# The Economic Contributions of Formaldehyde in Building & Construction

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## Executive Summary

The American Chemistry Council's Economics and Statistics Department conducted research to explore the role of formaldehyde in the building and construction industry. This report presents the findings of that research and describes the essential role that formaldehyde has in supporting the broader US economy and specifically, the building and construction industry. The economic contributions of formaldehyde are substantial and extensive.

In the US, about two-thirds of formaldehyde is consumed by the building and construction sector. The economic contributions of formaldehyde to that sector go well beyond the advantages of formaldehyde compared to possible substitute materials or applications. The products used in the building and construction sector that contain formaldehyde already generate nearly 90,000 direct jobs. Formaldehyde is essential to the production of many products used throughout building and construction.

Opportunity costs were estimated and used to quantify the benefits of using formaldehyde products instead of alternatives. This approach better reflects the consumer benefits that arise from the properties of formaldehyde in these applications that allow products to be manufactured at lower relative costs while providing greater utility to consumers in the form of longer service life (durability), enhanced performance, and in some cases more aesthetically-pleasing design. The economic benefit of using formaldehyde-derived products in building and construction, in total, range from a conservative $1.16 billion to as much as $8.33 billion per year.

The manufacture of formaldehyde-based building and construction products directly supports more than 100,000 direct jobs in industries, panel products such as plywood, roofing shingles, insulation, laminate countertops and flooring, adhesives, coatings, plumbing fixtures, and electrical components. Including indirect jobs supported by these industries' supply chains and induced jobs supported by the household spending of workers; more than 400,000 jobs are supported by the production of formaldehyde-based products used in building and construction. In total, these jobs generate $21 billion in annual salaries and wages. The jobs and businesses supported by formaldehyde-based products manufacturing also produce tax revenue. Federal taxes on payrolls, households, and corporations yield about $4.4 billion per year. On a state and local level, $3.1 billion per year is generated. In total, through direct, indirect, and induced effects, the formaldehyde industry generated a total of $79 billion in output.



This report was prepared by ACC's Economics and Statistics Department.

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# Section I

## Introduction

The formaldehyde value chain includes the flow of formaldehyde and its derivatives from production to end-use products containing formaldehyde as material input. This report examines the benefits of formaldehyde and formaldehyde-derivatives to the building and construction sector in the United States. In addition, it quantifies the economic contributions of businesses producing and using formaldehyde-derivatives in construction-related applications.

## What is Formaldehyde?

Formaldehyde is the simplest aldehyde and from a commercial viewpoint, the most important aldehyde. It exists as a colorless gas at room temperature and is soluble in water, alcohol and other polar solvents. The concentrations in which formaldehyde is produced, consumed and traded may vary. The data on formaldehyde in this report are presented on a 37% basis[1] unless specified otherwise.

Formaldehyde is produced from methanol by either: 1) dehydrogenation-oxidation using a stationary bed silver catalyst; or 2) catalytic oxidation using a metal oxide (iron-molybdate) catalyst.

1) Silver Catalyst Process

$$CH_3OH \longrightarrow HCHO + H_2$$

Methanol → Formaldehyde + Hydrogen

2) Metal Oxide Process

$$CH_3OH + 1/2O_2 \longrightarrow HCHO + H_2O$$

Methanol → Formaldehyde + Water

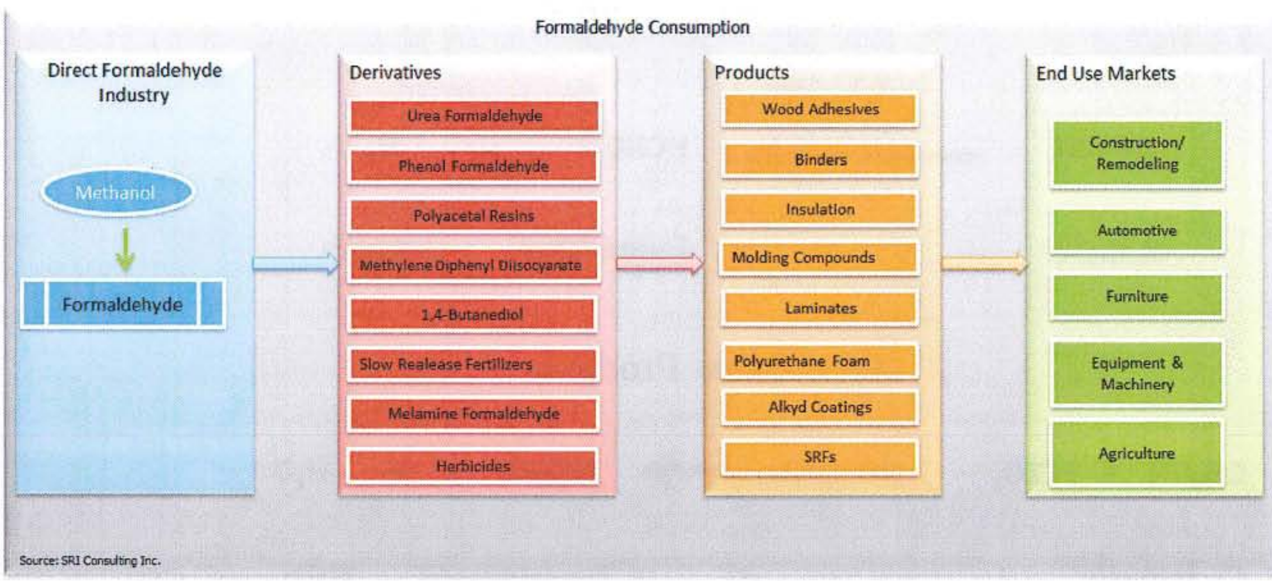
[1] 37% basis implies an aqueous solution containing 37% formaldehyde by mass

Based on data from SRI Consulting, in the United States formaldehyde is produced by 12 companies operating 37 plants in 18 states. Most of the formaldehyde produced is for captive use and for the local market. The transportation costs for formaldehyde are high and, in addition, formaldehyde is not stable over a long period of time. Even with the addition of methanol as a stabilizer (inhibited formaldehyde), formaldehyde polymerizes. Polymerization can be prevented by maintaining elevated temperatures in the bulk liquid; however, this results in degradation of formaldehyde to methanol and formic acid. As a result of these challenges, formaldehyde is not shipped over long distances and thus, there is very little international trade of formaldehyde.

## Formaldehyde Derivatives

Almost all formaldehyde is combined with other compounds to produce formaldehyde derivatives. These derivatives include thermoset resins such as urea-formaldehyde and phenol formaldehyde as well as other compounds such as herbicides and chelating agents. In the United States, 60-70% of total formaldehyde is consumed by the construction and remodeling sector to manufacture synthetic plastic resins, primarily urea-, phenol-, and melamine-formaldehyde resins used as adhesives and insulation in building and construction application. Other uses for these resins include molded parts in the appliance, electronics, furniture, and light vehicle industries. Formaldehyde is also used as an intermediate for the production of rigid and other polyurethane foam and for the production of butanediol and other intermediates to manufacture adhesives, biocides, disinfectants, elastomers, plastic resins, preservatives, and solvents. A wide variety of other uses exist as well.

**Figure 1: Formaldehyde Consumption**



## Overview of the Building and Construction Industry

In the US, 60-70% of formaldehyde is consumed by the construction and remodeling sector. The building and construction sector represents a large share of the US economy, totaling more than $800 billion in 2010 and accounting for nearly 7% of US Gross Domestic Product (GDP). Though the composition of construction spending varies from year to year depending on economic trends, each segment accounts for roughly a third of the total. The residential segment includes new single-family and multifamily buildings in addition to remodeling and improvement activity. Private nonresidential spending includes commercial and office space, hotels, hospitals, manufacturing facilities, and other types of privately-funded nonresidential structures. Public construction spending is funded by taxpayers. The largest categories of public construction spending are roads and schools. The entire construction sector employed nearly 6 million people in 2010, down by 25% from the peak in 2006.

**Figure 2: US Construction Spending (2010)**

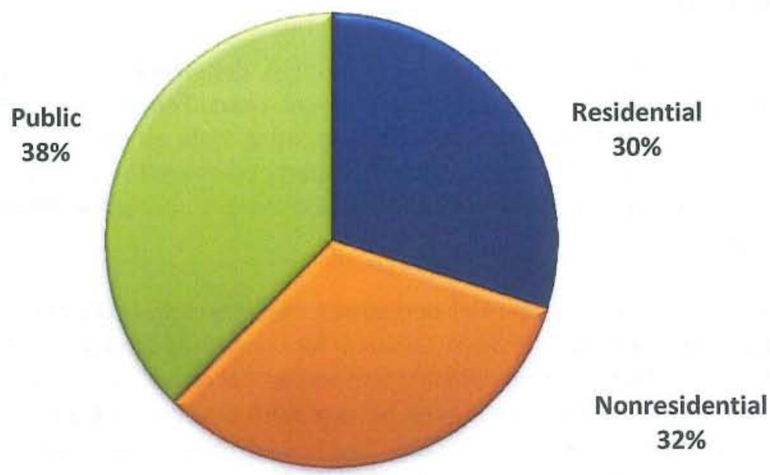



**Figure 3: US Construction Spending**


Source: Census Bureau

Each segment has its own dynamics and cycles. During normal economic times, residential housing is driven by household formation, income, and the cost of borrowing. The recent protracted downturn in homebuilding resulted from the collapse of the housing boom fueled by low interest rates, lax lending standards, and distorted incentives across homebuyers, lenders, and investors. This resulted in dropping home values and a surge in home inventories due to foreclosures. Years after the peak in 2006, new homebuilding remains at historically low levels. In time, however, the imbalances will clear and the housing market will return to its normal fundamentals.

