

AN IHS ECONOMICS REPORT

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

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Executive summary

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. PVC is widely used in a variety of applications because of its low cost and desirable physical and mechanical properties. It is fabricated efficiently into a 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 either 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. 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, while replacement, repair, and pumping costs are much higher for the substitute materials relative to PVC pipe. PVC piping systems have provided superior performance, with breakage rates as low as 1% of the breakage rates of cast and ductile iron systems. Furthermore, according to research at Utah State University's Buried Structures Laboratory, PVC pipe can be expected to provide reliable service in excess of 100 years.^[1]

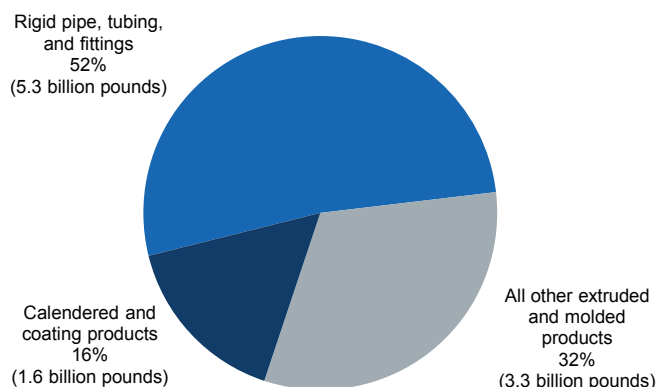
The net cost to consumers in the United States and Canada for the substitution of alternative materials for PVC-based products currently used would be almost \$14 billion per year. In addition to these costs, consumers would be forced to pay additional costs because producers of the substitute materials would need \$3.3 billion in new investment to manufacture the incremental volume of substitute material, and incur the associated \$1.4 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 \$15 billion per year.

1 Steven Folkman, "PVC Pipe Longevity Study," Utah State University, May 2014, p. 7.

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 2014 in the United States and Canada amounted to over 10.2 billion pounds.

Consumption of PVC resin in the United States and Canada, 2014



PVC consumption totaled 10.2 billion pounds

Source: IHS Chemical based on ACC Monthly Statistical Report

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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 compilation of some of the many products made from PVC is presented below.

Some representative products manufactured from PVC

CONSTRUCTION

Piping and fittings for water distribution, irrigation and sewers; grey water recycling kits; electrical conduits; siding, awnings, soffit, skirting, weather stripping, gutters and downspouts; decking and fencing; window, door frames and cladding; landfill liners and geomembranes; swimming pool liners; single-ply roofing; conveyor belts; piping used in food processing, chemical processing and other manufacturing; floor and wall coverings; coated paneling; adhesives; maintenance coatings

MEDICAL & HEALTHCARE

Blood bags and tubing; prostheses; cannulae; caps; catheters; connectors; cushioning products; device packages; dialysis equipment and 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

PACKAGING

Sterile medical packaging; tamper-proofing over-the-counter medication; shrink wrap for software, games, and household products; saran wrap/cling wrap; blister and clamshell packaging to protect toys, hardware, electronics, personal care products, and foods such as eggs and meat; bottles for household and personal care products, cooking oils and automotive lubricants; closures for bottles and jars; can coatings

AUTOMOTIVE

Interior upholstery; "soft" dashboard and 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 and sealants; boots and bellows; battery separators; audio and video components; lighting components; steering cover and transmission parts; A/C system components

ELECTRICAL & ELECTRONICS

Computer housing and cabling; printed circuit board trays; power wire insulation and sheathing; communication cable jacketing; backing for power cable; electrical plugs and connectors, wall plates, connection boxes; soft keyboards; keyboard trays; coating for optical mouse pads; memory stick and USB covers/casings; LED product components; laminate for plastic security passes and "smart cards"; mobile phone casing; vinyl records; wrist watch straps

CONSUMER PRODUCTS & OTHER

Machinery parts; housings and handles for tools; garden hoses; tarpaulins; patio furniture, upholstery; appliance housings; window shades and blinds; table cloths, place mats, shower curtains; sporting goods, beach balls, swimming gear- rafts, arm bands; vinyl leather goods; luggage, footwear, gloves, rainwear; handbags; apparel; coated paper; holiday decorations; toys; credit cards

Source: IHS

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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.^[2] The ability to manipulate its characteristics through selection of the appropriate manufacturing and fabrication processes and the 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. Ninety-four percent 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 that are 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 primarily for rigid applications such as construction products and blow molded bottles.

