Chapter 4. Formaldehyde

Five Chemicals Alternatives Assessment Study

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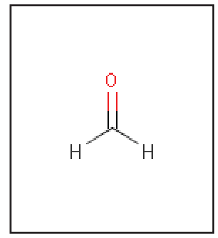
4.1 Overview



The metal catalyst oxidation process to create formaldehyde from methanol was discovered in 1868 by A. W. Hofmann. Formaldehyde's use grew rapidly throughout the 19th and 20th centuries, and formaldehyde (CH_2O, CAS#50-0-0) remains a common and important industrial chemical. Profoundly simple, inexpensive and useful, many products are made from or contain formaldehyde, including resins, permanent press fabric treatments, tissue preservatives, lawn fertilizers, cosmetics and disinfectants. Combustion of fuels and biomass is a significant source of formaldehyde in the environment. Formaldehyde is produced in animals and plants as a result of natural metabolic processes, but is rapidly metabolized through a dedicated metabolic pathway (formaldehyde dehydrogenase) (Agency for Toxic Substances and Disease Registry (ATSDR) 1999b; Liteplo et al. 2002).

Wood adhesives used to make plywood, particleboard and other manufactured wood products are the dominant end use for this chemical, accounting for 64% of the total 24 million metric tons consumed worldwide each year (Bizzari 2004). The plastics industry also uses formaldehyde-based resins extensively, especially for car parts. Because the polymerization of these resins can partially incomplete or can reverse under certain circumstances, construction materials, furniture and consumer products have been identified as sources of formaldehyde in indoor air at levels consistently higher than outdoor air, and at levels with the potential to cause health effects, such as respiratory irritation. In the early 1980's attention to high average levels in mobile homes helped bring about emission standards for formaldehyde-resin building materials that have decreased product "off-gassing." While humans have evolved to metabolize the very low levels of formaldehyde that are endogenous to human cells, at higher levels these metabolic processes are overwhelmed (Agency for Toxic Substances and Disease Registry (ATSDR) 1999b). Thus, formaldehyde can be highly toxic to humans. It has strong odor, is highly irritating, is a potent sensitizer, and has been determined by IARC, EPA, OSHA and NIOSH to be a carcinogen.

4.1.1 Characteristics of the Chemical

Formaldehyde is a gas at room temperature and is soluble in polar solvents, including water. It is easily synthesized from methanol. It has a strong irritating odor and a low odor threshold. It is colorless and flammable (Agency for Toxic Substances and Disease Registry (ATSDR) 1999a). Formaldehyde polymerizes readily with heat which makes it especially useful in resin production, and especially expensive and challenging to transport. Because of these limitations, it is usually made close to where it is used and there is very little trade in pure formaldehyde. Formaldehyde is most often produced, transported and used as a 37% solution in water known as formalin. These solutions also contain a stabilizer, typically methanol (at 12%), to prevent polymerization. In the presence of air and moisture at room temperature, formaldehyde readily polymerizes to paraformaldehyde, a solid form that is also a commercial product.

Table 4.1.1 A: Chemical/Physical Characteristics of Formaldehyde
(Agency for Toxic Substances and Disease Registry (ATSDR) 1999b; Environmental Science Center 2004; Hazardous Substances Data Bank)

Characteristic	Description
Melting/Boiling Point	-92° C /-21° C
Vapor Pressure	Gas
Octanol/Water Partition Coefficient	Log Kow = 0.350
Density	0.815 g/mL at -20° C; Gas: 1.067 (Air = 1)
Solubility	Very soluble in water and polar solvents; up to 55% (freshwater at 20 °C). Soluble in alcohol, ether, acetone, benzene
Soil Sorption Coefficient	Log Koc = 1.567; very high mobility in soil
Bioconcentration Factor	3.2 (estimated based on the chemical's octanol/water partition coefficient); formaldehyde is not expected to bioaccumulate
Henry's Law Coefficient	3.27 x 10^{-7} atm-m^3/mol @ 25 °C
Biodegradation	Half-Life (in sunlight) 1.6-19 hours producing H_2 and CO or H^+ and HCO^-

4.1.2 Health and Environmental Impacts

Exposure and Effects on Human Health

Because formaldehyde is highly reactive, water soluble and rapidly metabolized, people may experience its toxic, irritating and sensitizing effects at the site of contact, such as the upper respiratory tract, the eyes and the skin (Liteplo et al. 2002). Such symptoms may be experienced by those exposed at their jobs, but also have been reported among students in gross anatomy labs who are exposed to formaldehyde used to preserve human and animal specimens (Kriebel et al. 2001) and occupants of mobile homes constructed largely of particleboard. (Liu et al. 1991) Inhaled formaldehyde is readily absorbed by the upper respiratory tract and can be rapidly metabolized and detoxified into formate by almost every cell in the body (Agency for Toxic Substances and Disease Registry (ATSDR) 1999b). Skin contact results in severe irritation and burns and some formaldehyde may pass through the skin, though it is unlikely to cause systemic effects due to rapid metabolism. Repeated prolonged exposures may result in sensitization of the individual to formaldehyde. Sensitized individuals are more likely to experience contact dermatitis and asthma attacks than the non-sensitized. Formaldehyde exposure may also trigger asthma attacks in individuals with underlying asthma. Headaches, chest pains, and other symptoms may also be linked to exposure to low levels of formaldehyde in indoor air. While unlikely occurrences, ingestion of formaldehyde or very high air concentrations can quickly cause death due to burning of the lungs and subsequent edema ("flooding" of the lungs).

In 2004 IARC moved formaldehyde from the 2A – probable human carcinogen group, to Group 1: sufficient evidence that it is a human and animal carcinogen (International Agency for Research on Cancer (IARC) 2004). This determination was based on several epidemiological studies. Occupationally exposed industrial workers and those handling embalming fluids or preserved tissues were found to have elevated risks of nasopharyngeal cancer. Six of seven studies of embalmers and pathologists and two of three studies of industrial workers also found excess risk of leukemia. It has been hypothesized that because formaldehyde is a natural part of the environment and humans have evolved to cope with such low level exposures, high levels of exposure are required to induce carcinogenesis (Natz 2006). ATSDR and WHO reviewed toxicology and epidemiological studies and did not conclude that formaldehyde causes adverse reproductive and related outcomes, although some animal and human studies have found reproductive or developmental effects (Taskinen et al.

1999; Zeljenkova, Szabova 2004). Formaldehyde has been found to be toxic to cells and genes (ATSDR 1999b). Human health effects are summarized in Table 4.1.2 A

Table 4.1.2 A: Human Health Effects

Acute	• Irritation of the eyes, nose, throat, and skin. • Burns. • Narrowing of the bronchi and an accumulation of fluid in the lungs. • Risk of death from severe inhalation exposure: throat swelling, chemical burns to the lungs. • Drinking as little as 30 mL (about 2 tablespoons) of formalin can cause death.
Cancer	• Nasopharyngeal cancer. Possibly leukemia and cancer of the sinuses.
Other chronic	• Sensitization: contact dermatitis and possibly asthma (case reports only) • Central nervous system depression: headache, depression, mood changes, insomnia, irritability, attention deficit, and impairment of dexterity, memory, and equilibrium. • Genotoxic: sister chromatid exchange and chromosomal aberrations. • Cytotoxic

People – workers, children, community members, building occupants – are exposed to formaldehyde through natural sources, and those that are human-made, in many contexts. The main human-made sources of exposure are summarized in Table 4.1.2 B, along with some measured exposure levels in Table 4.1.2 C. Note that many of the values reported in this table of historical exposures come from exposure studies conducted in the 1970's and 1980's; exposure levels today are expected to be lower as a result of the reduction in free formaldehyde in building products and compliance with the 1992 OSHA formaldehyde standard, which lowered permissible exposure levels in workplaces.

Table 4.1.2 B: Sources of formaldehyde exposure

Occupational	• Industrial production (resins, molding compounds, fertilizer, paper, wood products, furniture, laminates, plastics, pesticides, chemical manufacture, rubber, leather tanning, iron foundries, photographic film, textiles, scientific supply, and cosmetics) • Agriculture (sugar production, grain and seed preservative) • Oil extraction (well-drilling fluids) • Funerary work (embalming fluid) • Hospitals, laboratories and schools (preserved tissue and specimens) • Construction (manufactured wood products) • Transportation and energy (combustion) • Beauty salons (sanitizer, cosmetics)
Environmental	• Smog in the lower atmosphere • Mobile sources (exhaust from cars, trucks) • Stationary combustion sources (power plants) • Cigarettes and other tobacco products • Gas cookers and open fireplaces • Consumer products (antiseptics, medicines, cosmetics, dish-washing liquids, fabric softeners, shoe-care agents, carpet cleaners, glues and adhesives, lacquers, paper, plastics) • Indoor air in buildings made with or containing furniture made with plywood, particleboard, medium density fiberboard, oriented strand board; insulation; carpets and other flooring; adhesives • Industrial emissions and waste • Fertilizer • Foods (cheese, fumigated grains, naturally occurs in plants and animals)

Table 4.1.2 C: Historical Exposure Levels in Air

(Hazardous Substances Data Bank ; Hiipakka et al. 2001; Hodgson et al. 2002; Kriebel et al. 2001; Olcerst 1999)

Outdoor	• Rural areas 0.2 ppb; suburban areas 2–6 ppb; heavily populated area or near some industries 10–20 ppb
Non-industrial indoor	• Averages: Mobile homes: ~37 ppb; conventional homes ~14 ppb, classrooms~18 ppb; offices ~13 ppb • Funeral Homes: averages between 0.25 ppm and 1.4 ppm; occupational exposure avg 4.8 ppm • Cosmetology classroom (paraformaldehyde sterilent): 0.08 ppm
Industrial	• Permanent-press fabric plants: 0.3 ppm to 2.7 ppm • Resin manufacturing plants: 0.08-12 ppm • Plywood mills, particle-board mills, furniture factories, other wood product and paper mills: 0.07-6 ppm • Textile mills and garment factories: 0.08 to 1.6 ppm • Foundries and other industrial facilities: 0.03 to 31 • Mortuaries, hospitals, and laboratories: 0.04 to 3.4 ppm
Laboratory	• 0.70 ppm average exposure and 11 ppm highest short-term exposure for gross anatomy laboratory students

Formaldehyde has been identified as an important indoor air contaminant (Spengler et al. 2001). As part of their efforts to reduce sources of formaldehyde in indoor air, the California Air Resources Board commissioned a study of the emission rates of products and materials that contain or generate formaldehyde. At the end of the 20-hour test period, investigators measured the emission rates of products placed in special chambers where temperatures and air flows approximated "typical" indoor air conditions. The following table shows that wood floor finish can contribute significant amounts of formaldehyde to indoor air as can many common products and building materials. Materials such as particleboard that are coated or covered with an impermeable surface emit far less formaldehyde than materials without such a barrier.

Table 4.1.2 D: Formaldehyde Emission Rates from Selected Indoor Sources
(Kelly 1997)

	Typical Conditions (µg/m²/h)
wood floor finish	11,000
fingernail hardener	300
latex paint	9
Cabinet door with acid-cured finish	460
medium-density fiberboard cabinet door	360
Particle board	240
Particle board with vinyl laminate	16
softwood plywood	4
new permanent-press shirts	110
washed permanent-press shirts	42
fiberglass insulation	32

Environmental Effects

Formaldehyde is a natural component of the environment and of the human body. The main effects of formaldehyde in the environment are discussed above as human health effects from exposures that exceed "normal" levels. In outdoor or indoor air, as a combustion product, an industrial pollutant, "off-gassed" from consumer products or building materials, or in smog, formaldehyde can cause acute and chronic health problems for exposed humans. Formaldehyde biodegrades readily in air, water and soil under both aerobic and anaerobic conditions (Hazardous Substances Data Bank). It is not commonly found in drinking water and only in limited quantities in food, such as in cheeses and grains where it occurs naturally and is added to kill pathogens. Formaldehyde in the air breaks down in sunlight during the day into carbon monoxide and formic acid, a component of acid rain. In animals, formaldehyde breaks down into formate and carbon dioxide. Formaldehyde is not bioaccumulative (does not build up in plants and animals).

