FORMALDEHYDE EMISSIONS REGULATIONS: IMPLICATIONS FOR THE NORTH AMERICAN INTERIOR WOOD COMPOSITE PANEL RESIN INDUSTRY

A Thesis in
Forest Resources
by
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Submitted in Partial Fulfillment of the Requirements for the Degree of

Master of Science

May 2010
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ABSTRACT

Formaldehyde is a known carcinogen and elevated formaldehyde levels in indoor environments can induce a variety of undesirable respiratory conditions. Therefore, governmental agencies such as the California Air Resources Board (CARB) have enacted legislation to limit indoor formaldehyde concentrations. Pressed wood composite panels (WCPs) and the resins that act as binders for these panels have been identified as major sources of indoor formaldehyde; and therefore have been targeted by formaldehyde emissions regulations. The purpose of this study is to examine domestic and international formaldehyde emissions regulations for WCPs and determine the effect of formaldehyde emissions regulations on WCP resin development.

A thorough review of public documents and scientific literature was conducted to develop an understanding of domestic and international formaldehyde emissions regulations that apply to WCPs. Additionally, contacts were developed in governmental agencies and trade associations to confirm our understanding and interpretation of each regulation. Historical context, product-specific emissions limits, test methodologies, and product certification requirements were detailed for each emissions standard. In particular, the recently enacted California Air Resources Board (CARB) formaldehyde regulation was compared to established international formaldehyde regulations and four key differences in the areas of emissions limits, documentation, deconstructive testing, and enforcement were highlighted.

Eight North American resin suppliers participated in an exploratory phone survey (conducted July – August, 2008), designed to better understand their product positioning and “green” resin strategies. These eight firms were identified as the largest suppliers to
the interior wood composite panel (IWCP) industry, which includes particleboard, medium density fiberboard, hardwood plywood, and hardboard. In 2007, the IWCP resin industry was highly concentrated and dominated by urea-formaldehyde (UF) resins. The regulatory environment (i.e. 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 as highly important over all four time periods. Overall, results confirm the importance of formaldehyde emissions regulations as drivers for WCP resin development.
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Preface

The overarching goals of this project were to develop a better understanding of domestic and international formaldehyde emissions regulations as they relate to interior wood composite panel products and to determine how these regulations affect green wood adhesives development. To present this material in a clear, logical manner, this document is divided into four chapters. Chapter one provides a description of the problem, study objectives, and research methodology. The second and third chapters are presented in manuscript form and should be considered stand-alone publications.

Chapter two is the result of an extensive review of the relevant domestic and international emissions regulations which place restrictions on formaldehyde emissions from wood composite panel products. Chapter three details a survey of key resin suppliers to the North American interior wood composite panel industry designed to determine how formaldehyde emissions regulations affect green resin development. The final chapter presents a summary of pertinent findings, discusses limitations, and provides suggestions for future work.
ACKNOWLEDGEMENTS

First, I would like to thank everyone who has been a part of my life throughout my college years and who has provided support during this project. Without the support of my advisors, Dr. Nicole Brown and Dr. Paul Smith, my family and friends, this project would not have been possible. I extend a special thanks to my advisor Dr. Nicole Brown. Her enthusiasm for research, knowledge, support, and confidence has motivated me throughout all aspects of this project.

A thank you also goes out to everyone who influenced the direction of this work and otherwise made it possible. I thank the Composite Panel Association and the Hardwood Plywood and Veneer Association for their support and knowledge in developing and moving this project forward. I also thank my committee, Drs. Chuck Ray, Paul Smith, and Nicole Brown for their support and input throughout the research process. Dr. Paul Smith, in particular, has contributed significantly to developing the resin manufacturer market survey portion of this project and I will cherish the knowledge I have gained from him throughout my life.

Finally, I would like to thank my family for their support throughout my life. To my parents, Tom and Sharon Ruffing, without your support and encouragement I would have never made it this far. You believed in me when I did not believe in myself, always know that your unconditional love and support is appreciated. To my fiancée, Leann Henry, your love and support throughout my college years has gotten me through many rough spots and I look forward to your loving support in the future. Finally, thanks to my grandparents, aunts, uncles, and cousins who never fail to support me in whatever I do.
No matter where life takes me I always know that I have the full support of my loving family in whatever I do.
Chapter 1

Research Overview

Problem Statement

*Indoor Air Quality and Formaldehyde*

Recently there has been an increased awareness of indoor air quality issues with research focused on sources and concentrations of indoor air pollution. A growing body of scientific evidence indicates that indoor air may be more severely polluted than outdoor air, even in the largest and most industrialized cities (EPA 2009a). Additionally, research shows that people spend 90 percent or more of their time indoors; therefore, indoor air quality may have a greater impact on human health relative to outdoor air pollution (UCLA 1991).

There are many sources of indoor air pollution including tobacco smoke; combustion sources such as gas stoves; building materials and furnishings; cleaning, maintenance, and personal care products; central heating and cooling systems; and outdoor sources such as radon and outdoor air pollution (EPA 2009a). Concentrations of indoor air pollutants are influenced by temperature, relative humidity, and air exchange with the outdoor environment (EPA 2009a).

Formaldehyde has been identified as a key component of indoor air pollution (EPA 2009b). Formaldehyde (HCHO) is a colorless, flammable gas at room temperature and pressure with a highly irritating odor. At high concentrations formaldehyde gas can cause a series of deleterious health effects, including significant reductions in pulmonary function and burning sensations in the eyes, nose, and lungs (Lang et al. 2008). In 1987,
the EPA classified formaldehyde as a probable human carcinogen under conditions of unusually high or prolonged exposure (EPA 1989). More recently, the International Agency for Research on Cancer determined that there is now sufficient evidence to classify formaldehyde as a known human carcinogen; in particular, it causes nasopharyngeal cancer (IARC 2009). Elevated formaldehyde levels in homes also increase the risk for common respiratory conditions such as asthma and bronchitis (Krzyszanowski et al. 1990).