The PVC-containing products that consumers use every day are always produced from mixtures of PVC resin that have been compounded with other materials, sometimes 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, ortho-phthalate plasticizers 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, blown film processing, and cast film. 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 extruder which typically contains two screw-like shafts. The shafts are 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.

² PVC's principal ingredients are chlorine (derived from salt) and ethylene (derived mostly from natural gas liquids or alternatively from petroleum refinery streams).

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, then is 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 such as dishwasher racks and tool handles.

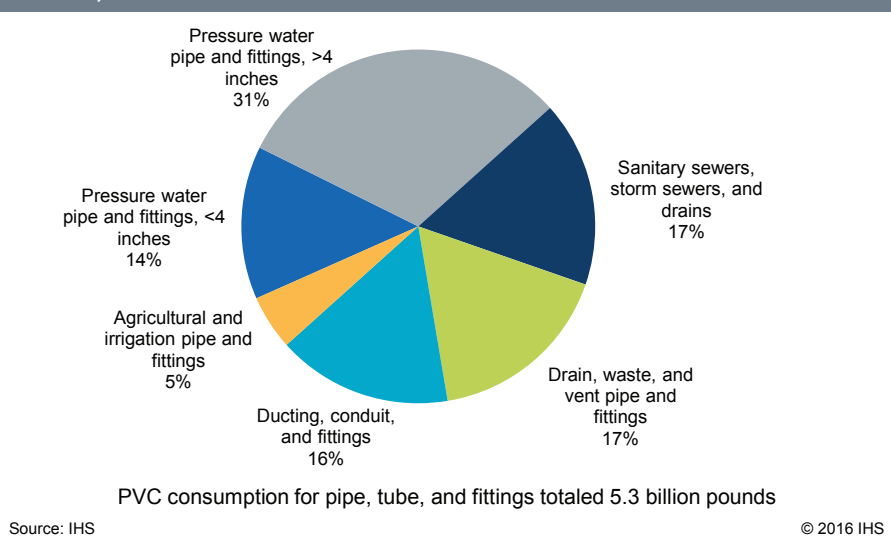
Production of PVC resin in North America takes place in large, efficient plants. The United States historically has been a large net exporter of PVC resin. In 2014, PVC exports from the US and Canada reached 4.5 billion pounds. We estimate that net exports currently amount to over 30% of resin production. During 2014, the distribution of PVC resin exports from the US was 36% to the Middle East and Africa, 31% to Latin America, 16% to Canada, 10% to Asia Pacific, and 7% to the rest of the world. In regards to US and Canadian imports, the largest segment is PVC wall coverings from China and Korea. This area has seen significant growth of over 30% since 2007.

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 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.

PVC rigid pipe, tubing, and fittings

More than 70% of PVC resin consumption is tied to building and 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 52% 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 48 inches in diameter, as well as sewage and drain pipe that is nearly six and a half feet in diameter and the fittings necessary to assemble piping systems, pipe for drain, waste and

Consumption of PVC pipe, tubing, and fittings in the United States and Canada, 2014



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.

PVC pressure water pipe of less than 4 inches in diameter

PVC pressure water pipe less than 4 inches 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 (CPVC) to provide improved mechanical properties when handling hot water.^[3] 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 costs relative to copper or 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. The labor costs involved with the fusion of HDPE pipes also causes the connection costs to be greater than for PVC pipes. Higher cost cross-linked polyethylene (PEX) is required to handle hot water under pressure.

PVC pressure water pipe of greater than 4 inches in diameter

PVC pressure pipe has captured a significant share of the buried pressure water pipe market in diameters greater than 4 inches.^[4]^[5] Longer life, lower maintenance, ease of installation, and reliability in service are the primary reasons for PVC pipe prominence.^[6] Historically, first 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, plus the costs of leak detection and pipe repair and replacement.^[7] PVC piping systems have provided superior performance, with breakage rates as low as 1% of the breakage rates of cast and ductile iron systems. Furthermore, PVC pipe can be expected to provide reliable service in excess of 100 years as evidenced by "dig-up studies of PVC pipe materials around the world report no degradation after decades of operational service."^[8] Empirical research on water main break rates at Utah State University found that PVC pipes have the lowest overall failure rate compared with these other materials.^[9] 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,

