Formaldehyde: A Brief History and Its Contributions to Society and the U.S. and Canadian Economies

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The Formaldehyde Council, Inc.
1300 Wilson Blvd., Suite 800
Arlington, VA 22209
www.formaldehyde.org
703-741-5750

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Introduction

Formaldehyde – a simple chemical made of hydrogen, oxygen and carbon – is a natural part of our world. We make it in our bodies and it occurs naturally in the air we breathe. Plants and animals also produce formaldehyde. Some vegetables, including Brussels sprouts and cabbage, emit it when they are cooked.

Manmade formaldehyde is the same as naturally occurring formaldehyde. It has been commercially manufactured and marketed for more than a century. Formaldehyde is a colorless gas at room temperature and is sold and used as a 36-50-percent solution in water; the solution is known as formalin.

An Historical Perspective[1]

Resins

Since pre-historic times, humans have used the properties of natural polymers such as horn, waxes and bitumens in everyday life. Over the years, we learned that the properties of such materials could be improved by techniques including purification or modification with other substances. By the early 20th Century, with the explosion of knowledge in chemistry and physics, coupled with demands for materials with properties that could not be found in nature, the scene was set for the development of a range of new materials – among them the early plastics.

When many people think of formaldehyde, the first (and perhaps only) thing that comes to mind is embalming. Formaldehyde (*formalin*) already was being used for this purpose when the 20th Century began. But formaldehyde's public health benefit through biological preservation and sanitation represented only the beginning of this useful chemical's value to the U.S. economy and society. Next came the material known as *casein formaldehyde*.

Resin was added to fat-free milk to form curds which, when dried, processed and colored, could be made into rods and sheets. The material then was hardened in a bath of formaldehyde, after which it was machined into end-use products. The brilliant colors and patterns made *casein formaldehyde* a leading material for making buttons, buckles, fountain pen barrels and knitting needles.

Not long after *casein formaldehyde* came into widespread use, formaldehyde became fundamental to making the first completely synthetic plastics -- *phenolic materials*, which are popularly known as Bakelite. Belgian-born inventor Leo H. Baekeland coined the name 'Bakelite' to describe the amber-colored, non-flammable synthetic resin made by the condensation of phenol and formaldehyde in the presence of a catalyst. He founded the Bakelite Corporation around 1910.

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[1] Much of this historical information is drawn from the British Plastics Federation website. www.bpf.co.uk; from deco-echoes.com, and from "A Short History of Adhesives and Sealants," www.specialchem4adhesives.com.

For the first 10 years or so after its introduction, Bakelite was used primarily to make electrical and automobile insulators and heavy industrial products. But this “material of a thousand uses,” as Bakelite was called, came into its own in the 1920s through ‘40s, making an enormous splash with consumers. It could be produced in colors, and omitting the pigment could produce a transparent or translucent effect.

As the 20th Century unfolded, *phenolic resins’* applications became innumerable, ranging from domestic items such as toasters, clocks, radios ashtrays and lavatory seats to car components and electrical fittings. Many still remember the plastic-cased radios made from Bakelite; now retro versions are being fabricated from more modern plastics. And early 20th century costume jewelry made from Bakelite can fetch a “pretty penny” today.

The darkish color of *phenolic resins*, particularly when subjected to heat, meant that only darker-toned moldings could be produced. The search for a colorless resin with similar properties led to the development in the 1920s and ‘30s of *urea formaldehyde resins*. When colored, the resins made possible the production of articles such as trays, cups, picnic-ware and lampshades in white and brilliant colors. *Urea formaldehyde resins* also found important industrial applications in varnishes, laminates and adhesives.

With the development of *melamine formaldehyde resins* in the mid-1930s, the family of thermosetting formaldehyde-condensation resins was complete. The melamines closely resembled urea formaldehyde plastics, but were more resistant to heat, water and detergents. Their porcelain-type appearance made an attractive material for cups, saucers, plates and similar domestic items.