Occupational and Environmental Standards and Guidelines

Formaldehyde is regulated as a human carcinogen, and classified as either a probable, potential or likely human carcinogen by IARC, OSHA, NIOSH, and EPA's NTP. OSHA's 1992 comprehensive standard requires employers to limit 8-hour exposures to less than 0.75 ppm, but they must take certain protective actions if exposures reach 0.5 ppm. Exposure monitoring, medical surveillance, and medical removal, engineering controls and respiratory protection, training and labeling are some of the extensive requirements of the standard. Formaldehyde is identified as a hazardous and toxic chemical in all media by the EPA and subject to Clean Air Act MACT standards, emissions permits and special disposal requirements.

Many manufacturers of consumer and building products have been reformulating to remove formaldehyde, or improving their products and processes to inhibit the release of formaldehyde. Urea-formaldehyde foam insulation, installed in the early 1970's across North America to conserve energy, and later found to contribute to high indoor formaldehyde levels, is restricted in many states, including Massachusetts, and manufacturers have stopped producing it. Beginning in 1985, the Federal Department of Housing and Urban Development restricted the use of wood products made with formaldehyde-based resins in mobile and prefabricated homes to those that met low emission limits as determined in standardized large chamber tests. Industry groups working with government and others have developed emission standards for particleboard and plywood and codified these in several ANSI standards. These standards are similar to HUD's. As a result of these standards and voluntary efforts by industry "manufacturers have reduced formaldehyde emissions from pressed wood products by 80-90% from the levels of the 1980's," according to the U.S. Consumer Product Safety Commission (CPSC 1997). However, over 50% of particleboard products destined for the US market (*e.g.,* furniture) are made in China; it is not known if these imported materials meet emission standards.

European and California restrictions on carcinogens in cosmetics have stimulated many makers to reformulate without formaldehyde (http://www.safecosmetics.org/newsroom/press.cfm?pressReleaseID=15). Because of concerns about formaldehyde's role in indoor air pollution and its impact on Californians' health and the economy, the California Air Resources Board is considering regulations to reduce formaldehyde emissions from consumer products and building materials. In its recent report on indoor air quality, CARB's highest priority recommendation to improve indoor air quality was to replace formaldehyde-emitting wood products with lower emitting ones (California Air Resources Board 2004).

Table 4.1.2 E: Exposure/Environmental Standards and Guidelines

(California Air Resources Board 2004)

OSHA (legal limits)	PEL: 0.75 ppm (averaged over an 8-hour workshift, 40-hour workweek) STEL: 2 ppm (15 minute) Comprehensive standard: requires workplace monitoring, labeling, and training and medical monitoring and engineering controls if employees are exposed above the action level of 0.5 ppm
NIOSH (recommended limits)	REL: 0.016 ppm (10-hr TWA) Ceiling: 0.1 ppm (15-minute) IDLH: 20 ppm Potential occupational carcinogen
ACGIH (recommended limits)	TLV®: Ceiling limit 0.3 ppm A2: Suspected human carcinogen
AIHA ERPG-2 (emergency response planning guideline)	10 ppm (1 hour)
EPA	Hazardous Air Pollutant under CAAA; hazardous waste under CERCLA, RCRA; hazardous substance under CWA; Federal drinking water guidelines: 1000 ug/l; Classification B1 probable human carcinogen
FDA	Food additive permitted in feed and drinking water of animals.
NFPA	(As 37% formalin liquid, no methanol): Health = 3; Flammability = 2; Reactivity = 0
HUD	Particleboard materials shall not emit in excess of 0.3 ppm; plywood 0.2 ppm measured in ASTM large chamber test
OEHHA* Chronic Reference Exposure Limit (based on irritant level)	27 ppb in indoor air over 8 hours
ANSI/Industry voluntary standards	Particleboard flooring: 0.2 ppm limit; other wood products 0.3 ppm

Table 4.1.2 E: Exposure/Environmental Standards and Guidelines

(California Air Resources Board 2004)

Carpet and Rug Institute (voluntary standard)	Carpets 0.04 ppm

4.1.3 Use and Functionality

Formaldehyde is a basic building block chemical and it finds its way, either directly or in derivative chemicals, into almost all sectors of the economy and thousands of products (Bizzari 2004). Over 24 million metric tons (26 million US tons) of formaldehyde were consumed in the US in 2003. Wood adhesives take the greatest share of production. Overall, US formaldehyde production has remained mostly flat as growth in formaldehyde-based products moves overseas, principally to China. Certain uses, such as in textile coatings and alkyd paints, are declining due to environmental concerns or increasing imports of pre-coated fabric. Major US uses of formaldehyde are summarized in Table 4.1.3.

Formaldehyde's readiness to polymerize makes it ideal for the production of resins that are durable, even in wet environments. The wood adhesives industry has made the greatest use of formaldehyde, accounting for 64% of formaldehyde consumed in the US. Plywood and other products that are "exterior-grade" or need to withstand wet conditions are usually made with the dark red phenol-formaldehyde resin. Hardwood plywood, particleboard and medium density fiberboard, often used for making furniture and cabinetry, are made with less expensive and higher-emitting urea-formaldehyde resins. Melamine-formaldehyde resins are also used in wood products and laminates and also molded plastic parts as are polyacetal resins. These resins are also formulated for giving specialty coatings to paper and fabrics.

Another important use for formaldehyde, (although not a large share of formaldehyde consumption), is as a sterilant and tissue preservative. Animal specimens used in high school and college biology classes traditionally have been fixed and preserved in formalin. In addition to its use in educational specimens, formaldehyde is the tissue preservative of choice for human and animal tissue preservation in medical and scientific laboratory settings. Formaldehyde is used by embalmers, and other funerary workers, who preserve human remains for burial. Formaldehyde is also used in small amounts as a pesticide in products such as latex paint and cosmetics. Its excellent disinfection properties are also made use of in paraformaldehyde salon disinfectants and in fumigants for grain and seeds.

Several commercially important chemicals are derived from formaldehyde including 1,4-butanediol (used to make polyurethane and spandex fibers), MDI, aminopolycarboxylic acids (*e.g.*, EDTA) used in cosmetics and as chelating agents, pesticides and lawn fertilizer; and "permanent-press" and flame retardant textile coatings. Interestingly, the leading substitute for formaldehyde in wood adhesives is methylene diisocyanate (MDI), which is made from formaldehyde. Additionally, 1,4-butanediol, 70% of which is made from formaldehyde, is the feedstock for the making of n-methyl pyrrolidone (nMP), a common chlorinated solvent substitute.

Many consumer products and cosmetics have added formaldehyde as resins and to kill microbes. Cosmetics that may include formaldehyde include: nail polish and hardeners (used as a film-forming resin), cuticle softener, shampoos and other hair preparations, suntan and dry skin lotions, makeup, mouthwashes, bath products, deodorants, and shaving cream. Household cleaning products that may include formaldehyde include: cleaners, dishwashing liquids, fabric softeners, shoe care agents, car shampoos and waxes, and carpet cleaning agents. Latex paint may also contain formaldehyde or formaldehyde precursors (ATSDR 1999b). Many "green" building products are made with formaldehyde resins including bamboo and cork flooring and particleboard substitutes made with agricultural waste (Greenseal).

Table 4.1.3 A: Formaldehyde Uses in the US

Major Use Category	Product Category	Uses/Applications
Resins	Urea-formaldehyde resin (23% of US consumption of 37% formaldehyde)	Wood Adhesive (particleboard, medium-density fiberboard, hardwood plywood and waferboard: Internal, non-structural applications)
		Glass fiber roofing mats
		Molding compounds: Ball milling
		Molding compounds: electrical switches, circuit breakers and other
		Cross-linking agent for surface coating including flame retardants
		Other: Low-pressure laminates, wet strength additives and coatings for paper products, textile treating, cross-linking agents for surface coating
	Phenol-Formaldehyde resin (17%)	Wood adhesives (plywood, oriented strand board (OSB), hardboard, molded wood, particleboard); Structural applications; wet strength
		Insulation (phenolic foam insulation, binders for insulation)
		Decorative and Industrial (circuit board and personal computers) laminates
		Foundry mold binders
		Molding compounds
		Other: clutch facings, disk brake pads, automatic transmission components and brake linings, protective coatings (food containers), rubber processing additives, and abrasives for metal finishings
	Polyacetal resin (13%)	High performance plastic parts for automobiles, industrial machinery, plumbing, appliances, tools, and consumer goods such as ski bindings, knife handles
	Melamine-formaldehyde resin (3%)	Adhesive in decorative laminates, OSB, plywood, mdf, particleboard
		Thermoset surface coatings
		Molding compounds such as dinnerware (medical products, household fixtures), tire cord and ceiling tiles
		Paper and textile treating (wallpaper, wrinkle resistant clothing)
		Used as cross-linking agent for flame retardant
	Coating resins (7%)	Pentaerythritol (5%) is used to make alkyd resins in solvent-based paints and finishes; Trimethylolpropane and trimethylolethane impart UV and chemical resistance to coating resins; Polyhydric Alcohols (Polyols) are alkyd resins for use in automobile paint, house paints, artists' oil paints and synthetic lubricant markets
Disinfectant/ Sterilant/ Preservative	Paraformaldehyde	EPA registered disinfectant, "Steri-dri"sanitizer and fungicide for barber and beauty and for households, ships, bedding, clothing, nonfood/non/feed transporting trucks

Table 4.1.3 A: Formaldehyde Uses in the US

Major Use Category	Product Category	Uses/Applications
	Formalin	Microbiologically active against bacteria, fungi, bacterial spores, many viruses: 8% solution with isopropanol: bacteriacidal, tuberculocidal and sporicidal 6-8% solution: sterilant 1-8%: low to high level disinfectant
		Embalming fluid
		Tissue fixation/Pathology
		Antimicrobial used in cosmetics, metal working fluids, latex paint and low VOC paint; secondary oil recovery
Derivative Chemicals	1,4-Butanediol (10%)	Used to make tetrahydrofuran (THF); urethane elastomers (spandex); gamma-butyrolactone which is used to make n-methyl pyrrolidone
	Methylene diisocyanate (MDI) (9%)	Rigid and flexible urethane foams (foam boards, furniture and bedding foam);
		Wood adhesive/binders in OSB and as a formaldehyde substitute in particleboard
		Eastomers (automotive bumbers, door panels; flexible tubing and cable jacketing; gaskets)
	Hexmethylenetetramine (3%)	Thermosetting catalyst for Novolac/phenolic resins (principal use) Manufacture of RDX explosive (cylonite) Rubber vulcanization accelerators Unisolated intermediate in the manufacture of nitrilotriacetic acid
	Aminopolycarboxylic acids (EDTA and NTA), salts (3%)	Chelating agents in industrial and household cleaners and wastewater treatment
		EDTA is also a penetration enhancer in many cosmetic products
	Fertilizers	Controlled-release urea-formaldehyde concentrates for lawn chemicals
	Herbicides (2%)	Paraquat is made from pyridine chemicals
	Textile chemicals	Wrinkle resistance (UF, MF, gyloxal-UF resins); fire retardants

4.2 Formaldehyde Use Prioritization

Chemical Use in Massachusetts

Formaldehyde is not intentionally manufactured in Massachusetts, but formaldehyde and its derivatives are used here in manufacturing other materials and products. Of the 4.8 million pounds of formaldehyde reported under TURA in 2003 (uses of less than 10,000 lbs are not reported), resins manufacture accounted for 60%, chemical manufacture 39% and energy production by-product 1%. One facility in western Massachusetts, used 2.7 million pounds in urea and melamine resins used to make molding compounds (ball milling), which, in turn, are made into plastic dinnerware and other consumer products. Massachusetts companies, institutions and consumers are significant users of formaldehyde-based products made elsewhere.