**FEMA Trailers**

Exposure to formaldehyde in indoor environments has gained attention recently, due in part to the highly publicized formaldehyde concentrations in FEMA trailers used as temporary shelters for Hurricane Katrina survivors. To address public concern, congressional hearings were held in 2007 and 2008 to determine what role the trailer manufacturers and FEMA played in responding to complaints of high formaldehyde levels.

After the first round of congressional hearings, the Centers for Disease Control and Prevention (CDC) conducted formaldehyde emissions testing in December 2007 and January 2008 on 519 occupied travel trailers, park models, and mobile homes supplied to survivors of hurricanes Katrina and Rita (CDC 2008). Results showed that the average level of formaldehyde in all trailers was 77 parts per billion (ppb) (CDC 2008). While this level is significantly higher than typical formaldehyde levels in U.S. homes—17 - 36 ppb—(Hodgson et al. 2000, Weisel et al. 2005); it is lower than 100 ppb, which is recognized by the CDC, Environmental Protection Agency (EPA), Consumer Products Safety Commission (CPSC), the National Institute of Occupational Safety and Health
(NIOSH), and the World Health Organization (WHO) as the level at which acute health effects begin to appear in healthy adults (Manufacturers 2008).

Broken down by trailer type, CDC test results are reported in Table X. Note the range of formaldehyde emissions from the trailers was wide—3 ppb to 590 ppb. The 95% confidence intervals indicate that the vast majority of all three types of FEMA-provided trailers were below the 100 ppb (0.1 ppm) threshold. However, the highest emission levels are definitely inappropriate for residences; OSHA requires medical monitoring of employees when their exposure exceeds 500 ppb (OSHA 2010).

Maddelena et al. suggested that extensive utilization and high surface loading of wood composites per unit area, and low fresh air circulation within the trailers may have led to the elevated formaldehyde concentrations (Maddalena et al. 2008).

Table 1-1: Formaldehyde emissions from FEMA-provided residences*

<table>
<thead>
<tr>
<th>Trailer type</th>
<th>Number tested</th>
<th>Mean Formaldehyde Emissions (ppb)</th>
<th>95% CI about the mean (ppb)</th>
<th>Range of Emissions (ppb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Travel trailer</td>
<td>360</td>
<td>81</td>
<td>72-92</td>
<td>3-590</td>
</tr>
<tr>
<td>Park model</td>
<td>90</td>
<td>44</td>
<td>38-53</td>
<td>3-170</td>
</tr>
<tr>
<td>Mobile home</td>
<td>69</td>
<td>57</td>
<td>49-65</td>
<td>11-320</td>
</tr>
</tbody>
</table>

*Table data from Manufacturers (2008)

The Lawrence Berkeley National Laboratory (LBNL) conducted further research on trailer construction materials. On May 8, 2008, the CDC released preliminary test findings from the LBNL study, reporting that 44 of the 45 samples taken from the travel trailers were “at or well below the HUD standard for wood products” (Manufacturers 2008). This begs the question of the appropriateness of the HUD standard as a reference.

The congressional hearing held on July 9, 2008 provides an interesting lens for this debate, as both sides of the issue are covered in painstaking detail. On one side, both
FEMA and trailer manufacturers were attacked for being aware of the formaldehyde problem and doing nothing. Detailed results of manufacturer-conducted tests are reported, revealing their awareness of exceedingly high formaldehyde levels in sealed unoccupied trailers. Not surprisingly, manufacturers defended their products, presenting the following tenets: 1) no national regulations or guidelines restrict formaldehyde levels in travel trailers and park models; 2) the Recreational Vehicle (RV) industry welcomed the development of such regulations; and 3) the RV Industry Association announced compulsory standards requiring all wood composite materials used after July 1, 2010 to comply with California Air Resources Board (CARB) emission limits (Manufacturers 2008). In sum, the testimony highlights the need for more data on formaldehyde emissions of construction materials in housing, particularly at various temperature, humidity, and air flow conditions, as well as the need for more widely applicable formaldehyde emissions regulations.

**Mechanism for Formaldehyde Emissions in Wood-based Composites**

Formaldehyde is a cross-linking agent in urea-formaldehyde (UF) resins that are commonly utilized as binders for interior wood composite panels (IWCPs) such as hardwood plywood (HWPW), medium density fiberboard (MDF), and particleboard (PB) (Maloney 1977, Sellers 2001). Mechanisms contributing to formaldehyde emissions from UF bonded panels include unreacted “free formaldehyde” from the resin, and hydrolysis of the partially cured and cured resin (Myers and Koutsky 1990, Yu and Crump 1999). The majority of formaldehyde emissions in new panels comes from the free formaldehyde present in the material and emissions typically decline exponentially until a “steady state” level is reached (Yu and Crump 1999). As panels age, the “bonded
formaldehyde” hydrolyzes and is the dominant mechanism for emissions (Yu and Crump 1999). Since unreacted formaldehyde can escape from the finished panels over time, IWCPs have been identified as major sources of airborne formaldehyde in homes (CARB 1991, Battelle 1996).

Study Objectives

The main objectives of this project are to develop a better understanding of domestic and international formaldehyde emissions regulations as they relate to WCP products and to determine how these regulations affect wood adhesive development for the interior wood composite panel industry. Specifically, this study will:

1. Review, compare, and contrast relevant domestic and international formaldehyde emissions regulations as they apply to interior wood composite panel products.

   a. Determine resin suppliers’ product positioning strategies (based on product and service attributes), markets served, and green resin product development strategies.
   b. Investigate the effect of formaldehyde emissions regulations on green resin product development.

Research Methodology

Literature Review

The goal of the literature review was to develop a thorough understanding of the relevant domestic and international formaldehyde emissions standards. Scientific literature and public documents were searched; additionally, national and international
contacts were developed to confirm our understanding and interpretation of the emissions standards.

