



# Alternative Resin Binders for Particleboard, Medium Density Fiberboard (MDF), and Wheatboard

Urea formaldehyde-based resins have been the standard binders used to glue the particles together in many composite wood products, including particleboard, wheatboard, and medium density fiberboard (MDF). In recent years, however, concerns have been rising about the risks of cancer and bronchial health impacts from formaldehyde.<sup>1</sup> Several market factors are driving major changes in the composition and technology of these resins. Pressure from the green building movement through market selection and certification programs, plus emissions regulations from the California Air Resources Board (CARB), are moving manufacturers to look for ways to reduce formaldehyde emissions or eliminate formaldehyde entirely from formulas.

This fact sheet evaluates health hazards associated with each of the major binder technologies. Manufacturers are currently using or undertaking research and

development into four major approaches to reduce the problem of exposure to formaldehyde from composite wood binders:

- 1) Modified urea formaldehyde resins with scavenger additives, such as melamine, to reduce the rate of emissions of formaldehyde;
- 2) Alternate formaldehyde resins, such as phenol formaldehyde, which cure at the factory during manufacture and hence have much lower formaldehyde emissions in use than urea formaldehyde;
- 3) Alternate fossil fuel-based binders containing no added formaldehyde, such as methylene diphenyl diisocyanate (MDI); and
- 4) Alternate binders based on renewable resource materials, such as soy flour.

## Formaldehyde-based Binders

There are three types of formaldehyde-based binders currently on the market. Formaldehyde is a known carcinogen, respiratory irritant and hazardous component of smog. For more detailed description of formaldehyde and its health hazards refer to "Health Hazards of Formaldehyde Found in Building Materials" at <http://www.healthybuilding.net/healthcare/index.html>.

## NOTE

*There are many concerns about the use of the term "formaldehyde free" in marketing or otherwise describing building products. A wide range of materials, including wood and paper, naturally emit very small trace amounts of formaldehyde. Therefore for clarity, we exclusively use the term "no added formaldehyde" instead of "formaldehyde free" to describe these products.*

## Urea Formaldehyde

Composite wood using binders composed of urea formaldehyde (UF)<sup>2</sup> were determined by the CARB to be significant sources of formaldehyde emissions in buildings due to the fact that urea formaldehyde continues to cure throughout its lifetime, outgassing formaldehyde in the environment for long periods after manufacture and installation.<sup>3</sup>

## Urea Formaldehyde and Scavenger Additives

Urea formaldehyde-based resins can be directly mixed with additives called scavengers, which bind with the urea formaldehyde to reduce emissions. Melamine and hexamine are the most common added scavengers. Alternatively, the board may be treated after pressing with a scavenger such as anhydrous ammonia or various solid ammonium compounds.<sup>4</sup> Scavengers can reduce formaldehyde emissions by 2 to 10 times, but cannot eliminate it. Significant quality control is required in manufacturing to maintain these reductions in mass production of the finished product. Furthermore, while reducing the rate of emission of formaldehyde from composite wood and providing short-term improvements, it is not clear if scavengers extend the time over which the formaldehyde emits from the board. As there is no threshold below which formaldehyde has no carcinogenic effect, this analysis does not focus on the scavenger alternative.

## Phenol Formaldehyde

Phenol formaldehyde (PF)<sup>5</sup> has long been used in composite wood products designed for exterior use due to its higher water resistance than urea formaldehyde.

Phenol formaldehyde results in 90% less formaldehyde emissions than urea formaldehyde, but does not completely eliminate formaldehyde emissions altogether.<sup>6</sup> Phenol formaldehyde formulations, like urea formaldehyde formulas, are derived from formaldehyde and hence share the same occupational exposure concerns. Additionally, the aromatic hydrocarbon, phenol,<sup>7</sup> that is used to make phenol formaldehyde, is on its own a chemical of concern. Finally, phenol formaldehyde is listed as a suspected immunotoxicant under NIH's Database on Hazardous Chemicals and Occupational Diseases.<sup>8</sup>