Table 4.2 A: Massachusetts Companies Reporting Formaldehyde Use in 2003
(source: MA TURA Data, 2003)

Use	Total Used (lb)	Generated Byproduct (lb)	Shipped in OR as Product (lb)	Total Emissions (lb)
TOTAL	**4,758,984**	**162,096**	**4,572,626**	**65,053**
Chemical intermediate (dispersant)	505,794	828	504,966	614
Combustion by-product	26,872	26,872	0	26,871
Organic chemical manufacturing	14,100	6	14,094	123
Embalming chemicals	768,054	7,443	767,431	510
Paper resin	17,000	8,400	8,400	6,300
Byproduct of LNG liquification/vaporization	16,540	16,540	0	16,540
Resin and resin-coated fabric manufacture	41,366	21,694	19,671	599
Molding compounds (resins)	2,732,087	2,023	2,730,064	2,023
Electroless copper solution manufacturing	530,000	9,900	528,000	10
Electroless copper for printed wiring boards	40,727	1,179	0	728
Resins, coatings, laminates*	Trade secret	770	Trade secret	770

(*TURA quantities not available due to trade secret claim)

Table 4.2 B: Massachusetts Companies' Use of Formaldehyde in 2003
(source: MA TURA Data, 2003)

Use	% of Total
Chemical intermediate (dispersant)	16.4%
Combustion by-product	0.6%
Organic chemical manufacturing	10.8%
Embalming chemicals	0.3%
Paper resin	0.4%
Byproduct of LNG liquification/vaporization	0.4%
Resin and resin-coated fabric manufacture	0.9%
Molding compounds (resins)	58.2%
Manufacture of electroless copper solutions for printed wiring board industry	11.3%
Electroless copper for printed wiring boards	0.9%
Resins, coatings, laminates	(Claim Trade Secret)

Summary of Stakeholder Input

Stakeholders were particularly concerned with "emissive" uses of formaldehyde: manufacture and use of products with potential exposures to workers, consumers and children. The stakeholders reviewed the major use categories and types of uses including industrial, commercial, consumer and school settings. Due to concern about health effects related to indoor air exposures, stakeholders were interested to learn about alternatives to formaldehyde in building products. Formaldehyde in school settings and small businesses was also highlighted as a high priority. These settings took precedence over other larger volume uses. Wood floor finishes have been reported to emit significant amounts of formaldehyde, but manufacturers stated that no formaldehyde is added to the finishes and stakeholders prioritized uses where formaldehyde was an ingredient.

Priority Uses

Using the previously described stakeholder priorities, and the criteria listed in Section 2.3.3, uses that were representative of the major formaldehyde use categories in Table 4.1.3 were evaluated for further study. From the resin and building materials category, particleboard/wood building panels are a large use of formaldehyde in Massachusetts, with significant exposure potential for construction workers and building occupants. In addition, these panels were identified as a very high priority for stakeholders. Urea-formaldehyde resins used in fiberglass insulation, were designated as a secondary choice. In the disinfectant and consumer category, stakeholders placed a high priority on the use of paraformaldehyde sterilants, currently required by the Massachusetts Board of Cosmetology. Salon patrons, workers and students in cosmetology classes are exposed to this formaldehyde source. Stakeholders indicated that exposures experienced by children were a very high priority, leading to the selection of formaldehyde use in preserved educational specimens. Textile finishing chemicals (formaldehyde derivatives) were designated as a secondary choice, if resources became available.

The resulting high priority uses for formaldehyde were:

- Sanitary Storage in Barbering and Cosmetology
- Preserved Educational Specimens for Dissection
- Building panels

Secondary priorities, if resources had become available, were textile permanent press finishes and fiberglass insulation binders.

4.3 Formaldehyde Alternatives Prioritization

Given the limited time span and scope of this project the Institute searched for alternatives to formaldehyde for the high priority uses that seemed most feasible. Potential alternatives would be more likely to be feasible if they contributed positive values to the criteria listed in Section 2.4.3.: performance, availability, manufactured in Massachusetts, cost, environmental health and safety, and global market effect.

4.3.1 Alternatives Associated with Sanitary Storage in Barbering and Cosmetology

The Massachusetts Board of Cosmetology establishes requirements for sanitation in beauty salons. Their regulations include three references to formaldehyde. In section 3.03 of the regulations (Equipment and Hygiene Procedures), item (17) says: "One of the following methods must be used to sanitize instruments and equipment after use on any patron or model:

(a) Physical Agents.

1. Boiling water at 212°F for 20 minutes.
2. Steaming dry heat.
3. 70% grain or denatured alcohol for at least ten minutes.
4. Ultraviolet (UV) rays in an electrical sanitizer.

5. Immersion in 10% formalin for at least ten minutes.

(b) Chemical Agents.

1. Antiseptics and disinfectants (hospital grade required).

2. Vapors, formalin and steri-dry."

A bleach solution is also offered as an alternative. Item (18) says: "(a) In cosmetology salons, there must be at least two covered waste receptacles and at least one air-tight container for storing sanitized instruments. Dry sanitizer must be used in drawers." Dry sanitizer is para-formaldehyde dry sterilant, known by the trade name, "Steri-Dry." The perforated plastic containers containing the solid form of formaldehyde "leak" formaldehyde as it de-polymerizes naturally into formaldehyde gas, filling the tool boxes, cabinets and drawers where hair brushes are kept, and entering the salon and classroom air as drawers are opened.

Alternatives to use of formalin for disinfection in salons and schools were not evaluated. Alternatives are generally used, including the popular blue Barbicide disinfectant solution. Evaluation of overall proper procedures for disinfection, and testing of disinfectants' relative effectiveness was beyond the scope of this report.

Available Alternatives

While salons generally select non-formalin chemistries for the disinfection of instruments, the Board's requirement to use dry sanitizer in drawers and student tool boxes has meant that formaldehyde is present in salons and cosmetology training schools, including vocational high schools. The alternative to this use is either the use of another dry sterilant or alternative procedures that do not require use of a sterilant in storage cabinets. No alternative chemical dry sterilants were identified for use in storage drawers to "maintain" disinfection. An additional alternative is for brushes and combs and other beauty implements to be stored in an ultra-violet light cabinet where the UV light source would kill pathogens on exposed surfaces. In summary, the following available alternatives were identified:

- Process change to eliminate the need for dry drawer sterilants
- UV light cabinets for storage

Alternatives Screened Out

No alternatives were screened out because they were carcinogens, PBTs or TURA SAB more hazardous chemicals.

Priority Alternatives for Salon Disinfection and Storage

The priority alternatives for use of para-formaldehyde dry sterilants in sanitary storage are

- Process Change: Storage of implements in a disinfected, dry, covered container and isolated from contaminants
- UV light cabinets for sanitary storage

4.3.2 Alternatives Associated with Preserved Educational Specimens for Dissection

High school and college students in anatomy classes dissect preserved specimens, including fetal pigs, frogs, cats, sharks and other species, to learn from their direct experience of the animal's anatomy. Traditionally, educational specimens have been preserved with a formalin solution to prevent the natural decay of the tissues. Formaldehyde both kills the bacteria that would decay the tissue and it polymerizes the tissue to maintain, to some degree, its texture, structure and color. Formaldehyde off-gasses during the period of time of the storage, use and disposal of the specimen. Students, lab instructors and technicians are exposed to formaldehyde through their repeated contact with these specimens. Smaller animals are usually dissected within a couple of weeks, but larger animals, such as cats, might be used by students over two semesters.

Specimens are ordered by schools from scientific supply companies that specialize in providing preserved specimens for educational and scientific uses. Specimens are first "fixed" with a fixative (traditionally, formalin) and then may be sold with a holding solution that may be formaldehyde, or some other preservative such as propylene glycol. Specimens fixed with formaldehyde may be repeatedly washed by the vendors to remove as much formaldehyde as possible prior to shipment. They may then be placed in a "humectant" such as propylene glycol, to keep them from drying out. In addition to specimen sales, scientific supply companies also sell fixative and holding solutions to be used by researchers and advanced students who preserve their own specimens or who maintain specimens long term in jars. In response to consumer demand, scientific supply companies have developed their own formaldehyde-free fixatives, specimens and holding solutions. Formaldehyde-free alternative specimens are evaluated here, as well as the technological alternative of video and virtual dissection.

Available Alternatives

The Institute evaluated specimens fixed and preserved in alternative solutions available for purchase by educators, rather than the solutions themselves. Specimens did not appear to be available in the following alternative preservatives: Carnoy's Solution made of ethyl alcohol, chloroform and acetic acid; "Prefer" made of ethyl alcohol and glyoxal; Ultrum II Tissue Fixative made of water, sodium acetate, zinc chloride and glutaraldehyde; as well as Caro-Safe Preservative, NOTOXhisto, Nebanol Concentrate and phenoxyethanol solutions. Thus, these alternative preservatives were not evaluated. A complete list of available alternatives and their ingredients is included in Appendix C.

The following alternatives were identified:

- specimens preserved in Formalternate by Flinn Scientific
- specimens preserved in Wardsafe by Ward Scientific
- specimens preserved in S.T.F. (Streck Tissue Fixative) Preservative by Nebraska Scientific
- specimens preserved in Carolina Biological Supply's Carolina's Perfect Solution®
- unpreserved specimens
- video/virtual dissection

Alternatives Screened Out

Specimens fixed with formalin (typically 37% formaldehyde, a carcinogen, and 12% methanol), were excluded even if they were sold or maintained in holding or preserving solutions that were formaldehyde-free. Maryland State Anatomical Solution and Bouin's Fixative Solution contained formaldehyde and were screened out.

Priority Alternatives for Educational Specimens

Because Carolina Biological Supply did not provide a description of the proprietary ingredients, the Institute did not evaluate specimens in Carolina's Perfect Solution® (technical review is available in Dr. Foxall's report to the Institute). The alternative of dissecting live or recently deceased, unpreserved specimens was also excluded for legal, ethical and practical reasons.

Three specimen alternatives and video/virtual dissection were selected as high priority alternatives for assessment. Due to limited time, only one specie was evaluated for each. Other species may be preserved in different chemical mixtures of the same fixative. For example, Ward's fetal pigs are preserved in "WardSafe" (glutaraldehyde, propylene glycol, ethylene glycol phenyl ether, diethylene glycol phenol ether) but the product contains different ingredients to the frog's "WardSafe" (gluteraldehyde). The three alternative-preserved specimens were grass frogs preserved in

- Formalternate by Flinn Scientific,
- Wardsafe by Ward Scientific, and
- S.T.F. (Streck Tissue Fixative) Preservative by Nebraska Scientific.
- Virtual/video dissection

Formalternate is a combination of propylene glycol, ethylene glycol phenyl ether and phenol. Wardsafe is primarily glutaraldehyde. S.T.F. is diazolidinyl urea, 2-Bromo-2-nitropropane-1, 3-diol (Bronopol), zinc sulfate, and sodium citrate.

4.3.3 Alternatives Associated with Building Panels

Adhesives used to make plywood, particleboard and other manufactured wood products account for 64% of the total 24 million metric tons of formaldehyde consumed worldwide each year (Bizzari 2004). Building panel boards designed to withstand loads even when wet are designated as "structural use panels" and include exterior- and interior-grade softwood and hardwood plywood and oriented-strand board. Structural use panels' uses include exterior sheathing, roof decking, and floor decking. Particleboard, medium density fiberboard, and hardwood plywood are primarily used for furniture, shelving, built-in furniture and cabinetry, and interior decorative paneling and flooring. Softwood plywood or oriented strand board (OSB) may be used for carpet and tile underlayment and some built-in furniture and cabinetry that requires less visual appeal and durability. (The red-black color of phenol-formaldehyde resin prevents it from being used in high-end decorative applications.)

While certain types of panels are primarily used for certain uses, they may substitute for each other at times, and softwood plywood, in particular, is quite versatile. As for substitutes that may replace wood panels made with formaldehyde-based resins, the potential substitutions are limited at this time, but, as is described below, that may change in the near future. Many factors influence the choice of materials for building including design and aesthetic considerations, technical specifications, environmental and health considerations, availability and price. Substitutes may match the expectations laid down by traditional products, or they may create new market niches, providing new qualities and stimulating new designs, specifications, and acceptable prices. Growing demand for "green" building products may also influence where and how these panels will be used. Additionally, use of alternative binders, such as the relatively benign polyvinyl acetate (PVA) glue, which is currently used on a special order basis because of its expense, may expand. Finally, "greener" resin technologies that are in the research and development stage may be commercialized in the next few years.

