products contain copolymers that incorporate other materials, such as vinyl acetate and vinylidene chloride, in order to impart desirable mechanical or processing properties. About 90% of PVC is produced by **suspension polymerization** in which the monomer is suspended in an aqueous mixture containing buffers, initiators, and colloid-forming agents, and reaction conditions are controlled to produce material with the desired molecular weight distribution, particle size, and particle morphology. The finished PVC resin is separated from the aqueous mixture, dried, and sold in powder form. PVC is made by other polymerization techniques when material with specific properties is required. For example, **emulsion polymerization** is used to produce plastisols, which are fluid dispersions of PVC in plasticizers, used to make calendered and coated products such as shower curtains and raincoats. **Nonaqueous solution polymerization** in organic solvents is used to produce specialty polymers and copolymers that are used in other coating and calendering applications such as floor tiles. **Bulk polymerization** is used to produce resins with high clarity for the manufacture of such products as blow molded bottles.

The PVC-containing products that consumers use every day are always produced from mixtures of PVC resin that has been compounded with other materials, often into pellet form, before being fabricated into their final forms. Rigid PVC products can contain from 10 to 20% by weight of various additives and fillers. The additives include stabilizers, pigments, impact modifiers, and processing aids that are used to facilitate the fabrication processes. PVC products can also incorporate significant amounts of inert filler materials that reduce product costs without compromising flexibility, toughness, and mechanical strength in many applications. Flexible PVC products may also contain additives for heat stabilization, UV absorbance, flame retardance, and lubrication. These products always contain significant amounts of plasticizers so that the fabricated article may contain as little as 50% PVC resin. Historically, phthalate plasticizers, particularly diethylhexyl phthalate (DEHP), have accounted for the great majority of plasticizer consumption in flexible PVC products. More recently, plasticizers based on adipates and other esters have been used in applications where they provide advantages in processing or performance.

### ***PVC Processing Techniques***

PVC-containing products are manufactured from compounded resin by a number of processes, including extrusion, injection molding, calendering, coating, thermoforming, blow molding, and blown film processing. The most important of these are described below:

- **Extrusion:** a manufacturing process that uses a device similar to a pasta machine. The PVC resin is fed into the process and a screw-like shaft is rotated to push the resin forward where it is extruded through the outlet die. This technology is used to make pipe, conduit, siding, window frames, interior moldings, film, and sheet.
- **Injection molding:** a manufacturing process that injects PVC resin into a metal mold by pressure. This process is best suited for production of three-dimensional structures. This technology is used to produce pipe fittings, containers, and buckets.
- **Calendering:** a manufacturing process in which resin is heated and kneaded while passing through several pairs of rollers to be pressed to the required thickness. This

technology is used to produce wide, flat products like floor tiles, geomembranes, artificial leather, and wall coverings.

- **Coating:** a manufacturing process that applies a PVC-based solution to one surface of PVC film or fabric and then dries it by heat to produce the final product. This technology is used to make large tents, connecting sections of trains, sign boards, and table cloths.
- **Thermoforming:** a manufacturing process in which PVC sheet or film (either extruded or calendered), is heated to soften it and pulled into a metal mold by a vacuum. This technology is used to make egg cartons, food trays, blister packaging, and press-through packaging for pills.

Both rigid and flexible forms of PVC can be extruded, but the equipment and processing techniques required are tailored to the properties of the compounded materials, and differ from those used with other thermoplastics. Injection and blow molding techniques are used to produce a variety of rigid products, while other molding techniques are used to produce flexible products. Calendering is used to produce both rigid and flexible products in film or sheet form, often with a backing material to form laminated products. PVC resins compounded into plastisols are applied to various substrates to produce a range of coated products for industrial and consumer applications.

Production of PVC resin in North America takes place in large, efficient plants. The United States historically has been a large net exporter of PVC resin and fabricated PVC products because of its favorable cost position. We estimate that net exports currently amount to about 9.5% of resin production. However, the United States and Canada recently have become net importers of labor-intensive PVC-containing products, mainly from the Far East, such as window blinds, apparel, and home furnishings. We estimate that the resin content of these products amounts to about 6.5% of total consumption.

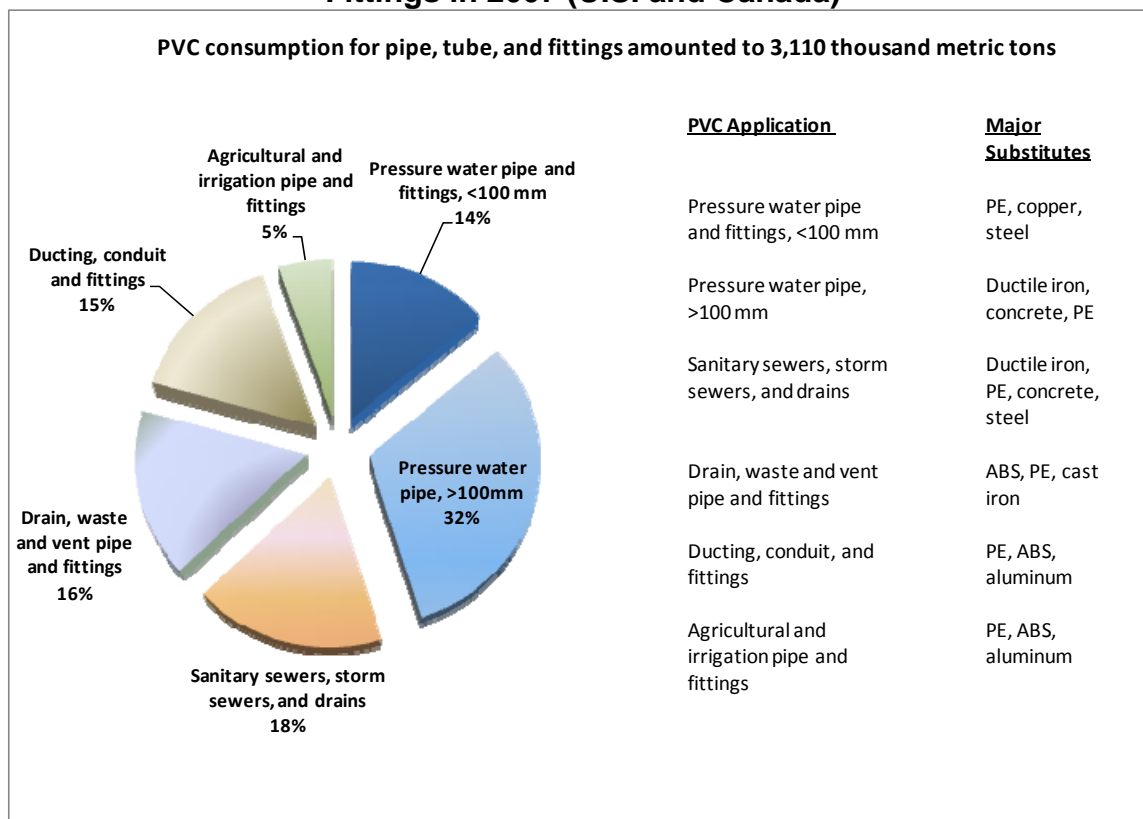
In the following sections, we describe the use of PVC in the production of rigid pipe and fittings, all other extruded and molded products, and in calendered and coated products. We identify and describe the materials that might be substituted for PVC in the various applications and the issues involved in such substitution. Following this step, we estimate the direct costs of substituting alternate materials for PVC-containing products. These costs are the monetary benefits that consumers currently enjoy from access to PVC. Finally, we estimate the indirect or derivative benefits that PVC production brings to the economy.