Major substitutes for PVC pipe, tubing, and fittings in the US and Canada, 2014

PVC application	Major substitutes
Pressure water pipe and fittings, <4 inches	PE, Steel, Copper
Pressure water pipe and fittings, >4 inches	Ductile Iron, Concrete, PE
Sanitary sewers, storm sewers, and drains	Concrete, Ductile Iron, PE, ABS
Drain, waste and vent pipe and fittings	ABS, PE, Aluminum
Ducting, conduit, and fittings	Steel, PE, ABS
Agricultural and Irrigation pipe and fitting	PE, ABS, Aluminum

Source: IHS

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3 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.

4 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.

5 "Buried No Longer: Confronting America's Water Infrastructure Challenge," American Water Works Association, 2012.

6 Baird, Gregory M., "Reforming Our Nation's Approach to the Infrastructure Crisis: How Competition, Oversight, and Innovation Can Lower Water and Sewer Rates in the U.S." National Taxpayers' Union, Alexandria, VA, April 2013.

7 "When Performance Counts," Uni-Bell PVC Pipe Association, publication 2010.

8 Folkman, "PVC Pipe Longevity Study," op cit., p. 7

9 Steven Folkman, "Water Main Break Rates in the USA and Canada: A Comprehensive Study," Utah State University, April 2012.

PVC does not form the scaly deposits that constrict water flow. A buildup of rough scaly deposits of a modest 0.1 inch 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 of its lower strength, 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. Reinforced concrete pipes, known as RCPs, 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.^[10]

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 – concrete and corrugated polyethylene 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 normally constrained only by the requirement that the material be stiff enough and have sufficient strength to support itself between support points. Acrylonitrile butadiene styrene (ABS), an alternative to PVC pipe, has reasonably good strength and slightly lower specific gravity than PVC resulting in comparable material and installation costs.^[11] 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 DWV 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.

10 "Buried Pipe Markets in North America, 1999-2004," report to members of the Uni-Bell Pipe Association.

11 ABS, or acrylonitrile butadiene styrene, is a common plastic used to make light, rigid, molded products like pipe.

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.

Rigid PVC construction materials

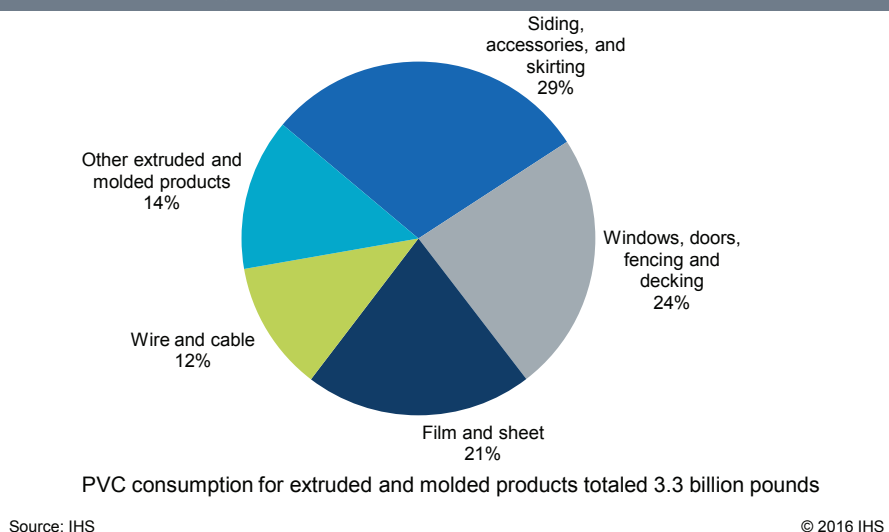
Siding, siding accessories, and skirting are major consumers of PVC resin.^[12] Even though its share of the new, single-family housing market in the US shrunk by 8% from 2004 to 2014, vinyl siding still remains the number one choice of exterior cladding in the US and Canada, with 30% of the new single-family houses built in 2014 utilizing it. Vinyl siding faces competition for market share with other materials, such as brick, stucco, fiber cement, and wood.^[13]

The choice of siding material is made primarily on local preferences plus performance properties, cost, maintenance, and aesthetic considerations. However, it varies

regionally and by the size and cost of the structure. For example, vinyl siding has a larger market share and growth rate in the Northeast and Midwest than in the South and West. With its ability to resist temperature changes and moisture, in addition to its ability to withstand high winds, vinyl siding retains its original appearance and performance capabilities over time. Vinyl siding is the number one choice for new single-family homes at price points up to \$500,000.