Available Alternatives

The following types of alternatives to formaldehyde-resin based wood panels were identified:

- "low emitting" phenol formaldehyde resin panels
- MDI (methylenediphenyl diisocyanate) based resin panels
- panels made with cement, sand and wood fibers
- Columbia Forest Products soy-based resin hardwood veneer core plywood panels
- Homasote's recycled paper panel boards
- Viroc's wood fiber-Portland Cement panels
- JER EnviroTech's plastic-wood fiber panel

Late in our review the Institute learned that PVA glue is used on a special order basis by many hardwood plywood manufacturers, especially for architects building interiors to the U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED) specifications. Points under the LEED system are awarded for composite wood products that do not use urea-formaldehyde resins. PVA glue is a water-based synthetic latex glue that is used extensively in furniture and laminate manufacture. It is known as white or yellow glue (*i.e.*, Elmer's or carpenters' glue). It can be used with the equipment and processes that currently are used to make panels with urea-formaldehyde resins and has excellent performance characteristics for interior and possibly some exterior applications. It is relatively non-toxic with the exception of a very small amount of un-reacted vinyl acetate monomer (0.4%). Vinyl acetate is an animal and possible human carcinogen, an irritant and a cause of heart problems and other systemic effects in humans (Hazardous Substances Data Bank). Some PVA glues are enhanced with an isocyanate catalyst (isocyanates are sensitizers and can cause asthma and dermatitis). PVA-based panels do not appear to be advertised or readily commercially available. PVA is more expensive than urea-formaldehyde resins.

Alternatives Screened Out

Two categories of alternatives were screened out: "lower-emitters" of formaldehyde and products made with other hazardous chemicals. The "low-emitters," principally products made with phenol-formaldehyde that meet ANSI emissions standards, were excluded because they are made with formaldehyde and still emit low amounts during use. Therefore, they did not pass the carcinogenicity screen. Wood products may also generate formaldehyde as a natural process; products made with no "added" formaldehyde are evaluated here.

Some companies are producing boards made with polyurethane adhesives based on methylenediphenyl diisocyanate (MDI) in place of formaldehyde-based resins. MDI did not pass our initial health and safety screen because it is on the TURA SAB "more hazardous chemical list" due to its acute toxicity and sensitizing properties (Toxics Use Reduction Institute (TURI)). Additionally, while lifecycle issues are not a major focus of this study, MDI is made from formaldehyde. A popular product made with a combination of Portland cement, silica sand and wood fibers was also screened out because of the significant amount of crystalline silica, an IARC Group 1 carcinogen, in the product. These products represent no known environmental threat or risk to building occupants, but significant silica dust is generated during construction activities. Forest Stewardship Council certified-sustainable wood or "agrifiber" composite panels are "green" products that were not included because they use either phenol-formaldehyde resins, MDI or similar resins (see for example http://www.agriboard.com/index.htm).

Priority Alternatives for Alternative Panels

The four remaining alternatives were identified as high priority for assessment as alternatives for formaldehyde resin-based building panels. The first of these is a hardwood veneer core plywood panel that could directly substitute for the equivalent traditional product used to make cabinets, built-in furniture, paneling, shelving, doors and other uses requiring a high end wood product. This alternative is Columbia Forest Product's PureBond panel made with a soy-based resin. This was the only alternative that used an alternative resin. (The other three products are formed by different processes.)

Two other products that were evaluated may substitute for plywood or OSB in building sheathing, roof decking or floor decking. They are Homasote's recycled paper panel boards and Viroc's wood fiber-Portland Cement panels. The fourth product, JER EnviroTech's plastic-wood fiber panel, is an "emerging technology" and may substitute for particleboard and possibly for structural uses as well. Four specific manufacturers' products were evaluated although similar products may be made by other companies. For example, another recycled paper board is ThermoPly by Covalence Coated Products (see http://www.covalencecoatedproducts.com/pages/thermoply.html). The selection of particular representative products does not constitute an endorsement by the Institute, or imply that other similar products are not worthy of further assessment.

Columbia Forest Product's PureBond veneer core plywood was a high priority for assessment because it was the only traditional type of product that used an alternative resin and that passed the screen.

In addition, there was a great deal of stakeholder interest in this product. PureBond is made with soy flour and a resin manufactured by Hercules Chemical called Kymene® 624 Wet Strength Resin. The resin is a cationic amine polymer-epichlorohydrin amine called polyamide-epichlorohydrin (PAE) and it is widely used in as a wet-strength resin in paper and textile manufacturing. Epichlorohydrin has been determined to be an animal and a probably human carcinogen by IARC and EPA's NTP Program and has several other serious potential health and environmental hazards. Epichlorohydrin is not listed on the Hercules' MSDS for Kymene® 624 nor is it listed on the PureBond MSDS. According to the manufacturer and the EPA, epichlorohydrin is completely consumed in the batch manufacturing process used to make the resin. There are no emissions from this process and no residual or "free" epichlorohydrin in PAE where it is irreversibly transformed in the polymer matrix (Steib 2006; USEPA 1984). Despite the lack of potential for worker, consumer or environmental exposure to epichlorohydrin during PureBond building panel manufacture, use or disposal, the health and safety and environmental assessment of this alternative will include a review of epichlorohydrin's potential hazards.

The final list of high priority alternatives to be assessed for wood panels is as follows:

- Columbia Forest Products hardwood plywood panels made with PureBond core and laminated veneers
- Homasote's recycled paper panel boards
- Viroc's wood fiber-Portland Cement panels
- JER EnviroTech's plastic-wood fiber panel

4.4 Formaldehyde Alternatives Assessment

4.4.1 Alternatives Assessment for Sanitary Storage in Barbering and Cosmetology

Two potentially feasible alternatives to the use of paraformaldehyde were found: elimination of the process step and UV storage cabinets. The technical, environmental and health and safety and financial evaluation of these alternatives follows.

Technical Assessment

Helen Peveri, the Executive Director of the Massachusetts Board of Cosmetology was interviewed about the Board's perspective on the use and alternatives for the use of paraformaldehyde dry sterilant. Ms. Peveri noted that, until recently, the Board had not been aware that paraformaldehyde was a potential hazard in salons and that they were interested in alternatives. She said that the Board required paraformaldehyde because they were concerned that hairdressers might not do a good job of cleaning and disinfecting brushes and the Board wanted to have some extra measure of security that the brushes were "clean." Ms. Peveri felt that the opening and closing of the drawer and putting used brushes back in would contaminate the brushes.

Denise Graham, Senior Director of Public Policy for the Association for Professionals in Infection Control and Epidemiology was consulted for the infection control perspective. Ms. Graham stated that she was unaware of guidance or requirements specific to beauty salons. Two industry groups were consulted. Both the Professional Salon Association and the National Accrediting Commission of Cosmetology Arts and Sciences said that they had no guidance, special concerns or other comments on the issue.

To represent the perspective of salon regulators and to determine best practices in infection control in salons, the Institute consulted Sue Sansom, of the Arizona Board of Cosmetology and Chair of the Health and Safety Committee of the National-Interstate Council of State Boards of Cosmetology. The National-Interstate Council's (NIC) mission is to establish best practices, standards and uniform requirements for Boards of Cosmetology and cosmetology exams in the United States is composed of members of licensing boards of cosmetology from each of the fifty states and the U.S. territories. Ms. Sansom stated that she was unaware of any state requiring use of paraformaldehyde. According to the NIC, formaldehyde-based dry sterilants are not recommended due to their carcinogenic potential. In place of dry sterilants, the NIC recommends an alternative procedure of proper cleaning, wet disinfection, drying and storage. NIC's Infection Control standard for dry storage is "Disinfected implements must be stored in a disinfected, dry, covered container and be isolated from contaminants" (National-Interstate Council of State Boards of Cosmetology).

Ms. Sansom was also consulted on the use of UV sanitizers. Ultraviolet sanitizers can be used as dry sanitary storage, but she felt that they were an unnecessary expense and "sent the wrong message" about their role in infection control. She felt that use of UV cabinets can confuse the public and the licensee by suggesting that proper disinfection is occurring when it is not.

The disinfection and storage practices recommended by the NIC are reiterated in the rules of many other Boards of Cosmetology and in the instruction offered in Milady's Standard Cosmetology – the field's primary textbook and practice guidance. This text recommends the same process iterated by the NIC: proper cleaning followed by use of U.S. Environmental Protection Agency-registered disinfectants and storage in clean, sanitized storage (Alpert 2004). Milady's Standard Cosmetology does not discuss use of dry sterilants.

The primary performance criterion by which to evaluate alternatives in comparison to formaldehyde is the ability to control harmful pathogens and to maintain sanitary storage. No studies were found that evaluate the extent of pathogen contamination, transmission and control in the salon environment. Thus, paraformaldehyde sterilant's efficacy is unknown, as is the extent of the problem of growth and transmission of harmful bacteria, etc. in salon storage and instruments.

Because instruments are required to be cleaned and disinfected and storage cabinets are also required to be cleaned and disinfected, and instruments are not to be used and then replaced in the drawers, there is minimal likelihood for potential serious contamination if these procedures are followed. For this evaluation, it is assumed that Board of Cosmetology requirements for cleaning, disinfection and hygienic storage would be followed and therefore the pathogen load in drawers would not be significant.

Given this assumption, and the input of technical experts, it was determined that the alternative of eliminating paraformaldehyde and replacing it with a process of cleaning and disinfecting of a storage container that may be placed in a drawer, or the drawer itself is technically feasible. Following cleaning (dirty surfaces cannot be disinfected), disinfection of the container may be performed with a hospital-grade EPA-registered disinfectant (as already allowed by the Board's rules). From a technical perspective, all references to formaldehyde, formalin or dry sanitizer may be eliminated from the Board's rules without any compromise of infection control as long as the correct and recommended process of cleaning, disinfecting, drying and storing is required and followed. Cosmetology inspectors may inspect such containers to insure that nothing else is stored in them and that they are clean and dry. This process also meets best practice criteria as described in the previous section. The NIC's Infection Control standard for dry storage is "Disinfected implements must be stored in a disinfected, dry, covered container and be isolated from contaminants" (California's Board of Cosmetology rules follow this process).

Ultraviolet light sanitizing cabinets are available from many sources including from the PIBBS beauty supply company (www.pibbs.com). Milady's Standard Cosmetology says that these cabinets are "useful storage containers" but will not disinfect salon implements. UV germicidal light is effective at killing pathogens, but it must strike all surfaces and this is difficult to achieve on a brush. Additionally, the cabinets may become reservoirs of pathogens if they are not regularly cleaned and disinfected, which is difficult to do given the design of the cabinets. Texas has recently revised their regulations to permit the use of UV cabinets as storage containers (83.102. Health and Safety Standards--General Requirements http://www.license.state.tx.us/cosmet/cosmetrules.htm#83106) A further performance concern is the space required for these cabinets at each station.

Financial Assessment

The elimination of paraformaldehyde will result in a modest cost savings for schools and salons (approximately $3.00 for a two ounce container that lasts six months). UV storage cabinets cost approximately $160 each. Germicidal bulbs may cost as much as $30 to replace, and there is an operating cost for energy. It is difficult to gauge the financial comparison to use of Steri-Dry, but it is estimated that the initial equipment cost and replacement bulb "operating costs" of the sanitizing cabinet would generally exceed that of using Steri-Dry.

Human Health and Safety and Environmental Assessment

Elimination of paraformaldehyde is not expected to introduce any new environmental or health and safety concerns. If the cleaning and disinfecting processes are not followed, there is a risk that elimination of use of formaldehyde in storage containers could result in contaminated brushes. However, according to experts, no other state requires use of formaldehyde in salons. The public health risk of its elimination is, therefore, likely to be very low. Massachusetts Board of Cosmetology regulations currently require the cleaning and disinfection of dry storage containers and cabinets. It should be noted that EPA-registered disinfectants may contain gluteraldehyde or quaternary ammonium compounds, both of which are sensitizers. Evaluation of safer cleaning and disinfection strategies is beyond the scope of this project but is an important related concern.

As mentioned above, UV storage cabinets may become reservoirs of pathogens if salon workers encounter difficulty in disinfecting all surfaces inside them. Exposure to UV light can cause skin cancer or eye irritation, although exposure is unlikely if the cabinet is turned off when instruments are loaded or unloaded.

