# Resin Suppliers' Perspectives on the "Greening" of the North American Interior Wood Composite Panel Market

Thomas C. Ruffing
Paul M. Smith
Nicole R. Brown

**Abstract**

Eight North American resin suppliers, representing 100 percent of the polymeric diphenylmethane diisocyanate (pMDI) market and >95 percent of the urea-formaldehyde (UF) market for interior wood composite panels (IWCPs), participated in an exploratory phone survey conducted in July and August 2008 that was designed to better understand their product positioning and ''green'' resin strategies. These eight firms were identified as the largest suppliers to the IWCP industry, which includes particleboard, medium density fiberboard, hardwood plywood, and hardboard. In 2007, the IWCP resin industry was highly concentrated and dominated by UF resins. Resin suppliers rated research and development work and technical support as the most important competitive advantage factors they used. Moreover, resin suppliers perceived the following product and service attributes to have the greatest importance to their IWCP customers: low formaldehyde emissions from finished panels (4.8 of 5), fast resolution of customer complaints (4.5), reduced volatile organic carbon emissions during panel pressing (4.3), support during resin trials (4.3), and on-time delivery (4.2). The regulatory environment (i.e., California Air Resources Board [CARB]) was the most important driver of IWCP resin manufacturers' green resin programs. Results showed a trend of increasing importance for green IWCP resin market development for the time periods defined as today, next 2 years, next 5 years, and next 10 years for pMDI suppliers, whereas UF suppliers rated green IWCP resin market development highly important over all four time periods.

The advent of ''green'' building programs and energy-efficient buildings has fostered an increased focus on indoor air quality. Formaldehyde has been identified as an important component of indoor air pollution (US Environmental Protection Agency [EPA] 2009); it is a known carcinogen and can increase the risk for common respiratory problems such as asthma and chronic bronchitis (Krzyzanowski et al. 1990, International Agency for Research on Cancer [IARC] 2009). As a result, regulations have been promulgated in the United States and abroad to limit formaldehyde in indoor spaces.

## Formaldehyde Emission Regulations

Sources of formaldehyde in indoor environments include building materials, cigarette smoke, household products, and unvented fuel-burning appliances such as gas stoves (EPA 2009). In particular, pressed wood composite products (WCPs) have been identified as major sources of indoor formaldehyde (Comitè Europèen De Normalisation [CEN] 1989, Battelle 1996, EPA 2009). Therefore, formaldehyde emission reductions for WCPs have been a primary focus of international and domestic air quality regulations.

Internationally the European Union, the People's Republic of China, and Japan represent key markets that have placed restrictions on formaldehyde emissions from WCPs (Ruffing et al., in press). These regulations are well established, with emission limits ranging from approximately 0.04 ppm for F**** products in Japan to approximately 0.2 ppm for certain WCPs in China (Ruffing et al., in press).

The authors are, respectively, Graduate Research Assistant, Professor of Forest Products Marketing, and Associate Professor of Wood Chemistry, School of Forest Resources, The Pennsylvania State Univ., University Park (tcr131@psu.edu, pms6@psu.edu, nrb10@psu.edu). This paper was received for publication in September 2009. Article no. 10677.

Forest Prod. J. 60(2):119–125.

In the United States, the US Housing and Urban Development Agency (HUD) enacted the first legislation restricting formaldehyde emissions from WCPs in 1985. The HUD emission limits are product specific, limiting formaldehyde emissions from hardwood plywood (HWPW) and particleboard (PB) to 0.2 ppm and 0.3 ppm, respectively (HUD 2006). It is important to note that the HUD regulation only applies to materials used to construct manufactured housing units and does not place emission limits on medium density fiberboard (MDF; HUD 2006).

Recently, the California Air Resources Board (CARB) enacted legislation to limit formaldehyde emissions from WCPs sold in California. Emission limits follow a two-phase calendar. The majority of phase I reductions became effective January 1, 2009, while more restrictive phase II reductions take effect between 2010 and 2012 (CARB 2007). The CARB emission limits are more stringent than the HUD regulation, with product-specific phase II limits in the range of 0.05 to 0.11 ppm for HWPW, MDF, and PB (CARB 2007).

The 111th Congress recently passed a bill (S. 1660, 2009) to nationalize CARB emission limits under the Toxic Substances Control Act. The bill, which is currently awaiting the President's signature, would direct the EPA to establish protocols for implementation and compliance.

## Interior Wood Composite Panels and Formaldehyde Emissions

For consistency and clarity, we will use the term interior wood composite panel (IWCP) to denote nonstructural wood composite panel products intended for indoor use. The IWCP industry often refers to these products as industrial panels because they are commonly sold to fabricators or other industrial customers for further processing before being sold to a consumer. The most important IWCP products are PB, MDF, HWPW, and hardboard.