Adhesives

Adhesives were used first many thousands of years ago. Early hunters may have seen improvement in their aim by joining feathers to arrows with beeswax. Carvings from ancient Egypt show a glue pot and brush to bond veneer to a plank of sycamore. Most early adhesives evolved from vegetable, animal or mineral substances.

The modern adhesive age began about 1910 with the development of *phenol formaldehyde adhesives* for the plywood industry, where they are still widely used. The development of these new adhesives based on formaldehyde paralleled closely the development of new resins. These new adhesives displaced many of the naturally occurring products owing to their stronger adhesion, greater formulation possibilities and superior resistance to various environments. At that time and still today, casein (see Resins section) adhesive (a dairy byproduct) was used for bonding porous materials like wood, paper and cardboard; other non-polymeric adhesives remain in widespread use.

Adhesives and sealants found important markets in the construction industry, which was providing much of the rapidly expanding infrastructure in the United States in the early decades of the century. Significant growth occurred again in the 1940s and ‘50s with the development of structural adhesives and sealants for the military aircraft industry. Over the years since then, *urea-formaldehyde*, *melamine-formaldehyde*, *resorcinol-formaldehyde* and *phenol-resorcinol-formaldehyde* resins have played increasingly important roles in making products that are part of everyday items and, therefore, the infrastructure of society.

Formaldehyde Today[2]

Formaldehyde Uses and Economic Values

While embalming may be the first thing that comes to mind when you think about formaldehyde, this use accounts for only a very small percentage of the formaldehyde in commerce today. In fact, this application -- while important -- does not even register as a percentage on assessments of formaldehyde's contribution to the economy.

On the other hand, formaldehyde's chemistry makes it an extremely versatile contributor to the production of hundreds of items that improve everyday life. Studies have shown that in the United States, production of formaldehyde and formaldehyde-containing goods accounts for more than five percent[3] of the yearly U.S. Gross National Product (GNP) – or about $500 billion out of a GNP exceeding $10 trillion. Formaldehyde's wide-ranging use makes it essential to operations of nearly 50,000 U.S. facilities in 17 major industries, and it serves as a basic raw material in another 70 industries. Annual U.S. formaldehyde production exceeds five million metric tons.

While little or no formaldehyde is present in many final products, the chemical is an essential component in making consumer items including medicines, vaccines, furniture, cabinets, insulation and other building products, photographic film, paper products, shampoos, deodorant, toothpaste, lipstick, nail polish, and as an anti-bacterial agent in cosmetics.

Formaldehyde is the most commercially important aldehyde (class of highly reactive organic chemical compounds obtained by oxidation of primary alcohol), according to the most recent *CEH Marketing Research Report on Formaldehyde* from SRI International. More than half of all formaldehyde is used primarily to make urea-, phenol-, melamine-formaldehyde (UF, PF and MF) resins and polyacetal resins – altogether a business valued at nearly $10 billion.

Let's look closer at these resins' primary uses:

- *Urea-formaldehyde (UF) resins'* largest use is in binders or adhesives for word products composites including mainly particleboard, medium-density fiberboard (MDF), hardwood plywood and glass fiber roofing mats. *UF resins* account for more than 95 percent of wood adhesives used in particleboard. Most particleboard is used to make cabinets, case goods, doors, countertops, furniture and fixtures; some is use for flooring under-layment and decking in new homes. Formica is the well-known trademark for one type of *UF resin*. MDF is used primarily to make furniture and case goods. Hardwood plywood is used primarily for furniture, decorative interior applications and do-it-yourself projects. Glass fiber mats are the preferred roofing method for shingles, asphalt tiles and built-up (roll) roofing.

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[2]This information is drawn from the *CEH Marketing Research Report on Formaldehyde*, 2004, from SRI International; from The Innovation Group's June 2004 profile on formaldehyde; from the "Formaldehyde Chemical Backgrounder" on the National Safety Council website, www.nsc.org, and from "Formaldehyde: it's history, chemistry and uses" at www.chm.bris.ac.uk/webprojects2002/robson/Home%20page.htm.

[3] Figures in this paragraph are estimates based on available knowledge. The Formaldehyde Council, Inc., has commissioned an assessment of formaldehyde's impact on the U.S. economy, which will be made available when completed in 2005.