The share of exterior walls in residential construction sided in brick and stucco are second after PVC, at roughly 25% each. These materials are costlier to install and weigh far more than the alternatives, particularly brick, but regional differences dictate material selection. The share of brick siding on new houses is highest in the South, where it is a local material which may provide some cost advantages. According to the Annual Brick Industry Report, over 75% of brick shipments come from the South/Southeast, which is also the largest destination. Besides its regional logistical advantages, the physical properties of brick – for example, the ability to withstand high winds and provide an effective water barrier – contribute to its relatively high market share. The West favors 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.

Consumption of other PVC extruded and molded products in the United States and Canada, 2014



Major substitutes for other PVC extruded and molded products in the US and Canada, 2014

PVC application	Major substitutes
Siding, accessories, and skirting	Stucco, Brick, Fiber Cement, Wood
Windows, doors, fencing and decking	Wood, Aluminum, Fiberglass, Composites
Film and sheet	PE, other plastics and elastomers
Wire and cable	PE, PP, TPE
Other extruded and molded products	PE, PP, TPE, ABS, PET, other plastics and elastomers

Source: IHS

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¹² Skirting material provides a border running along the edge or corners of a building or room.

¹³ US Census Bureau, Manufacturing, Mining, and Construction Statistics, Characteristics of New Housing Sold, Exterior Wall Material, 1992-2014.

Approximately 36 million windows with PVC framing are installed annually in new construction and in replacement projects in existing structures in the US and Canada. Almost twenty years ago, vinyl windows only accounted for 36% of the residential window market. By 2012, vinyl window market share grew to 68%. While vinyl windows are the material of choice overall, their market share is greatest in the residential replacement sector at approximately 73%. Aluminum windows have historically been losing share steadily to PVC in the residential market, but recently, aluminum actually saw an increase in demand in new construction market; however, the decline continues in the replacement sector.^[14] Window selection also has a regional component. For example, selection of impact-resistant aluminum windows has grown in appeal over the years in areas prone to hurricanes and high winds like the Southeast or Gulf Coast due to resistance to impact, structural pressure, and air and water leakage. PVC has 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. Due to its strength and durability, fiberglass is growing in popularity for entry and patio doors. The American Architectural Manufacturers Association (AAMA) in conjunction with the Window and Door Manufacturers Association (WDMA) in their US National Statistical Review and Forecast Report estimate that fiberglass doors grew 55% from 2009 to 2015 and totaled 4.5 million units in 2015.^[15]

PVC fencing and decking have been gaining market share against the traditional galvanized steel and wood products because they are 1) more resistant to attack by the elements, 2) have an extended service life, 3) require reduced maintenance, and 4) demonstrate 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 costlier than common lumber. As is the case in siding and windows, regional differences tend to dictate which material is used.

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 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.^[16]

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.

14 American Architectural Manufacturers Association, 'Vinyl Windows: An Impressive Growth History', 2013.

15 AAMA/WDMA US National Statistical Review and Forecast, 2014/2015.

16 The most important electrical properties of polymers are volume resistivity, dielectric constant and dielectric strength, dissipation factor, and arc resistance.

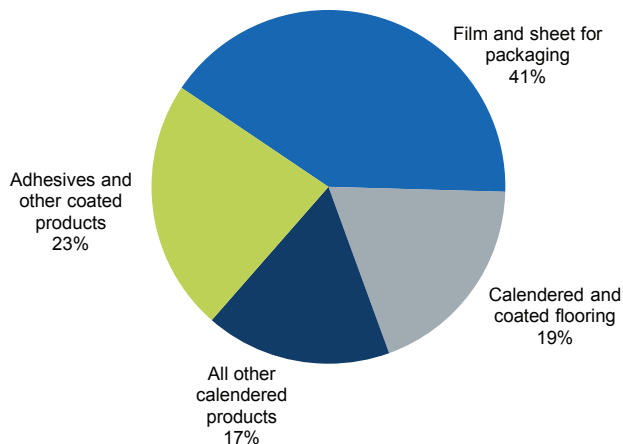
Calendered and coating products

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.