In 2008, North American IWCP production totaled approximately 7.3 billion square feet of panel product worth nearly US$4 billion (Table 1). The recent economic downturn and housing market crash have reduced demand for IWCPs in North America significantly. Production and value are down 17 and 16 percent, respectively, in 2008, from the 2007 total volume of 8.8 billion square feet and value of US$4.7 billion (Table 1).

The primary source of formaldehyde in IWCPs is typically the resin. Urea-formaldehyde (UF), melamine-formaldehyde, melamine-urea-formaldehyde (MUF), phenol-formaldehyde (PF), phenol-melamine-urea-formaldehyde, phenol-melamine-formaldehyde, polymeric diphenylmethane diisocyanate (pMDI), polyvinyl acetate (PVAc), emulsion polymer isocyanate (EPI), or soy-based resins are used in the production of IWCPs (Maloney 1977, Vick 1999, Youngquist 1999, Sellers 2001, Kennedy 2005). Note that the emission characteristics of these resins are drastically different; some of the resins are formaldehyde free.

Resin selection is influenced by a variety of factors, including production cost, wood material type and quality, end use, formaldehyde emission characteristics, and the desired level of panel durability. Since most resins are produced from fossil fuel derivatives, resin costs often constitute a considerable portion—up to 32 percent—of the panel manufacturing cost (Sellers 2001). As a result, UF resins have historically been the predominant IWCP binder because of low cost, fast cure times, and adequate bond strength; additionally, they are colorless in cured form and easily adaptable in a variety of curing conditions (Pizzi 1983, Lorenz et al. 1999). However, bonding IWCPs with traditional UF resins also introduces some challenges, including a lack of moisture resistance and relatively high formaldehyde emissions (Pizzi 1983).

Reduction of resin formaldehyde emissions has been a primary focus within the US IWCP resin industry since the 1980s (Sellers 2001). The mechanisms causing formaldehyde emissions include (1) unreacted ''free formaldehyde'' in the resin, which typically declines exponentially until a steady state emission level is reached and (2) hydrolysis of the ''bonded formaldehyde'' in the panel (Yu and Crump 1999). To achieve emissions reductions, UF resins are produced with lower formaldehyde to urea mole ratios and/or with scavenger solutions based on urea, melamine, lignosulphonates, and mixtures of carbohydrates with urea (Sellers et al. 1990, Sellers 2001, Dunky 2005). However, these methods often lead to reduced physical and mechanical panel properties, requiring additional modifications to the resin (Myers 1984, Sellers 2001, Dunky 2005). Additionally, scavengers can add to resin costs, and mole ratio adjustments may lead to increased press times, which impacts production costs (Dunky 2005). Low-emitting and formaldehyde-free formulation resins are available and are of great interest. Many developments in this area were showcased at the 2009 International Conference on Wood Adhesives sponsored by the Forest Products Society.

We hypothesized that tighter formaldehyde emission regulations are affecting the competitive landscape in the IWCP resin market. This article explores regulatory and other competitive factors affecting key resin suppliers. The primary objective of this research was to examine the North American IWCP resin industry in 2007 in terms of its markets, product positioning strategies, and green resin product development. The effect of formaldehyde emission

*Table 1.—2007/2008 North American IWCP production (thousand sq. ft. ⅓-in. basis).*[a]

| | Quantity, thousand square feet (%) | | Value, thousands of US$ (%) | |
|---|---|---|---|---|
| | 2007 | 2008 | 2007 | 2008 |
| Particleboard | 4,748,699 (54) | 3,961,847 (54) | 1,793,880 (38) | 1,365,000 (35) |
| MDF | 2,711,825 (31) | 2,220,681 (30) | 1,409,397 (30) | 1,320,000 (33) |
| HWPW | 736,213[b] (8) | 631,857[b] (9) | 785,432 (17) | 727,682 (18) |
| Hardboard | 637,772 (7) | 513,184 (7) | 714,661 (15) | 550,000 (14) |
| Total | 8,834,509 (100) | 7,327,569 (100) | 4,703,370 (100) | 3,962,682 (100) |

[a] Sources: Composite Panel Association 2008, 2009; Hardwood Plywood and Veneer Association 2008, 2009.
[b] Estimated by standardizing all panels to ⅓-inch basis.

regulations on IWCP resin development was of particular interest.

## Methods

Discussions with industry experts identified eight major resin suppliers to the North American IWCP industry. Top-level product and market development managers from each firm were provided with a brief e-mail message explaining the study. Attachments included a detailed cover letter explaining the survey and the importance of the respondent's participation and a copy of the questionnaire. The correspondence also requested a phone interview to complete the questionnaire and to address participant questions. A second e-mail, with attached cover letter and questionnaire, was sent to nonrespondents 1 week later. All eight firms participated for a response rate of 100 percent ($n = 8/8$). Respondents included four technical/research and development managers and four marketing directors/managers. One respondent chose to abstain from select questions in compliance with company policy, making the response rate for those questions 88 percent ($n = 7/8$).