## II. PVC Rigid Pipe, Tubing, and Fittings

Approximately three-quarters of PVC resin consumption is fabricated into products that are used in construction, and the largest amount is used to manufacture rigid pipe, tubing and fittings. We estimate that PVC pipe and tubing products currently account for over 48% of PVC consumption in the United States and Canada. These products are used in residential households, commercial establishments, industry, and agriculture and in our buried pipe infrastructure that supplies consumers with drinking water and manages waste water flows of sewage and storm runoff. The products include residential water transmission and distribution pipe up to 1.22 meters in diameter as well as sewage and drain pipe that is nearly two meters in diameter and the fittings necessary to assemble piping systems, pipe for drain, waste and venting service, ducts and conduits, and pipe for agricultural and irrigation use. About 94% of the PVC consumed in these

applications is extruded into pipe and tubing and the rest is molded into fittings. These products typically contain 90% resin, with the balance being functional additives. Figure 2 summarizes our estimates of the amount of PVC resin consumed within each pipe category as well as the major alternate materials that might be substituted for PVC.

**Figure 2: Estimated Consumption and Substitutes for PVC Pipe, Tubing, and Fittings in 2007 (U.S. and Canada)**



<sup>1</sup> Polyethylene includes HDPE and PEX.

<sup>2</sup> Totals may not add due to rounding.

Source: Whitfield and Associates

***PVC Pressure Water Pipe of Less than 100 Millimeters Diameter***

PVC pressure water pipe less than 100 millimeters in diameter is used mainly to distribute water relatively short distances to and within residences and commercial establishments. Smaller diameter pressure pipe is usually composed of chlorinated PVC<sup>2</sup> (CPVC) to provide improved mechanical properties when handling hot water. Pipe segments usually are joined by solvent welding and are easy to assemble and install reliably. PVC and CPVC piping systems are virtually leak free, have long service lives, and are not prone to destruction by corrosion or environmental stress. They have supplanted the light gauged copper tubing and steel or galvanized steel pipes formerly used in these applications because of PVC/CPVC’s lower installed cost and better reliability. More recently, piping systems made with polyethylene components have gained share because of their ease of installation and lower cost than copper or

<sup>2</sup> CPVC is a modified form of PVC in which extra chlorine is added to the polymer structure, improving the thermal stability and increasing the melt viscosity.



steel. Because of its relatively low tensile strength and stiffness, heavier walled polyethylene pipe must be used to contain the water, which increases the cost of materials for this substitute. Higher cost cross-linked polyethylene (PEX) is required to handle hot water under pressure.

### ***PVC Pressure Water Pipe of Greater than 100 Millimeters Diameter***

PVC pressure pipe has captured an 80% share of the buried pressure water pipe market in diameters greater than 100 millimeters.<sup>3</sup> Longer life, lower maintenance, ease of installation, and reliability in service are the primary reasons for PVC pipe prominence. Historically, cast iron followed by ductile iron have held sizeable shares in large diameter pressure water piping systems, but they are prone to deterioration from corrosion, which has resulted in premature breakage and leakage. It has been estimated that leakage of water from these metal piping systems costs consumers in the United States about \$3 billion per year<sup>4</sup>, plus the costs of leak detection and pipe repair and replacement. PVC piping systems have provided superior performance, with breakage rates as low as 1% of the breakage rates of cast and ductile iron systems. In addition, PVC pipe is hydraulically smoother than iron pipe and is far less prone to support the buildup of deposits that can harbor harmful microorganisms. Being corrosion-free, PVC does not form the scaly deposits that constrict water flow. A buildup of rough scaly deposits of a modest 3 millimeters in thickness can double the pressure drop and pumping power requirements in piping systems.

Polyethylene pipe has not captured a significant share of installed large diameter pressure water and sanitary sewer applications because of its relatively low tensile strength and stiffness. As a consequence, polyethylene pipe requires thicker pipe walls compared with PVC. The need for additional material and resources increases the cost of a linear foot of polyethylene pipe. Concrete pipes are also widely used for large diameter applications.

### ***Sanitary Sewers, Storm Sewers, Drains, Vent Piping, Ducting and Conduit***

Sanitary sewers generally rely on gravity flow and do not operate under internal pressure. Their design is governed by external earth and traffic loadings. PVC pipes provide an excellent combination of stiffness and strain capacity that have made PVC the preferred pipe for sanitary sewers. PVC sanitary sewer joints are leak-free, flexible and easy to assemble. Moreover, PVC sewer pipes are highly resistant to the aggressive chemical and biological environments that have long plagued traditional sewer pipe alternatives. As a result, PVC pipes account for over 80% of all newly installed sanitary sewers.<sup>5</sup>

Storm sewers and drains are not required to contain water under high pressures, and pipe designs may be constrained only by the need to support earth loads transmitted to them. Water-tight joints are not generally required in these less demanding applications. As a result, PVC pipe has a smaller share - corrugated polyethylene, steel pipe, and concrete hold the dominant shares.

PVC pipe also dominates the market for drain, waste and vent (DWV) piping, ducting and conduit. These applications are not required to contain fluids under pressure, so the design is

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<sup>3</sup> For the pipe market, market share is measured as a percent of linear feet of installed pipe rather than pounds of material due to significant difference in material density and usage factors.

<sup>4</sup> "When Performance Counts," Uni-Bell PVC Pipe Association, publication 10-04.

<sup>5</sup> "Buried Pipe Markets in North America, 1999-2004," report to members of the Uni-Bell Pipe Association.