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, stretch wrap packaging for others goods, 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 other thermoplastics yet is has maintained a dominant position in meat wrap since it preserves the freshness of meat longer.

Consumption of calendered and coating products in the United States and Canada, 2014



PVC consumption for calendered and coated products totaled 1.6 billion pounds

Source: IHS

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Major substitutes for calendered and coating products in the US and Canada, 2014

PVC application	Major substitutes
Film & sheet for packaging	PE, PP, other thermoplastics
Calendered & coated flooring	Carpeting, Laminates, Ceramics, Engineered wood, Hardwood
All other calendered products	PE, Urethanes*, Silicones*, other plastics
Adhesives & other coated products	Urethanes, TPE, Silicones, other plastics and elastomers

Source: IHS

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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.

Substitution summary

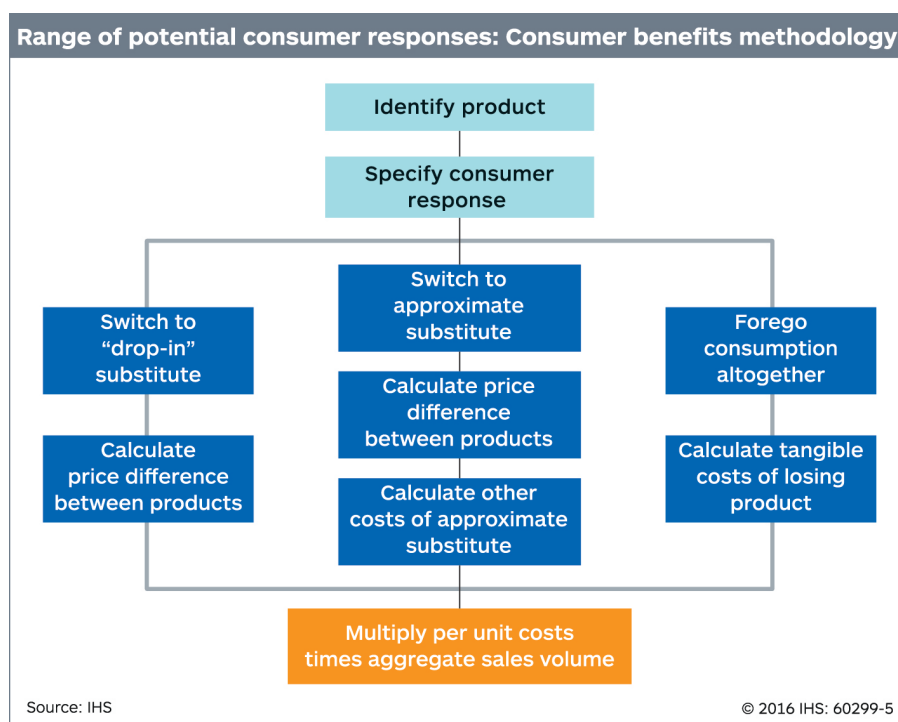
In this section, we examine the wide range of applications for PVC-containing products – rigid pipe and tubing, all other extruded and molded products, and calendered and coating products. The majority of these products go into construction applications. However, significant volumes also go into automotive, electrical/electronic, packaging, and medical/healthcare applications. The key finding is 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 market share, 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 prefer them over 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.

The economic benefits of polyvinyl chloride to consumers^[17]

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 PVC-containing 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.

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, and 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



¹⁷ All economic benefit estimates in the sections below apply to consumers in the United States and Canada.

initial prices of the products. Differences in product prices could result from differences in the costs of the raw materials used, in the costs of converting them into the finished products, and in the costs 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 costlier 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, however, the additional consumption of the substitute materials required investments to provide new production capacity, 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 US and Canada of PVC used in the production of rigid pipe, tubing, and fittings is estimated to be \$7.4 billion per year, with over 50% of the benefits arising from the use of PVC small and large diameter pressure water pipe.