## Results and Discussion

### Market overview

To develop a profile of the North American IWCP resin market, participants were asked to provide an estimate of their 2007 resin sales in pounds for each resin type. For these suppliers, UF resins were dominant in 2007 with approximately 98 percent market share. Isocyanate (pMDI) resins represented only 1 percent of the IWCP resin market; however, these resins merit further discussion because they represent an important no-added-formaldehyde (NAF) option with an interesting value proposition. In fact, isocyanate (pMDI) resins offer several key benefits compared with traditional UF or PF systems, including reduced press temperatures, greater moisture resistance in cured form, and superior panel physical properties (Galbraith and Newman 1992). Yet pMDI has several key disadvantages, including high cost and increased risk that in-plant production workers will develop respiratory sensitization (Maloney 1977, Lay and Cranley 1994).

Respondents indicated that remaining market demand (1%) is met by a variety of resins, including PVAc, EPI, MUF, PF, and soy-based resins. For brevity, these resins will simply be referred to as *other*. Like pMDI, resins in the other category represent low or no formaldehyde options, and these resins may potentially gain market share as emission limits tighten.

Two participating firms offered both UF and other resins in 2007; however, since the vast majority (>95%) of these firms' resin sales in 2007 were UF, they will be classified as UF suppliers in subsequent analysis and discussion. One firm offered only other resins in 2007; therefore, data from that firm was only included in the all firms category.

Participants were asked to estimate the percentage of their total 2007 resin sales (weight basis) to each of the four IWCP customer types (MDF, HWPW, hardboard, PB). Total resin sales for each responding firm were added to determine a grand total for each resin type. Each firm's total was divided by the grand total to determine the firm's percent market share. Resin sales data (to each IWCP customer type) were then weighted by company size by multiplying by the percent market share for each firm (Fig. 1). All major IWCP types are adequately represented, with the majority of resins sold to PB and MDF manufacturers (Fig. 1).

The four UF respondents (identified here as companies A, B, C, and D) were then queried as follows: ''The cumulative sales (lbs) of companies A, B, C, and D represents: (a) 50–74% of the 2007 North American UF IWCP market; (b) 75–89% . . . ; (c) 90–94% . . . ; (d) 95–99% . . . ; (e) 100%. . . .'' The same question (except pertaining to pMDI sales) was asked of the three pMDI respondents. Results confirmed that responding firms represent all pMDI and nearly all (>95%) UF resin sold to the North American IWCP industry in 2007. Since our survey covers almost the entire population, inferential statistics are not necessary.

### Competitive strategy

In an open-ended question, participants ranked, in order of importance, the top three factors that their firm used for competitive advantages from the list of eight factors shown in Table 2. For each participant, their No. 1, No. 2, and No. 3 rankings were assigned 3, 2, and 1 point(s), respectively. To standardize results, total points were set equal to 100 percent for each of the three participant categories (all, UF, and pMDI suppliers). Overall, research and development (R&D) and technical support were perceived by all participants ($n = 7$) as the two most important aspects of their firm's competitiveness, followed by customer relationships and green product development (Table 2). Market share was not ranked as one of the top three competitive advantages by any of the seven participating firms (Table 2).

By resin type, pMDI suppliers perceived technical support as the most important competitive advantage factor, whereas UF suppliers placed the greatest emphasis, by far, on R&D (Table 2). This difference in competitive strategy may be a reflection of the increasing pressure to lower formaldehyde emissions from IWCP products. UF suppliers

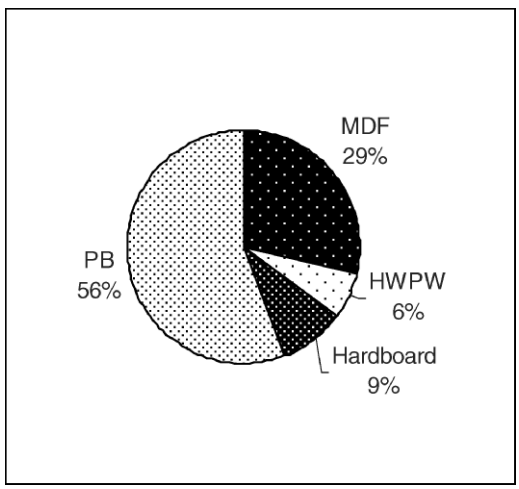


*Figure 1.—Respondents' estimates of percentage of resin sold to the four primary panel types in 2007 by sales (*n *= 7/8; one firm in the UF category chose to abstain from answering this question in compliance with company policies). Responses were weighted by company size as follows: each firm's total was divided by the grand total for all firms to develop a percentage of market share for that firm. This percentage was then used to weight responses.*