## MDI and pMDI

Polymeric MDI (pMDI)<sup>9</sup> is the primary technical/commercial form of methylene diphenyl diisocyanate (MDI).<sup>10 11</sup> MDI and pMDI are used in the production of polyurethane foam as well as for binders. MDI and pMDI are produced from aniline,<sup>12</sup> formaldehyde,<sup>13 14</sup> and a large number of other chemicals, including MDI and benzene.<sup>15</sup> The bulk of the scientific information assessing the health or environmental hazards of MDI/pMDI involve the use of MDI in the production of polyurethane foam.<sup>16</sup>

### Health impacts—cancer

The International Agency for Research on Cancer (IARC) classifies MDA (4,4'-methylenedianiline,<sup>17</sup> an aniline building block of MDI, as a probable human carcinogen (Group 2B).<sup>18</sup> While IARC has not classified aniline as a human carcinogen, both the EPA<sup>19</sup> and California Proposition 65<sup>20</sup> have done so. The National Institute of Health's National Toxicology Program (NTP) states that MDA is reasonably anticipated to be a human carcinogen.<sup>21</sup> MDA is listed in California's Proposition 65 as a known

carcinogen<sup>22</sup> and is a cardiovascular, kidney, and neurodevelopmental toxicant in the Registry of Toxic Effects of Chemical Substances.<sup>23</sup>

Studies recently are finding emerging evidence that the solvent benzene, used to produce MDI, is not only a volatile organic compound, but may also be linked to leukemia, multiple myeloma, prostate cancer, and non-Hodgkins lymphoma.<sup>24</sup>

#### Health impacts—non-cancer

MDI is a member of a class of chemicals known as isocyanates. Isocyanates in general are skin irritants, as well as eye, mucous membrane, and respiratory tract irritants.<sup>25</sup> The primary adverse effect on humans from MDI is asthma and then secondarily contact dermatitis, as well as hypersensitivity pneumonitis (HP). Acute inhalation exposure to aniline at high levels can result in respiratory problems in humans.<sup>26</sup>

#### Occupational exposures

Isocyanates are a class of chemicals implicated in workplace exposures and occupational health. The U.S. Environmental Protection Agency (EPA) says, "exposure to isocyanates is a leading cause of occupational asthma worldwide."<sup>27</sup> Researchers have found isocyanate-induced asthma showing up in 5–10% of workers in diisocyanate production facilities,<sup>28</sup> 5–25% in polyurethane production plants,<sup>29</sup> and 5–30% in polyurethane seat cover operations.<sup>30</sup> The Center for Disease Control's (CDC) National Institute on Occupational Safety and Health (NIOSH) regulates MDI occupational exposures.<sup>31</sup>

#### User exposures

Actual test data is limited, but indications are that once MDI is cured, the emissions

from the product are insignificant and not comparable to the hazards of formaldehyde binder emissions. Like epichlorohydrin, below, the issue with MDI is occupational exposure in the making of the resin binder itself.

### Emerging alternatives: Soy-Based Binders

Columbia Forest Products made headlines in 2006 with announcement of PureBond,<sup>®</sup> its new soy-based resin technology. This was a first break from the industry dependence on resins that use a form of formaldehyde in the resin or as a feedstock, replacing it with a resin based upon a renewable resource (soy flour). It is first being utilized as a binder in hardwood plywood panels and is currently being tested for use in other composite wood products.

The soy flour component is a renewable resource and, while not studied extensively as a building material component, it is not expected to have health impacts as significant as the formaldehyde and MDI-based binders. Soy products can cause allergic reactions in some people and contain plant estrogens. The compounds are, however, expected to be completely destroyed in processing and not be present in the proteins used in the adhesive.<sup>32</sup>

PureBond does, however, have another primary component—Kymene—with problematic feedstocks. Kymene is produced using polyamide-epichlorohydrin (PAE)<sup>33</sup> resin, which in turn is manufactured from a chemical known as epichlorohydrin, or chloropropyl oxide. Kymene resin is manufactured by Hercules Chemical and previously primarily marketed as a resin in paper

manufacturing.<sup>34</sup>

## Epichlorohydrin<sup>35</sup>

Epichlorohydrin<sup>36</sup> is a highly volatile and unstable liquid epoxide. It is prepared from propene, found in coal gas or synthesized by cracking petroleum, which is chlorinated to allyl chloride.<sup>37</sup> Epichlorohydrin is a major raw material used in the manufacture of epoxy and phenoxy resins. It is also used as a solvent and in the synthesis of glycerol. Other uses include as an insect fumigation and as a chemical intermediate for the formation of glycidyl acrylate derivatives.<sup>38</sup>