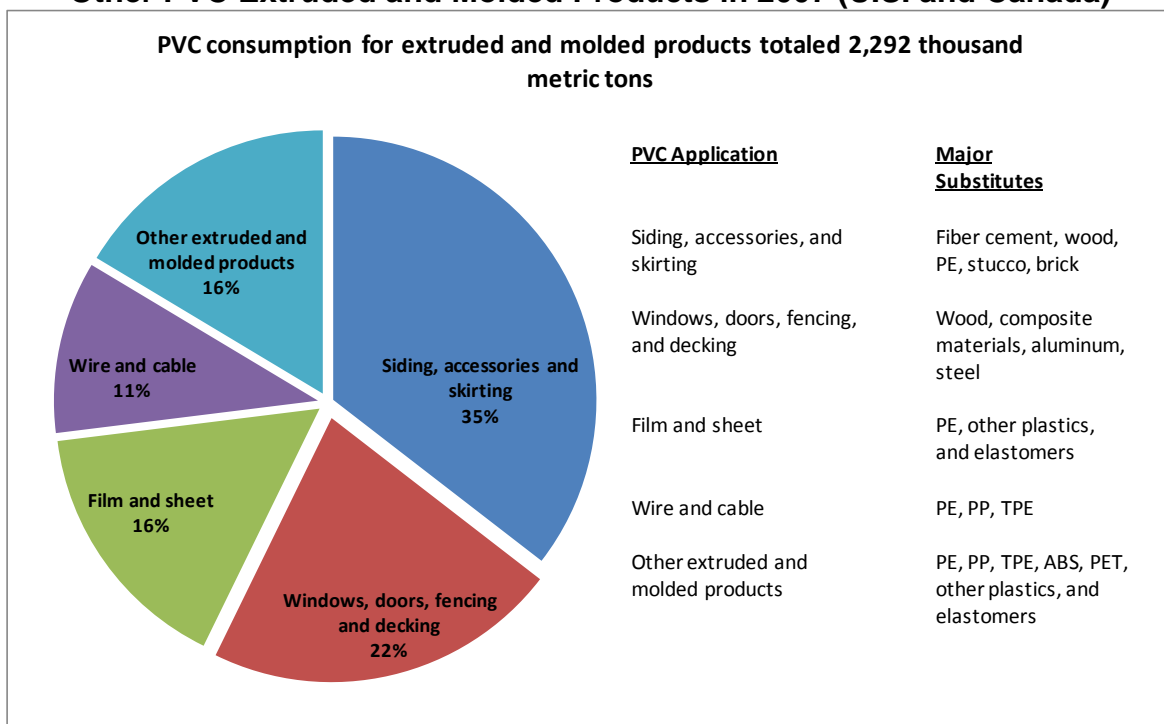
normally constrained only by the requirement that the material be stiff enough and have sufficient strength to support itself between support points. ABS<sup>6</sup> has reasonably good strength and slightly lower specific gravity than PVC so that the cost of materials and installation is comparable. Like PVC and ABS, polyethylene DWV systems cost less than those of the traditional cast iron systems because they are much lighter, thereby reducing the cost of materials and installation. However, ABS and polyethylene lack PVC's flame resistance.

PVC piping systems in agricultural and irrigation applications have large shares because they are low in cost for both materials and installation. High density and cross-linked polyethylene often are suitable substitutes in these applications; when even greater strength is required, ABS and aluminum are appropriate alternatives.

### III. All Other Extruded and Molded Products

This category includes a very large number of products that are consumed mainly in construction and in the manufacture of consumer goods, packaging, electrical and electronic goods, home furnishings, and in transportation and medical applications. The category includes both rigid and flexible products and resin contents can range from 50% to 85% in the finished product. Estimated resin consumption for major categories of these products and the most likely substitute materials are summarized below.

**Figure 3: Estimated Consumption and Substitutes for Other PVC Extruded and Molded Products in 2007 (U.S. and Canada)**



Source: Whitfield and Associates.

<sup>6</sup> ABS, or acrylonitrile butadiene styrene, is a common plastic used to make light, rigid, molded products like pipe.

### ***Rigid PVC Construction Materials***

Siding, siding accessories, and skirting<sup>7</sup> are major consumers of PVC resin. In recent years, PVC's share of siding in the exterior walls of new single-family residential construction in the United States has exceeded 30%, consistently the largest share of any exterior cladding. Most of the remaining new homes are sided with brick, stucco, wood, and fiber cement.<sup>8</sup> The choice of siding material is made primarily on local preferences, plus performance properties, cost, maintenance, and aesthetic considerations. It varies regionally and by the size and cost of the structure. Regionally, the share of new houses whose exterior walls are sided with vinyl is highest in the Midwest and Northeast. In 2007, vinyl's market share of new single-family homes in these two regions was 70%. Vinyl siding is the number one choice for homes at price points up to \$250,000 and second only to stucco at price points between \$300,000 and \$500,000. On the other hand, the share of brick siding on new houses is highest in the South, with the West favoring stucco and fiber cement siding, respectively. Relatively little fiber cement siding is being applied to the exterior walls of houses in the Midwest and Northeast. These choices are influenced by the effects that the more severe climates in the Midwest and Northeast have on materials and maintenance costs. The share of exterior walls in residential construction sided in stucco and brick is lower for both economic and technical reasons: not only are the materials more costly to install but they weigh far more than the alternatives, particularly PVC.

Approximately 58 million windows and doors with PVC framing are installed annually in new construction and in replacement projects in existing structures in the U.S. and Canada. Units framed with PVC have largely replaced units framed with aluminum and captured more than half of the market from wood-framed units because of a longer service life and lower maintenance costs. In fact, most of the lower cost wood framed units are actually sheathed with PVC or aluminum to protect them from the elements, prolong their lives, and reduce maintenance and repair costs. The integrity of the seal with double-paned glass windows is more effectively maintained with PVC framing than with wood, which reduces energy loss and heating and cooling costs over time. Fiberglass-based composite units compete with PVC where consumers seek longer life and reduced maintenance than are possible with wood.

PVC fencing and decking have been gaining market share against the traditional galvanized steel and wood products because they are more resistant to attack by the elements, have an extended service life, reduced maintenance requirements, and good weathering properties. The initial cost of PVC-based products in these applications is higher than the cost of the common lumber normally used in these applications, although use of rot-resistant or pressure treated woods raise costs significantly. Composite materials made of recycled plastics have also gained share in these applications, and these materials are also significantly more costly than common lumber.

### ***Flexible PVC Construction Materials***

Flexible PVC that is extruded into film and sheet applications is used in construction as geomembranes, single ply roofing membranes, and other membranes used as barriers to water migration. Some flexible PVC and rigid sheet is used in selected packaging applications and a variety of other consumer products. Polyethylene as well as specialty elastomers and other

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<sup>7</sup> Skirting material provides a border running along the edge or corners of a building or room.

<sup>8</sup> U.S. Census Bureau, Manufacturing, Mining, and Construction Statistics, Characteristics of New Housing Sold, Exterior Wall Material, 1978-2007.