*Table 2.—Competitive advantages used by IWCP resin manufacturers (n = 7/8; one firm in the UF category chose to abstain from answering this question in compliance with company policies).*

Question: Of the eight comparative factors listed in question No. 3, please rank (in order of importance) the top three factors that your firm employs for competitive advantages (open-ended responses)

| | % weighted responses[a] | | |
|---|---|---|---|
| Competitive advantage | All firms ($n = 7$)[b] | UF ($n = 3$)[c] | pMDI ($n = 3$) |
| Research and development work | 31.0 | 50.0 | 11.1 |
| Technical support | 26.2 | 27.8 | 33.3 |
| Customer relationships | 16.7 | 16.7 | 16.7 |
| Green product development | 14.3 | 0 | 16.7 |
| Competitive prices | 4.7 | 0 | 11.1 |
| Intensive personal selling | 4.7 | 0 | 11.1 |
| Effective marketing | 2.4 | 5.5 | 0 |
| Market share | 0 | 0 | 0 |
| Total | 100 | 100 | 100 |

[a] Responses were weighted as follows: first choice = 3 points, second choice = 2 points, third choice = 1 point. Results were standardized by setting the total points for each of the three categories equal to 100 percent, with each factor representing a percentage of the total.
[b] Includes data from one firm that did not sell UF or pMDI resin in 2007.
[c] UF category is composed of approximately 99 percent UF resins and 1 percent other (PVAc, EPI, PF, MUF, PUF, soy) resins.

are currently striving to develop new low-emitting resins, whereas pMDI suppliers already have a formaldehyde-free product. This may allow pMDI firms to place a greater emphasis on assisting customers with technical issues.

## Product/service attributes

Participants rated their perceptions of the overall importance of 19 product and service attributes to their IWCP customers on a 5-point interval scale from 1 = not at all important, to 3 = neither important nor unimportant, to 5 = extremely important (Table 3). Five product attributes were categorized separately as green attributes and will be discussed subsequently.

IWCP resin manufacturers perceived superior customer service as most important to their customers, since four of the top five ranked attributes are service oriented (Table 3). This service attribute emphasis is consistent for commodity products, where it is logical to focus on superior service and/or pricing to compete in the market (Sinclair 1992, Dasmohapatra and Smith 2008). Fast resolution of customer complaints, support during resin trials, and on-time delivery were perceived as the three most important attributes to IWCP customers. This underscores the results from the previous section (shown in Table 2). Vendor managed inventory was the least important attribute, perhaps because of fluctuating downstream demand and the desire of IWCP producers to control their own inventory.

PMDI suppliers perceived low cost as more important to IWCP customers than UF suppliers (Table 3). Since the 95 percent confidence interval (CI) around the mean for pMDI suppliers does not include the midpoint value of 3 on the 5-point scale (Table 3), we conclude that pMDI suppliers view low cost as important. Alternatively, the midpoint of 3 is included in the interval for UF suppliers, indicating that at least some suppliers may not view low cost as important to their IWCP customers. The higher cost of pMDI resins

*Table 3.—Resin suppliers' perception of the relative importance of 19 product and service attributes to their IWCP customers (n = 8/8).*[a]

Question: Please rate your perception (best guess) of the overall importance of the following resin product and service attributes to your IWCP customers.