Summary

From a technical, health and safety, environmental and financial standpoint, it appears feasible for paraformaldehyde to be eliminated from barbering and cosmetology drawers and cabinets.

Table 4.4.1 A: Assessment Summary for Sanitary Storage in Barbering and Cosmetology

Assessment Criteria		Steri-Dry (Reference)	Comparison Relative to Formaldehyde	
			Elimination	UV Storage
Technical/ Performance Criteria	Protects Public from Pathogens	?	=/+	-
	Meets Best Practice Guideline	**No**	+	+
Financial Criteria	Cost/yr/drawer	**$6.00**	+	-
Environmental Criteria	Hazardous Air Pollutant	**Yes**	+	+
	Drinking Water Contaminant	**No**	=	=
	Persistent/ Bioaccumulative	**No**	=	=
Human Health Criteria	Carcinogen	**Yes**	+	+
	Irritation	**Yes** (Dermal, Ocular, Respiratory)	+	+
	LD50, oral, mg/kg	rat 100 mouse 385	+	n/a
	Fire Hazard	**Yes** (NFPA 4)	+	+
	Exposure Potential	Low levels, high probability of exposure	+	+

Comparison Key + Better = Similar - Worse ? Unknown

4.4.2 Alternatives Assessment for Preserved Educational Specimens for Dissection

Because there are no published studies comparing the performance characteristics of preserved biological specimens for dissection, the Institute relied on an evaluation by an outside technical expert. Professor Thomas Foxall, Chair of the Department of Animal and Nutritional Sciences at the University of New Hampshire evaluated the alternatives with regard to their technical issues and performance. He developed criteria and used these to compare the alternatives to a formalin-preserved specimen. He used his own extensive experience in teaching gross anatomy, consultation with other anatomy teachers, his direct examination of the alternatives specimens and consultation with pathologists at the New Hampshire Veterinary Diagnostic Laboratory at the University of New Hampshire. He also evaluated a number of virtual and video dissection materials and collected cost information for all alternatives. The health, safety and environment evaluation was conducted by the Institute staff.

The following alternatives for preserved grass frogs were assessed:

- Formalternate by Flinn Scientific,
- Wardsafe by Ward Scientific, and
- S.T.F. (Streck Tissue Fixative) Preservative by Nebraska Scientific.
- Virtual/Video dissection

Technical Assessment

The main technical criteria are those that impact the educational potential of the dissection experience. Those criteria are the color, texture, and stiffness of the specimen tissue. The texture and the stiffness of the tissue directly relate to the ease of "blunt dissection," i.e., separation of the tissues without using a knife. While no preserved specimen's qualities will be true to the living animals, the preserved specimen should approximate them. Other important qualities are the odor of the specimen and whether the specimen lasts long enough for students to complete the dissection. Special handling, training and equipment requirements due to the potential hazard of the specimen are both health, safety and environment concerns and a technical concern as they impact the laboratory experience and duties of the laboratory personnel. The availability of alternatives and if they are available from reputable companies are also important considerations. Finally, a "composite" criterion representing the potential for desirable educational experience for the student was also utilized to compare the specimens. The first three criteria do not apply to video/virtual dissection.

In general, results of the expert's study showed that all of the frog specimens would be acceptable as alternatives to formaldehyde fixed animals, preserving reasonably good color, shape, size and orientation of organs so as to teach basic vertebrate anatomy. Other anatomy professors who had used alternatives were consulted and reported good experiences with them. The criteria are discussed in turn, followed by a discussion of video/virtual dissection:

Color

The color of the alternative specimens was as good as or better than the formalin-preserved specimen. S.T.F. specimen was very good; the Formalternate and Wardsafe frogs had better (more life-like) color than the formalin frog in the skin, skeletal muscle and organs.

Texture

The tissues of the frog preserved in Formalternate were the softest (softer than the formalin frog). It was pliable and easy to move organs and blunt dissect skeletal muscle. The S.T.F. frog's tissues were very soft and it was easy to move organs and blunt dissect. The Ward's frog's tissues were more hardened and less easy to blunt dissect.

Stiffness

The S.T.F. frog was the least stiff and much less stiff than the formalin frog; the Formalternate frog was also less stiff than the formalin frog. The Ward frog was rigid and more like the formalin frog.

Odor

Formalternate had no offensive or intense irritating odor; S.T.F.'s frog had a very slight "chemical" odor; and the Ward frog had an "aldehyde" odor similar to formalin.

Longevity

Longevity could not be evaluated in the timeframe of this study, however formalin will preserve specimens indefinitely. Nebraska Scientific guarantees their S.T.F. specimens for 90 days. This is within the typical timeframe of an anatomy course, but would require that specimens be ordered close to the time of the beginning of the course or dissection. The anatomy professors who had used these alternatives had not experienced problems with the longevity of the specimens as long as they were stored according to instructions (generally sealed in plastic bags).

Special Handling and Training

The alternative specimens do not require any special handling or training other than good laboratory practices. Formalin-fixed specimens may need to be disposed of as hazardous waste. These procedures may be mostly avoided with alternative specimens. With either formaldehyde or the alternatives, students must be made aware of the potential for skin reactions to chemicals and safe procedures such as washing thoroughly after dissection, not ingesting any of the specimen, and following proper storage procedures. Instructors and students should be aware that specimens in S.T.F. may release formaldehyde due to the presence of diazolidinyl urea, a formaldehyde-releasing chemical.

Availability

The alternative products are readily available from well-established companies.

Educational Value

The educational value of these alternatives is equivalent to that of the formalin-fixed specimen.

Dr. Foxall summarized his findings by saying "Anatomy professors and pathologists interviewed agreed that the alternative specimens were less noxious, had good color and texture, and were easier to dissect. Gross preservation was very good and would serve as excellent educational tools to demonstrate anatomy. The alternatives provide for a better and safer laboratory environment with less potential hazard, less odor and less protection needed."

While virtual/video dissection experiences have no detectable odor or special chemical handling and their longevity should be comparable to formalin, many experts have the opinion that watching a video is not the same as, and does not substitute for, hands-on dissection of specimens in a laboratory class. However, the educational utility of video and/or virtual dissection may vary with the class or instructor. Such on-line or video tools (see for example the virtual pig dissection at http://www.whitman.edu/biology/vpd/main.html) may, however, be a useful adjunct to actual dissection. Several sites are free and videos are inexpensive[5]. Virtual, video and CD-ROM software programs also potentially expand the learning opportunity to include study of human anatomy. CD-ROM based programs such as Bodyworks and A.D.A.M. are very well produced, comprehensive, interactive, colorful and provide a very good human anatomy learning experience for even very young children. Although these software packages can be expensive, they are a one-time cost to a school. They may be used as a complete lesson or in addition to actual animal dissections.

[5] $30 at http://www.educationalimages.com/it030022.htm

Financial Assessment

The prices of alternative specimens were similar to each other and generally less expensive than the formalin-fixed frog from NASCO. Formalin-fixed specimens that are also shipped in formalin without washing may be less expensive, but Dr. Foxall did not believe that educators were likely to purchase such specimens. All companies offered bulk discounts. Regulatory costs associated with formaldehyde use are avoided.

Table 4.4.2 A: Specimen Costs

Grass Frogs	Cost Each in a Package of 10
Formalternate	$2.85
Ward's	$4.10
S.T.F.	$3.63
NASCO Formalin-Fixed, Washed and Propylene Glycol Shipped	$5.60

Human Health and Safety Assessment

Educational specimens themselves contain very little preservative chemical when shipped—no more than a few percent of the specimen is preservative. Handling and dissecting specimens potentially exposes students and instructors to skin and inhalation hazards. The exposures are likely to be short in duration on any given day, but extend over a period of weeks. For instructors, these exposures occur with the teaching of every class. None of the alternatives contain ingredients known to be carcinogens or to cause long-term or reproductive health effects. However, all of them have some potential for skin irritation and some have potential to sensitize after repeated exposure, leading to allergic skin reactions and sometimes asthma. Both Formalternate and S.T.F. are chemical mixtures making evaluation of their potential impact more complicated. For example, Formalternate contains propylene glycol which, by itself, has very low toxicity. However, it may enhance skin penetration of other chemicals.

Flinn's Formalternate is a proprietary mixture of propylene glycol, ethylene glycol phenyl ether, and phenol in undisclosed proportions. Propylene glycol can be assumed to be the main ingredient by the MSDS's description of Formalternate as a "propylene glycol-based formaldehyde substitute." Propylene glycol—a main component of anti-freeze and de-icing solutions—is accepted by the Food and Drug Administration as a food, cosmetic and drug additive and is considered "generally recognized as safe." It has an extremely low vapor pressure and is unlikely to get into the air to be inhaled. In a very few people, especially those with underlying conditions, it may cause skin irritation, hives or an allergic contact dermatitis. It will cause eye irritation if placed directly in the eye.

Ethylene glycol phenyl ether, also known as 2-phenoxyethanol, has an even lower vapor pressure and lower potential for inhalation. It is not readily adsorbed through the skin, although it may cause some irritation.

Phenol is toxic and highly corrosive to the skin. Since it has a low vapor pressure but is absorbed by the skin, the skin is the most likely route of exposure. Phenol is an EPA-registered pesticide and animal studies have shown high acute oral toxicity (USEPA 2006). Its male rat LD50 is 317 mg/kg (compared to formaldehyde's 100 mg/kg). There are no known potential long-term or reproductive health effects of the chemical ingredients in Flinn's Formalternate.

Ward's frogs are preserved with glutaraldehyde with the MSDS reporting that the frog contains less than 1% glutaraldehyde. Glutaraldehyde is a strong irritant and a sensitizer. Acute health reactions including irritation, nausea, headaches and nosebleeds, and allergic reactions including asthma are have occurred in workers in healthcare settings where glutaraldehyde is a common disinfectant (and registered as such by EPA)(NIOSH 2001). OSHA does not have a PEL for glutaraldehyde although it has proposed a limit of 0.2 ppm which is the California OSH PEL for an eight-hour exposure (this compares to the 0.75 ppm OSHA standard for formaldehyde.) ACGIH has a ceiling TLV of 0.05 ppm (15 min maximum exposure) for glutaraldehyde which is approximately the odor threshold. This compares to the formaldehyde OSHA ceiling limit of 2 ppm. Glutaraldehyde becomes irritating at about 0.3 ppm whereas formaldehyde can irritate at 0.1 ppm although these are subjective values. Acute toxicity values reported for glutaraldehyde vary widely, with oral-rat LD50 values varying from 134 mg/kg to 820 mg/kg, carrying a determination of moderately to slightly toxic. The EPA is currently reviewing glutaraldehyde in order to determine its eligibility for re-registration and will most likely publish consensus values in this process. In summary, glutaraldehyde has many of the same hazards as formaldehyde although it has not been judged a carcinogen by any agency. Glutaraldehyde is a liquid at room temperature with a fairly low vapor pressure of 17 mm Hg (at 68° F). Thus, a 1% solution of glutaraldehyde is likely to result in a lower air concentration than the formaldehyde concentration released from an equivalent amount of formalin.

Nebraska Scientific's S.T.F. or Streck Tissue Fixative is composed of diazolidinyl urea; 2-Bromo-2-nitropropane-1, 3-diol (Bronopol); zinc sulfate and sodium citrate. Percentages are only given for Bronopol (less than 3%) and zinc sulfate (less than 2%). This mixture is slightly acidic and therefore potentially irritating to the skin, eyes and respiratory system, but is not likely to be inhaled based on the low vapor pressures of constituents. All of the ingredients are irritants.

Diazolidinyl urea and Bronopol have been found to be skin sensitizers in patch testing studies and case reports, although sensitization is rare. In a study of 8,149 patients in European dermatology practices, 0.5% of patients had allergic reactions to Bronopol (Frosch et al. 1990). The male rat LD50 is 307 mg/kg (compared to formaldehyde's 100 mg/kg). Diazolidinyl urea is a "formaldehyde-releaser" in aqueous solutions. An aqueous product containing 0.5% diazolidinyl urea (the US and European standard for cosmetics), will thus contain and potentially release 0.215% free formaldehyde (Scientific Committee on Cosmetic Products and non-Food Products Intended for Consumers 2002). There is no information about the long-term effects of exposure to diazolidinyl urea, zinc sulfate and sodium citrate, but all are FDA-approved for use in cosmetics, drugs and food. Zinc sulfate was once an EPA-registered pesticide, but is no longer used in pesticide products on the market.