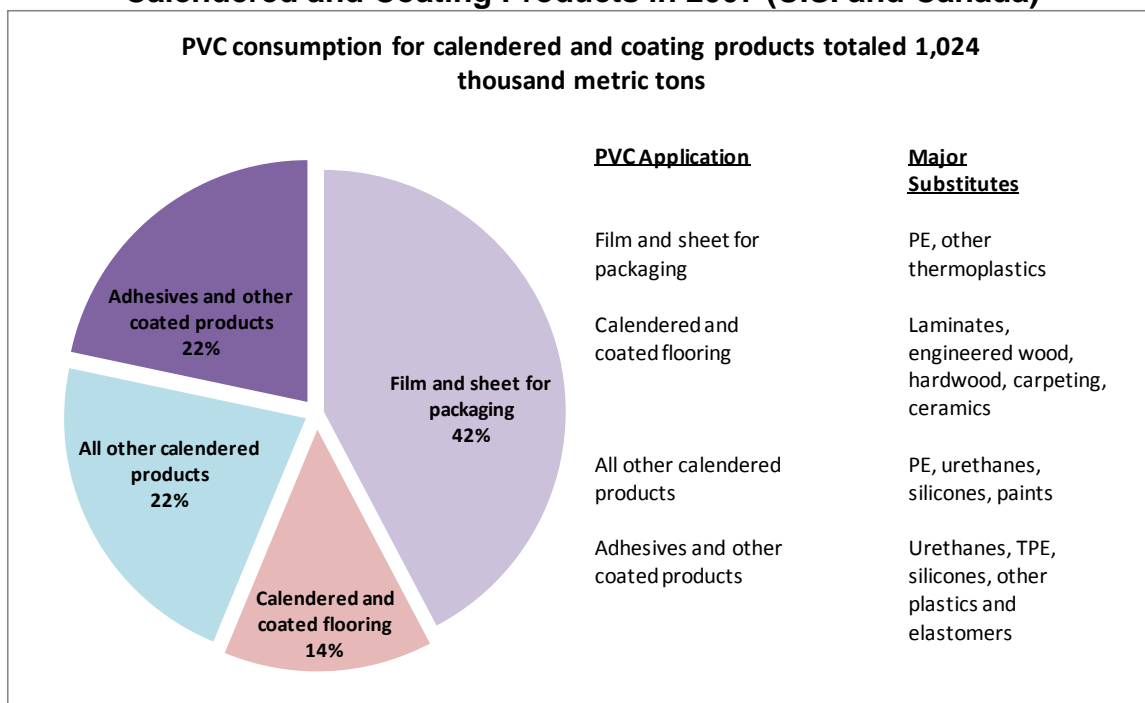
thermoplastics are the most likely substitutes in these applications. PVC is extruded into insulating jacketing for power cables, signal wire, and wires used in appliances, extension cords, and automotive applications. It is selected for its fire resistance and toughness, even though substitutes such as polyolefins and other thermoplastic elastomers have somewhat better electrical properties.<sup>9</sup>

All other extruded and molded products include a wide variety of rigid and flexible products used in construction, consumer goods, home furnishings, and medical and transportation applications. They include such items as automotive parts, the flexible tubing used in dialysis, blow molded bottles, household goods, casings for business machines, luggage and handbags, window treatments, and many others. Substitute materials consist mainly of other thermoplastics, elastomers, and, to a lesser extent, metals and natural products such as leather.

#### IV. Calendered and Coating Products

Most of the products included in this category are used in packaging and construction applications and in consumer goods. The type of resin used and the amounts of additives, fillers, and plasticizers added vary greatly, depending on the properties required in the manufactured product. Estimated resin consumption and the most likely substitute materials in each major application area are summarized below.

**Figure 4: Estimated Consumption and Substitutes for Calendered and Coating Products in 2007 (U.S. and Canada)**



Source: Whitfield and Associates

<sup>9</sup> The most important electrical properties of polymers are volume resistivity, dielectric constant and dielectric strength, dissipation factor, and arc resistance.

## ***PVC Packaging***

Both rigid and flexible PVC sheet and film have been used in packaging applications for many years, both alone and as laminated films with improved barrier properties. They are used in blister wrap packaging for a variety of hard goods, as stretch wrap packaging for others, and shrink wrap packaging for food and pharmaceutical containers. They have been used widely as stretch and shrink wrap packaging for foodstuffs, particularly meats. In some of these areas PVC has lost share to polyethylene products and other thermoplastics such as PET as consumer preferences and economics have shifted.

## ***PVC Calendered Products***

PVC is calendered onto substrates, and often embossed for decorative purposes, to produce vinyl flooring for use in residential, commercial, and institutional settings. PVC in plastisols is also coated onto substrates to produce floor treatments. Flooring material choices are made in consideration of cost, the traffic expected, and aesthetics. Substitutes include traditional alternatives such as hardwood, ceramic tile, carpeting, and newer materials such as engineered wood panels and laminates.

Other calendered products include flexible sheet and film calendered onto textile or other substrates to produce covering for furniture, automotive seating, wall coverings, and a wide range of other consumer goods. Plastisols are coated on substrates or laminated directly onto rigid surfaces to serve as wall coatings. They are also coated on paper, fabrics, wood, and metals to provide protection from the elements and to serve as maintenance coatings. In these applications, PVC competes on the basis of cost, aesthetics, and performance with traditional materials such as paint, other plastics, elastomers, and adhesives.

## **V. Substitution Summary**

In this section, we examine the wide range of applications for PVC-containing products – rigid pipe and tubing, all other extruded and molded products, and calendered and coating products. The majority of these products go into construction applications. However, significant volumes also go into automotive, electrical/electronic, packaging, and medical/healthcare applications. The key research finding is the fact that consumers can find alternatives for PVC-based products for all applications and product types that were examined. Generally the substitutes are materials with which PVC currently competes or has competed in the past. In the applications in which PVC-containing products have a commanding share of the market, as is the case with large diameter pressure water pipe, the vinyl products are so highly favored due to their many advantages that the choice of substitutes may be limited. In those applications where PVC-containing products have lost market share, as is the case with blow molded bottles, the substitute materials offer advantages in either performance or cost.

In general, substitution for PVC-containing products would be easiest in those applications where another thermoplastic material has the physical and mechanical properties that would permit the substitute material to provide the same performance as PVC, and allow the product to be manufactured at a comparable cost. Substitution would be more difficult for products in which no other thermoplastic or elastomeric material could be substituted and heavier, more difficult and expensive-to-manufacture materials would be required. We know that consumers

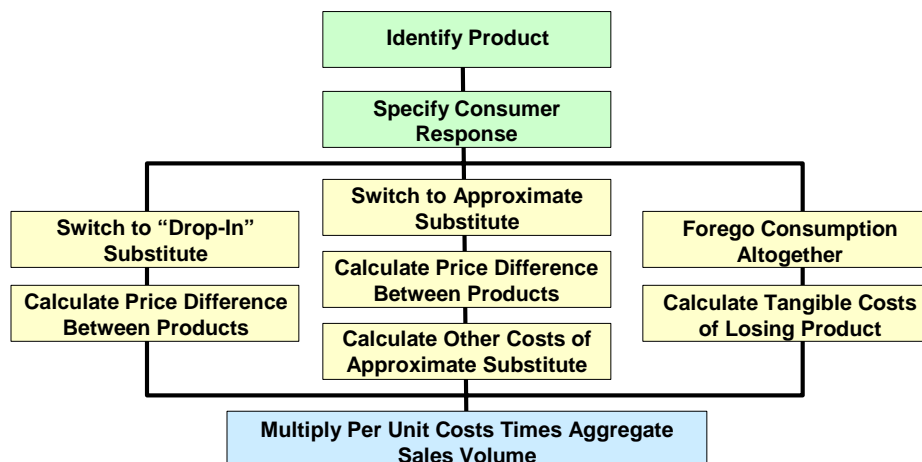
derive benefits from access to PVC-containing products because they select them in preference to others, even when the initial cost is higher than for the alternatives. The issues involved in the estimation of the magnitude of the benefits are discussed below.