Private nonresidential construction spending is driven by growth in GDP and the cost of borrowing. With a lag, commercial and retail construction is also driven by expansion of residential construction. As housing developments are built, they are soon followed by retail and commercial building and ultimately by other types of nonresidential construction. The nonresidential construction sector, in particular, is prone to boom and bust cycles. Rapid expansion in nonresidential construction leads to overbuilding and then long periods with slow activity as the overhang is absorbed.

Public construction spending is funded by the tax payers and is dependent on tax receipts. Most public construction is funded by state and local governments. In recent years, Federal stimulus from the American Reinvestment and Recovery Act (ARRA) has partially offset declining state and local tax receipts. Sales taxes generate more than half of state government revenues and property taxes are the primary source of funding for most local governments. Both of these revenue sources dropped sharply during the recession as home values fell and consumer spending weakened.

For manufacturers of formaldehyde and its first-tier derivatives, the residential construction sector is the most important. In a typical year, the residential segment accounts for two-thirds of plywood and engineered wood used in building and construction. Further, homebuilding and residential remodeling account for the majority of laminates demand (for countertops and flooring) as well. Sales of both new and existing homes spur demand for furniture, another important end-use for formaldehyde. The use of formaldehyde derivatives in furniture is discussed in a forthcoming ACC report, "The Economic Contributions of Formaldehyde in Furniture."

## Formaldehyde-Based Products Used in Building and Construction

The economic contributions of formaldehyde to the building and construction sector go well beyond the advantages of formaldehyde compared to possible substitute materials or applications. The products used in the building and construction sector that contain formaldehyde already generate nearly 90,000 direct jobs. Formaldehyde is essential to the production of many products used throughout building and construction.

Building and construction applications (including remodeling activities) account for two-thirds of total US formaldehyde consumption. In addition to urea-, phenol-, and melamine-formaldehyde resins, the building and construction market also includes polyacetal resins and various products derived from 1,4-Butanediol (BDO), methylene diphenyl diisocyanate (MDI), pentaerythritol, and hexamethylenetetramine (HTMA). Other formaldehyde-based products include pentaerythritol, neopentyl glycol and trimethylolpropane used mainly in alkyd and polyester resins for surface coatings.

Demand for formaldehyde-derivatives in construction materials is driven by trends in housing, remodeling, and nonresidential building. Since the housing crisis began in 2006, housing starts have fallen to a fraction of their peak level. Lower home valuations have curbed remodeling activity and new nonresidential projects declined as well. As a result, sales of formaldehyde-derived construction materials has declined substantially in recent years. When the housing imbalances are worked through and the housing sector recovers, demand for these materials is expected to increase.

***Plywood and engineered wood products*** - One of the most important uses of formaldehyde derivatives is as binders and adhesives in the manufacture of plywood, oriented strandboard (OSB), particleboard, fiberboard and other engineered wood products. These basic building materials are found in nearly all structures. Phenolic formaldehyde resins are used to bind softwood plywood used in framing.

Generally, products made with urea-formaldehyde UF resins are used in interior applications while phenolic resins are suitable for exterior applications. UF resins are used to make particleboard and medium density fiberboard (MDF) which are predominantly used in cabinets, vanities, moldings, interior doors, shelving, flooring substrate, etc. UF resins are also used to produce hardwood plywood products used for moldings. Methylene diphenyl diisocyanate (MDI) resins are also used as binders.

***Roofing shingles*** – Urea-formaldehyde resins are used to bind glass fibers together which are then coated with asphalt. Glass fiber roofing mats are the predominant roofing material and are used in shingles and roll roofing systems for residential and commercial buildings.

***Urethane foam insulation*** – MDI is used in rigid foam insulation in both residential and non-residential buildings.

***Flooring laminates*** – Low cost, durable flooring laminates come in many decorative designs and are used in residential and commercial spaces. Melamine-formaldehyde and phenol-formaldehyde resins are used in these applications.

***Laminate countertops*** – Laminate countertops for kitchens, bathrooms, etc. continue to maintain solid market share due to their relatively low cost. Melamine-formaldehyde resins are widely used in these applications to bond the decorative coating to a paper or cloth backing. Phenol-formaldehyde resins are also used. UF adhesives are used to adhere laminates to cabinetry.

***Electrical components*** – Polyacetal and urea-formaldehyde resins are used to make molded plastic components for electrical applications, such as switches and circuit breakers.

***Other laminates*** – Other laminates include paneling and laminated shelving or work surfaces in commercial/retail applications.

***Architectural coatings*** – Formaldehyde is used indirectly (via pentaerythritol) in the production of alkyd resins used in architectural surface coatings, primarily used in exterior applications.

***Plumbing fixtures*** – Polyacetal resins are extremely durable and are used in a variety of plumbing applications where durability of mechanical parts is critical.

***Adhesives and Sealants*** – Formaldehyde is also used indirectly (via 1,4 butanediol) to produce polyurethane adhesives and sealants used at the construction site to bond roofing materials to substrates, adhere plastic or foam insulation panels to a frame, etc. MDI is also used in polyurethane adhesives. For the purposes of this analysis, to avoid double counting, adhesives and binders used to produce derivative products, such as plywood or laminates are counted in those applications.

The use of formaldehyde-based products is pervasive in building and construction of all types. The construction sector depends on these types of products and the utility they provide. As discussed below, the use of formaldehyde and its derivatives is essential to making strong, durable building products at the least cost.

# Section II

## The Economic Contributions of Formaldehyde-Based Products to Consumers

The economic benefits of a product can be measured and is related to the concept of opportunity costs, a key concept in economics. Opportunity costs represent the real cost of output (or use) forgone, lost time, or any other benefit that provides utility to the consumer or user. Opportunity cost is the cost of any activity measured in terms of the value of the next best alternative that is not chosen (that is foregone). It is the sacrifice related to the second best choice available to the consumer or user. As related to this analysis, the opportunity costs of choosing the next best alternative (or substitute) are actually the benefits of using the product currently being used. Thus, the economic benefits are the savings that occur when the product is used compared to its next best alternative, or substitute.

This analysis uses the concept of opportunity costs to measure the benefits of formaldehyde. The analysis employs an innovative and robust methodology that is based on this economic concept and employs engineering, technical, and economic analysis. The economic benefits provided by formaldehyde-based products reflect the net dollar value of the savings that consumers enjoy by using them instead of substitutes. That is, consumer savings are the increased costs that consumers would have to bear if access to formaldehyde-based products now enjoyed were eliminated. Benefits arise from properties of formaldehyde in these applications that allow products to be manufactured at lower costs relative to substitutes as well as providing greater utility to consumers in the form of longer service life (durability), enhanced performance, and in some cases more aesthetically-pleasing design. Table 1 summarizes the opportunity costs of using formaldehyde-derived products in building and construction. That is, their economic benefits.

**Table 1: Economic Benefits of Using Formaldehyde-Derived Products in Building and Construction (Millions of US dollars)**

| | Benefits | |
|---|---|---|
| | Low | High |
| **Urea-Formaldehyde** | $440 | $1,622 |
| **Phenol-Formaldehyde** | $596 | $5,846 |
| **Polyacetal Resins** | $35 | $48 |
| **1,4-Butanediol (BDO)** | $1 | $2 |
| **Methylene Diphenyl Diisocyanate (MDI)** | $38 | $265 |
| **Pentaerythritol** | $4 | $47 |
| **Melamine-Formaldehyde** | $52 | $487 |
| **Hexamethylenetetramine (HTMA)** | $3 | $4 |
| **Other** | $7 | $9 |
| | | |
| **Total – Building & Construction** | **$1,177** | **$8,329** |

Substitutes to formaldehyde-derived products in building and construction applications are manifold and include alternative binder chemistries as well as completely differing systems. In total, the economic benefit of formaldehyde used in building and construction applications range from $1.16 billion to $26.48 billion per year. By far, the major areas where the economic benefits are highest include phenol-formaldehyde applications such as softwood plywood, oriented-strand board (OSB), other wood products, insulation, foundry materials, laminates, and abrasives; urea-formaldehyde applications such as medium-density-fiberboard (MDF), particleboard, roof shingles, hardwood plywood, surface coatings, and molding compounds for electrical components; and melamine- formaldehyde applications such as laminates and wood adhesives. Other uses include polyacetal resins, 1,4-Butanediol (BDO), methylene diphenyl diisocyanate (MDI), pentaerythritol, hexamethylenetetramine (HTMA), and other products and applications.

The following is a review of the use of formaldehyde-derived products, their advantages and disadvantages, potential substitutes, and estimates of the opportunity costs, or economic benefits.