Original, government-issued copies of each emission standard were obtained and reviewed. Key contacts were developed in grading and trade associations such as the Composite Panel Association (CPA) and the Hardwood Plywood and Veneer Association (HPVA). These contacts provided useful information on regulation enforcement and industry reaction to the regulations. Contacts were also developed within governmental agencies that administer regulations such as the California Air Resources Board (CARB) and the European Commission. These contacts primarily provided information on regulation enforcement.

**Market Survey**

The methodology for data collection, follow-up efforts, and data analysis was conducted in accordance with the methods of Dillman (2000). The following sections explain these methods in greater detail.

**Sample Design and Sampling**

The population for this study was resin suppliers to the North American IWCP industry. Key informants suggested eight major resin suppliers represented the majority of the North American IWCP resin market. To validate the claims of our informants, we asked each of the eight respondents to estimate what percentage of the market (in pounds) the participating firms represented (a list of all participating firms was provided). Results confirmed that responding firms represented the entire volume of pMDI resin and nearly the entire volume (>95%) of UF resin sold to the North American IWCP industry in
2007, therefore the use of inferential statistics has been omitted from the discussion of survey results.

Data Collection

Data on sales volume and value for each IWCP product type was obtained through trade association publications such as the Composite Panel Association’s annual North American Shipments Report (CPA 2008).

Primary data from the eight resin suppliers was collected through a phone interview process utilizing a questionnaire. Due to the small sample size, a phone interview was selected because phone interviews can provide a better response rate from a list sample compared to mail surveys (Fowler 1986).

In general, survey design and implementation followed Dillman’s “Total Design Method” (TDM) (Dillman 2000). Initial contact was made via e-mail. Top-level product and market development representatives from each firm were provided with a brief email message explaining the study. Attachments included a detailed cover letter explaining the survey, the importance of the respondent’s participation, and a copy of the questionnaire. The correspondence also requested an appointment for a phone interview to complete the questionnaire and to address participant questions. A second email, with attached cover letter and questionnaire, was sent to non-respondents one week later. Respondents who did not respond to the second email were contacted directly by phone.

Data Analysis

Survey responses were collected and entered into a Microsoft Excel spreadsheet and average values were computed for each question or product/service attribute.
References


Chapter 2

A Review of U.S. and International Formaldehyde Emissions Regulations for Interior Wood Composite Panels

Abstract

This paper compares and contrasts formaldehyde emissions regulations for interior wood composite panels in the United States, European Union, Japan, and China. Historical context, product-specific emissions limits, test methodologies, and product certification requirements are detailed for each emissions standard. In particular, the recently enacted California Air Resources Board (CARB) formaldehyde regulation is compared to established international formaldehyde regulations and four key differences in the areas of emissions limits, documentation, deconstructive testing, and enforcement are highlighted. Additionally, an update is provided regarding the U.S. Environmental Protection Agency’s (EPA’s) proposed formaldehyde regulatory action at the national level as of March 2010. Implications of CARB and EPA regulatory actions are discussed and future work is suggested in the rapidly evolving and highly debated arena of formaldehyde emissions policy.
Introduction

Exposure to formaldehyde in indoor environments gained attention as a public health concern in the early 1980’s, due in large part, to problems with mobile homes (Groah et al. 1985). More recently, indoor formaldehyde exposure has gained attention, due in part to the highly publicized formaldehyde concentrations in FEMA trailers used as temporary shelters for Hurricane Katrina survivors. To address public concern, congressional hearings were held in 2007 and 2008 to determine what role the trailer manufacturers and FEMA played in responding to complaints of high formaldehyde levels.

After the first round of congressional hearings, the Centers for Disease Control and Prevention (CDC) conducted formaldehyde emissions testing in December 2007 and January 2008 on 519 occupied travel trailers, park models, and mobile homes supplied to survivors of hurricanes Katrina and Rita (CDC 2008). Results showed that the average level of formaldehyde in all trailers was 77 parts per billion (ppb) (CDC 2008). While this level is significantly higher than typical formaldehyde levels in U.S. homes—17-36 ppb—(Hodgson et al. 2000, Weisel et al. 2005); it is lower than 100 ppb, which is recognized by the CDC, Environmental Protection Agency (EPA), Consumer Products Safety Commission (CPSC), the National Institute of Occupational Safety and Health (NIOSH), and the World Health Organization (WHO) as the level at which acute health effects begin to appear in healthy adults (Manufacturers 2008).

Broken down by trailer type, CDC test results are reported in Table 2-1. Note the range of formaldehyde emissions from the trailers was wide—3 ppb to 590 ppb. The 95% confidence intervals indicate that the vast majority of all three types of FEMA-
provided trailers were below the 100 ppb (0.1 ppm) threshold. However, the highest emission levels are definitely inappropriate for residences; OSHA requires medical monitoring of employees when their exposure exceeds 500 ppb (OSHA 2010). Maddelena et al. suggested that extensive utilization and high surface loading of wood composites per unit area, and low fresh air circulation within the trailers may have led to the elevated formaldehyde concentrations (Maddalena et al. 2008).

The Lawrence Berkeley National Laboratory (LBNL) conducted further research on trailer construction materials. On May 8, 2008, the CDC released preliminary test findings from the LBNL study, reporting that 44 of the 45 samples taken from the travel trailers were “at or well below the HUD standard for wood products” (Manufacturers 2008). This begs the question of the appropriateness of the HUD standard as a reference.

The congressional hearing held on July 9, 2008 provides an interesting lens for this debate, as both sides of the issue are presented in detail. On one side, both FEMA and trailer manufacturers were attacked for being aware of the formaldehyde problem and doing nothing. Detailed results of manufacturer-conducted tests are reported, revealing their awareness of exceedingly high formaldehyde levels in sealed unoccupied trailers. Not surprisingly, manufacturers defended their products, presenting the following tenets: 1) no national regulations or guidelines restricting formaldehyde levels in travel trailers and park models existed; 2) the Recreational Vehicle (RV) industry welcomed the development of such regulations; and 3) the RV Industry Association announced compulsory standards requiring all wood composite materials used after July 1, 2010 to comply with California Air Resources Board (CARB) emission limits (Manufacturers 2008).
In sum, the testimony highlights the need for more data on formaldehyde emissions of construction materials in housing, particularly at various temperature, humidity, and air flow conditions, as well as the need for more widely applicable formaldehyde emissions regulations. In 2001, the California Air Resources Board [CARB] took action to develop such standards. The CARB regulation, effective January 1st 2009, places limits on formaldehyde emissions from wood composite panel products. California is a large and important market and the CARB legislation is driving major changes within the U.S. and international wood composite panel [WCP] industry as well as the resin industry that supplies the WCP industry. Additionally, the U.S. Environmental Protection Agency [EPA] is considering regulatory action on the national level to protect against risks posed by formaldehyde emitted from pressed wood panels (EPA 2008; EPA 2009).