## VI. The Economic Benefits of Polyvinyl Chloride to Consumers<sup>10</sup>

The magnitude of the direct economic benefits that accrue to consumers in the United States and Canada by virtue of their access to PVC-containing products can be determined by estimating the differences in the total costs between the products they now use and the products that would be substituted for them if they were not available. A general methodology for estimating these benefits is illustrated in the figure below.

**Figure 5**  
**Range of Potential Consumer Responses**

### *Consumer Benefits Methodology*



Consumers normally make product selection decisions based on many considerations, not just the initial purchase price. At the manufacturing level, these factors may include ease of fabrication, compatibility with other components of a system, performance advantages, or the ability to reduce total costs through ease of installation, parts consolidation, or weight reduction. At the user level, reduced maintenance requirements, longer life, improved aesthetics, or increased convenience of use may be important considerations. If an alternative to a PVC-containing product met all of these criteria, it would be considered a perfect or "drop-in" substitute, and the benefit to consumers of access to the PVC-containing product would be simply the difference in the initial prices of the products. Differences in product prices could

<sup>10</sup> All economic benefit estimates in the sections below apply to consumers in the United States and Canada.

result from differences in the costs of the raw materials used, in the costs of converting them into the finished products, and the cost of putting them into service or installing them.

In practice, however, perfect substitution is quite difficult to achieve because different materials have different properties and attributes. It is, perhaps, most closely approached if a product made from one resin were to be substituted for a product made from a different resin that had very similar mechanical and processing properties. If this were the case, and if the costs of the starting resins were not too dissimilar, the products should have comparable market shares in that application since consumers would have little reason to prefer one over the other. When a specific product has a commanding market share in a particular application, it usually indicates that products made from substitute materials are less desirable because of higher costs or lack of some other important performance attribute.

To the extent that an alternative material produces products that are deficient in one or more important attribute, substituting it for one containing PVC would constitute imperfect substitution. Imperfections could result from higher costs to put the product into service, differences in product life, higher maintenance requirements during use, differences in mechanical properties that would require changing component dimensions or altering other system components to accommodate them, or simply differences in the aesthetics due to changes in surface appearance or color. In these cases, the differences in costs to consumers would include not only the differences in initial costs, but differences due to the loss of utility experienced when using the imperfect substitute. In some cases, the loss of utility can be measured directly, as would be the case if a shorter life required that the consumer repurchase a substitute more frequently, or if the substitute material required more frequent or more costly maintenance. In other cases, utility loss is more difficult to measure, particularly when aesthetics are important in decision-making.

In extreme cases, if no good substitutes were available, consumers might be forced into making not-in-kind substitution choices or be forced to forgo consumption altogether. These conditions generally do not apply in the case of PVC-containing products because substitutes are available, although most of them are imperfect in some respects. In some applications, however, insufficient capacity may exist to produce or fabricate the amount of substitute materials required to displace the large volumes of PVC currently used. Additional fabrication capacity usually can be added relatively quickly and with low capital requirements, and the increased costs for fabrication would be passed on to the consumers of the substitute-containing products.

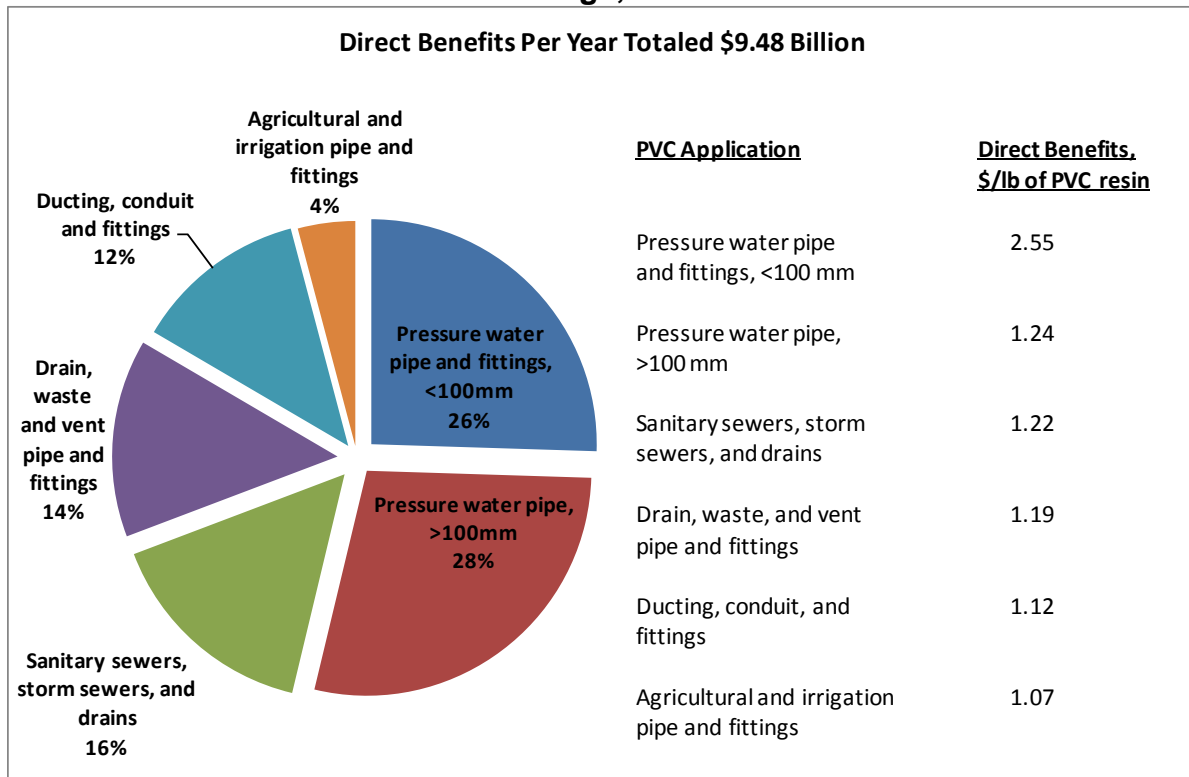
If the additional consumption of the substitute materials were to require investments to provide new production capacity, however, the substitutes' prices would have to increase by amounts sufficient to justify the returns required on the capital invested. Avoidance of such price increases throughout the rest of the economy, and not just to the consumers of PVC-based products, represents an additional, indirect or derivative benefit that consumers enjoy through their access to PVC.