## Urea-Formaldehyde

About 2.0 billion pounds of formaldehyde is used in the production of UF resins, 24% of the total formaldehyde consumption. Urea-formaldehyde (UF) is a thermosetting polymer produced by a series of condensation reactions between formaldehyde and urea. UF resins are commodity resins used mainly as adhesives for particleboard and MDF. Compared to phenol-formaldehyde (PF) resins, UF resins are less expensive, light in color, faster curing and provide superior hardness and arc resistance. However, UF resins are less durable, are not water resistant, tend to break down in hot and cold water and have less resistance to a variety of chemicals. As a result, interior applications account for most consumption of UF resins. UF resins provide significant economic benefits in building and construction. Major building and construction applications for UF resins include medium-density fiberboard (MDF), particleboard, roof shingles, hardwood plywood, and molded electrical parts.

***Medium-density-fiberboard (MDF)*** is an engineered wood product formed by breaking down hardwood or softwood residuals into wood fibers, combining them with a resin binder, and forming panels by applying high temperature and pressure. MDF is made up of separated fibers (not wood veneers) and competes against plywood and particleboard as it is stronger and denser. About 1.42 billion square feet of MDF are produced every year, MDF represents a major 420 million pound per year market for UF resins. These resins offer low price, physical characteristics and fast cure time. MDF is primarily used as a core stock for furniture and case goods, in such products as doors, jambs and millwork, edge shaping and machining, embossing, laminate flooring, laminating and finishing, molding, office and residential furniture, paneling, store fixtures, and kitchen cabinets. Furniture applications predominate but nearly 25% of MDF is used in building and construction. MDF competes against particleboard, solid lumber, and veneer cores and provides better binding strength and stillness, a smooth surface, tight edges, and compared to particleboard greater moisture resistance and less swelling or shrinking.

Alternatives to UF resins include soy- and blood-based, casein, emulsion polymer isocyanate (EPI), polyurethane, and vinyl acetate emulsions (VAE), polymeric MDI, and epoxy adhesives as well as edge-glued solid wood. MDI is perhaps the closest substitute but presents performance challenges (e.g., greater creep) and board fabrication challenges as it tends to stick to metals, thus requiring mod release agents. Blood- and casein-based resins, however, do not exactly provide the performance requirements needed and because their availability is tied to slaughterhouse production, availability is limited. EPI possesses high dry and wet strength, moisture resistance, clear glue line, and quick curing but has a higher cost, additional process steps, and fabrication challenges. Polyurethane presents tackiness and too quick bonding challenges and in addition, the traditional route for MDI production involves the use of formaldehyde. VAE offers some good characteristics but does not perform as well in moderately-high temperature and moist/humid environments and require a larger investment in application technology. Epoxies offer high performance but with much higher cost, longer cure time, and require special equipment. The cost differential per pound of alternatives ranges from nearly $0.75 for casein to over $3.75 per pound for some epoxies. Solid wood construction represents a potential substitute with cost differentials ranging from $1.10 to $3.25 per square foot depending upon application. The economic benefit of formaldehyde (as used in urea-formaldehyde resin) for MDF building and construction products applications range from $149 million to as much as $210 million per year.

***Particleboard*** is composite engineered wood product manufactured from wood particles (wood chips, sawmill shavings, and saw dust) and uses synthetic resin or some other suitable binder. Some 2.25 billion square feet is produced every year. Particleboard represents a major 700 million pound per year market for UF resins. These resins offer low price, good physical characteristics and fast cure time, and are the resin of choice. Since UF resins, however, do not perform well in environments with long exposure to heat and moisture, the use of particleboard is restricted to interior applications. Most particleboard is used in countertops, door core, floor underlayment, kitchen cabinets, shelving, case goods, manufactured and other home decking, office and residential furniture, stair treads, and store fixtures. Furniture applications predominate but over 10% of particleboard is used in building and construction. Lower cost imports of particleboard continue to erode domestic production. Alternatives include soy- and blood-based casein, EPI, polyurethane, VAE, polymeric MDI, and epoxy adhesives as well as edge-glued solid wood. The cost differentials are similar to those with MDF. Blood- and casein-based resins, however, do not exactly provide the performance requirements needed and because their availability is tied to slaughterhouse production, availability is limited. EPI possesses high dry and wet strength, moisture resistance, clear glue line, and quick curing but has a higher cost, additional process steps, and fabrication challenges. Polyurethane lacks tack and can be slower curing and, as a result, may not work in some applications. In addition, the traditional route for MDI production involves the use of formaldehyde. VAE offers some good characteristics but perform less in moderately-high temperature and moist/humid environments and require a larger investment in application technology. Epoxies offer high performance but are also much higher cost, longer cure time, and special equipment. The economic benefit of formaldehyde (as used in urea-formaldehyde resin) for particleboard in building and construction products applications could range from $80 million to $335 million per year.

***Roofing*** represents a major application for UF resins and includes glass fibers mats used for roof shingles, asphalt roofing tiles, and built-up roll roofing. UF resins are the binder that holds the glass fibers together before the asphalt coating is applied and offer low cost, ease of installation, dry tensile strength, fire resistance, and thermal resistance. Over 85 million squares using about 210 million pounds of UF resin are produced and used every year in the United States. Asphalt roofing has captured share away from older cellulose felt mat systems. UF resins are less costly than other polymeric systems. To a limited extent, acrylic emulsions could be employed as a binder resin but cost is an issue. It is conventional organic paper felt and cellulosic fiber that would likely be employed as a substitute. Although organics are less expensive, the typical roofer's daily output of fiberglass is 10-15% higher than that of organics. The economic benefit of formaldehyde (as used in urea-formaldehyde resin) for roofing building and construction products applications could range from $150 million up to $687 million per year.

***Hardwood plywood*** represents a major application for UF resins. Hardwood plywood is usually made either of red oak, birch, or other hardwoods and is typically used for construction and industrial purposes. Some 765 million square feet are used every year in the United States, primarily for furniture, but also for interior decorating applications and DIY projects. The production of hardwood plywood (and related veneers) uses nearly 75 million pounds of UF resins per year. UF resins offer high dry strength, dimensional stability, a clear glue line, and other properties. The primary substitute is polyvinyl acetate (PVA) resins, which is already used in veneer but its higher cost, a quick curing time, poorer dimensional stability, and poorer heat and moisture resistance preclude its widespread adoption. Other near-substitutes include emulsion polymer isocyanate (EPI), polyurethane, and soy-based binders. Efficacy depends upon the type of alternative resin used. Substitutes include solid wood construction. Finally, a costly alternative would be to switch to completely different materials and construction technologies. Solid wood for interior applications could be used but feature much higher costs. The economic benefit of formaldehyde (as used in urea-formaldehyde resin) for hardwood plywood used in building and construction products applications could range from $16 million to $332 million per year.

***Surface coatings*** represent a 15 million pound market for US resins, which are used to crosslink alkyds, acrylics, polyesters and other coatings to impart scratch and chemical resistance. They compete primarily on cost and typical building and construction applications largely include kitchen cabinets. Radiation curing has been making inroads into this market and would be a very viable alternative. So would waterborne and powder coatings systems. The economic benefit (i.e., cost differential) of formaldehyde (as used in urea-formaldehyde resin) for surface coating applications in building and construction products could range up to $8 million per year.

***Molding compounds for electrical applications*** represent a 65 million pound per year market for UF resins. About 75% are used in electrical applications (switches, circuit breakers, etc.) with the rest in toilet seats, door knobs and other hardware, buttons, housings, and other items. Molded parts from UF resins offer good durability, strength, hardness, break and chip resistance, rigidity, and chemical resistance as well as arc resistance, high dielectric strength, and good flame and chemical resistance. Substitutes include ABS, polyethylene, and polypropylene, all of which offer superior cost-performance. Potential substitutes also include epoxies, polyester, silicones, and other thermoset resins. The economic benefit (i.e., cost differential) of formaldehyde (as used in urea-formaldehyde resin) for these molding compounds for building and construction products could range from $33 million to $43 million per year.

***Other applications*** for UF resins in building and construction are modest. UF resins are used in the bonding of decorative laminates to plywood; as sand core binders in the foundry industry; with PF resin binders for glass fiber and other insulation; as binders for ceiling tile; adhesives; and other applications. Substitutes vary among these end-use markets and include polyester, vinyl ester, and epoxy for laminates; silicates, furan, other resins and oils for foundry operations; polyacrylic acid for insulation; and other resins. The economic benefit of formaldehyde (as used in urea-formaldehyde resin) for these other miscellaneous building and construction applications could range up to $8 million per year.

**Table 2: Economic Benefits of Using Urea-Formaldehyde-Derived Products in Building & Construction (Millions of US dollars)**

| | Benefits | |
|---|---|---|
| | Low | High |
| **Medium-Density-Fiberboard (MDF)** | $149 | $210 |
| **Particleboard** | $80 | $335 |
| **Roofing** | $150 | $687 |
| **Hardwood Plywood** | $16 | $332 |
| **Surface Coatings** | $6 | $8 |
| **Molding Compounds - Electrical Applications** | $33 | $43 |
| **Other** | $6 | $8 |
| | | |
| Total – Urea-Formaldehyde in B&C | **$440** | **$1,622** |

Substitutes to urea-formaldehyde resins in building and construction applications are manifold and include alternative binder chemistries as well as use of completely differing systems in some applications. In total, the economic benefit of formaldehyde used in phenol-formaldehyde resin building and construction applications range from $440 million to $1.62 billion per year.