- *Phenol-formaldehyde (PF) resins* are used as wood adhesives for oriented strandboard (OSB), plywood, for insulation, laminates, foundry materials and molding compounds. OSB finds application as a lower-cost replacement for plywood for structural panel applications, roofing and flooring. Plywood finds use primarily in packaging, transportation, furniture and construction. In insulation, *PF resins* are used to bind glass fiber, mineral wool (rock wool) or shredded waste products for structural and acoustical insulation. Decorative applications account for the lion's share of laminates' uses, including wall paneling, cabinet faces, furniture, tables and countertops. In foundries, *PF resins* are used as adhesives in molds to produce castings. These resins are used for heat-resistant components in automotive and aerospace applications, appliances and housewares.

- *Melamine-formaldehyde (MF) laminates* are used almost entirely for decorative applications including cabinets, furniture, paneling and flooring. *MF resins* are used in automotive applications (acrylic clear coats and base costs and polyester primer-surfacers), coil coatings, dinnerware, paper and textile treating, wood adhesives, tire cord and ceiling tiles.

- *Polyacetal resins* are used in a variety of applications that once would have used fabricated metal parts for cars, trucks, vans and buses. They can be used to make gears, cams, bearings, levers and other mechanical parts (e.g., plumbing fixtures, sporting goods, gardening tools), exhibiting characteristics including flexibility, abrasion resistance, self-lubrication and resistance to long-term exposure to heat, hot water, steam and motor oil.

Other important formaldehyde-based materials include 1,5-butanediol, methylenebis(4-phenyl isocyanate), pentaerythritol, and hexamethylenetetramine. While you may not recognize their chemical names, these compounds form the basis for countless important products and processes. They include polyurethane foam for construction and appliances; polyurethane elastomers for sports surfaces and footwear; architectural coatings; printing inks; rubber making; soil disinfection, textile treating, and refrigeration systems.

Smaller volumes of formaldehyde are used to produce controlled-release fertilizers and crop protection chemicals that improve agricultural productivity, to make lubricants, in leather tanning, paper coating and laminating, photographic chemicals, dyes, well-drilling muds, and to impart wrinkle resistance to fabrics.

Human medical uses include making vaccines, as a treatment for athlete's foot, in cough drops, skin disinfectants, mouthwashes, and as a disinfectant for vasectomies and root canals. In veterinary medicine, formaldehyde is used as an antiseptic and fumigant, and in the treatment of diarrhea, pneumonia and internal bleeding.

Clearly, many of the items that make up modern-day life rely on formaldehyde -- in one way or another – for quality and value.

Formaldehyde Production

In 1859, Russian scientist Alexander Mikhailovich Butlerov discovered formaldehyde accidentally as he investigated the structure of organic compounds. Nine years later, German scientist August Wilhelm Hofmann found a reliable way to make it. Hofmann passed a mixture of methanol and air over a heated platinum spiral and then identified formaldehyde as the product. This method led to the major way in which formaldehyde is manufactured today – the oxidation of methanol with air using a metal catalyst. Catalysts include copper, molybdenum alloy, platinum and silver. Commercially, formaldehyde is manufactured in the form of a water solution usually containing 37 percent by weight of dissolved formaldehyde; this solution is called *formalin*.

Today, 13 companies produce formaldehyde at 40 U.S. plants in 20 states. In Canada, six companies make formaldehyde at 11 locations in five provinces. For maximum cost effectiveness, formaldehyde usually is made close to the point of consumption. By capacity, Borden Chemical is the largest U.S. formaldehyde producer, followed by Georgia-Pacific Resins, Celanese, D.B. Western and Dynea. Borden also is the largest formaldehyde producer in Canada, followed by Dynea Canada Ltd., Celanese Canada, and ARC Resins Corp.