### Health impacts—cancer

The International Agency for Research on Cancer (IARC) classifies epichlorohydrin as a probable human carcinogen (Group 2A).<sup>39</sup> The National Institute of Health's National Toxicology Program (NTP) states that epichlorohydrin is reasonably anticipated to be a human carcinogen.<sup>40</sup> The chemical is listed in California's Proposition 65 as a carcinogen.<sup>41</sup>

### Health impacts—non-cancer

Epichlorohydrin is listed in California's Proposition 65 as a reproductive toxicant (as well as a carcinogen—see above). Researchers have found that epichlorohydrin is acutely toxic to humans and overexposure can cause severe damage to the liver, kidneys, eyes, and respiratory tract.<sup>42</sup> It is also mutagenic and may cause infertility in men.<sup>43</sup> It is also regulated in drinking water,<sup>44</sup> as a hazardous air pollutant,<sup>45</sup> as a pesticide,<sup>46</sup> as an air contaminant,<sup>47</sup> and as an aquatic toxicant.<sup>48</sup>

### Occupational exposures

NIOSH conducted industry-wide studies of exposure to epichlorohydrin in the 1970s and found exposures in the workplace well below the PEL and the ACGIH TLV.

Though workplace issues are paramount, the EPA also regulates epichlorohydrin in drinking water.<sup>49</sup> Those employed in the manufacture of epichlorohydrin are likely to have greatest potential for exposure, as well as those working in the Kymene plants, rather than workers exposed during the manufacturing of the PureBond resin itself.<sup>50</sup> CDC's NIOSH regulates epichlorohydrin occupational exposure.<sup>51</sup>

### User Exposure

Columbia Forest Products says that the epichlorohydrin is completely consumed in the batch manufacturing process used to make the resin, so there are no emissions from the process and no epichlorohydrin remaining in the final product.<sup>52</sup> The manufacturer has stated that the addition and mixing of PAE with the soy flour is a "closed process" and therefore manufacturing workers and/or users do not have contact with the PAE or the mixed PAE-soy resin.<sup>53</sup> Massachusetts Toxics Use Reduction Institute (TURI) concluded in its study of PureBond, that "[w]hile 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."<sup>54</sup>

## Summary Conclusions

At this point in the development of alternatives to urea formaldehyde (UF) resins in particleboard, MDF, and wheatboard products, there has yet to be a product that can replace UF that does not raise some environmental health concerns.<sup>55</sup> Taking into account any potential added costs associated with the production of the alternatives

(some alternative products require more curing time, which gets built into the product price), health care institutions will have to take into account the health risks, alongside the costs and performance characteristics of the products themselves, to determine which alternatives to use in casework. Alternatives to formaldehyde, such as MDI or soy-based resins, appear to virtually eliminate the exposures to chemicals in the curing processes that continue after installation in formaldehyde-based products, significantly reducing user exposure to hazardous chemicals. These chemicals do, however, raise occupational health concerns for those making the resin binders.

In summary, the health concerns are as follows:

- 1) Modified urea formaldehyde resins with scavenger additives bind the formaldehyde better in the wood, reducing but not eliminating the formaldehyde emissions from the resin. Like other urea formaldehyde based resins, they will offgas formaldehyde, exposing occupants for long periods of time, just at lower rates;
- 2) Alternate formaldehyde resins, such as phenol formaldehyde, also have lower formaldehyde emissions in use, but do not eliminate emissions altogether. In addition, they raise occupational health and safety concerns during the production process;
- 3) Alternate fossil fuel-based binders containing no formaldehyde, such as methylene diphenyl diisocyanate (MDI), do not release formaldehyde during use. They are, however, made from formaldehyde. In addition, MDI raises other significant occupational health and safety concerns during the production and manufacturer of the composite wood products. We were not able to determine at this time whether there are sufficient remediation efforts that can be utilized in the workplace to reduce occupational exposure concerns, but hope to be able to address these issues in future work; and
- 4) Alternate binders based on renewable resource materials, such as soy flour, do not release formaldehyde during use. What we know of a primary component, epichlorohydrin, currently used in combination with the soy flour in the resin, does raise some concerns for occupational health and safety. The primary manufacturer of the technology claims that the product is manufactured in such a way as to reduce occupational exposure and eliminate potential user exposure. We were not able to determine at this time whether there are sufficient remediation efforts that can be utilized in the workplace to reduce occupational exposure concerns, but hope to address these issues in future work.