## Phenol-Formaldehyde

Phenol-formaldehyde (PF) is a thermoset polymer manufactured by condensation of formaldehyde and phenol. PF resins are resistant to moisture and solvents and can withstand temperatures up to 200°C. They also have good electrical resistance and are noncombustible. Due to these properties, PF resins are more advantageous than UF resins. About 1.3 billion pounds of formaldehyde is used in the production of PF resins, 15% of the total.

PF resins provide significant economic benefits in building and construction. They offer several advantages over UF resins, most notably greater strength and rigidity, greater chemical resistance, and waterproof properties. Major building and construction applications for PF resins include softwood plywood, oriented-strand board (OSB), other wood products, insulation, laminates, abrasives, and foundry materials.

***Softwood plywood*** represents a major application for PF resins. Softwood plywood is usually made either of cedar, Douglas fir, spruce, pine, or redwood and is typically used for construction and industrial purposes. Production of softwood plywood amounts to 9.1 billion square feet per year. As much as on-half billion pounds of PF resins are used in this application. Building and construction applications account for over 70% of the plywood sold in the United States (about 6.6 billion square feet) with furniture and industrial applications accounting for the balance. Softwood plywood is primarily used in finish work and underlayment, with more economical grades used for wall- and roof-sheathing, subfloors and siding. It is used for concrete forms, box beams, soffits, stressed-skin panels, paneling, doors, cabinets, and many other items. For both interior and exterior applications PF resins used in softwood plywood offer high strength, dimensional stability, moisture resistance, and thermal stability. These resins also feature properties that foster manufacturing of the panels.

Substitutes could include melamine-formaldehyde resins and resorcinol formaldehyde resins but because formaldehyde is used in producing both they are not a viable substitute. The other major alternatives to PF resin are blood-based and casein resins. Prior to the development of synthetic resins, blood-based adhesives were the binder of choice. For interior plywood applications, casein adhesives were once used. Both resins, however, do not provide the performance requirements needed of exterior applications. In addition, because their availability is tied to slaughterhouse production, availability is limited. Soy-based adhesives are possible substitutes and have been used to a limited extent but they are generally lower in strength and less moisture resistant. This leaves emulsion polymer isocyanate (EPI) and polyurethane adhesives as potential near substitutes. EPI offers good wet and dry strength, dimensional stability, and moisture resistance but material costs and the cost of fabricating represents barriers. Polyurethane adhesives possess good heat and moisture resistance but are also more costly. Waterborne epoxy systems or emulsions of acrylic/epoxy, vinyl acetate, or styrene-butadiene copolymers offer good hardness, durability, moisture resistance, and thermal stability and are thus potential substitutes. In some sheathing, cladding, roofing, and flooring applications, cement board or acrylic-coated gypsum board could be used although their cost is much higher. These are higher in weight and would necessitate more dimensional lumber for bracing, thus increasing the installed cost. Finally, a costly alternative would be to switch to completely different materials and construction technologies. Prior to World War II, wood frame houses generally were constructed using solid wood for sheathing and other applications but due to their much higher cost, they are rarely used today. This construction system could once again be employed at a much greater cost to consumers. Insulating concrete form, steel frame, concrete or brick construction could be employed as well. The economic benefit of formaldehyde (as used in phenol-formaldehyde resin) for softwood plywood building and construction applications range from $165 million to $2.54 billion per year.

***Oriented-Strand Board (OSB)*** is an engineered wood product formed by layering cross-oriented strands (flakes) of thin, rectangular wooden strips compressed and bonded together with resin adhesives. Production of OSB amounts to 10.3 billion square feet per year and consumes about 390 million pounds of PF resins. Building and construction applications account for nearly 70% of the plywood sold in the United States (about 6.9 billion square feet) with industrial and furniture applications accounting for the balance. In building and construction applications OSB is primarily used in structural panels, sheathing, I-joist web material, decorative molding, and many other construction applications. OSB does not require fully mature trees used to produce plywood and with low cost, good performance properties (good stiffness, strength, durability, and dimensional stability), and limited availability of plywood because of logging restrictions, OSB has been gaining market share from softwood plywood. By controlling resin content, strand size, orientation, and density, OSB panel characteristics can be tailored to specific application. PF resins are the binder of choice in OSB due to their relatively low cost, high dry and wet strength, moisture resistance, and thermal stability.

The major substitute resin is MDI with phenolic resins competing effectively based on price and ease of panel fabrication. But because formaldehyde is used in producing MDI, it could be considered not a substitute for this discussion. Other alternatives include blood-based and casein adhesives. These do not have the favorable performance characteristics of PF resins and because their availability is tied to slaughterhouse production, availability is limited. Soy-based adhesives are potential substitutes but offer lower strength and moisture resistance. This leaves EPI and polyurethane adhesives as potential near substitutes. EPI offers good wet and dry strength, dimensional stability, and moisture resistance but material costs and the cost of fabricating represents barriers. Polyurethane adhesives possess good heat and moisture resistance but are also more costly and may not work. Waterborne epoxy systems or emulsions of acrylic/epoxy, vinyl acetate, or styrene-butadiene copolymers offer good hardness, durability, moisture resistance, and thermal stability and are thus potential substitutes. In some sheathing, cladding, roofing, and flooring applications, cement board or acrylic-coated gypsum board could be used although their cost is much higher. These are higher in weight and would necessitate more dimensional lumber for bracing, thus increasing the installed cost. Finally, a costly alternative would be to switch to completely different materials and construction technologies. Prior to World War II, wood frame houses generally were constructed using solid wood for sheathing and other applications but due to their much higher cost, are rarely used today. This construction system could once again be employed at a much greater cost to consumers. Insulating concrete form, steel frame, concrete or brick construction could be employed as well. The economic benefit of formaldehyde (as used in phenol-formaldehyde resin) for OSB building and construction applications could range from $243 million up to $2.70 billion per year.

***Other fibrous wood products*** that use PF resins include hardboard, particleboard, and molded wood. About 95 million pounds of PF resins are used in these molded wood products. About 35% is used in building and construction with most used in furniture. Major building and construction uses include door and window assemblies, countertops, flooring, paneling, and other minor applications. Alternatives include soy- and blood-based, casein, emulsion polymer isocyanate (EPI), and polyurethane adhesives as well as completely alternative construction. For example, injection-molded thermoplastics are a viable substitute and have taken market share away from molded wood. Other indirect substitute materials and construction systems and technologies are possible as well but are generally much more costly. The economic benefit of formaldehyde (as used in phenol-formaldehyde resin) for these other fibrous wood products in building and construction applications could range from $30 million up to $81 million per year.

***Insulation*** represents a 210 million pound market for PF resins. In this market the resins are used to bind glass fiber, mineral wool, and other materials for structural and acoustical insulation used in homes and commercial construction as well as equipment and pipe insulation. Glass fiber is the most prominent and is widely used because of its low costs, versatility, ease of installation, excellent insulating properties, and fire and moisture resistance. The major substitute binder for glass fibers is polyacrylic acid, which is more expensive than PF resins and because of the corrosive nature of acrylic acid features more complicated and costly fiber processing. Polyacrylic acid has been capturing market share away from PF resins and further substitution would reflect these cost differentials. The economic benefit of formaldehyde (as used in phenol-formaldehyde resin) for insulation in building and construction applications could range from $120 million up to $140 million per year.

***Laminates*** consist of layered materials such as paper or fabrics bound together using PF resins. They are used in decorative and industrial applications and represent a 95 million pound market for PF resins. Decorative laminate applications are found in building and construction, furniture, and industrial settings. Building and construction applications account for nearly 70% of laminate demand and include wall paneling, cabinet faces, countertops, sheathing and other products. Advantages of PF resins include low manufacturing costs and also offer flexibility in design and other good properties. Close substitutes include melamine-formaldehyde laminates and low-pressure laminates of polyester as well as vinyl ester, epoxy resins and silicones. Other possible substitutes include non-laminate surfaces such as solid wood, Corian®, granite, marble, other natural stone, ceramic tile and other materials in countertops and vinyl film, decorative foils, paper, and other materials in other applications. The economic benefit of formaldehyde (as used in phenol-formaldehyde resin) for laminates in building and construction applications could range from $28 million up to $1.36 billion per year.

***Abrasives*** represent a 20 million pound market for PF resins, which are used as binders for grinding wheels and sanding paper. PF resins offer greater strength, thermal-shock resistance, and lower costs. Substitution is possible and substitutes include animal-based glues, epoxy, shellac, rubber, and other bonded materials. The economic benefits of formaldehyde (as used in phenol-formaldehyde resin) for abrasives in building and construction applications could range up to $10 million per year.

***Foundry materials*** represent a 100 million pound market for PF resins, which are used as an adhesive to bond sand for cores in a mold for casting metal products. Foundry products such as ductile iron pipe fittings are used in building and construction. PF resins provide good binding properties, including dimensional stability and thermal resistance. Substitutes are available, most notably silicates, furan, and other resins as well as oils. The economic benefits of formaldehyde (as used in phenol-formaldehyde resin) for foundry materials in building and construction applications could range up to $6 million per year.