This paper reviews national and international formaldehyde emissions regulations and the test methods used to quantify formaldehyde emissions from wood composite panel products. The CARB regulation will be detailed in the context of existing international regulations.

**Interior Wood Composite Panels**

Interior wood composite panels [IWCPs] such as hardwood plywood [HWPW], medium density fiberboard [MDF], and particleboard [PB] are often used to construct furniture, cabinets, flooring, and wall panels. The IWCP industry is an important segment within the construction materials sector, with 2007 North American production exceeding 14.3 million m³ [8.1 billion square feet, 3/4” basis], translating to $4 billion (CPA 2008, HPVA 2008).
PB is the most important IWCP product, representing approximately 58 and 45 percent of production volume and value respectively. MDF accounts for approximately 33 and 35 percent of production volume and value respectively. HWPW only accounts for approximately 9 percent of production volume; however, it is a higher value product and represents about 20 percent of annual production value.

**Formaldehyde Resins**

Formaldehyde is a cross-linking agent in many of the resins utilized as IWCP binders (Maloney 1977, Sellers 2001). Urea-formaldehyde [UF] resins have traditionally been the predominant binder for particleboard, MDF, and HWPW; however, melamine-formaldehyde [MF], melamine-urea-formaldehyde [MUF], phenol-formaldehyde [PF], phenol-melamine-urea formaldehyde [PMUF], phenol-melamine formaldehyde [PMF], polymeric diphenylmethane diisocyanate [pMDI], polyvinyl acetate [PVAc], or soy-based resins could also be used depending on the desired panel properties (Maloney 1977, Vick 1999, Youngquist 1999, Sellers 2001, Kennedy 2005).

UF resins are popular because they are low cost, offer fast cure times, provide adequate bond strength for panels in low moisture applications, are colorless in cured form, and are easily adaptable to a variety of curing conditions (Pizzi 1983, Lorenz et al. 1999). The main disadvantages of traditional UF resins are their lack of moisture resistance and formaldehyde emissions (Pizzi 1983). Mechanisms contributing to formaldehyde emissions from UF-bonded panels include unreacted “free formaldehyde” from the resin, and hydrolysis of the partially cured and cured resin (Myers and Koutsky 1990, Yu and Crump 1999).
The majority of formaldehyde emissions in IWCPs are attributed to free formaldehyde, and research shows these emissions typically decline exponentially until a steady state is reached (Yu and Crump 1999). As panels age, the “bonded formaldehyde” that is susceptible to hydrolysis will make a greater contribution to panel emissions (Yu and Crump 1999). Since formaldehyde can escape from finished panels over time, IWCPs have been identified as major sources of airborne formaldehyde in homes (CARB 1991, EPA 2009).

**U.S. Formaldehyde Regulations**

**HUD**

*History* - The first U.S. legislation to limit IWCP formaldehyde emissions was enacted by the U.S. Housing and Urban Development Agency [HUD] in 1985. This regulation was intended to limit indoor formaldehyde exposure in manufactured homes and is the only national regulation restricting emissions from IWCPs in the United States.

*Emission limits* - The product-specific emission limits and test methods associated with the HUD standard appear in Tables 2-2 and 2-3 respectively. HUD regulations do not cover MDF panels, even though it is commonly used to construct cabinetry, moulding, and millwork that may be installed in manufactured housing units (HUD 2006).

*Certification* - To attain or maintain certification, a government-approved third-party certification laboratory must witness or conduct the chamber test (large or small chamber) on randomly selected panels at least quarterly and approve a written quality
control plan for each plant (HUD 2006). If certified IWCPs are subsequently treated with paint, varnish, or any other substance containing formaldehyde, the certification becomes invalid and the panel label must be removed (HUD 2006). These panels can then be recertified (HUD 2006).

Although the HUD standard only applies to a specific residential market [materials used to construct manufactured homes], the regulation established a baseline target for IWCP formaldehyde emissions and encouraged many HWPW and PB manufacturers to modify their products to comply with the standard (CARB 2007a). Industry developed voluntary product standards incorporating the HUD emission limits and test methods (ASTM 2002, CPA 1999, CPA 2002, HPVA 2004). ANSI requires certified third-party testing facilities to develop their own protocols for product testing frequency and quality control testing to ensure that products meet the emission limits (CPA 2010, HPVA 2010). The industry continued to produce products that complied with the voluntary standard until CARB was introduced (Turner et al. 1996).

**CARB Regulation**

*History* - On March 12, 1992, the California Air Resources Board [CARB] identified formaldehyde as a toxic air contaminant [TAC] with no safe exposure threshold level (CEPA 2008). During the initial evaluation of indoor formaldehyde exposure in California, the ARB found that IWCPs containing formaldehyde-based resins were a major source of formaldehyde exposure. The airborne toxic control measure [ATCM] to control formaldehyde emissions from composite wood products was approved on April
18, 2008, by the Office of Administrative Law and emissions standards were implemented on January 1, 2009 (CEPA 2008).

The numerical emission limits in the CARB regulation were developed through an interactive process in which CARB conducted meetings with industry associations such as the Hardwood Plywood and Veneer Association (HPVA), the Composite Panel Association (CPA), resin manufacturers, and other interested stakeholders (CARB 2007a). Additionally, CARB conducted a survey of IWCP manufacturers in 2003 to gather data on formaldehyde emissions from finished products and evaluated the available scientific literature to determine the feasibility of the proposed emission limits (CARB 2007a).