## ENDNOTES

- 1 Formaldehyde (CAS No. 50-00-0) is also known as methanal, methylene oxide, oxymethylene, methylaldehyde, or oxomethane and has the chemical abbreviation HCHO. For more in depth analysis of formaldehyde, see "Health Hazards of Formaldehyde Found in Building Materials," May 2008.
- 2 CAS No. 9011-05-6
- 3 California Air Resources Board, "Fact Sheet Proposed Airborne Toxic Control Measure (ATCM) to Reduce Formaldehyde Emissions from Composite Wood Products" (<http://www.arb.ca.gov/toxics/compwood/background.htm>).
- 4 California Air Resources Board, Staff Report: Initial Statement Of Reasons For Proposed Rulemaking - Adoption Of The Proposed Airborne Toxic Control Measure To Reduce Formaldehyde Emissions From Composite Wood Products, April 2007 (<http://www.arb.ca.gov/regact/2007/compwood07/isor.pdf>).
- 5 CAS No. 9003-35-4
- 6 CARB. Ibid.
- 7 CAS No. 108-95-2
- 8 National Institute of Health, "Relational Database of Hazardous Chemicals and Occupational Diseases" (<http://hazmap.nlm.nih.gov/hazmapadv.html>).
- 9 CAS No. 101-68-8
- 10 CAS No. 9016-87-9
- 11 World Health Organization, "Concise International Chemical Assessment Document 27: Diphenylmethane Diisocyanate (MDI)," 2000 (<http://www.inchem.org/documents/cicads/cicads/cicad27.htm>).
- 12 CAS No. 62-53-3
- 13 WHO, Ibid.
- 14 Massachusetts Toxics Use Reduction Institute (TURI) at the University of Massachusetts Lowell (June 2006) [hereinafter TURI document], page 4-16 of 456 ([http://www.turi.org/library/turi\\_publications/five\\_chemicals\\_study](http://www.turi.org/library/turi_publications/five_chemicals_study)).
- 15 McRandle, P.W., "What is Polyurethane?" April 2003 (<http://www.thegreenguide.com/doc/ask/poly>).
- 16 U.S. Environmental Protection Agency, Toxicological Review Of Methylene Diphenyl Diisocyanate (MDI) (CAS No. 101-68-8 and 9016-87-9) In Support of Summary Information on the Integrated Risk Information System (IRIS) February 1998 (<http://www.epa.gov/iris/toxreviews/0529-tr.pdf>).
- 17 CAS No. 101-77-9
- 18 International Agency for Research on Cancer (IARC) Summaries & Evaluations: 4,4'-Methylenedianiline and its Dihydrochloride (Group 2A), Vol. 39, page 347 (1986) and Suppl. 7 (1987) (p. 66: Group 2B). (<http://www.inchem.org/documents/iarc/vol39/4,4'-methylenedianiline.html>).
- 19 US EPA, Integrated Risk Information System – Aniline is classified as a Group B2 "Probable Human Carcinogen" (<http://www.epa.gov/IRIS/subst/0350.htm>).
- 20 California Safe Drinking Water and Toxic Enforcement Act of 1986 (Proposition 65). ([http://www.oehha.org/prop65/prop65\\_list/files/032108list.pdf](http://www.oehha.org/prop65/prop65_list/files/032108list.pdf)).
- 21 National Institute of Health 11th Report on Cancer, National Toxicology Program (1998) (<http://ntp-server.niehs.nih.gov/index.cfm?objectid=32BA9724-F1F6-975E-7FCE50709CB4C932>).
- 22 Proposition 65, Ibid.
- 23 Registry of Toxic Effects of Chemical Substances (RTECS) cited in Scorecard.org based on a review of RTECS conducted by Environmental Defense.
- 24 Clapp R, Jacobs M, Loechler E, Environmental and Occupational Causes of Cancer: New Evidence, 2005-2007, Lowell Center for Sustainable Production, University of Massachusetts, Lowell, October 2007.
- 25 Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute of Occupational Safety and Health, "A Summary of Health Hazard Evaluations: Issues Related to Occupational Exposure to Isocyanates, 1989 to 2002", January 2004 (<http://www.cdc.gov/niosh/docs/2004-116/pdfs/2004-116.pdf>).