**Table 3: Economic Benefits of Using Phenol-Formaldehyde-Derived Products in Building & Construction (Millions of US dollars)**

| | **Benefits** | |
|---|---|---|
| | Low | High |
| **Softwood Plywood** | $165 | $9,660 |
| **Oriented-Strand Board (OSB)** | $243 | $10,074 |
| **Other Wood Products** | $30 | $124 |
| **Insulation** | $120 | $140 |
| **Laminates** | $28 | $1,361 |
| **Abrasives** | $6 | $10 |
| **Foundry Materials** | $5 | $6 |
| | | |
| Total – Phenol-Formaldehyde in B&C | **$596** | **$21,376** |

Substitutes to phenol-formaldehyde resins in building and construction applications are manifold and include alternative binder chemistries as well as completely differing systems. In total, the economic benefit of formaldehyde used in phenol-formaldehyde resin building and construction applications range up from $596 million to $21.38 billion per year.

## Polyacetal Resins

Polyacetal resin is a polyoxymethylene thermoplastic engineering polymer produced by anionic polymerization of formaldehyde (or its trimer 1,3,5-trioxane). The polymer is formed as dense crystals. As a result, polyacetal resins are hard, rigid and resilient. About one billion pounds of formaldehyde is used in the production of polyacetal resins, 12% of the total US formaldehyde use.

The excellent strength, creep and fatigue resistance, self-lubricating properties, and good chemical and water resistance of polyacetal resins fosters its use in building and construction applications. About 15% of US polyacetal demand (or 150 million pounds per year) is in these applications, most notably plumbing. Within building and construction applications, polyacetal is the engineering resin preferred for many plumbing applications due to its long-term resistance to hot water, mechanical properties and high-gloss appearance. The resin is used in shower heads, valve components, faucets, and ball-cocks. In these applications, polyacetal largely competes against brass and has been capturing market share away from brass. The latter can corrode and attract scale build-up. Because it does not have these issues, use of polyacetal allows for longer term maintenance free operations. In a more indirect way, polyacetal is also used in building and construction applications because of its use in paint sprayer parts and other tools. Here, substitutes include nylon, polycarbonate, thermoplastic polyester, and other resins.

Substitution by other products is possible for polyacetal resin used in building and construction. In total, the economic benefit of formaldehyde used in polyacetal resin building and construction applications range from $35 million up to $48 million per year.

## 1,4-Butanediol (BDO)

1,4-Butanediol (BDO) is a bifunctional, primary alcohol with various industrial applications. There are various ways to manufacture BDO; however, in the US the Reppe process is predominant. This process combines formaldehyde and acetylene to yield BDO via multistep process. About 900 million pounds of formaldehyde is used in the production of 1,4-butanediol (BDO), 11% of the total.

Mainly used to produce terahydrofuran (THF), gamma butyrolactone, and polybutylene terephthalate (PBT) resins, BDO provide economic benefits in building and construction. Most of the applications are indirect. For example, gamma butyrolactone is used to produce solvents, one use of which is as a paint stripper. THF has been used as a solvent as well, and some of its applications (PVC thermoplastic polyurethane coatings, etc.) are used in building and construction. Substitutes include other solvents and there would be cost differentials (i.e., benefits to society) involved. In total, the economic benefits of formaldehyde used in BDO building and construction applications range up to $2 million per year.

## Methylene Diphenyl Diisocyanate (MDI)

Methylene Diphenyl Diisocyanate (MDI) is produced by reacting formaldehyde with aniline hydrochloride. The initial reaction yields diphenylmethane diamine which reacts with additional formaldehyde to form trimmers, tetramers and higher oligomers. The diisocyanate from the diamine is known as MDI. About one billion pounds of formaldehyde is used in the production of methylene diphenyl diisocyanate (MDI), 11% of the total.

MDI is the most important diisocynate used in commercial applications. Although more expensive than toluene diisocyanate (TDI), MDI provides better performance and is converted into a variety of forms (by reaction with polyols) into rigid and flexible foams, binders, coatings, adhesives, sealants, and elastomers. About 2.2 billion pounds of MDI are used every year in the United States and of this, about 35% or over 750 million pounds per year are used to produce polyurethanes. These polyurethanes are used in a variety of building and construction applications.

The excellent insulation properties of MDI-based polyurethane rigid foam finds make it a choice material for use in walls and roofs of commercial and residential buildings. These rigid foams can be fabricated into products that are self-supporting, making them ideal for residential sheathing insulation, insulation for commercial and industrial roofs with a low slope, structural panels, and other applications. The high R-value of these polyurethane foams allows for thinner insulation and reduced roofing system costs. Polyurethane coatings, adhesives, sealants, and elastomers find use in building and construction in addition to light vehicles and other applications. MDI is also used directly as a binder in the manufacture of oriented strand board (OSB) and other fabricated wood products using urea-formaldehyde.

A major substitute for MDI-based polyurethanes is an alternative isocyanate (TDI or other) and other aromatic isocyanates as well as polyol combinations, most of which may not offer the same performance characteristics. TDI is less expensive than MDI but features significant losses in performance. Other substitutes would require a major change of materials and the manufacturing/fabrication process. A number of thermoplastic substitutes such as expanded polystyrene (EPS), expanded polyethylene (EPE), expanded polypropylene (EPP), and expanded PVC could be used. These don't perform as well and would require thicker layers of insulation. Fiberglass, polycarbonate structural foams, SBR and other latexes, and other materials can be employed as well. Some of these may offer lower costs but insulation and other properties are not as good. As a result, additional material would be needed to have the same effect and this would increase costs, not only for materials but also for product fabrication and installation. Aliphatic isocyanate-based urethanes could substitute in coatings applications as they offer favorable weatherability and UV protection properties but they are most costly.

The benefits to society of using MDI and formaldehyde are significant. In total, the economic benefit of formaldehyde used in MDI building and construction applications range from $65 million up to $265 million per year.

## Pentaerythritol

Pentaerythritol is produced by reacting excess formaldehyde with acetaldehyde in an alkaline medium to produce a while, crystalline powder. About 225 million pounds of formaldehyde is used in the production of pentaerythritol, 3% of the total formaldehyde consumed.

Roughly 55 million pounds of US pentaerythritol consumption is in the production of alkyd coating resins used in architectural coatings, OEM (original equipment manufacturer) product finishes, and special-purpose coatings. Of this, less than two-thirds is in building and construction. Other applications include rubber accelerators, rosin and tall oil esters, explosives, chemical intermediates, and pharmaceuticals. Many rubber products and some rosin and tall oil esters (in adhesives, caulking compounds, coatings, varnishes, etc.) are used in building and construction applications.

There is no non-formaldehyde route to pentaerythritol so substitution would have to arise from different chemistries or materials. Substitutes for use in alkyd resins include glycerin (which doesn't perform as well, takes longer to dry and is less favorable in durability, versatility and flow property) and other polyol-based alkyds. Pentaerythritol-based alkyd resins offer faster drying times, greater gloss retention, greater chemical and water resistance, greater durability, and greater heat and color stability. Other alkyd resin substitutes include waterborne coating systems and other coating technologies. In architectural applications, waterborne acrylics compete while powder coatings, high solid polyesters, and other waterborne coating technologies compete in some OEM product finishes. Acrylics, latexes, epoxies, and urethanes compete in special—purpose coatings and surface coatings. Alternatives to rosin and tall oil esters in coating systems are hydrocarbon resins. In total, the economic benefits of formaldehyde used in pentaerythritol building and construction applications range from $4 million up to $62 million per year.

## Melamine-Formaldehyde

Melamine-Formaldehyde is a thermoset amino resin made from melamine and formaldehyde. MF resins are more water and heat resistant than urea-formaldehyde resins. About 265 million pounds of formaldehyde is used in the production of melamine-formaldehyde, over 3% of the total.

Although more costly and less moisture resistant than phenol-formaldehyde resins, melamine-formaldehyde resin is widely used in building and construction applications due to its chemical resistance, toughness, thermal stability, aesthetic, and other favorable properties. It tends to be used in demanding applications and as a binder, most notably in laminates and wood adhesives.

Laminates for building and construction represent a major use for melamine-formaldehyde resins. Roughly 285 million square feet of laminate (consuming nearly 50 million pounds of melamine-formaldehyde resins) are used in building and construction applications. Major uses include decorative laminates used in countertops, cabinets, flooring, wall coverings, and sheathing, among other applications. Included are both low pressure (LP) and high pressure (HP) laminates. The latter involves laminating a sheet of melamine-formaldehyde impregnated decorative paper onto sheets of phenol-formaldehyde impregnated decorative paper at high pressure and heat to produce a laminated sheet that is extremely tough and moisture and temperature resistant. The laminated paper is then adhered to a substrate such as particleboard or plywood for use as counter-tops, cabinet and drawer faces, laminated flooring and wall coverings. Since other formaldehyde resins are used in conjunction in these application substitution involves replacing each component. (The cost here reflects only melamine-formaldehyde resins.) Substitute decorative laminate materials include polyester resins, epoxy resins, acrylic/polyvinyl alcohol co-polymer dispersions. In countertop applications, solid surface countertops such as Corian® and Silestone, marble, granite/ slate, solid wood, or other solid materials are possibilities. In vertical application such as drawer faces, vinyl films, tile and solid wood can be used. The annual cost of substitution could range from $37 million to $295 million per year.