The highest benefit per pound of PVC is found in small diameter pressure water pipes and fittings. In order to meet the more rigorous performance requirements for this application, cross-linked polyethylene (PEX) – which is stronger than standard polyethylene – must be used. Other substitutes include copper and steel, but they are generally more expensive to purchase and install than PVC pipe. In these systems, the cost of installation can be as much as ten times the cost of the pipe itself, so even small differences in the ease of installation can result in large differences in the total cost of using a substitute material instead of PVC.

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 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, ducting and conduit, and in agricultural and irrigation system applications as 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. Ducting, conduit, & fittings substitution costs are relatively higher as some market share is taken by steel.

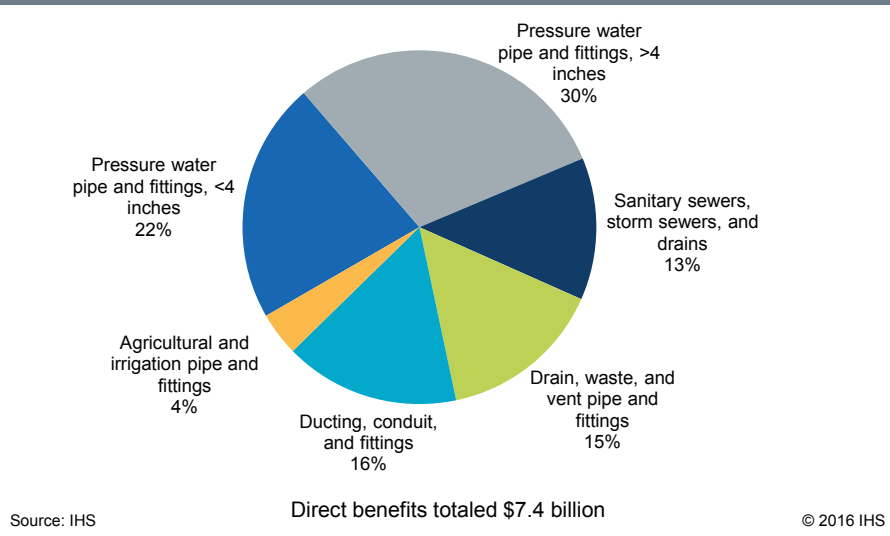
Overall, we estimate that about 60% of the total increase in cost to substitute these materials in piping systems that now use PVC pipe and fittings is due to the increased materials costs for the substitutes. About 27% is due to the increased costs of installing them and about 13% is due to the increased costs due to more frequent replacement, maintenance and repair requirements relative to PVC piping systems.

Economic benefits of all other extruded and molded PVC products

The economic benefit to consumers in the US and Canada for all other extruded and molded products is estimated to be nearly \$5.4 billion per year with over 45% of the benefits arising from the use of PVC siding, accessories, and skirting.

Although the installed costs of brick, stucco, and stone are much higher than the costs of PVC siding, their share of building material siding has been growing for aesthetic and other reasons. Polyethylene, and perhaps other thermoplastics, could be substituted for PVC in such areas as soffits and skirting. We estimate that over 60% of the total PVC consumption for siding, accessories, and skirting would be substituted by brick, stucco, and stone with higher shares in the South and West. 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 West, and wood's share higher in the Midwest, Northeast, and Canada.

Direct benefits of PVC pipe, tubing, and fittings in the United States and Canada, 2014



Direct benefits of PVC pipe, tubing, and fittings in US and Canada, 2014

PVC application	Direct benefits, \$/lb of PVC resin
Pressure water pipe and fittings, <4 inches	2.18
Pressure water pipe and fittings, >4 inches	1.31
Sanitary sewers, storm sewers, and drains	1.03
Drain, waste and vent pipe and fittings	1.22
Ducting, conduit, and fittings	1.46
Agricultural and Irrigation pipe and fitting	1.13

Source: IHS

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Since higher cost brick, stucco and stone are the major substitutes for PVC siding, close to 70% of the estimated increase in cost would come from the substitution of these materials for PVC siding, and about another 25% would be from the substitution of fiber cement and wood. Although replacement and maintenance costs can be higher for some of the substitutes relative to 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.