Like formaldehyde, many of the chemicals used in alternative preservatives are irritating to the skin, eyes and respiratory tract, and some may be sensitizers. Phenol may penetrate latex gloves, but this is not likely given the limited contact time and the low concentration of the chemical in the specimens. The alternatives do not have other known long-term health effects or reproductive health effects. Additionally, none of the alternatives contains chemicals that are especially volatile, thus the potential for exposure through the inhalation route is low.

Environmental Assessment

Like formaldehyde, phenol is classified under the Clean Air Act as a "hazardous air pollutant," but unlike formaldehyde, which is a gas at normal temperatures, pure phenol is a solid at room temperature with a low vapor pressure. Phenol is also acutely toxic to fish and several other species. Zinc compounds are also toxic to fish. Phenol, bronopol, and glutaraldehyde are EPA-registered pesticides and therefore toxic to some organisms. Neither formaldehyde nor any of the alternatives are likely to persist or bioaccumulate. Specimens preserved in these alternatives can be disposed of with regular waste.

Summary

All of the alternatives assessed here, with the exception of video/virtual dissection, match or exceed the important technical and performance criteria for educational specimens. Additionally, while the alternatives contain chemicals that can irritate the skin, eyes and respiratory system, they are less likely to do so than formalin-preserved specimens. The alternatives contain ingredients that have been found in some people to be sensitizers, with gluteraldehyde the most likely of the chemicals to cause dermatitis and asthma. The alternatives do not contain any chemicals known to have long-term or reproductive health problems and are not classified as carcinogens as is formaldehyde. However, S.T.F. includes a formaldehyde-releasing chemical. Specimens preserved with this fixative may, in fact, release some formaldehyde. Additional studies may be required to determine the long-term effects of exposure to these alternative chemicals.

Formaldehyde must be disposed of as hazardous waste and formalin-preserved specimens may require special waste handling, but the alternatives and specimens preserved in them do not. Some of the chemicals used in the alternative fixatives are more toxic to fish and other species than is formaldehyde. In general, the low volatility and small amounts of preservative in the alternative specimens suggests that exposure to humans and the environment are likely to be very low. Life cycle considerations for the alternatives include the use and disposal of some ingredients, such as phenol and zinc sulfate that are potential environmental pollutants. Table 4.4.2 B summarizes the findings of this assessment.

Table 4.4.2 B: Assessment Summary for Preserved Specimens for Educational Dissection

Assessment Criteria		Formalin-Fixed Specimen (Reference)	Comparison Relative to Specimens in Formalin			
			Form-alternate (propylene glycol based)	STF (includes Diazolid-inyl urea)	Ward's (glutar-aldehyde based)	Video/ Virtual Dissection
Technical/Performance Criteria	Color	Not life-like	+	+	+	n/a
	Texture	Hardened	+	+	=	n/a
	Stiffness	Rigid	+	+	=	n/a
	Odor	Irritating	+	+	=	+
	Longevity	Indefinite	?	?	-	+
	Special handling	Extensive	+	+	+	+
	Availability	Good	=	=	=	=
	Educational value	Good	=	=	=	-
Financial Criteria	Cost (per specimen)	$5.60	+	+	+	n/a
Environmental Criteria	EcoToxicity	Not acutely toxic, except to zooplakton	-	-	-	+
	Hazardous Waste Storage/ Disposal	Regulated	+	+	+	+
	Carcinogen	Yes	+	+	+	+
Human Health Criteria	LD50 (oral rat)	100 mg/kg	+	+	+	+
	Sensitizer	Yes	+	+	=/+	+
	Skin Adsorption	Yes	=	=	=	+
	Irritation	Severe	+	+	+	+

Comparison Key + Better = Similar - Worse ? Unknown

4.4.3 Alternatives Assessment for Hardwood Plywood and Structural Use Building Panels

The choice of building materials by architects, engineers, specifiers, and builders is based on many different criteria: the expected performance of materials, client demands, codes and standards, site specific concerns, project constraints, marketing opportunities, available supply, current and costs and many intangibles such as aesthetic appeal and familiarity. The assessment presented here is a product of the Institute's interviews with product manufacturers, marketers and users; input from stakeholders; and evaluations by outside experts.

Technical Assessment

Different technical criteria apply to building panels depending upon the specific application. For example, exterior panels need to be able to withstand the elements during construction and over time. Interior panels used for high-end applications need to look good and many need to tolerate kitchen and bathroom moisture. Non-structural panels do not need to meet mechanical requirements related to bearing loads. Because of these varying technical criteria, the alternatives are evaluated below in groups:

1. Hardwood plywood
    - traditional hardwood veneer core plywood with formaldehyde-based adhesive (baseline)
    - hardwood plywood with PureBond soy-based adhesive
2. Structural use building panels
    - OSB/softwood plywood using formaldehyde-based adhesive (baseline)
    - Homasote recycled paper-based panels
    - Viroc wood fiber-Portland cement panels
3. A separate discussion of JER Envirotech plastic-wood composite panel board as a potential "near-horizon" particleboard alternative is also included.

Hardwood veneer core plywood

Columbia Forest Products began producing PureBond no-added formaldehyde hardwood plywood with a no-added formaldehyde veneer core in 2005. The design of the proprietary soy-based resin used in the PureBond products is based upon the work of Dr. Kaichang Li at Oregon State Universities' School of Forestry and has been commercialized by Hercules Incorporated (Liu, Li 2002). Soy resins have failed in the past because they lacked strength in the presence of moisture and degraded with time. Dr. Li combined soy proteins with a nylon polymer manufactured by Hercules, Inc. *i.e.*, Kymene® 624 Wet Strength Resin, a product based upon polyamide-epichlorohydrin (PAE). Kymene is typically used by the paper industry to impart wet-strength to paper products such as tissues and towels. (Hercules is marketing this product as ChemVisions™ CA1000 for application in wood products.)

Columbia has further developed the application of this resin to the manufacture of wood panels. This has involved an extensive research and development effort including substantial capital investment in new equipment and processes. Columbia is in the process of converting all of its operations, including the manufacture of flooring, plywood, particleboard, MDF, and agrifiber board, to the use of this new resin. Currently, only the hardwood veneer core plywood is available, but they expect the flooring products to be available soon. (They report that they have succeeded in producing particleboard with PureBond, as well, and will be contracting with a particleboard plant to begin commercial production soon.) Columbia is the largest manufacturer of hardwood plywood in North America.

According to the Hardwood Panel and Veneer Association, the principal performance criteria and characteristics for hardwood panels are: appearance characteristics per wood species, such as number of knots and burls; panel construction; fire resistance; core and back grades; glue bond performance; formaldehyde emissions; moisture content; dimensions; and finish of the panel (Hardwood Plywood & Veneer Association (HPVA)). The association has developed its own voluntary standard called the "ANSI/HVPA HP-1" standard that incorporates these criteria.

No independent test results were available for the Purebond product, so the assessment relied on the manufacturer's own testing and input from those who had used the product. Appearance characteristics are the most important technical criteria. The adhesive generally does not affect appearance characteristics, so these are considered equal between the PureBond product and the traditional product. (Columbia provides a full comparison of their products with the ANSI on their website at: http://www.columbiaforestproducts.com/products/default.asp.)

The second important characteristic is the glue bond performance. Columbia in-house tests found significantly improved water resistance in comparison to a board made with urea-formaldehyde adhesive. They found that the PureBond board performs as well as type II urea formaldehyde adhesive construction in hardwood plywood as defined by ANSI/HPVA HP-1-2004 standards. These standards require manufacturers to conduct three-cycle boil and three-cycle soak tests. Ninety percent of PureBond panels passed the boil test (vs. 0% of traditional urea-formaldehyde bonded panels) and 100% passed the soak test. Because PureBond panels do not pass the boil test 100% of the time, Columbia's panels are not rated as structural or exterior-grade.

A third important characteristic is the fire resistance of the product. The standard for fire resistance is the ASTM-E-84 test which rates products by a flame spread index. The test determines the distance and the rate of travel of flame in ten minutes. Columbia reports that its PureBond product rates within the requirements for Class C Flame spread index of 76-200. The HPVA reports the flame spread of other veneer core plywood panels as between 114-173 (American Forest & Paper Association, Inc. 2002). Generally, products that have a flame spread index of less than 200 will meet all building code requirements for interior applications.

An outside expert, Mark Kalin, received feedback that a woodworking firm that had found that the PureBond panel did not lay flat. Columbia's response was that the PureBond panel is as flat as any veneer core hardwood plywood panel and that they have not had returns or complaints. According to the Architectural Woodwork Institute, the veneer core panel type rates "fair" in comparison with alternatives like particleboard and MDF panel types that are rated as "excellent" for flatness (American Woodworking Institute (AWI) 2003). Veneer core panels may buckle with climate-related temperature and humidity changes and the PureBond product is no different from others in this respect, according to a product supplier (Laing 2006). Paul Quimby of Neil Kelly Cabinets of Portland, Oregon uses PureBond for a small amount of their business and has not had problems with the product. Columbia's PureBond products are available in Massachusetts from Atlantic Plywood Supply in Woburn. They have had no customer complaints about the product. They also anticipate a significant market for no-added formaldehyde products.

While the resin chemistry is not exclusive to Columbia Wood Products, other manufacturers who want to use it will have to invest significant process development and redesign resources, as Columbia has done.

Structural Use Panels

Homasote's recycled paper panels and Viroc's wood-Portland cement panels may be used in place of softwood plywood and OSB in exterior sheathing, roof decking and floor decking. Homasote has been made in New Jersey since 1909 and is primarily marketed as an acoustical barrier (see www.homasote.com). Homasote also makes a product (ComfortBase) that may be used in place of plywood as a carpet or tile underlayment over concrete and one that may be used in place of plywood for concrete forming. Due to time limitations, those uses could not be evaluated. Viroc is made in Portugal and represented and distributed in the US by Allied Building Supply (see www.viroc.pt and www.alliedbuilding.com). The company began producing the product in 1994 and it is used extensively in Europe.

Technical and performance criteria for these uses relate to strength, weight, how they handle moisture, storage, handling, fastening, finishing, fire resistance, thermal resistance, and mold, rot and insect resistance. (Some of the values for these criteria are shown in Table 4.4.3 A) The APA (the Engineered Wood Association formerly known as the American Plywood Association) has developed a rating and grading scale for plywood and OSB that manufacturers use to mark their products according to the accepted use. Panels are given one of four "exposure durability" ratings: Exterior, Exposure 1, Exposure 2 and Interior (the U.S.'s sister organization in Canada uses a similar Can-Ply rating system). This rating system is based upon the strength of the glue bond, as weather will delaminate the boards and cause them to deteriorate. Only member mills can use these ratings and markings, thus imported products and non-wood panels will not be APA-rated. Because Homasote and Viroc are not members of the APA and do not use glue, they are not APA-rated.

The strength of a panel is measured in several ways and is a very complex phenomenon. ASTM has standardized tests for panels for shear strength, compressive strength, impact resistance, wind resistance and tensile strength. Additionally, structural panels have span ratings that reflect both the load that can be carried and the stiffness of the board. Panels used for roof and floor decking must meet building codes designed to prevent collapse. The span rating or load value is how much load a panel can take when fastened to joists at various distances from each other. The span rating can be increased by using thicker panels, but that will increase the weight of the panel. One reason why wood panels are so popular is their excellent strength to weight ratio.

Homasote's floor deck product is sold in either 1-11/32 in. thick panels for 16 in. spans or 1-3/4 in. thick panels for 24 in. spans and is designed to withstand live loads of 100 lb/in^2. The latter material weighs 4.1 lb/ft^2 compared to about 2.3 lb/ft^2 for a similarly span rated ¾ in. plywood or OSB panel. Viroc will bear a 100 lb/in^2 load with 24 in. span in the 7/8 in. thickness and weighs 5.7 lb/ft^2. Thus, relative to plywood or OSB, Homasote and Viroc both must be thicker and heavier, to carry the same load.