Wood adhesives used in curved plywood and interior structural panels represent another use of melamine-formaldehyde resin in building and construction applications; about 13 million pounds per year. This represents a specialty application where the aesthetics, high dimensional stability, moisture resistance, smoke/fire resistance, and other high performance requirements exceed those provided by other formaldehyde-based resins. Potential close substitutes include emulsion polymer isocyanate (EPI), polyurethane, and epoxy resins, On the other hand, substitute end-use materials (or systems) such steel and solid wood construction can be employed. Thus, the annual cost of substitution could range from $10 million to $184 million per year.

Other building and construction applications for melamine-formaldehyde include adhesives for ceiling tiles, flame retardants for flexible PU foam, and other applications. About six million pounds per year of melamine-formaldehyde resins are used in the United States for these applications. Substitutes include other binders and flame retardants. The cost differential (i.e., benefits to society) would range from $5 million to $8 million per year.

**Table 4: Economic Benefits of Using Melamine-Formaldehyde-Derived Products in Building & Construction (Millions of US dollars)**

| | Benefits | |
|---|---|---|
| | Low | High |
| **Laminates** | $37 | $295 |
| **Wood Adhesives** | $10 | $184 |
| **Other** | $5 | $8 |
| | | |
| Total – Melamine-Formaldehyde in B&C | **$52** | **$487** |

Substitutes to melamine-formaldehyde resins in building and construction applications are manifold and include alternative binder chemistries as well as completely differing systems. In total, the economic benefits of formaldehyde used in HTMA building and construction applications range up from $52 million to $487 million per year.

## Hexamethylenetetramine (HTMA)

Hexamethylenetetramine (HTMA) is a crystalline powder (or a crystal) with a fused heterocyclic structure. HMTA is produced by reacting aqueous formaldehyde with ammonia. Nearly 200 million pounds of formaldehyde is used in the production of HTMA, 3% of the total.

Within building and construction applications, HTMA is not extensively used directly. HTMA is primarily used as a cross-linking agent to cure Novolac resins which are used in foundry resins, abrasives, frictions materials, and other applications. Foundry products such as ductile iron pipe and fittings are widely are used in building and construction, totaling about seven million pounds. Substitutes are available, most notably epoxy and other resins as well as oils. HTMA is used in applications such as rubber accelerators, explosives, chemical intermediates, and pharmaceuticals. As a rubber accelerator for vulcanization, benefits accrue to the extent that rubber products are used in building and construction. Over 95% is used in automotive and other applications but some rubber products (adhesives, sealants, etc.) are used in building and construction. HTMA is used as a raw material for high explosives and its nitration produces trimethylene trinitramine. it is also an ingredient in cyclonite (RDX) and cyclotetramethylene-tetranitramine (HMX). In addition to mining and defense applications, these explosives are also used in construction.

There is no non-formaldehyde route to HTMA. Substitutes include epoxies and other intermediates. For the small amount of rubber (and HTMA) ultimately used in building and construction, substitution by other products is possible as are alternative explosives. In total, the economic benefits of formaldehyde used in HTMA building and construction applications range up to $4 million per year.

## Other Applications

About 1.2 billion pounds of formaldehyde (14% of total US consumption) is used to manufacture a variety of other end-use products. A number of these other formaldehyde end-use markets feature products that are ultimately used in building and construction applications. These include the manufacture of trimethylolpropane (TMP) and neopentyl glycol, as well as other applications.

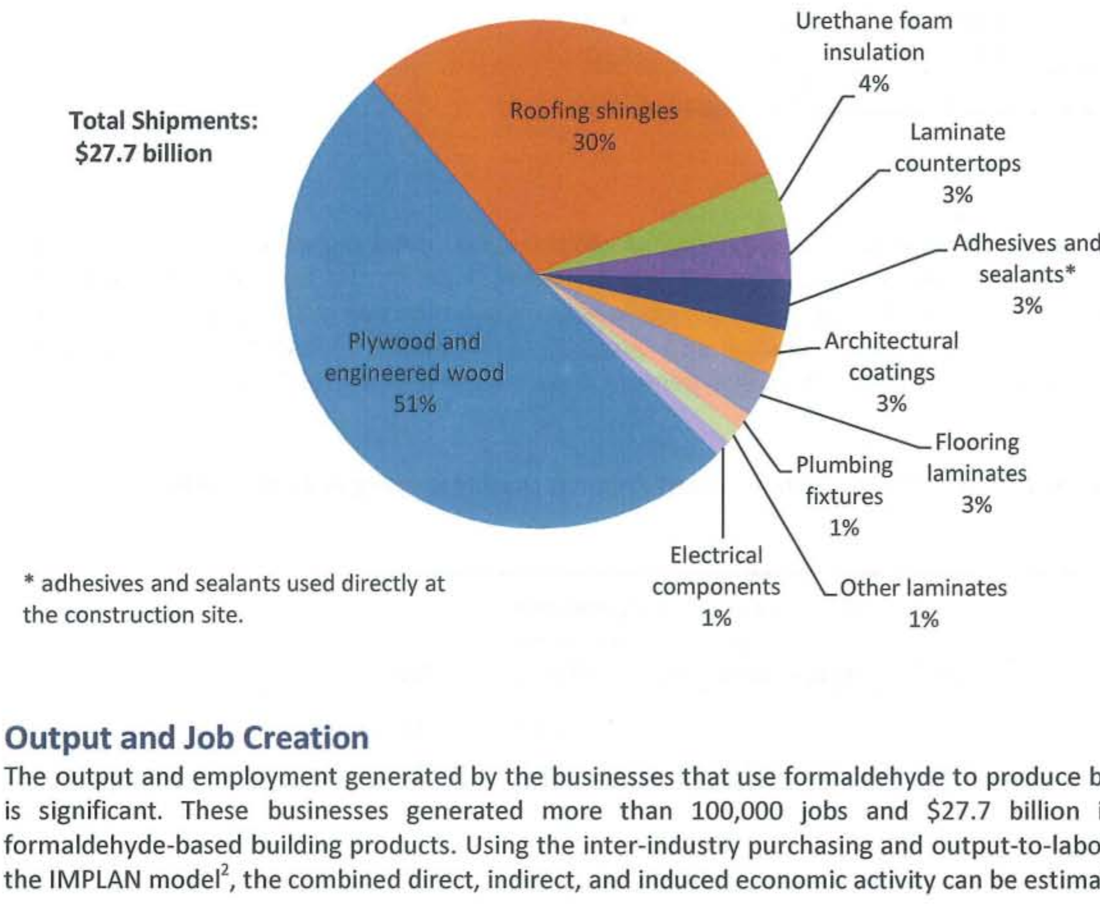
TMP is a trifunctional alcohol used in the manufacture of alkyd and polyester resins, PU-foams, lacquers, and adhesives. Furthermore, TMP is used for the production of pigments, paints and silicone products. These products find uses in building and construction. Most notable are floor surface coatings applications, where TMP is used in both finishes to wood (to impart hardness and durability) and vinyl resilient flooring. About seven million pounds of TMP per year end up in building and construction applications. Substitutes vary but the major substitute for flooring applications is radiation-cured coatings. In other applications, other neopentyl polyhydric alcohols can be used. Neopentyl glycol is another formaldehyde-based product that is used in polyester and alkyd coating resins, polyether polyols for urethanes, methacrylates, and other products that can be used in building and construction. About 13 million pounds of neopentyl glycol per year end up in building and construction applications. Substitutes vary and include radiation-cured coatings, phosphate esters, and other polyols. Other formaldehyde-based products include trimethyloethane, paraformaldehyde (used in foundry resins), and some miscellaneous chemicals and applications. About 11 million pounds per year end up in building and construction applications. The costs involved with TMP, neopentyl glycol and these other applications of these are about evenly divided. In total, the economic benefits of formaldehyde used in building and construction applications associated with these products range from $7 million to $9 million per year.

# Section III

## The Economic Contributions of Producers of Formaldehyde-Based Products

As discussed above, formaldehyde contributes to the economy by providing low cost, strong, and durable materials for the building and construction sector. This section describes the economic contributions associated with the production of formaldehyde-based products used in the construction sector. The manufacture of formaldehyde-based building and construction products supports more than 100,000 direct jobs in industries, such as plywood, roofing shingles, insulation, laminate countertops and flooring, adhesives, coatings, plumbing fixtures, and electrical components. After including indirect jobs supported by these industries' supply chains and induced jobs supported by the household spending of workers, more than 400,000 jobs are supported by the production of formaldehyde-based products used in building and construction.

**Figure 4: Shipments of Formaldehyde-Based Products Used in Building and Construction (by share)**




## Output and Job Creation

The output and employment generated by the businesses that use formaldehyde to produce building materials is significant. These businesses generated more than 100,000 jobs and $27.7 billion in shipments of formaldehyde-based building products. Using the inter-industry purchasing and output-to-labor relationships in the IMPLAN model[2], the combined direct, indirect, and induced economic activity can be estimated.

In addition to the direct sales of formaldehyde-based construction products, the businesses that produce them purchase raw materials, services, and other supplies throughout the supply chain. Thus, through indirect effects, another 135,000 jobs are supported by production of formaldehyde-based building materials in the United

[2] A discussion of the methodology and use of the IMPLAN model can be found in the Appendix.