Emission limits - Emissions reductions will occur in a two-phase process with the majority of phase I reductions taking effect January 1, 2009, followed by more restrictive phase II reductions which take effect between 2010-2012 (CARB 2007b). The CARB Phase I [P1] and Phase II [P2] emission limits appear in Table 2-2. A more complete listing of the CARB Phase I and II emission limits including effective dates appears in Appendix A.

The CARB regulation requires documentation throughout the value chain to ensure that finished goods sold in California contain CARB-compliant materials. Each panel or bundle must be clearly labeled with the manufacturer’s name, lot or batch number, a marking to denote compliance with the applicable phase 1 or 2 emissions standards, and the ARB assigned number for the third-party certifier (CARB 2007b). Additionally, fabricators must label finished goods and the bill of lading or invoice
provided to distributors, importers, other fabricators, or retailers must indicate that the goods were made with compliant materials (CARB 2007b).

Certification - In-house quality control (QC) testing, third-party certifier inspections, and CARB inspections will provide product certification. The majority of the testing burden falls on IWCP manufacturers. Manufacturers are required to either 1) establish an in-house formaldehyde-testing lab which is certified by a third-party organization; or 2) to contract QC testing to a third-party certified facility (CARB 2007b). Typical large and small chamber third-party testing facilities are depicted in Figures 2-1 and 2-2 respectively.

In addition to small-scale QC testing, the third-party certifier will randomly select samples of each product type and conduct a primary (large chamber) or secondary (small chamber or desiccator) test method to determine compliance with the standard (CARB 2007b). The CARB-approved test methods and chemical analysis methods for QC testing and product certification testing are outlined in Table 2-3.

Fabricators who produce laminated products do not need to comply with the manufacturer requirements regarding third-party certification, even though fabricators may use resins containing formaldehyde to apply surface treatments or assemble products (CARB 2007b). This fabricator exemption has sparked controversy within the IWCP industry since fabricators often apply veneers to the face and back of plywood, PB, or MDF cores—effectively forming a HWPW product—which they do not have to third-party certify. Although fabricators do not need to comply with the manufacturer requirements in the regulation, they are subject to periodic inspection by CARB
personnel to audit records and secure samples for testing, including samples from finished goods (CARB 2007b).

Further discussion on CARB regulations is provided following an overview of international regulations.

**International Formaldehyde Regulations**

**European Union**

*History* - In 1988, the European Parliament enacted the Construction Products Directive [CPD] (Council Directive 89/106/EEC) which requires construction products circulated in E.U. member countries to meet an essential requirement for “Hygiene, Health and the Environment” as defined in European Union or national regulations (ECC 2009a). The essential requirement for hygiene, health and the environment includes national provisions limiting common indoor air pollutants including formaldehyde (ECC 2009b). Emission limits for wood composite panel products were subsequently developed in the European Standardization Organization [CEN] to ensure compliance with the national regulations in Austria, Germany, Denmark, and Sweden (Fuchs 2009).

*Emission limits* - The European system places panel products into two classes, E1 or E2, based on formaldehyde emissions (BSI 2004). The emission limits for the more stringent E1 class appear in Table 2-2. A more complete listing of the European E1 and E2 emission limits appears in Appendix A. The emissions limits are not product specific; however, different quality control test methods are used for some products [Table 2-3]. It is important to note that E.U. member countries can choose to enact more stringent
emissions standards. For example, some countries only allow products of E1 emission class to be circulated (BSI 2004).

Certification - Government-approved, third-party certification bodies develop specific product testing arrangements in cooperation with manufacturers to certify products (Fuchs 2009). Generally, manufacturers are required to conduct quality control testing once per 24-hour production period [once per week for plywood and solid wood panels] using the QC test methods outlined in Table 2-3 (BSI 2004).

Japan

History - In 2003, a revised version of the Japanese building standard law [BSL] took effect, adding restrictions on building materials containing chlorpyrifos [a pesticide] and formaldehyde (BCJ 2009). The regulation places restrictions on the surface area of formaldehyde-emitting building materials which can be used as interior finishing materials (BCJ 2009). Use restrictions are based on the emission class of the panel product, the type of habitable room, and the ventilation frequency of the room (BCJ 2009). In addition to restrictions on use in habitable rooms, the regulations also place restrictions on formaldehyde emissions from building materials used in ceiling cavities, attics, crawl spaces, and storerooms (BCJ 2009). The emission limits for the two most stringent emission classes, F**** and F***, appear in Table 2-2. A more complete listing of the Japanese emission limits including the less stringent emission classes appears in Appendix A.
**Emission limits** - The BSL regulations do not place restrictions directly on finished products; however, applicable finished products intended for use in habitable rooms must be made with certified materials (Matsuyama 2009). Building materials made of more than one formaldehyde emitting material are classified in accordance with the lowest class among the materials used (MLIT 2003). Likewise, unit products such as cabinets and doors or windows assembled at factories using multiple building materials are classified according to the materials used to construct the finished product (MLIT 2003). Testing is conducted on the finished panel product, so it is possible to use high emitting material in the core of a product and then apply decorative surface treatments which sufficiently seal the surface to restrict formaldehyde emissions (Matsuyama 2009).

**Certification** - Products must be certified by third-party testing facilities and both primary and secondary products must carry labels identifying the emission class (Mazikins 2003, MLIT 2003). The manufacturer should conduct QC testing to ensure compliance with the formaldehyde emissions criteria; however, in practice this testing is often conducted by grading agencies that are JAS accredited (Matsuyama 2009). Certification and QC test methods are outlined in Table 2-3.

**China**

**History** - In 2001, the Standardization Administration and the General Administration for Quality Supervision, Inspection, and Quarantine of the People’s Republic of China enacted comprehensive national emission standards limiting harmful substances from indoor decorating and refurbishing materials. These regulations included ten national
standards which place restrictions on wood-based panels, wood-based furniture, adhesives, and solvent coatings for wood products.