| Attribute | All firms ($n = 8$)[b] | UF ($n = 4$)[c] | pMDI ($n = 3$) | 95% CL for UF | 95% CL for pMDI |
|---|---|---|---|---|---|
| Fast resolution of customer complaints | 4.5 | 4.5 | 4.7 | 3.93, 5.07 | 4.01, 5.32 |
| Support during resin trials | 4.3 | 4.3 | 4.3 | 3.76, 4.74 | 3.68, 4.99 |
| On-time delivery | 4.2 | 4.5 | 4.2 | 3.93, 5.07 | 3.84, 4.49 |
| Wide operating window | 4.1 | 4.0 | 4.3 | 3.20, 4.80 | 3.68, 4.99 |
| Support customer's new product development at the vendor's research and development facility | 4.0 | 4.4 | 3.7 | 3.93, 4.94 | 3.01, 4.32 |
| High internal bond strength | 4.0 | 4.3 | 3.7 | 3.76, 4.74 | 3.01, 4.32 |
| Low cost | 3.9 | 3.5 | 4.7 | 2.52, 4.48 | 4.01, 5.32 |
| Fast cure | 3.9 | 4.3 | 4.3 | 3.76, 4.74 | 3.68, 4.99 |
| Viscosity on spec. | 3.8 | 4.3 | 3.3 | 3.76, 4.74 | 2.68, 3.99 |
| Long storage life | 3.6 | 3.8 | 3.7 | 3.26, 4.24 | 3.01, 4.32 |
| Assistance in new production equipment setup at customer's production facility | 3.6 | 3.8 | 3.7 | 2.52, 4.98 | 1.94, 5.40 |
| Resin does not discolor finished panel product | 3.5 | 3.0 | 4.0 | 2.20, 3.80 | 2.87, 5.13 |
| Geographic proximity of resin manufacturing facility to the customer | 3.3 | 3.0 | 3.3 | 1.61, 4.39 | 2.68, 3.99 |
| Vendor managed inventory | 2.5 | 2.5 | 2.7 | 1.93, 3.07 | 2.01, 3.32 |
| Green IWCP resin product attributes ranked by importance | | | | | |
| Low formaldehyde emissions from finished panel product | 4.8 | 4.8 | 4.7 | 4.26, 5.24 | 4.01, 5.32 |
| Reduced VOC emissions during panel pressing | 4.3 | 4.5 | 3.7 | 3.93, 5.07 | 2.36, 4.97 |
| Low energy requirements for composite panel pressing | 3.3 | 3.0 | 3.7 | 2.20, 3.80 | 3.01, 4.32 |
| Environmentally friendly adhesive synthesis processes | 3.0 | 3.3 | 2.3 | 2.31, 4.19 | 1.03, 3.64 |
| Green resin components (e.g., soy protein, lignin additives | 3.0 | 3.5 | 1.7 | 2.93, 4.07 | 0.36, 2.97 |

[a] Scale: 1 = not at all important, 3 = neither important nor unimportant, 5 = extremely important.
[b] Includes data from one firm that did not sell UF or pMDI resin in 2007.
[c] UF category is composed of approximately 99 percent UF resins and 1 percent other (PVAc, EPI, PF, MUF, PUF) resins.

relative to traditional UF systems is likely responsible for this discrepancy. UF resin suppliers perceived viscosity on specification higher compared with pMDI resin suppliers (Table 3), perhaps because of the lower stability and shorter shelf life of UF resins.

UF suppliers also perceived support customer's new product development at vendor's R&D facility as more important than pMDI suppliers, supporting the notion that UF suppliers need to be engaged with their IWCP customers while developing new low-emitting products. Finally, UF suppliers perceived high internal bond strength as more important to their customers than pMDI suppliers, possibly because modifications to UF resins to improve formaldehyde emissions characteristics can be detrimental to strength.

## Green product attributes

To determine the importance of formaldehyde emissions relative to other green resin attributes, participants rated their perceptions of the importance of five environmental/green attributes to their IWCP customers (Table 3). For all participants, low formaldehyde emissions from the finished panel product and reduced volatile organic carbon (VOC) emissions during pressing were perceived as the two most important green resin attributes (Table 3). These results reflect the growing concern over formaldehyde emissions within the IWCP industry and the demand for low-emitting resins to meet tightening environmental regulations.

By resin type, pMDI suppliers perceived the importance of low energy requirements for panel pressing as important (midpoint of 3 not included in 95% CI), whereas at least some UF participants may not view this attribute as important to their IWCP customers (Table 3). Perhaps pMDI respondents were considering their historic advantages in cure times when answering; however, new UF formulations allow comparable or faster cure times (Galbraith and Newman 1992, Hawke et al. 1992). It is more likely that pMDI respondents were considering overall energy, since their resin can effectively bond high moisture content furnish, thus alleviating furnish drying requirements (Galbraith and Newman 1992, Hawke et al. 1992).

The higher perceived importance by the UF group on reduced VOC emissions during panel pressing, environmentally friendly adhesive synthesis processes, and green resin components (e.g., soy protein, lignin additives) underscores the pressure being felt by UF suppliers to create new green resin products.

In an open-ended question, participants were asked, ''How would you personally define green as it relates to IWCP resins?'' All participants ($n = 8$) included terms like low VOC or low formaldehyde emissions from the finished panel product in their definition, underscoring the importance of low-emission resin products. Four definitions incorporated renewable or environmentally friendly materials, indicating a desire to reduce dependence on nonrenewable resources. Finally, two participants included references to green rating systems such as the US Green Building Council's Leadership in Energy and Environmental Design (LEED) program, signifying the potential importance of green rating programs as drivers for IWCP resin development. Participants were asked to use their definition of green when answering the remaining questions.