States. It is in these indirect jobs, that jobs in formaldehyde and its derivatives (i.e., phenol formaldehyde, urea-formaldehyde, melamine formaldehyde, polyacetal resins, etc.) are found.

Finally, the wages earned by workers in these businesses and those throughout the supply chain are spent on household purchases and taxes generating more than 160,000 jobs induced by the response of the economy to changes in household expenditure as a result of labor income generated by the direct and indirect effects. All told, the additional $27.7 billion output of the formaldehyde-based building materials industry generates an estimated $78.7 billion in output to the economy and more than 400,000 jobs in the United States generating a payroll of $21.2 billion. A detailed table on jobs created by industry is presented in Appendix Table 1.

**Table 5: Economic Contributions of Formaldehyde-Based Products Used in Building and Construction**

| Impact Type | Employment | Payroll ($ Billion) | Output ($ Billion) |
|---|---|---|---|
| Direct Effect | 104,796 | 6.5 | 27.7 |
| Indirect Effect | 135,766 | 7.4 | 27.8 |
| Induced Effect | 161,292 | 7.2 | 23.2 |
| **Total Effect** | 401,854 | $21.2 | $78.7 |

## Tax Revenues

The IMPLAN model allows a comprehensive estimation of additional tax revenues that would be generated across all sectors as the result of increased economic activity. Table 11 details the type and amount of tax revenues generated by the output of these formaldehyde-based products. The jobs and businesses supported by formaldehyde-based products manufacturing also produce tax revenue. Federal taxes on payrolls, households, and corporations yield about $4.4 billion per year. On a state and local level, $3.1 billion per year is generated.

**Table 6: Economic Contributions of Formaldehyde-Based Products Used in Building and Construction ($ billion)**

| | Payroll | Households and Proprietors | Corporations and Indirect Business Taxes | Total |
|---|---|---|---|---|
| Federal | $2.0 | $1.5 | $0.9 | $4.4 |
| State & Local | $0.0 | $0.5 | $2.5 | $3.1 |

# Conclusion

The analysis presented in this study by ACC describes the significant and extensive contributions of the formaldehyde industry to the construction and building industry of the US economy. From a consumer perspective, the economic benefit of formaldehyde used in building and construction applications range from $1.16 billion to $8.33 billion per year. Furthermore, the formaldehyde industry generated a total of $79 billion in output, approximately 0.4 million jobs, and $21 billion in annual salaries and wages. The analysis presented here illustrates the extensive role and support that formaldehyde industry provides to the construction and building industry and to the broad U.S. economy.

## ACC Economics & Statistics

The Economics & Statistics Department provides a full range of statistical and economic advice and services for ACC and its members and other partners. The group works to improve overall ACC advocacy impact by providing statistics on American Chemistry as well as preparing information about the economic value and contributions of American Chemistry to our economy and society. They function as an in-house consultant, providing survey, economic analysis and other statistical expertise, as well as monitoring business conditions and changing industry dynamics. The group also offers extensive industry knowledge, a network of leading academic organizations and think tanks, and a dedication to making analysis relevant and comprehensible to a wide audience.

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## Appendix 1

### Methodology – Consumer Benefits

The economic benefits of a product can be measured and is related to the concept of opportunity costs. Opportunity cost is a key concept in economics and is not restricted to monetary or financial costs: the real cost of output forgone, lost time, or any other benefit that provides utility should be considered opportunity costs. Opportunity cost is the cost of any activity measured in terms of the value of the best alternative that is not chosen (that is foregone). It is the sacrifice related to the second best choice available to someone, or group. As related to this analysis, the opportunity costs of choosing the next best alternative (or substitute) is actually the benefits of using the product currently being used. It is savings that occur when the product is instead of its next best alternative, or substitute.

This analysis uses the concept of opportunity costs to measure the benefits of formaldehyde. The analysis employs an innovative and robust methodology that is based on this economic concept and employs engineering, technical, and economic analysis. The economic benefits provided by formaldehyde-based products reflect the net dollar value of the savings that consumers enjoy by using them instead of substitutes. That is, consumer savings are the increased costs that consumers would have to bear if access to formaldehyde-based products now enjoyed were eliminated. Benefits arise from properties of formaldehyde in these applications that allow products to be manufactured at lower costs relative to substitutes as well as providing greater utility to consumers in the form of longer service life (durability), enhanced performance, and in some cases more aesthetically-pleasing design.

The economic benefits to US consumers in using formaldehyde-derived products reflect the savings incurred by forgoing the next best alternative or substitute. A wide variety of alternatives are available, ranging from other synthetic resins and organic chemistry (e.g., other binder resins) to solutions based on completely different technologies, such solid wood products or metals. Formaldehyde-based products are generally chosen by consumers over alternative materials because of: 1) cost; 2) performance attributes; or 3) some combination of the two.

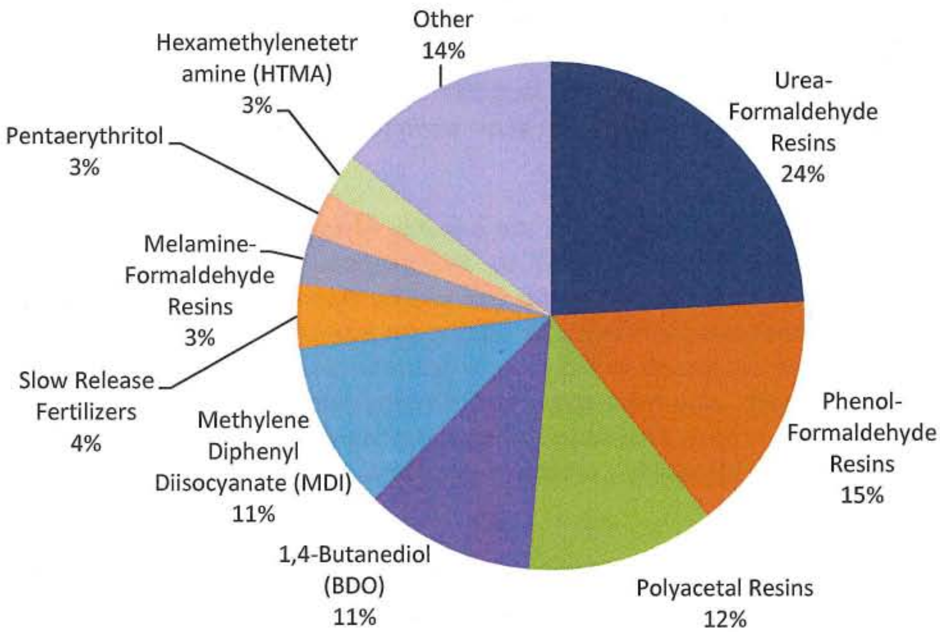
In terms of cost, formaldehyde-based products are often less expensive than the next best alternative. For example, formaldehyde-based products used as binder adhesives in structural panels, for example, are often less expensive on a per pound basis than comparable adhesives based on more complex chemistry. Although the performance attributes of these alternatives may offset some of their additional cost, the low cost of formaldehyde-based products is persuasive in its specification in that use. In addition to low cost, the properties of formaldehyde-based products are also valued in-use. These properties may foster easily fabricated products that are lighter, stronger, more rigid, more stable, easier to install or use, feature a longer service life, or feature greater resistance (to temperatures, chemicals, etc.) that over the service life of the item may provide even more economies even if initial costs between the formaldehyde-based products and substitute are comparable. In some applications, the favorable attributes of formaldehyde-based products may be the over-riding factor allowing for the product that would otherwise be unattainable in a cost effective manner.

The decision to choose a formaldehyde-based product over its alternative is rarely made on the basis of cost alone or even on one physical attribute. In general, a number of physical, cost, and manufacturing issues are considered in specifying a product. These can extend well beyond the specific product to include service life, other aspects of a broader system, and even aesthetics. In the case of a ban on formaldehyde or de-selection in a specific application, these factors would be considered as the loss of benefits to consumers.

For purposes of estimating these economic benefits, the domestic consumption of formaldehyde is separated into nine major derivative classes as shown in Figure 1: urea-formaldehyde resins; phenol-formaldehyde resins;

polyacetal resins; 1,4-butanediol (BDO); methylene diphenyl diisocyanate (MDI); slow release fertilizers; melamine-formaldehyde resins; pentaerythritol, and hexamethylenetetramine (HTMA). These derivatives account for 86% of current formaldehyde consumption. Other applications and products account for the remaining 14%.

**Appendix Figure 1: Formaldehyde Consumption by Derivative**




Source: SRI Consulting, *Chemical Economics Handbook,* 2010

The consumer benefits analysis started with an examination of the products made from each of the formaldehyde derivatives. The volumes of product used in each major end-use or application was estimated. The various substitute materials (e.g., binder A vs. binder B) that are currently being used or could be used were then examined. These were evaluated in terms of their cost and/or performance for why the substitute could be selected. In some cases, completely different solutions were evaluated. For example, in the case of laminates used in kitchen countertops, different binder resins could be used with laminates but laminates could also be supplanted by completely different countertop materials or systems (granite, marble, etc.).