- 26 US EPA Hazard Summary for Aniline, Revised January 2000. (<http://www.epa.gov/ttn/uatw/hlthef/aniline.html>).
- 27 US EPA, Toxicological Review of MDI (February 1998).
- 28 US EPA, Ibid.
- 29 US EPA, Ibid.
- 30 US EPA, Ibid.
- 31 National Institute for Occupational Safety and Health, "International Chemical Safety Card: MDI." (<http://www.cdc.gov/niosh/ipcsneng/neng0298.html>).
- 32 Brown, Valerie, "Better Bonding with Beans," Environmental Health Perspectives. 2005 August; 113(8): A538–A541 (<http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=1280368>).
- 33 CAS No. 68583–79–9
- 34 Kymene is marketed as a "wet strength" technology to provide strength to paper. See Hercules Paper Technologies website at [http://ppd.herc.com/innovations/kymene%2%AE\\_wet\\_strength\\_technology.asp](http://ppd.herc.com/innovations/kymene%2%AE_wet_strength_technology.asp).
- 35 TURI, Ibid.
- 36 CAS No. 68583–79–9
- 37 Chemical Land 21, Arokor Holdings, Inc. (<http://www.chemicalland21.com/petrochemical/EPICHLOROHYDRIN.htm>).
- 38 Office of Environmental Health Hazard Assessment (OEHA), "Chronic Toxicity Summary: Epichlorohydrin (1-chloro-2,3-epoxy-propane)," 2000. ([http://www.oehha.ca.gov/pdf/2ApnA\\_DCB-Isoph.pdf](http://www.oehha.ca.gov/pdf/2ApnA_DCB-Isoph.pdf)).
- 39 International Agency for Research on Cancer (IARC) Summaries & Evaluations: Epichlorohydrin (Group 2A), Vol. 71 (1999) (p. 603) (<http://www.inchem.org/documents/iarc/vol71/020-epichlorohydrin.html>).
- 40 National Institute of Health, Ibid.
- 41 Proposition 65, Ibid.
- 42 National Library of Medicine, "Hazardous Substances Data Bank (HSDB)." (<http://toxnet.nlm.nih.gov/cgi-bin/sis/search/f?./temp/~aVEyeS:1.>).
- 43 International Programme On Chemical Safety: "Environmental Health Criteria 33" (1984). (<http://www.inchem.org/documents/ehc/ehc/ehc33.htm>).
- 44 U.S. Environmental Protection Agency, Safe Drinking Water Act of 1974. and National Primary Drinking Water Contaminants Regulations. (<http://www.epa.gov/safewater/contaminants/index.html#listmcl>).
- 45 Title III of the Clean Air Act Amendments of 1990 ([http://www.epa.gov/appcdwww/aptb/hap\\_list.pdf](http://www.epa.gov/appcdwww/aptb/hap_list.pdf)).
- 46 Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA). (<http://a257.g.akamaitech.net/7/257/2422/01jan20051800/edocket.access.gpo.gov/2005/pdf/05-22384.pdf>).
- 47 Occupational Safety and Health Agency (OSHA). "Chemical Sampling Information Epichlorohydrin." ([http://www.osha.gov/dts/chemicalsampling/data/CH\\_238700.html](http://www.osha.gov/dts/chemicalsampling/data/CH_238700.html)).
- 48 World Health Organization, "Epichlorohydrin Health And Safety Guide", International Programme On Chemical Safety, Health And Safety Guide No. 8, Geneva 1987 (<http://www.inchem.org/documents/hsg/hsg/hsg008.htm>).
- 49 Proposition 65, Ibid.
- 50 Proposition 65, Ibid..
- 51 National Institute for Occupational Safety and Health, "International Chemical Safety Card: Epichlorohydrin" (<http://www.cdc.gov/niosh/ipcsneng/neng0043.html>).
- 52 TURI 2006, page 4-17.
- 53 TURI 2006, page 4-33.
- 54 TURI 2006, page 4-35.
- 55 For detailed information about concerns with UF, please see "Health Hazards of Formaldehyde Found in Building Materials." (<http://www.healthybuilding.net/healthcare/index.html>).