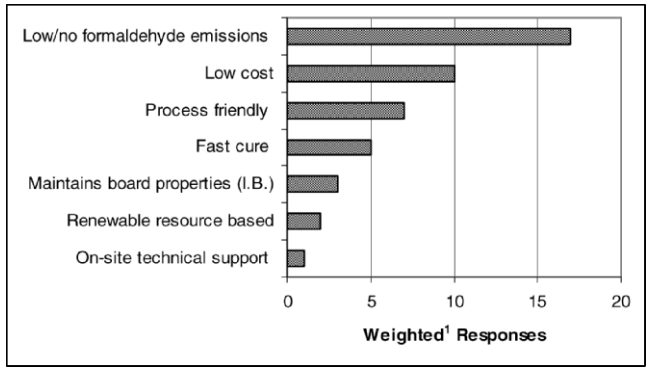


*Figure 2.—Respondents' opinion of the most important green product attributes (*n *= 8/8). Question: "What are the three most important resin product and/or service attributes (in your opinion) to your IWCP customers for green interior wood composite panel resins?" (open-ended responses). Responses were weighted as follows: first choice = 3 points, second choice = 2 points, and third choice = 1 point.*

Participants then answered, ''What are the three most important resin product and/or service attributes (in your opinion) to your IWCP customers for green interior wood composite panel resins?'' Responses were weighted as follows: first choice = 3 points, second choice = 2 points, and third choice = 1 point. Overall, the seven resin suppliers rated low/no formaldehyde as the most important green attribute, followed by low cost, process friendly, and fast cure (Fig. 2). These findings support the fixed response attribute question (shown in Table 3) and underscore the emphasis these suppliers place on low cost and low or no emitting products.

## Green program drivers

Green resin program drivers were investigated by asking respondents the following question, ''My firm's green resin program is driven by: (please indicate your best estimate of the percentage attributed to the following factors).'' Overall, the regulatory environment (i.e., CARB) was the most important driver for green programs, followed by IWCP customer demand (Fig. 3). Several respondents indicated that customer demand is directly related to customer conformance to CARB regulations.

When the results were analyzed by resin type, pMDI suppliers' green resin programs were driven by the regulatory environment (Fig. 3). Perhaps pMDI suppliers see tighter emissions limits as an opportunity to expand their presence in a market traditionally dominated by lower cost UF resins.

## Green resin market development

Participants rated the level of importance your firm places on green resin product market development over four time periods (today, within the next 2 years, within the next 5 years, and within the next 10 years) on a 7-point scale from 1 = unimportant to my company, to 4 = somewhat important to my company, to 7 = critically important to my company (Fig. 4).

Overall, a trend of slightly increasing importance from today to the next 2 years to the next 5 years to the next 10 years was observed. By resin type, UF suppliers rate green

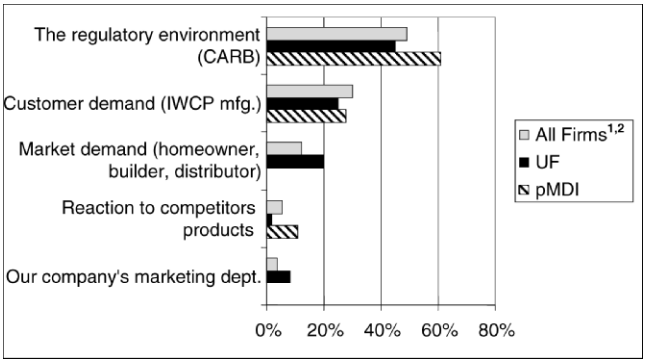


*Figure 3.—Respondents' perception of factors driving their firm's green resin program (*n *= 7/8; one firm in the UF category chose to abstain from answering this question in compliance with company policies). Question: "My firm's green resin program is driven by: (please indicate your best estimate of the percentage attributed to the following factors)." All Firms includes data from one firm that did not sell UF or pMDI resin in 2007.*

resin market development highly (between 5.7/7 and 6.0/7) over all time periods, whereas pMDI suppliers show a trend of increasing importance from today (4.7/7), to the next 2 years (5/7), to the next 5 years (5.7/7), to the next 10 years (6/7; Fig. 4). These results indicate that all IWCP resin suppliers are concerned with green resin market development in the future, but UF suppliers are more concerned today.

## Conclusions

The North American IWCP industry, consisting of PB, MDF, HWPW, and hardboard, purchases the majority of their panel adhesives from eight resin suppliers. This study surveyed these eight resin suppliers to better understand their product positioning and green resin strategies.

In 2007, the IWCP resin industry was highly concentrated and dominated by UF resins. UF suppliers primarily emphasize research and development in their competitive strategies, whereas pMDI suppliers emphasize technical support. Product and service attributes of the greatest importance include fast resolution of customer complaints (4.5 of 5), support during resin trials (4.3), and on-time delivery (4.2). The most important green product attributes were low formaldehyde emissions from the finished panel product (4.8) and reduced VOC emissions during pressing (4.3). Further, in an open-ended question asking respondents to indicate the most important green product attributes to their IWCP customers, low/no formaldehyde emissions was rated as most important followed by low cost, process friendly, and fast cure. This underscores the importance of keeping costs low while concurrently meeting emissions requirements for the IWCP industry. Additionally, when asked how they would personally define green as it relates to IWCP resins in an open-ended question, all participants ($n = 8$) included terms like low VOC or low formaldehyde emissions from the finished panel product in their definition of a green IWCP resin, underscoring the importance of low-emission resin products. These exploratory results provide a refined list of resin attributes for further research.