_Emission limits_ - The Chinese standards and test methods are essentially adaptations of European and Japanese standards and test methods. Regulations cover both structural and non-structural panel products. Emission limits are product specific and place limitations on end-use [Table 2-2]. A complete listing of the Chinese emission classes and limits appears in Appendix A. Additionally, higher emission E2 class materials can be used in indoor applications only after a decorative surface treatment is applied (GAQSIQ 2001a). Decorative surface treatments often create a barrier to formaldehyde emissions, effectively reducing panel emissions by as much as 95% (Groah et al. 1992, CPA 2003, Barry and Corneau 2006). This provision for upgrading panels with higher emissions by adding a surface treatment is unique to the Chinese standards and recognizes the effectiveness of surface treatments as formaldehyde emission barriers.

In addition to the panel standard, the Chinese also have a standard that places restrictions on formaldehyde emissions from finished furniture (GAQSIQ 2001b). The emission limits for furniture products and the relevant test methods appear in Tables 2-2 and 2-3 respectively. This standard also restricts the amounts of four heavy metals [lead, cadmium, chromium, and mercury] in the surface layer of furniture (GAQSIQ 2001b).

_Certification_ - Product certification is achieved through voluntary application to third-party, independent testing centers. These testing centers are approved by the Certification and Accreditation Administration of China. Government accredited
certification centers include the China Quality Certification Center [CQC], China Environmental United Certification Center [CEC], and China Standard Certification Center [CSC]. Each certification center establishes their own technical requirements, including test methods and emissions limits which are based on the national standards outlined in Table 2-3 (CQC 2003, CSC 2004).

Comparison of Regulations

Four key differences in the areas of emission limits, required documentation, deconstructive testing, and enforcement exist between the CARB regulation and the established international regulations.

Emission limits – The emission limits in the CARB regulation are not radically different from the equivalent international standards. CARB phase-2 emission limits are lower than the equivalent European and Chinese E1 limits, approximately equivalent to the Japanese F*** limits, and higher than the Japanese F**** limits [Table 2-2]. However, it is important to note that the CARB emission limits represent “ceilings” which cannot be exceeded, whereas the Japanese limits in Table 2-2 are average values and allow some panels to exceed the mean—up to a maximum allowable limit—so long as the mean value is attained during a normal production period (JSA 2003b). To meet CARB standards, manufacturers will target emissions levels below the ceilings in order to account for the variability in panel emissions.
Documentation - A major difference between CARB and other IWCP formaldehyde emissions regulations is the CARB chain-of-custody requirements. Arguably, this makes CARB the toughest standard in the world (Bradfield 2008). Fabricators must take “reasonable prudent precautions” to purchase IWCPs and IWCP-containing products that meet the applicable phase 1 or phase 2 standards (CARB 2007b). Fabricators must also keep documents showing the date of purchase and supplier of IWCPs and/or finished goods containing IWCPs, plus they must document the precautions they have taken to ensure that all components in their finished goods comply with the applicable CARB standards (CARB 2007b). Records must be maintained for at least 2 years in hard copy or electronic format (CARB 2007b). Distributors and retailers must maintain similar records to ensure that finished goods sold in California are compliant and that the raw materials in the finished product can be traced through the value chain to the IWCP manufacturer (CARB 2007b).

Deconstructive testing – Also unique to the CARB regulation is its provision for deconstructive testing. This is an attempt to verify that compliant panels were used to construct finished products; in other words, this will provide an avenue to catch falsely certified products. CARB personnel will likely use a secondary test method such as the small chamber method [ASTM 6007-02] to test pieces of HWPW, PB, and MDF that are removed from finished goods (CARB 2007b). A detailed protocol for the isolation of samples is currently in development by CARB personnel who are reportedly in consultation with both industry and academic professionals (Bradfield 2008).
A potential approach is using either abrasive sanding or planing to remove decorative surface treatments from panels (Bradfield 2008). However, this may introduce several sources of error, causing potentially inflated emissions test results. A layer of minimum permeability exists just below the surface of typical particleboards, and this provides resistance to formaldehyde emissions (Christensen et al. 1987). This layer may only be 0.040 inches thick—easily removed via a sanding or planing treatment—allowing formaldehyde emission values to exceed those noted in the panel production facility (Christensen et al. 1987). Another flaw with this approach is that it targets emissions from panel components that may be sealed within finished products. An argument can clearly be made that the total emissions from an intact finished product should be the paramount concern. As previously noted, materials sealed within an assembly do not have the same emissions characteristics as those exposed to surfaces (Groah et al. 1992, CPA 2003, Barry and Corneau 2006).

*Enforcement* - Enforcement varies widely among the standards, making compliance more important in some areas. The United States is an extremely litigious environment compared to China, Japan, or the E.U. and U.S. firms who fail to comply with regulations are often targets for large, class-action lawsuits. Therefore, companies operating in the U.S. will likely follow strict quality control practices with frequent product testing to provide a measure of protection from litigation. Companies operating in less litigious countries may conduct minimal testing to comply with government regulations.
Discussion

With increased public awareness of indoor air quality issues, the prospect for a national formaldehyde emissions regulation remains high. Two procedures are concurrently underway, either of which could effectively nationalize CARB regulations. First, a bill was introduced to the U.S. Congress (S.1660) in September 2009, which would amend the Toxic Substances Control Act (TSCA). Second, the U.S. Environmental Protection Agency [EPA] has been considering regulatory action on the national level (EPA 2008). At this time, the EPA has ended a public commentary period and is reviewing comments and data provided by industry, trade associations, academics, and the public (EPA 2008). Avenues for EPA regulation include either the TSCA or voluntary consensus standards such as the American National Standards Institute [ANSI] standards issued by the Composite Panel Association [CPA] and the Hardwood Plywood and Veneer Association [HPVA] (EPA 2008). The voluntary standards will likely contain more stringent emissions limits in the near future, as the CPA is currently incorporating CARB Phase 1&2 limits into the ANSI standards for PB and MDF and the HPVA is considering revising the ANSI standards for HWPW and engineered hardwood flooring to include the CARB emission limits (EPA 2008).