U.S. formaldehyde manufacturers and their plant locations are, as follows:

Borden Chemical (14 sites)

Baytown, Texas
Demapolis, Ala.
Diboll, Texas
Fayetteville, N.C.
Fremont, Calif.
Geismar, La.
Gonzales, La.
Hope, Ark.
La Grande, Ore.
Louisville, Ky.
Missoula, Mont.
Sheboygan, Wis.
South Glens Falls, N.Y.
Springfield, Ore.

Capital Resin Corporation

Columbus, Ohio

Celanese Ltd. Chemicals Division

Bishop, Texas

D.B. Western, Inc.,

LaPorte, Texas

DuPont Chemical Solutions Enterprise

Parkersburg, W.Va.

Dynea USA, Inc. (five sites)

Andalusia, Ala.
Moncure, N.C.
Springfield, Ore.
Toledo, Ohio
Winnfield, La.

Georgia-Pacific Resins, Inc. (11 sites)

Albany, Ore.
Beaver Creek, Mich.
Columbus, Ohio
Conway, N.C.
Crossett, Ark.
Healing Springs, N.C.
Louisville, Miss.
Lufkin, Texas
Russellville, S.C.
Taylorsville, Miss.
Vienna, Ga.

GEO Specialty Chemicals, Inc.

Allentown, Pa.

Hercules Incorporated

Louisiana, Mo.

Perstorp Polyols

Toledo, Ohio

Praxair, Inc.

Geismar, La.

Solutia Inc.

Alvin, Texas

Wright Chemical Corporation

Ridgewood, N.J.

Canadian formaldehyde manufacturers and their plant locations are, as follows:

ARC Resins Corp.

Longueuil, Quebec

Borden Chemical (4 sites)

Edmonton, Alberta
Laval, Quebec
Saint Romuald, Quebec
Vancouver, British Columbia

Celanese Canada Inc. (Chemicals Division)

Edmonton, Alberta

Dynea Canada Ltd. (three sites)

North Bay, Ontario
Sainte Therese, Quebec
Thunder Bay, Ontario

Uniboard Canada Inc. (Unires Division)

Val d'Or, Quebec

Woodchem Canada Ltd.

St. Stephen, New Brunswick

The 40 U.S. formaldehyde manufacturing plants contributing to state and local economies are located in:

Alabama

Demapolis
Andalusia

Arkansas

Hope
Crossett

California

Freemont

Georgia

Albany
Vienna

Kentucky

Louisville

Louisiana

Geismar (two sites)
Gonzales
Winnfield

Michigan

Beaver Creek

Mississippi

Louisville
Taylorville

Missouri

Louisiana

Montana

Missoula

New Jersey

Ridgewood

New York

South Glens Falls

North Carolina

Conway
Fayetteville
Healing Springs
Moncure

Ohio

Columbus (two sites)
Toledo (two sites)

Oregon

Albany
La Grande
Springfield (two sites)

Pennsylvania

Allentown

South Carolina

Russellville

Texas

Alvin
Baytown
Bishop
Diboll
LaPorte
Lufkin

West Virginia

Parkersburg

Wisconsin

Sheboygan

Formaldehyde Industry Employment

The formaldehyde industry provides thousands of jobs where workers are employed directly in producing the chemical and managing its marketing, sale and distribution. These workers operate and maintain the formaldehyde production facilities, and have responsibility for management, research and development, sales and marketing.

Beyond these jobs derived directly from formaldehyde, hundreds of thousands of workers are supported indirectly through formaldehyde. These individuals are employed through a network of suppliers and the downstream industries detailed in the "Formaldehyde Uses and Economic Values" section. Additionally, individuals are supported because of the personal expenditures of all these direct and indirect workers.

Hard data on formaldehyde industry employment, wages, fixed business investments, taxes and so forth is in development and will be made available as soon as the assessment is complete in 2005.

Where to Get More Information

The Formaldehyde Council, Inc. (FCI) is the science and advocacy center for the formaldehyde industry. FCI and the formaldehyde industry are committed to the safe and responsible use and benefits of formaldehyde and products made from it, and to ensuring formaldehyde's accurate scientific evaluation. For more information, visit FCI's website -- www.formaldehyde.org -- or call 703-741-5750.