After the types of formaldehyde derivatives have been identified, volumes used estimated, and potential substitutes identified, the likely consumer responses were assessed. Two main responses are likely: 1) switching to a near (or approximate) substitute; or 2) switching to a far (or distant) substitute, usually a completely different material, system or solution. In addition, forgoing consumption altogether is a possibility.

The first consumer response would be to switch to a near (or approximate) substitute (e.g., from binder A to binder B). In perfect substitution, the formaldehyde-based product and substitute products have identical attributes, including ease of manufacturing and performance so that the consumer would notice only the difference in initial cost of the product. In most cases, it is not possible to identify a perfect substitute for a formaldehyde-based product in a specific application. In these cases the performance characteristics of the near substitute were assessed. In these applications, substituting for a formaldehyde-based product would entail a loss of utility to the consumer. This could take the form of a variety of performance characteristics, most of which center around decreased quality or shorter service life. In other cases, the substitute product may have attributes that are similar to the formaldehyde-based product, but would be more difficult and costly to manufacture or use. Taking into account the differing performance characteristics, the price differential between the two products was calculated. Other costs of the near substitute were also assessed. These costs were then multiplied (or scaled-up) to the aggregate sales volume for that application. In the tables presenting the economic benefits of using formaldehyde-derived products in building and construction, these costs (or benefits of near substitutes) were usually presented in the "low" column.

The second consumer response would be to switch to a completely different material, system or solution. That is, a far (or distant) substitute (e.g., using granite countertops in place of laminate). In this case the cost differential between the two products was calculated. These costs were then multiplied (or scaled-up) to the aggregate sales volume for that application. In the tables presenting the economic benefits of using formaldehyde-derived products in building & construction, these costs (or benefits of near substitutes) were usually presented in the "high" column.

Finally, forgoing consumption altogether is another possibility, or consumer response. In some industries the unavailability of a key input (or raw material) would require consumers to forego consumption altogether because no substitute is available. In this case, the tangible cost of losing the product would be calculated. These costs would then be multiplied (or scaled-up) to the aggregate sales volume for that application. In the course of the analysis, no explicit instances of this nature were identified.

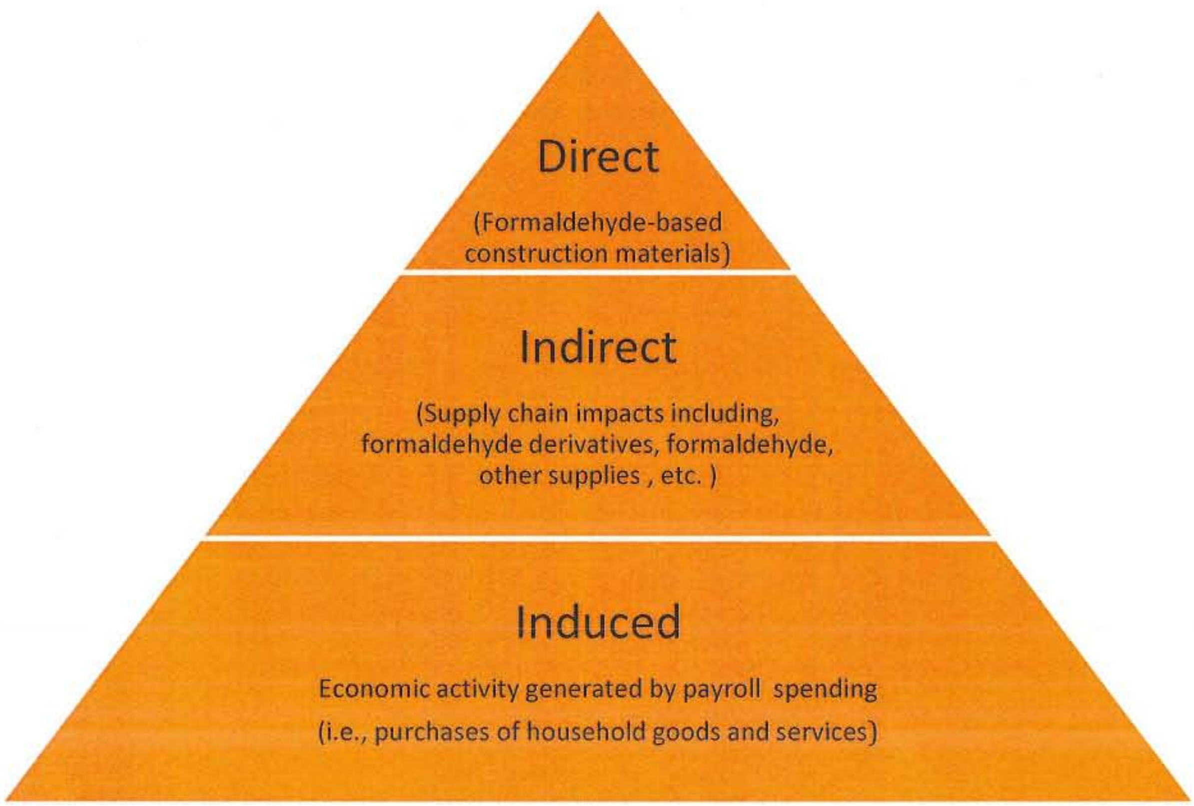
In reality, the costs of substitution (or benefits) will be some combination of these consumer responses. Different income and other socio-economic characteristics among consumers will elicit different consumer responses.

## Appendix 2

### Methodology – Producer Benefits

To estimate the economic contributions from production of formaldehyde-based products used in building and construction, the IMPLAN model was used. The IMPLAN model is an input-output model based on a social accounting matrix that incorporates all flows within an economy. The IMPLAN model includes detailed flow information for 440 industries. As a result, it is possible to estimate the economic impact of a change in final demand for an industry at a relatively fine level of granularity. For a single change in final demand (i.e., change in industry spending), IMPLAN can generate estimates of the direct, indirect and induced economic impacts. Direct impacts refer to the response of the economy to the change in the final demand of a given industry to those directly involved in the activity. Indirect impacts (or supplier impacts) refer to the response of the economy to the change in the final demand of the industries that are dependent on the direct spending industries for their input. Induced impacts refer to the response of the economy to changes in household spending as a result of labor income (payrolls) generated by the direct and indirect effects. The relationship between the direct, indirect and induced effects is presented in Appendix Figure 2.

**Appendix Figure 2: Relationship between Direct, Indirect and Induced Effects**




To run the IMPLAN model, the shipments of formaldehyde-based products were estimated using data from the Census Bureau. For each category, shipments were adjusted to estimate the share used in building and construction applications. For categories where multiple materials may be used, the share of formaldehyde-based products was estimated using data from the Census Bureau, Bureau of Economic Analysis, and SRI Consulting. This analysis looks only at the contributions of the manufacturing of these formaldehyde-based products. It does not include any economic activity generated from the construction sector that ultimately uses formaldehyde-based products to construct homes and buildings.

To avoid double counting, direct production of formaldehyde and its first-tier derivatives were excluded from the direct impact. The jobs and output associated with the production of formaldehyde and its first-tier derivatives are included within the indirect effects. For example, the output of countertop laminates generates indirect jobs in melamine resin and formaldehyde. Were these materials also included in the direct impact, their contribution would be counted twice. In addition, certain finished adhesive materials that are used as intermediates in the production of plywood, laminates, roofing shingles, etc. are excluded from the direct impact because their economic contributions appear as part of the indirect impacts. Formaldehyde-based adhesives used at the construction site are included in the direct impact, however.

**Appendix Table 1: Jobs Supported by the Manufacture of Formaldehyde-Based Products used in Building and Construction**

| | Direct | Indirect | Induced | Total |
|---|---|---|---|---|
| **Agriculture** | - | **45,146** | **3,224** | **48,370** |
| **Mining & Utilities** | - | **4,286** | **1,359** | **5,645** |
| **Construction** | - | **1,724** | **1,515** | **3,239** |
| **Durable Manufacturing** | **85,494** | **14,976** | **3,250** | **103,721** |
| Wood products | 78,582 | 9,409 | 217 | 88,207 |
| Furniture (including fixtures) | 6,912 | 233 | 347 | 7,492 |
| Other durable manufacturing | - | 5,334 | 2,686 | 8,021 |
| **Nondurable Manufacturing** | **19,302** | **4,836** | **4,691** | **28,829** |
| Petroleum and coal products | 8,621 | 491 | 79 | 9,191 |
| Chemicals | 2,900 | 1,896 | 635 | 5,431 |
| Plastics and Rubber Products | 7,782 | 1,032 | 468 | 9,282 |
| Other nondurable | - | 1,908 | 3,587 | 14,116 |
| **Trade** | - | **11,382** | **30,609** | **41,990** |
| **Transportation** | - | **10,872** | **4,805** | **15,677** |
| **Information** | - | **2,134** | **3,248** | **5,382** |
| **Finance, Insurance and Real** | - | **7,092** | **20,767** | **27,859** |
| **Services** | - | **33,318** | **87,825** | **121,143** |
| Professional and technical | - | 10,611 | 8,032 | 18,644 |
| Management of companies | - | 4,389 | 1,548 | 5,937 |
| Business and support services | - | 8,447 | 8,555 | 17,002 |
| Other services | - | 9,871 | 69,690 | 79,561 |
| **TOTAL JOBS** | **104,796** | **135,765** | **161,291** | **401,855** |

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