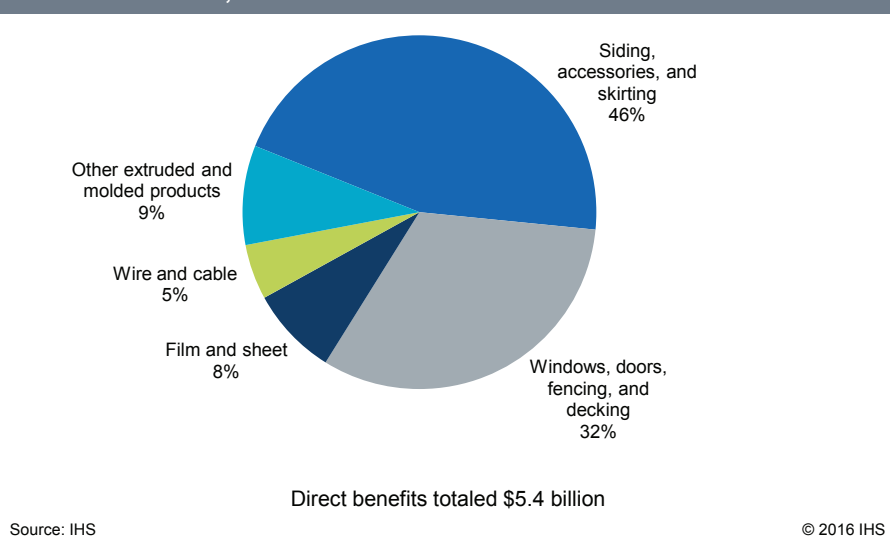
The most important substitute for PVC in windows, doors, fencing and decking applications is wood. However, increasing amounts of composite materials are being used in windows, doors, decks and fencing. Aluminum has gained market share in windows and doors in recent years. Doors and windows are installed as units with their framing and glass included. The installed cost differences that arise solely from differences in the choice of construction materials 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. It is to be noted that aluminum windows are conductive and bring unwanted heat or cold from the outside to the inside of the structure. Therefore, aluminum windows are often constructed with “thermal breaks” to compete with vinyl windows for energy efficiency, adding to their total cost. 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 materials and fabrication costs of PVC that provides most of the consumer benefits. Higher cost aluminum and thermoplastics used in composites also contribute to the higher direct benefit in this segment.

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 calendered and coating products. Around 400 million pounds of PVC was used in medical applications in 2014. In fact, about 20% of the medical plastics and over 50% of all disposable medical goods are made

Direct benefits of all other extruded and molded PVC products in the United States and Canada, 2014



Direct benefits of all other extruded and molded PVC products in US and Canada, 2014

PVC application	Direct benefits, \$/lb of PVC resin
Siding, accessories, and skirting	2.49
Windows, doors, fencing and decking	2.21
Film and sheet	0.65
Wire and cable	0.71
Other extruded and molded products	1.11

Source: IHS

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from PVC. PVC is the medical material of choice since it is transparent, durable, easily sterilized, and flexible without kinking. Examples of medical applications include blood bags and tubing, intravenous containers and components, catheters, dialysis equipment and tubing, ear protection, inflatable splints, oxygen delivery components, surgical wire, thermal blankets, and gloves.

A significant volume 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, 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.

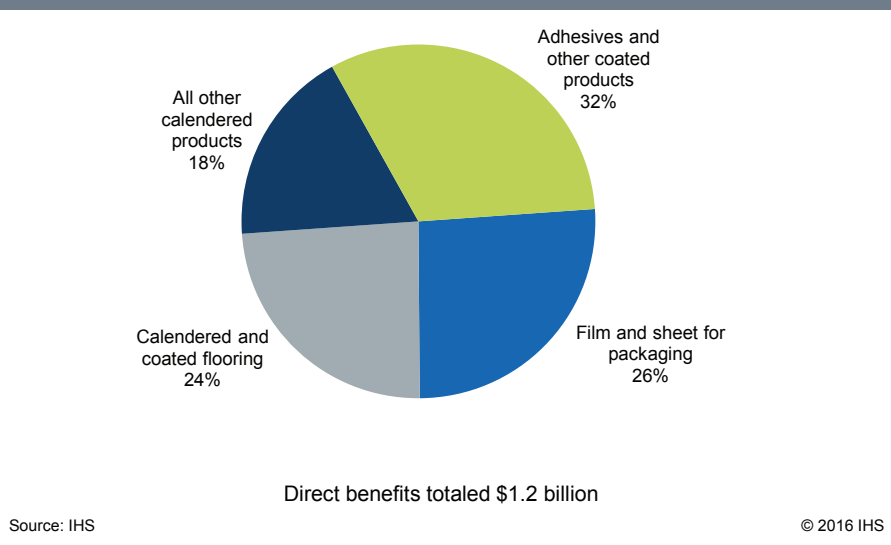
For over half a century, PVC's performance and protectiveness have made it a critical material in numerous medical applications, such as intravenous bags, cardiac catheters, extracorporeal membrane oxygenation support, and endotracheal tubes. It is optically clearer than most alternative materials, kink resistant, radio-frequency (RF) heat sealable, 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 \$0.3 billion per year.