### ***Economic Benefits of PVC Pipe, Tubing and Fittings***

The direct economic benefit to consumers in the U.S. and Canada of PVC used in the production of rigid pipe, tubing, and fittings is estimated to be \$9.5 billion per year with nearly 55% of the

benefits arising from the use of PVC small and large diameter pressure water pipe. A breakdown of the estimated benefits is presented below.

**Figure 6: Estimated Direct Benefits of PVC Pipe, Tubing, and Fittings, 2007**



Source: Whitfield and Associates

The small diameter pressure water pipe and fittings show the highest benefit per pound of PVC because the substitutes include significant amounts of copper and steel, which are more expensive to purchase and install than PVC pipe, and use of the higher cost cross-linked polyethylene pipe (PEX) to provide the required service. Installation costs may be as much as ten times the cost of the purchased pipe in these systems, so even small differences in the ease of installation result in large differences in the total costs to put a substitute in service.

PVC pipe holds a commanding share in large diameter pressure water and sanitary sewer pipe because of its low cost, ease of installation, long and reliable service life, and its low replacement and repair cost. Ductile iron and concrete are the major substitutes in these applications, and while the cost per foot of pipe may be comparable to PVC, installation costs are higher, particularly for concrete, since many more pipe joints are required. Replacement and repair costs are much higher for concrete than for PVC pipe as well. Additional costs are imposed by the loss of water due to main breaks and pumping costs may be higher for these surrogate materials. The higher installation cost for concrete pipe also contributes to the high substitution cost for PVC in storm sewers, although lower cost corrugated polyethylene pipe has a higher share in that application than in sanitary sewers.

Substitution costs are somewhat lower for drain, waste and vent piping, and significantly lower for ducting and conduit, and in agricultural and irrigation system applications. While some cast



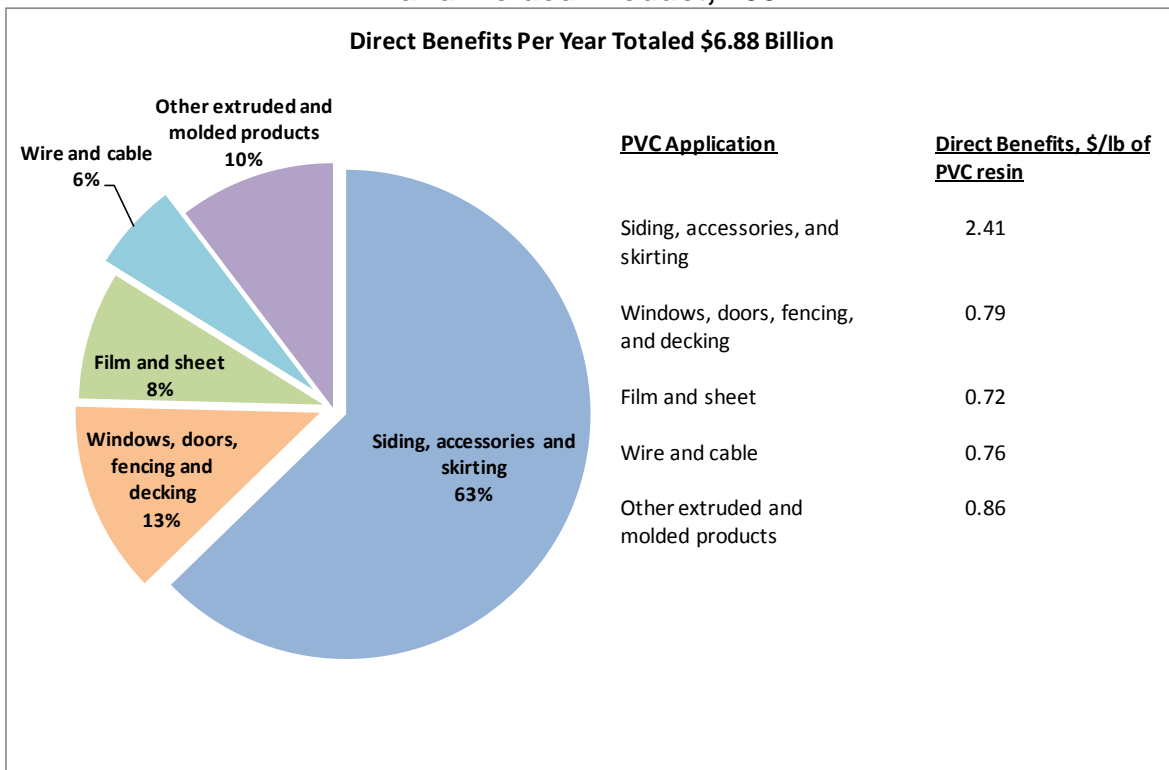
iron would be used in the DWV systems, polyethylene and ABS are the major substitutes. Installation costs are significantly lower than for buried piping systems, and replacement and repair costs are lower as well.

Overall, we estimate that about 47% of the total increase in cost to substitute these materials in piping systems that now use PVC pipe and fittings is due to the increased materials costs for the substitutes. About 39% is due to the increased costs of installing them, and about 15% is due to the increased costs for the more frequent replacement, maintenance and repair requirements than are required for PVC piping systems.

***Economic Benefits of All Other Extruded and Molded PVC Products***

The economic benefit to consumers in the U.S. and Canada for all other extruded and molded products is estimated to be nearly \$6.9 billion per year with over 60% of the benefits arising from the use of PVC siding, accessories, and skirting. A breakdown of the estimated benefits in these applications is presented below.

**Figure 7: Estimated Direct Benefits of All Other PVC Extruded and Molded Product, 2007**



Source: Whitfield and Associates

Because the installed costs of brick, stucco, and stone are of the order of five times the costs of PVC siding, it is unlikely that their share of either new or replacement siding would increase significantly if PVC were not available. Polyethylene, and perhaps other thermoplastics, could be substituted for PVC where it is used currently in such areas as soffits and skirting. We estimate that no more than 20% of the total PVC consumption for siding, accessories, and skirting would be substituted by brick, stucco, and stone; polyethylene would account for the

majority of the substitution in skirting.<sup>11</sup> The balance of PVC's current share of the siding market would be taken by fiber cement and wood, with the fiber cement share higher in the South and West, and wood's share higher in the Midwest, Northeast, and Canada.

Even though we estimate that their combined share would be less than 10%, over half of the estimated increase in cost would come from the substitution of stucco, brick, and stone for PVC siding, and about another 45% would be from the substitution of fiber cement and wood. Although replacement and maintenance costs can be higher for some of the substitutes than for PVC, the total cost increase is driven by the initial costs of installing the substitutes. This is not the case for windows, doors, fencing and decking, however.