Dimensional stability, or the ability of a material to retain its shape when exposed to changes in temperature or moisture, is an important characteristic of a structural board. Changes in dimensional stability can affect the structural integrity of the board and therefore the building. Moisture induced buckling may persist even after a board has dried out. There are several tests that assess factors related to dimensional stability and the results of which may predict the success of a product in an exterior application. Linear expansion is evaluated with ASTM D1037 and is how much the panel will grow when exposed to a change in humidity. Like plywood and OSB, Viroc and Homasote will absorb and desorb moisture according to the climate, and therefore potentially grow or shrink. Both companies stress the need to condition the products at the site prior to use.

In plywood and OSB, significant expansion and shrinkage will wear the glue bonds; its impact on differently bound panels is difficult to predict. Viroc has a slightly better value for this metric, while Homasote does not perform as well as plywood or OSB. In addition, how quickly and thoroughly a panel dries out or "wicks" moisture is also important, but there are no standardized tests for wicking ability. While exterior sheathing is not designed to be constantly exposed to the elements, water may get under cladding or siding and so an overall assessment of weatherability is important and will be discussed below. In additional to the structural integrity of the panel, moisture may lead to mold problems.

Permeance is a measure of the ability of a material to retard the diffusion of water vapor, which is measured in ASTM test E-96 in units called "perms." Traditional softwood plywood and OSB are classified as "semi-vapor permeable" or vapor-retarders (Lstiburek 2002). In cold climates, it is better to have a more permeable exterior sheathing because buildings will dry from the inside out. Less permeable exterior sheathing may trap moisture leading to mold problems. Homasote and Viroc have greater permeance results than plywood and OSB.

A very important criterion is the structural integrity of the product over time given exposure to actual conditions, with the most important condition being moisture. Unfortunately, there are no standards or ASTM tests for "weatherability" outside of the APA's rating system which is based on glue bond integrity. Because Homasote is made of recycled paper, architects and others have assumed that it will fall apart when exposed to moisture. The company claims that it will dry out and maintain its structural integrity (see http://www.homasote.com/about.html). Homasote is reportedly a very good "wicker" (there are no standard values for this) and when place in a vertical plane, moisture will run to the bottom of the panel via gravity. In a horizontal plane when exposed to moisture, it is likely not to hold up. However, plywood and OSB will also delaminate under such conditions.

Homasote was used extensively in exterior applications from the 1930's until the 1980's when OSB became the less expensive alternative to plywood. (With the increasing cost of OSB, the manufacturer notes increased sales of Homasote for exterior applications.) Homasote's website has pictures of a demonstration of weatherability that show it holding up to the elements as experienced in New Jersey. Consisting of 80% Portland Cement, Viroc's weatherability is reported to be excellent. Despite the importance of this technical criterion, until there are long-term standardized tests of weatherability, it is not possible to definitively compare these products on this measure.

While Homasote and some plywood and OSB panels are treated with borate to improve insect and fire resistance, Viroc is not combustible and will not be attacked by termites, mold or other organisms. Homasote has the same fire rating as plywood and OSB (Class C), but like other composite products, it can be treated with fire retardants to become a Class A product (N.C.F.R. Homasote). Homasote claims that its panels are not very attractive to insects. Viroc reports independently conducted tests of its impact and wind resistance and claims these qualities as a particular benefit of the product (ICC Evaluation Services, Inc. 2003). Viroc is being used to construct temporary school units in Florida and was specified because of its expected durability in the face of Florida's complement of termites, mold, moisture, and hurricanes. Homasote gives a "Janka ball" hardness test result of 230 lb, meaning that only 230 lb of force are required to imbed a 0.444 in. steel ball halfway into the material. This compares with a 660 rating for soft Douglas fir.

Product handling is very important and the principal concerns are weight, storage conditions, cutting, fastening and finishing. These factors differ between plywood/OSB and Homasote and Viroc. Viroc is considerably heavier than the other products. Homasote is lighter in the equivalent thicknesses, but as was mentioned earlier, may need to be thicker and therefore, heavier, to withstand the same loads.

All of the panels, including plywood and OSB, need to be stored and handled in such a way as to prevent warping, contact with moisture, and impact by forklifts – generally covered with tarps on pallets. All would need to dry out prior to being "sealed" in a building under cladding or flooring. Plywood may be more forgiving than the others of rough handling and Viroc stresses the importance of avoiding "breakage." Viroc can be machined like wood, but thicker boards will need to be cut with tungsten carbide tipped saw blade (preferably equipped with vacuum extraction) and pilot holes will need to be first drilled or self-drilling ("grabber") screws need to be used. It may be difficult to use nails with Viroc. It is likely to wear out bits and blades at a quicker rate than the others.

Ringshank nails or drywall screws can be used with Homasote, but the company specifies that distance between nails be 3 in. or 6 in. depending on the span and location of the panel. It may be easier to nail Homasote, but more nailing is required—plywood and OSB need fasteners 6 in. or 12 in. apart for sheathing and subfloors. Homasote is easy to cut with a saw and can be cut with a mat knife depending upon the thickness. Nails in Homasote and Viroc are much more secure than in plywood or OSB according to results of ASTM dry "nail pull" tests. Both Viroc and Homasote can be finished with latex paint. The unpainted surfaces of both are a dull gray with some texture.

The "R" factor, or thermal resistance factor, of Homasote is twice that of plywood and OSB making it a better insulator. Viroc's R factor is considerably lower than plywood and OSB.

Both Homasote and Viroc are available in Massachusetts. Viroc is distributed in the U.S. by Allied Building Supply (www.alliedbuilding.com); their supplier in Massachusetts is United Builders Supply (40 Waverly St, Framingham, MA (508) 879-1000). Homasote is available through Home Depot and dozens of other building products suppliers in Massachusetts.

Table 4.4.3 A: Performance Values for Structural Use Panels

	Softwood Plywood	OSB	Homasote	Viroc
Weight (1/2 in.) lb/ft^2	1.6	1.7	1.2 (heavier at equivalent span rating)	3.1
Tensile Strength lb/in^2	1,500-4,000	1,000-1,500	450-700	793
Shear	165 lb/ft	175 lb/ft	225 (field)	n/a
Permeance	.8	.8	12	2.7
Linear Expansion (50-90% RH)	.15	.15	0.25%	0.14%
Nail Pull (Dry)	50 lbs	40 lbs	125	325
R Value	.6	.6	1.2	0.36

Human Health and Safety Assessment

Columbia's Purebond veneer core panel is made with hardwood species wood glued together with soy flour "blended with a very small amount of proprietary resin," according to Columbia's website. That resin is Hercules Inc. chemical Kymene® 624 Wet Strength Resin, now called ChemVisions™ CA1000, a liquid cationic amine polymer-epichlorohydrin amine called polyamide-epichlorohydrin (PAE). Neither the PureBond MSDS nor the Kymene® 624 MSDS notes the inclusion of any hazardous ingredients. The Kymene® 624 MSDS warns that repeated contact with the resin may cause skin, eye and respiratory tract irritation and skin sensitization in "susceptible" individuals resulting in dermatitis. Columbia reports that the addition to and mixing of the PAE with the soy flour is a closed process and manufacturing workers do not have contact with the PAE or the mixed PAE-soy resin.

Although life cycle considerations are limited within the scope of this report, it is important to consider that the PAE chemical is manufactured with epichlorohydrin, a probable human and confirmed animal carcinogen. Epichlorohydrin is also acutely toxic to humans and overexposure can cause severe damage to the liver, kidneys, eyes and respiratory tract (Hazardous Substances Data Bank). It is also a skin and respiratory sensitizer, causing asthma and dermatitis. It is mutagenic and may cause infertility in men. According to the manufacturer and the EPA, epichlorohydrin is completely consumed in the batch manufacturing process used to make the resin. There are no emissions from this process and no residual or "free" epichlorohydrin in PAE where it is irreversibly transformed in the polymer matrix (Steib 2006; USEPA 1984). Because of this, there is apparently no potential for worker, consumer or environmental exposure to epichlorohydrin during PureBond building panel manufacture, use or disposal.

Those employed in the manufacture of epichlorohydrin are likely to have to greatest potential for exposure, followed by those exposed in the Kymene manufacturing process. NIOSH conducted industry wide surveys of epichlorohydrin exposures in five facilities in the 1970's. Three of these were plants that manufactured kymene resins, including a Hercules plant in Georgia. In that survey, the two sampled production workers were exposed well below the PEL of 5 ppm and also well below the ACGIH TLV® of 0.5 ppm. Their time weighted average exposures were 0.15 and 0.05 ppm (Bales 1978). Epichlorohydrin has a vapor pressure similar to water and can be absorbed through the skin.

Soy flour is not known to have any negative health effects. Wood dust can cause skin and respiratory tract irritation and even sensitization. Additionally, both IARC and the EPA's NTP program have designated wood dust as a carcinogen with hardwood dust, specifically, associated with adenocarcinoma of the nasal cavities and paranasal sinuses (Hazardous Substances Data Bank).

Like PureBond, Viroc and Homasote do not present a health and safety or environmental hazard to building occupants. Since they are not bound with a resin, per se, the health and safety issues they present relate to the substrate itself. Considerable dust may be generated in cutting Viroc and Homasote. Viroc recommends that vacuum fitted cutting tools and dust masks be used. The dust generated would be composed of wood dust and Portland cement dust both of which present potential hazards. As mentioned above, wood dust is a potential carcinogen and a respiratory irritant. Cement dust may contain free silica.

Homasote dust is recycled newspaper (cellulose). Studies of paper and pulp workers have found exposure-related chronic bronchitis and excess cancers, but these mills workers were exposed to many chemicals in addition to cellulose. Exposure to cellulose dust and fibers was found to cause reversible respiratory tract inflammation in rats, and cellulose dust is thought to be of low toxicity, despite the durability of cellulose fibers in the lung (Cullen et al. 2000). Pulmonary and intraperitoneal inflammation induced by cellulose fibres.)

Portland cement is made of calcium compounds including tri and dicalcium silicate, tricalcium aluminate, tetracalcium aluminoferrite, and gypsum (calcium sulfate dihydrate). Due to its alkalinity, Portland cement can be irritating to the respiratory tract, skin and eyes. Trace contaminants of hazardous metals and minerals may be present in Portland cement including free crystalline silica, chromium, nickel, calcium and magnesium oxide, potassium and sodium sulfate. Crystalline silica is a human carcinogen according to EPA's NTP program and IARC. The trace amounts of chromium in Portland cement are thought to contribute to allergic contact dermatitis in a small percentage of exposed workers, although such skin problems may also be due to repeated exposure to the drying effects of prolonged skin contact with wet cement (Sahai 2001).

European Union Directive 2003/53/EC limits the amount of chromium IV in Portland Cement to 0.0002% or 2 ppm due to its sensitizing properties. This is being done through selection of raw materials less likely to contain trace chromium and by the addition of reducing agents. Both the OSHA standard and the ACGIH TLV for Portland Cement are set at 10 mg/m^3 (compared to 0.5 mg/m^3 for lead, for example).

Potential manual material handling hazards are significant for Viroc due to its greater density. Company materials address this concern and recommend that panels be lifted and carried by two or more people and that trollies and other devices be used to transport panels.

Environmental Assessment

The PureBond hardwood plywood board is not expected to have any environmental impact beyond those of traditional boards. (Customers may specify PureBond veneer core hardwood panel certified sustainable by the Forest Stewardship Council). Soy flour has no known environmental impact. The Kymene resin, itself, is acidic (pH 2.6-3) and therefore toxic to several aquatic species. Safe disposal of the resin requires pH neutralization. It does not readily biodegrade. Epichlorohydrin is a hazardous air pollutant, a regulated water pollutant, and must be treated as hazardous waste. It will volatilize from soil and water and has a half life of 36 days in air. It does not bioaccumulate.