Economic benefits of PVC in calendered and coating products

The economic benefit to consumers in the US and Canada for PVC in calendered and coating applications is estimated to be \$1.2 billion per year.

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 since they are 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.

Direct benefits of PVC in calendered and coating products in the United States and Canada, 2014



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 costlier 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.

Direct benefits of calendered and coating products in US and Canada, 2014

PVC application	Direct benefits, \$/lb of PVC resin
Film and sheet for packaging	0.47
Calendered and coated flooring	0.93
All other calendered products	0.77
Adhesives and other coated products	1.01

Source: IHS

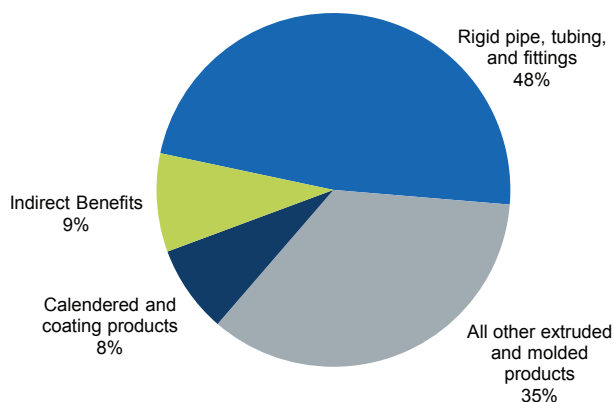
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Summary of economic benefits

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 \$14 billion 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 \$3.3 billion in new investment to manufacture the incremental volume of substitute material, and incur the associated \$1.4 billion per year in capital recovery charges. The avoidance of these costs is 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 \$15 billion per year, as shown below. If we examine these total benefits more closely, US consumers would receive economic benefits of \$13.7 billion per year and Canadian consumers \$1.6 billion.

Avoiding the additional costs to purchase and install the substitute materials, especially those that are not other thermoplastics or elastomers, accounts for almost 90% 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 PVC compared with its 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.

Total economic benefits of PVC to consumers in the United States and Canada, 2014



Direct and indirect economic benefits of PVC totaled \$15.4 billion

Source: IHS

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From blood bags to the Ebola epidemic

In the early years of blood transfusions, donations were collected in glass bottles. Today, donated blood is collected into specially designed polyvinyl chloride (PVC) plastic bags/packs. The move from glass to plastic significantly improved the viability of donor banks, extending the shelf life of blood donations and decreasing bacterial contamination. The integrity and sterility of blood bags is of critical importance to patient safety.

The role of flexible vinyl and other plastic-based products has been crucial to virus containment efforts. Those products include isolation suits, chambers and gowns, goggles, masks, hair covers, filters, helmets and hoods for both isolation and healthcare worker protection. Disposable gloves, shoe covers, utensils, meal trays, trash bags, and burial bags are all constructed using flexible PVC. In addition, fluid bags and blood bags are made predominantly from flexible PVC.

The importance of plastics in disposable medical equipment was dramatically underscored during the recent outbreak of the deadly Ebola virus in Western Africa. The TV news was filled with striking scenes of doctors and nurses striving to deal with the outbreak while protecting them from exposure. They were all covered virtually from head to foot in a variety of plastic materials which are the ideal material for personal protection from contagious agents.

Though the worst of the epidemic seems to have passed, the US Centers for Disease Control and Prevention (CDC), our nation's lead public health agency, continues a major effort to deal with isolated pockets of the disease and to prevent another outbreak.

Source: Plastics Market Watch: Healthcare and Medical Devices, Society of the Plastics Industry, Fall 2015. <http://www.cdc.gov/vhf/ebola/outbreaks/2014-west-africa/case-counts.html>