The CARB regulation has renewed interest in the formaldehyde emissions arena and created research opportunities. For example, little is known about how various deconstructive testing methods will affect emissions test results. Additionally, some uncertainty remains when comparing international emission limits and there is a need for better data comparing U.S. test methods to the various international test methods so that IWCP producers can better navigate the various international emissions standards.
Acknowledgements

The authors would like to thank the Composite Panel Association and the Hardwood Plywood and Veneer Association for their contributions of time, data, and formaldehyde testing expertise. We also gratefully acknowledge the following groups and individuals who made important contributions to the final manuscript: the California Air Resources Board; Mr. Manfred Fuchs, Directorate General Enterprise and Industry, European Commission; Mr. Edward Matsuyama, Japan Director, American Forest and Paper Association; and Ms. Qing Yuan Kong, Beijing Bureau of Quality and Technical Supervision.
Figure 2-1: Typical Large Chamber Testing Facility at a CARB-Approved Third-Party Certifier
Figure 2-2: Typical Small Chamber Testing Facility at a CARB-Approved Third-Party Certifier
Table 2-1: Formaldehyde emissions from FEMA-provided residences*

<table>
<thead>
<tr>
<th>Trailer type</th>
<th>Number tested</th>
<th>Mean Formaldehyde Emissions (ppb)</th>
<th>95% CI about the mean (ppb)</th>
<th>Range of Emissions (ppb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Travel trailer</td>
<td>360</td>
<td>81</td>
<td>72-92</td>
<td>3-590</td>
</tr>
<tr>
<td>Park model</td>
<td>90</td>
<td>44</td>
<td>38-53</td>
<td>3-170</td>
</tr>
<tr>
<td>Mobile home</td>
<td>69</td>
<td>57</td>
<td>49-65</td>
<td>11-320</td>
</tr>
</tbody>
</table>

*Table data from Manufacturers (2008)
Table 2-2: Comparison of U.S. and International Emission Limits

<table>
<thead>
<tr>
<th>Product(s)</th>
<th>Numerical Value (mg/m³)</th>
<th>Approximate U.S. Large Chamber Value¹ (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CARB²</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phase I</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HWPW</td>
<td>0.08</td>
<td>0.08</td>
</tr>
<tr>
<td>PB</td>
<td>0.18</td>
<td>0.18</td>
</tr>
<tr>
<td>MDF</td>
<td>0.21</td>
<td>0.21</td>
</tr>
<tr>
<td>Thin MDF³</td>
<td>0.21</td>
<td>0.21</td>
</tr>
<tr>
<td><strong>CARB</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phase II</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HWPW</td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
<td>PB</td>
<td>0.09</td>
<td>0.09</td>
</tr>
<tr>
<td>MDF</td>
<td>0.11</td>
<td>0.11</td>
</tr>
<tr>
<td>Thin MDF</td>
<td>0.13</td>
<td>0.13</td>
</tr>
<tr>
<td><strong>U.S. (HUD)⁴</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HWPW</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>PB</td>
<td>0.3</td>
<td>0.3</td>
</tr>
<tr>
<td><strong>Europe</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E1⁵</td>
<td>All</td>
<td>0.12</td>
</tr>
<tr>
<td>E1⁶</td>
<td>PB, MDF, OSB</td>
<td>8 mg/100 g</td>
</tr>
<tr>
<td><strong>Japan⁷</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F***</td>
<td>All</td>
<td>0.5 mg/L</td>
</tr>
<tr>
<td>F****</td>
<td>All</td>
<td>0.3 mg/L</td>
</tr>
<tr>
<td><strong>China</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E1⁸</td>
<td>PB, MDF, OSB</td>
<td>≤ 9 mg/100 g</td>
</tr>
<tr>
<td>E1⁹</td>
<td>HWPW</td>
<td>≤ 1.5 mg/L</td>
</tr>
<tr>
<td>Wood-Based</td>
<td>N.A.</td>
<td>≤ 1.5 mg/L</td>
</tr>
<tr>
<td>Furniture¹⁰</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

¹Approximate ASTM E1333 values from CARB 2007a. Approximate ASTM E1333 values for China were estimated based on the equations for the European and Japanese test methods in CARB 2007a and Risholm-Sundman et al. 2007.
²Emission limits from large chamber test (CARB 2007b)
³MDF with a maximum thickness of 8mm (CARB 2007b)
⁴Emission limits from large chamber test (HUD 2006)
⁵Value for EN 717-1 chamber test (BSI 2004)
⁶Value for EN 120 perforator test (BSI 2004)
⁷Emission limits from large chamber test (JSA 2003b)
⁸Value for perforator test (GAQSIQ 2001a)
⁹Value for perforator test (9-11L) (GAQSIQ 2001a)
¹⁰Value for desiccator test (9-11L) (GAQSIQ 2001b)
### Table 2-3: Comparison of U.S. and International Emissions Test Methods