Epichlorohydrin is not a potential environmental release from the panel manufacturing process. It is released from Hercules manufacturing facilities, however. According to TRI data, Hercules reported over 19,500 pounds of epichlorohydrin environmental releases in 2002 (combining all facilities' releases), almost all of these were releases to air (Green Media Toolshed, Inc.). The amount of these releases attributable to the manufacture of the PAE resin for the production of PureBond is not known, but is likely to be very small considering that the main use of PAE is in paper manufacture and that Hercules uses epichlorohydrin to make other chemicals. Nevertheless, a dramatic increase in the use of PAE resin for the production of wood products could result in increases in epichlorohydrin environmental releases.

Neither Homasote nor Viroc (nor their constituents cellulose and Portland Cement) are expected to have any negative impact on the environment from a toxicity standpoint. From a resource conservation standpoint, Viroc is only 20% wood and can be made with waste wood thus avoiding harvest of virgin forests. However, Portland cement must be mined and therefore is not a renewable resource. Homasote not only does not use any virgin wood, it is at least 80% post-consumer recycled materials that otherwise would be headed for landfills or incinerators. Homasote touts its environmental performance as follows:

> Each year Homasote building products help conserve more than 1,370,000 trees and eliminate more than 100,000,000 pounds of solid waste each year. Each production day up to 300 tons of post-consumer paper are recycled into Homasote, diverted from waste stream disposal into landfills or other methods. All water used to manufacture Homasote® products — hundreds of thousands of gallons per day — is completely recycled in a "closed loop" system.

From an energy use standpoint, Viroc has several concerns. The making of Portland Cement in one of the world's most energy intensive industrial activities resulting significant greenhouse gas, dioxin,

NO_x, SO_2, and particulates emissions. For every ton of Portland cement produced, one ton of carbon dioxide is released to the atmosphere (Portland Cement Association). Additionally, significant amounts of fossil fuels are consumed in the production of Viroc as the Portland Cement and wood fibers are transported to Portugal and then back to the United States and then around the country. Building Green Inc., publishers of Environmental Building News, have not given Viroc its imprimatur as a "green" product because of this extreme energy intensivity.

Financial Assessment

Veneer core hardwood plywood is a high quality, high cost product. Columbia PureBond product costs the same as the traditional product produced with urea-formaldehyde resin (approximately $1.25/ft^2.)

Homasote's sheathing panels are more expensive at $15-25 for ½ in. 4x8 panel, than OSB ($13) and plywood ($14), but costs are within reach, especially if OSB mill problems arise. Homasote's floor decking is much more expensive than traditional alternatives.

At $96 for a ½ in. 4x8 panel, Viroc is more than seven times the cost of OSB and plywood, but offers qualities such as fire, wind, impact and insect and mold resistance that may make it attractive to certain markets nonetheless. Viroc can be used without cladding, thus saving some portion of the additional expense.

Near Horizon Alternative: JER Envirotech plastic-wood composite panel

In British Columbia and in Malaysia, with support from the Canadian government, the JER Envirotech company is in process of developing an extruded building panel made of wood fiber and polypropylene thermoplastic (JER Envirotech Ltd.). They expect to begin selling these panels in the US in the next year. Currently, they view this product as a substitute for particleboard and not a structural product although they will be submitting it to a testing protocol and ultimately expect it to perform as a structural product. Wood-plastic composite products are used extensively in this country as substitutes for wood lumber, but JER Envirotech will be the first to produce a panel from this material. Their website describes the JER panel as superior to plywood due to its superior high temperature heat deflection, superior fire resistance, resistance to biological degradation (*e.g.,* insects, decay, termite etc.), very low water absorption, superior mechanical properties (tensile, flexural, and impact resistance), resistance to thermal degradation and its lack of formaldehyde. They also suggest that the price will be competitive. Polypropylene thermoplastic does not have recognized health and environmental effects except for a potential for respiratory irritation from exposure to polypropylene fumes during manufacture of the raw material (Hazardous Substances Data Bank). Wood dust is recognized as a carcinogen.

Summary

Columbia's PureBond compares well to the traditional product in the technical and financial assessment. While it eliminates potential formaldehyde exposures, it does introduce a new potential hazard, epichlorohydrin, into the lifecycle of building panels. This hazard is unlikely to threaten building occupants or workers exposed to the Kymene resin, but is a potential (although low) worker and environmental hazard in the manufacture of the intermediates.

Viroc and Homasote panels may satisfy enough technical requirements to be considered for structural uses in buildings, especially for those interested in "green" or low toxicity construction. Each has unique advantages and potential disadvantages. Advantages for Homasote include is lack of toxicity and beneficial environmental impact. Additionally, due to its high perm rating and wicking ability, it may prove to be a durable material that helps to prevent mold problems. Viroc has entered the US market at a time when builders in the South and around the country may be looking for hurricane, fire, mold and insect proof building materials that will not negatively impact indoor air quality. Its high cost is likely to prevent it from substituting directly for plywood or OSB, except where these qualities are highly desirable, or where designs utilizing Viroc can eliminate cladding or insulation. Although the Portland cement industry is working to reduce its environmental impact, Viroc's inherent energy intensivity will not appeal to green builders and customers with lifecycle perspectives.

"Green" building products are developing at a rapid pace. Concerns with resource and energy conservation and indoor air quality for building occupants has driven the development of programs such as the U.S. Green Building Council's LEED certification program. These types of initiatives have fostered innovation in new materials development and a market for greener construction materials. Additionally, traditional product suppliers may begin producing plywood and composite wood products made with soy-based (or other) resins and plastic-wood. If the demand for no-added formaldehyde products increases, plywood makers may use more polyvinyl acetate glue in their existing presses despite the increased cost and production challenges. In the meantime, in addition to the "no added formaldehyde" products evaluated here, use of wood products made with low-emission formaldehyde resins will continue to reduce exposures to formaldehyde.

Table 4.4.3 B: Assessment Summary for Hardwood Plywood Building Panels

Assessment Criteria		Traditional Formaldehyde-based Resin Plywood (Reference)	Comparison Relative to traditional formaldehyde resin Plywood PureBond soy-based adhesive
Technical/ Performance Criteria	Appearance/ Construction	ANSI/HVPA HP-1-2004	=
	Glue bond under moisture	Good (ANSI 3-cycle soak)	=
		Poor (ANSI 3-cycle boil)	+
	Fire Resistance	Good (ASTM E-85 Flame Spread Class C)	=
	Warp Resistance	Variable	=/?
	Product Availability	Good	=
Financial Criteria	Cost (1/2 in. 4x8)	$1.25/ft^2 (Columbia's price)	=
Environmental Criteria	Ecotoxicity	Minor	=
Human Health Criteria	Carcinogen in Resin	Yes	+
	Toxic Intermediate in Resin	Yes	=
	Irritant in Resin	Yes	+

Comparison Key + Better = Similar - Worse ? Unknown

Table 4.4.3 C: Assessment Summary for Structural Use Building Panels

Assessment Criteria		Softwood Plywood with formaldehyde-based resin (Reference)	OSB (Oriented Strand Board) (Reference)	Comparison Relative to formaldehyde-based resin Softwood Plywood and OSB	
				Homasote	Viroc
Technical/Performance Criteria	Weight (1/2 in.) lb/ft^2	Acceptable	Acceptable	+	-
	Fire Resistance	Good (Class C)	Good (Class C)	=	+
	Insect/Rot/Mold Resistance	Acceptable	Acceptable	+	+
	Load bearing/weight	Good	Good	-	-
	Impact Resistance	Good	Less than plywood	-	+
	Tensile Strength lb/in^2	Excellent	Excellent	-	-
	Shear	Good	Good	+	?
	Permeance	Acceptable	Acceptable	+	+
	Linear Expansion (50-90% RH)	Good	Good	-	+
	"Weatherability"	Acceptable	Acceptable but worse than plywood	?	?
	Nail Pull (Dry)	50 lbs	40 lbs	+	+
	R Value	.6	.6	+	-
Financial Criteria	Cost (1/2 in. 4x8)	$14	$13	-	-
Environmental Criteria	Ecotoxicity	Minor	Minor	+	+
	Natural Resource Conservation	Poor	Better than plywood	+	?
	Energy Intensity	Neutral	Neutral	?	-
Human Health Criteria	Carcinogen in Binder	Yes	Yes	+	+
	Irritant in Binder	Yes	Yes	+	=

Comparison Key + Better = Similar - Worse ? Unknown

4.5. Summary and Conclusions

Formaldehyde, a gas a room temperature, is widely used in industry and is a basic building block for the manufacture of many other chemicals and products. More than half of formaldehyde manufactured is used in the production of resins and adhesives and most of these are used in the manufacture of wood products such as plywood. Most formaldehyde is sold as formalin, a water solution of formaldehyde and some methanol to prevent polymerization. Formaldehyde is highly toxic to bacteria and other pathogens and, thus, it is used as a sterilizer. In addition to manufactured sources, formaldehyde can be a product of combustion.

Exposure to formaldehyde can cause irritation and dermatitis and has been found to cause nasopharyngeal cancer in some occupational groups, including embalmers who use formaldehyde to preserve the deceased. Because formaldehyde is highly reactive, water soluble and readily metabolized by almost all human cells, overexposures tend to do damage at the point of contact, most commonly the eyes and the upper respiratory tract.

Rising concerns about indoor air quality have drawn formaldehyde into the spotlight because of the tendency for formaldehyde-containing building elements and furniture to "off-gas" formaldehyde thereby causing irritation to occupants. In response, manufacturers have improved their processes to reduce the potential for off-gassing and standards have been set to certify products as "low-emitters."

We looked at alternatives to the use of formaldehyde in sanitary storage for barbering and cosmetology, preserved educational specimens for dissection, and building panels. These uses were chosen because of their potential to expose students, workers and the public to formaldehyde emissions.

Sanitary Storage in Barbering and Cosmetology

In salons and cosmetology classrooms in Massachusetts, paraformaldehyde sanitizers known as Steri-Dry tubes are required by the Board of Cosmetology to be placed along with brushes and combs in storage cabinets and drawers to maintain an extra level of protection for customers. However, national best practices experts recommend that paraformaldehyde not be used; that storage cabinets be cleaned and disinfected with standard procedures. Thus, the alternative to this use of formaldehyde is to not use it and to abide by sanitary standards.

A second alternative, the use of UV light cabinets, has potential maintenance concerns and could result in UV light exposure. They also represent a significant initial capital expenditure. They also could be used effectively as an alternative to Steri-Dry, however, eliminating the EH&S concerns associated with exposure to formaldehyde.

Educational Specimens

Students and instructors have been exposed to formaldehyde through the off-gassing of specimens such as fetal pigs and frogs dissected in gross anatomy classes. Several scientific supply companies are offering formaldehyde-free alternative specimens and these are generally less expensive, deemed equivalent or better from a technical standpoint, and are generally less toxic. However, these alternative preservatives do contain ingredients that can be irritating to the skin and should be used with skin protection.

Another viable alternative to formaldehyde-preserved specimens is the use of virtual/video dissection technology, which eliminates any exposure concerns associated with formaldehyde. From a technical standpoint, the use of virtual/video dissection offers certain advantages, but many instructors prefer physical dissection. It may also be a useful adjunct to dissection for classroom instruction.

Building Panels

The Institute identified and assessed acceptable alternatives being used by manufacturers of building panels. Two products, one that is recycled paper board and one that is cement-wood fiber board, are made without the use of formaldehyde-based resins, and are feasible alternatives for many structural panel applications. These alternatives are generally superior to the formaldehyde-based structural panels from an EH&S perspective, but are more expensive. In addition, the cement-wood fiber board uses significant amounts of energy in its manufacture.

In addition to material alternatives made without resins, one company is manufacturing wood panels (currently only veneer core hardwood plywood) with a soy-based resin. Because of the addition of a wet-strength ingredient borrowed from the paper industry, this soy-based resin has equivalent or better technical performance to the traditional product. The cost is also equivalent to the traditional product. While there are not expected to be environmental or health and safety hazards related to the use of this alternative resin, the lifecycle of this chemistry includes an intermediate chemical that is a carcinogen.

Finally, an emerging technology, extruded building panel made of wood fiber and polypropylene thermoplastic, is currently being developed as an alternative decorative wood panel. The Institute was not able to assess this alternative compared to formaldehyde-based building panels, however we encourage further study to determine how this alternative compares from an EH&S, technical and cost perspective

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