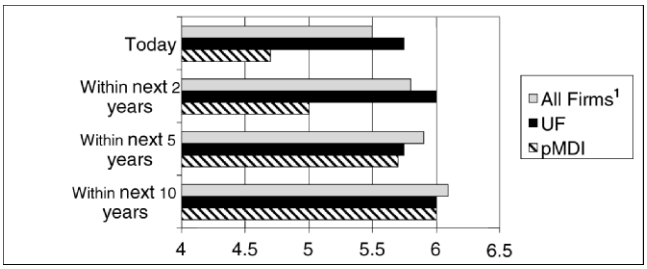


*Figure 4.—Importance of green IWCP resin market development over time (*n *= 8/8). Question: "Please rate the level of importance your firm places on green resin product market development over the four time periods listed below." Scale: 7 = critically important to my company, 4 = somewhat important to my company, and 1 = unimportant to my company. All Firms includes data from one firm that did not sell UF or pMDI resin in 2007.*

The regulatory environment (i.e., CARB) was the most important driver of IWCP resin manufacturers' green resin programs. These results emphasize the importance of regulations as drivers for green IWCP resin development. Results showed a trend of increasing importance for green IWCP resin market development over the next 10 years for pMDI suppliers, while UF suppliers rate green IWCP resin market development highly over all time periods.

Emissions, particularly from formaldehyde, have been a primary focus of the US IWCP industry over the past 25 years. With the newly enacted CARB regulation and the impending nationalization of CARB through the Toxic Substances Control Act, reduction of formaldehyde emissions will likely be the predominant issue within the US IWCP resin industry for the foreseeable future.

It is important to note that the results of this study represent a snapshot of an industry in transition. The North American IWCP resin industry will evolve as more stringent emission limits are enacted. Regulations are forcing IWCP manufacturers to drop traditional UF resins, and may eventually mandate a switch to NAF options such as pMDI, PVAc, or soy-based resins. Over the past 5 years, a growing number of IWCP manufacturers have added NAF panels to their product mix (C. E. Surak, Director of Certification Services, Composite Panel Association, personal communication, June 2010). Perhaps these manufacturers are attempting to get ahead of tightening emission regulations or are trying to capitalize on the growing green building market. The US Green Building Council's (USGBC) LEED program specifies NAF resins for certain composite wood products (USGBC 2005).

Future work may include primary data collection from North American resin customers in the IWCP industry to directly examine their perceptions of customer delivered value on these same product and service attributes as well as assessing how evolving emission regulations impact their product mix and green marketing strategies.

## Acknowledgments

The authors thank Terry Sellers, Chuck Frihart, and Rob Schmidt for their insight and assistance; likewise, the Composite Panel Association and the Hardwood Plywood and Veneer Association provided support in developing background knowledge on the IWCP industry. Additionally, we gratefully acknowledge the time participants dedicated to this study.

## Literature Cited


Battelle. 1996. Determination of formaldehyde and toluene diisocyanate emissions from indoor residential sources. Battelle, Columbus, Ohio. 138 pp.

California Air Resources Board (CARB). 2007. Airborne toxic control measure to reduce formaldehyde emissions from composite wood products. CARB, Stationary Sources Division, Sacramento. 59 pp.

Comitè Europèen De Normalisation (CEN). 1989. Formaldehyde emission from wood based materials: Guideline for the determination of steady state concentrations in test chambers. EUR 12196 EN. Central Secretariat, CEN, Brussels. 24 pp.

Composite Panel Association (CPA). 2008. 2007 North American shipments report, particleboard, medium density fiberboard and hardboard. CPA, Leesburg, Virginia. 21 pp.

Composite Panel Association (CPA). 2009. 2008 North American shipments report, particleboard, medium density fiberboard and hardboard. CPA, Leesburg, Virginia. 20 pp.

Dasmohapatra, S. and P. M. Smith. 2008. Customer value in the oriented strandboard industry. *Wood Fiber Sci*. 40(1):42–54.

Dunky, M. 2005. Resins for ultra-low formaldehyde emission according to the Japanese F**** Quality. *In:* Wood Adhesives 2005, November 4, 2005, San Diego, California; Forest Products Society, Madison, Wisconsin. pp. 343–349.

Galbraith, C. J. and W. H. Newman. 1992. Reaction mechanisms and effects with MDI isocyanate binders for wood composites. *In:* Proceedings of the Pacific Rim Bio-Based Composites Symposium, November 9–13, 1992, Rotorua, New Zealand; New Zealand Forest Research Institute, Rotorua, New Zealand. pp. 137–142.