The most important substitute for PVC in windows, doors, fencing and decking applications is wood, with smaller amounts of composite materials in windows, doors and decks, and some aluminum in the windows and doors and galvanized steel in fencing. Doors and windows are installed as units with their framing and glass included. The installed cost differences that arise solely from differences in the material of construction are mitigated because the costs for the glass, assembly of the unit and its installation do not depend strongly on the cost of the material. However, replacement and repair costs do depend on the material chosen, as they do for fencing and decking, and are much higher for wood than for PVC. The wood products must be maintained properly, which requires repeated painting or staining, to prevent them from deteriorating rapidly, whereas PVC-based products are virtually maintenance free and can have extended service lives. In these applications, it is the reduced replacement and repair costs of PVC that provides most of the consumer benefits.

Almost all of the substitutes for PVC in film and sheet, wire and cable, and all other extrusion and molding applications are other thermoplastics and elastomers, the largest of which is polyethylene. Substitution costs are relatively low with minimum impacts due to reduced service life, increased maintenance costs or other losses of utility. The majority of the benefits of PVC-containing products in these applications arise from the fact that they are lower in cost, easier to fabricate, and provide superior performance in service.

### **Medical Applications of PVC**

PVC-based products have important medical applications which include extruded and molded products as well as calendared and coating products. Examples include blood bags and tubing, intravenous containers and components, catheters, dialysis equipment and tubing, ear protection, inflatable splints, oxygen delivery components, surgical wire, and thermal blankets.

We estimate that about 80 thousand metric tons of PVC per year is fabricated into the small diameter flexible tubing used in medical applications for fluid and air transfer. Blood bags are another major use of PVC. Before the invention of plastic blood bags, blood was collected in glass bottles. Two common issues with glass bottles are inadequate sterilization, which induces contamination of the blood, and air or gas bubbles, which can cause complications in the bloodstream. The advent of the plastic blood-collection bag was a significant breakthrough in the history of blood collection and banking. Because blood bags are disposable, the external contamination of donated blood is reduced to unprecedented levels. Flexible and unbreakable,

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<sup>11</sup> Estimates based on interviews with PVC industry representatives.

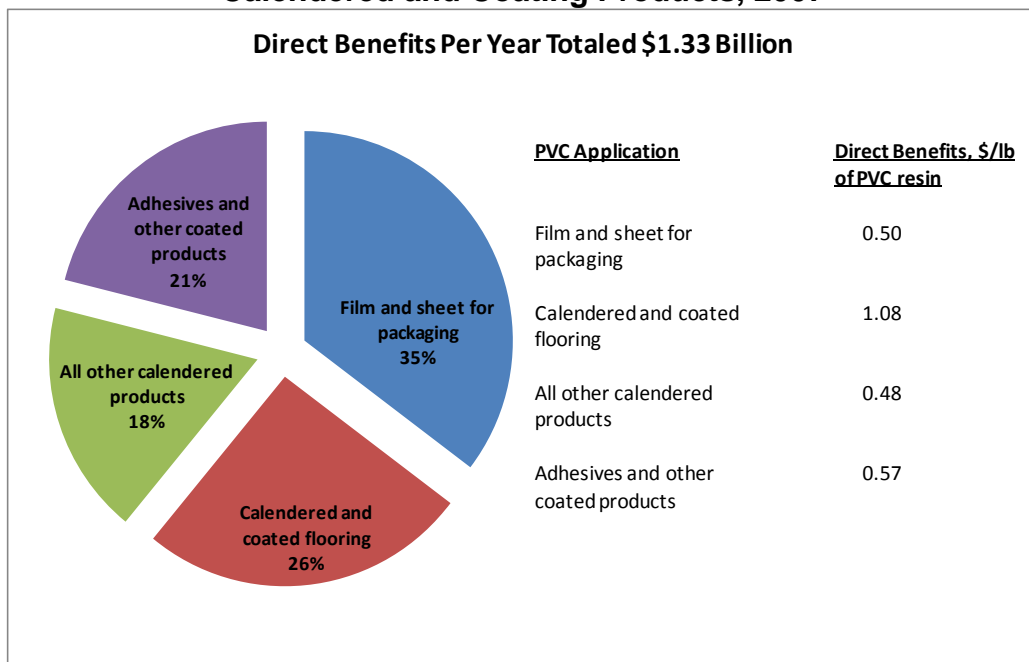
blood bags were also important to the development of ambulatory medicine. Furthermore, the plasticity of blood bags facilitates the separation of blood components and the resilience allows not only easy transportation but also economical freezing of blood and blood products. Modern blood banking depends on PVC – it has functional properties that are difficult to replicate in a simple, cost effective manner.

For over half a century, PVC’s performance and protectiveness have made it a critical material in numerous medical applications, such as intravenous bags, cardiac catheters, extracorporeal membrane oxygenation support, and endotracheal tubes. It is optically clearer than most alternative materials, kink resistant, can be radio-frequency (RF) heat sealed, withstands steam sterilization, and resists “necking down” – that is, constricting when pulled. This property provides patients with an assured flow of fluid. Moreover, PVC blood bag stored erythrocytes – red blood cells – have a longer shelf life than those in vessels made of alternative materials. And being the resilient material that it is, PVC blood bags can be air-dropped onto a battlefield for use by troops on the move. We estimate that the benefits of the PVC consumed in this and all other medical applications are about \$0.2 billion per year.

***Economic Benefits of PVC in Calendered and Coating Products***

The economic benefit to consumers in the U.S. and Canada for PVC in calendered and coating applications is estimated to be \$1.3 billion per year. A breakdown of the estimated benefits in these applications is presented below.

**Figure 8: Estimated Direct Benefits of PVC in Calendered and Coating Products, 2007**



Source: Whitfield and Associates

Polyethylene is the most likely substitute for PVC film and sheet for packaging, and other thermoplastics and elastomers are the most likely substitutes for most other calendered and

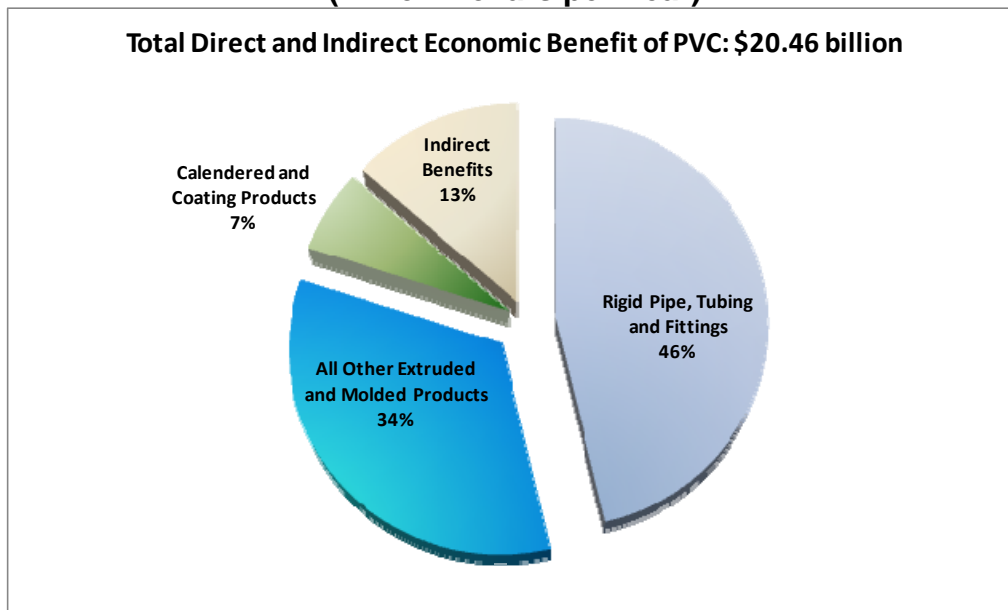
coated products and adhesives. These materials can be effective substitutes for PVC, being only somewhat higher in cost to produce and use. In addition, they have comparable performance characteristics in most applications. Aesthetic considerations may play a role in material selection for many of the consumer products in these areas, but not necessarily in such industrial applications as geomembranes or metal coating.

There are more choices with respect to substitutes in calendered and coated flooring, however, where aesthetics are more important. Vinyl flooring might be substituted by woods, other laminates, carpets, or ceramic tiles, all of which are more costly to install than PVC-containing products. Replacement and maintenance costs will differ as well, especially for flooring in commercial and institutional settings, and these added costs increase the direct benefits of PVC to consumers in these applications.

### *Summary of Economic Benefits*

To summarize, PVC is used in an enormous variety of applications and competes with a diverse range of substitute materials. The net cost to consumers in the United States and Canada for the substitution of alternative materials for the PVC-based products that they currently use would be almost \$17.7 billion dollars per year. In addition to these costs, we estimate that consumers would be forced to pay additional costs because producers of the substitute materials would need \$5.6 billion in new investment to manufacture the incremental volume of substitute material, and incur the associated \$2.8 billion per year in capital recovery charges. The avoidance of these costs is the part of the benefit that PVC manufacture brings to consumers. Thus, the total direct and indirect benefits of access to PVC to consumers in the United States and Canada amount to over \$20 billion per year, as shown below.

**Figure 9: Total Economic Benefits of PVC to Consumers in 2007  
(Billion Dollars per Year)**



Source: Whitfield and Associates

Avoiding the additional costs to purchase and install the substitute materials, especially those that are not other thermoplastics or elastomers, accounts for over 85% of the direct benefits in all of PVC's current applications. The remainder of the economic benefit is savings that consumers enjoy due to the lower replacement and maintenance costs of the PVC compared with the substitutes. While most thermoplastic and elastomeric substitutes for PVC are less dense, alternative substitute materials other than wood are not, and the total weight of the substitutes for PVC-containing products is more than double those that they replace. The reduced energy requirements to manufacture and transport vinyl products contribute to the benefits that consumers enjoy from their access to PVC.

### **Blood in a Bag – a PVC Bag**

Before the invention of plastic blood bags, blood was collected in glass bottles. Contamination due to inadequate sterilization and air embolism were common complications. The advent of the plastic blood-collection bag was a significant breakthrough in the history of blood collection and banking. Unbreakable and flexible, these blood bags were also important to the development of ambulatory medicine. The plasticity of blood bags facilitated the separation of blood components and the resilience allowed not only easy transportation but also economical freezing of blood and blood products. Because blood bags were disposable, the external contamination of donated blood was also reduced to unprecedented levels.

Over the past fifty years, PVC's performance and protectiveness have made it a critical material in not just blood bags but other health care products as well, such as intravenous bags, cardiac catheters, and endotracheal tubes. It is optically clearer than most alternative materials, kink resistant, can be radio-frequency (RF) heat sealed, withstands steam sterilization, and resists "necking down." Red blood cells have a longer shelf life when stored in PVC blood bags than in vessels made of alternative materials. And PVC is so tough it can air-dropped onto a battlefield for use by troops on the move.

When PVC is used to manufacture medical devices, a phthalate plasticizer, diethylhexyl phthalate (DEHP), is important for keeping PVC flexible and pliable. However, DEHP has been found to have adverse effects in animals at very high levels of exposure. Although there are very few human data from which to characterize DEHP toxicity, safety concerns over DEHP leaching from PVC blood bags have driven the search for substitute materials in medical devices. Current PVC-free alternatives are metallocene-based polyolefin, polypropylene, polyethylene, polyester, silicone, and ethylene vinyl acetate (EVA). In terms of performance and properties, metallocene-based polyolefin most closely competes with PVC plasticized with DEHP. But non-PVC blood bags are still too costly: they are many times more expensive than PVC blood bags.

Practical options are to prevent DEHP leaching from PVC or to substitute DEHP with another plasticizer. Indian scientists have found that by reacting PVC with sodium sulphide in water with a catalyst, the polymer chains cross-link and lock in the DEHP. When placed in a plasticizer extraction medium such as hexane, the amount of DEHP leaching out over a six month period was negligible. Another option is using an alternative, non-phthalate plasticizer in PVC. Canadian blood operators now use plateletpheresis bags made of PVC plasticized with butyryl-tri-n-hexyl-citrate (BTHC). BTHC is a citrate plasticizer.

*Source: Lakshmi S., Jayakrishnan A. "Properties and performance of sulfide-substituted plasticized poly(vinyl chloride) as a biomaterial" Biomaterials. 2002 Dec; 23(24):4855-62; "Simple treatment makes PVC safer" BBC News. 16 Dec 1998; Czuba, Len, "Opportunities for PVC Replacement in Medical Solution Containers" MD&DI. Apr 1999; Grøndahl Hansen, Ole. "PVC and Phthalates in Medical Devices: A Never Ending Story" Medical Device Technology. Apr 2006; Tickner, J., Hunt, P., Rossi, M., Haiama, N., and Lappé, M. "The Use of Di-2-Ethylhexyl Phthalate in PVC Medical Devices: Exposure, Toxicity, and Alternatives" Lowell Center for Sustainable Production University of Massachusetts Lowell, Mar 2001; "DEHP in Medical Devices: An Exposure and Toxicity Assessment" Health Canada, 24 Apr 2001; Khodayar Rais-Bahrami et al., "Follow-Up Study of Adolescents Exposed to Di(2-Ethylhexyl Phthalate (DEHP) as Neonates on Extracorporeal Membrane Oxygenation (ECMO) Support," Environmental Health Perspectives, vol 112, Number 13, Sep 2004; FDA; Health Canada; Vinyl Institute*