Hardwood Plywood and Veneer Association (HPVA). 2008. Hardwood stock panels—Annual statistical report for calendar year 2007. HPVA, Reston, Virginia.

Hardwood Plywood and Veneer Association (HPVA). 2009. Hardwood stock panels—Annual statistical report for calendar year 2008. HPVA, Reston, Virginia. 90 pp.

Hawke, R. N., B. C. H. Sun, and M. R. Gale. 1992. Effect of fiber mat moisture content on strength properties of polyisocyanate-bonded hardboard. *Forest Prod. J*. 42(11/12):61–68.

Housing and Urban Development (HUD). 2006. Manufactured home construction and safety standards. 24 CFR part 3280. Department of Housing and Urban Development, Office of the Assistant Secretary for Housing—Federal Housing Commissioner, Washington, D.C. pp. 138–139, 148.

International Agency for Research on Cancer (IARC). 2009. IARC classifies formaldehyde as carcinogenic to humans. IARC, World Health Organization, Lyon, France. (Press release.) http://www.iarc.fr/en/media-centre/pr/2004/pr153.html. Accessed May 26, 2009.

Kennedy, H. J. 2005. The North American wood adhesives market. *In:* Wood Adhesives 2005, November 4, 2005, San Diego, California; Forest Products Society, Madison, Wisconsin. pp. 33–38.

Krzyzanowski, M., J. J. Quackenboss, and M. D. Lebowitz. 1990. Chronic respiratory effects of indoor formaldehyde exposure. *Environ. Res*. 52(2):117–125.

Lay, D. G. and P. Cranley. 1994. Polyurethane adhesives. *In:* Handbook of Adhesive Technology. A. Pizzi and K. L. Mittal (Eds.). Marcel Dekker, New York. pp. 405–429.

Lorenz, L. F., A. H. Conner, and A. W. Christiansen. 1999. The effect of soy protein additions on the reactivity and formaldehyde emissions of urea-formaldehyde adhesive resins. *Forest Prod. J*. 49(3):73–78.

Maloney, T. M. 1977. Modern Particleboard and Dry-Process Fiberboard Manufacturing. Miller Freeman, San Francisco. 672 pp.

Myers, G. E. 1984. How mole ratio of UF resin affects formaldehyde emission and other properties: A literature critique. *Forest Prod. J*. 34(5):35–41.

111th Congress. 2009. S. 1660: Formaldehyde Standards for Composite Wood Products Act. http://www.govtrack.us/congress/bill.xpd?bill=s111-1660. Accessed June 28, 2010.

Pizzi, A. 1983. Aminoresin wood adhesives. *In:* Wood Adhesives, Chemistry and Technology. A. Pizzi (Ed.). Marcel Dekker, New York. pp. 59–104.

Ruffing, T. C., N. R. Brown, and P. M. Smith. A review of U.S. and international formaldehyde emissions regulations for interior wood composite panels. *Wood Fiber Sci*. (in press).

Sellers, T., Jr. 2001. Wood adhesives innovations and applications in North America. *Forest Prod. J*. 51(6):12–22.

Sellers, T., Jr., G. D. Miller, and W. L. Nieh. 1990. Evaluation of post-added ester and/or urea as a formaldehyde scavenger in UF resins used to bond southern pine particleboard. *Forest Prod. J*. 41(1):53–56.

Sinclair, S. A. 1992. Forest Products Marketing. McGraw-Hill, New York. 403 pp.

US Environmental Protection Agency (EPA). 2009. The inside story: A guide to indoor air quality. EPA, Washington, D.C. http://www.epa.gov/iaq/pubs/insidest.html. Accessed August 17, 2009.

US Green Building Council (USGBC). 2005. EQ Credit 4.4: Low-emitting materials: Composite wood & agrifiber products. *In:* LEED® for New Construction & Major Renovations. USGBC, Washington, D.C. p. 69. http://www.usgbc.org/ShowFile.aspx?DocumentID=1095. Accessed June 28, 2010.

Vick, C. B. 1999. Adhesive bonding of wood materials. Chap. 9. *In:* Wood Handbook—Wood as an Engineering Material. General Technical Report FPL-GTR-113. USDA Forest Service, Forest Products Laboratory, Madison, Wisconsin. 463 pp.

Youngquist, J. A. 1999. Wood-based composites and panel products. Chap. 10. *In:* Wood Handbook—Wood as an Engineering Material. General Technical Report FPL-GTR-113. USDA Forest Service, Forest Products Laboratory, Madison, Wisconsin. 463 pp.

Yu, C. W. F. and D. R. Crump. 1999. Testing for formaldehyde emission from wood-based products—A review. *Indoor Built Environ*. 8: 280–286.