<table>
<thead>
<tr>
<th>Purpose</th>
<th>Product(s)</th>
<th>Test Method</th>
<th>Chemistry</th>
</tr>
</thead>
<tbody>
<tr>
<td>Certification</td>
<td>All</td>
<td>Large/Small Chamber¹</td>
<td>Chromatropic Acid or DNPH²</td>
</tr>
<tr>
<td>Quality Control</td>
<td>All</td>
<td>Small Chamber or Desiccator³</td>
<td>Chromatropic Acid or DNPH</td>
</tr>
<tr>
<td>U.S. (HUD)</td>
<td>Certification</td>
<td>All</td>
<td>Large Chamber⁴</td>
</tr>
<tr>
<td>Quality Control</td>
<td>All</td>
<td>Not Specified</td>
<td>N.A.</td>
</tr>
<tr>
<td>Europe (E1)</td>
<td>Certification</td>
<td>All</td>
<td>Large Chamber⁵,⁶</td>
</tr>
<tr>
<td>Quality Control</td>
<td>PB, OSB, MDF</td>
<td>Perforator⁷</td>
<td>Acetylacetone</td>
</tr>
<tr>
<td>Quality Control</td>
<td>HWPW and Finished Panels</td>
<td>Gas Analysis⁸</td>
<td>Acetylacetone</td>
</tr>
<tr>
<td>Japan</td>
<td>Certification</td>
<td>All</td>
<td>Chamber or Desiccator⁹</td>
</tr>
<tr>
<td>Quality Control</td>
<td>All</td>
<td>Chamber or Desiccator</td>
<td>DNPH/Acetylacetone</td>
</tr>
<tr>
<td>China (E1 &amp; E2)</td>
<td>Certification</td>
<td>MDF, PB, OSB</td>
<td>Perforator¹¹</td>
</tr>
<tr>
<td>Certification</td>
<td>Plywood</td>
<td>9-11L Desiccator</td>
<td>Acetylacetone</td>
</tr>
<tr>
<td>Certification</td>
<td>Finished Panels</td>
<td>Chamber or 40L Desiccator</td>
<td>Acetylacetone</td>
</tr>
<tr>
<td>Quality Control</td>
<td>All</td>
<td>Not Specified</td>
<td>N.A.</td>
</tr>
</tbody>
</table>

¹ ASTM E 1333 large chamber (ASTM 2002) or ASTM D 6007 small chamber (ASTM 2006b)
² DNPH- dinitrophenylhydrazine method (ASTM 2003)
³ ASTM D 6007 small chamber (ASTM 2006b) or ASTM D 5582 desiccator method (ASTM 2006a).
The Japanese desiccator method (JIS A 1460), the European gas analysis method (EN 717-2), the Dynamic Microchamber, and European perforator method (EN 120) [only for PB, MDF, and thin MDF] are also CARB approved quality control test methods.
⁴ ASTM E 1333 large chamber method (ASTM 2002)
⁵ EN 717-1 large chamber method (CEN 1997a)
⁶ Quality control methods [perforator and gas analysis] may be used for certification testing (BSI 2004)
⁷ EN 120 perforator method (CEN 1997b)
⁸ EN 717-2 gas analysis method (CEN 1994)
⁹ JIS A 1901 chamber method (JSA 2003a) or JIS A 1460 desiccator method (JSA 2001)
¹⁰ Chamber method specifies DNPH method and desiccator method specifies acetylacetone method
¹¹ GB/T 17657-1999 perforator method (GAQSIQ 1999)
References


Chapter 3

Resin Suppliers’ Perspectives on the “Greening” of the North American Interior Wood Composite Panel Market

Abstract

Eight North American resin suppliers, representing 100% of the pMDI market and >95% of the UF market for interior wood composite panels (IWCPs), participated in an exploratory phone survey, conducted July – August, 2008, 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 urea-formaldehyde (UF) resins. Resin suppliers rated research and development work and technical support as the most important competitive advantage factors they employed. 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 (4.9 out of 5); fast resolution of customer complaints (4.4); reduced VOC emissions during panel pressing (4.3); support during resin trials (4.3); and on-time delivery (4.2). The regulatory environment (i.e. 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.
**Introduction**

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 (EPA 2009); it is a known carcinogen and can increase the risk for common respiratory problems such as asthma and chronic bronchitis (IARC 2009, Krzyzanowski et al. 1990). As a result, regulations have been promulgated in the U.S. and abroad to limit formaldehyde in indoor spaces.

**Formaldehyde Emissions Regulations**

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

Internationally the European Union (E.U.), the People’s Republic of China (PRC), and Japan represent key markets that have placed restrictions on formaldehyde emissions from WCPs (Ruffing et al. 2009). 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. 2009).

In the United States, the U.S. 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 2010-2012 (CARB 2007). The CARB emission limits are more stringent than the HUD regulation with product-specific phase II limits in the range of 0.05-0.11 ppm for HWPW, MDF, and PB (CARB 2007). Emission limits and effective dates for CARB phase I and II appear in Appendix A.

The U.S. Environmental Protection Agency (EPA) received a petition in March of 2008 to nationalize the CARB emission limits under the Toxic Substances Control Act (EPA 2009b). To date, the EPA is still considering this petition as well as alternatives such as regulating WCP formaldehyde emissions through voluntary consensus standards [i.e. American National Standards Institute (ANSI) issued by the Composite Panel Association (CPA) and the Hardwood Plywood and Veneer Association (HPVA)] (EPA 2009b).

**Interior Wood Composite Panels (IWCPs) and Formaldehyde Emissions**

For consistency and clarity, we will use the term “interior wood composite panel (IWCP)” to denote non-structural 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 an end-consumer. The most important IWCP products are particleboard (PB), medium density fiberboard (MDF), hardwood plywood (HWPW), and hardboard.

In 2008, North American IWCP production totaled approximately 7.3 billion square feet of panel product worth nearly $4 billion (Table 3-1). 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, valued at $4.7 billion (Table 3-1). The primary source of formaldehyde in IWCPs is the resin. Urea-formaldehyde (UF), melamine-formaldehyde (MF), melamine-urea-formaldehyde (MUF), phenol-formaldehyde (PF), phenol-melamine-urea formaldehyde (PMUF), phenol-melamine formaldehyde (PMF), 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 emissions 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 desired panel durability. Since most resins are produced from fossil fuel derivatives, resin costs often constitute a considerable portion—up to 32% — of the panel manufacturing cost (Sellers 2001). As a result, UF resins have historically been the predominant IWCP binder due to 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 U.S. 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 formulations 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 (Wood Adhesives 2010).

We hypothesized that tightening formaldehyde emissions regulations are impacting the competitive landscape in the IWCP resin market. This paper explores regulatory and other competitive factors affecting key resin suppliers. The primary objectives of this research were to examine the North American IWCP resin industry in 2007 in terms of their markets, product positioning strategies, and green resin product
development. The effect of formaldehyde emissions 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 email 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. Appendix B contains a copy of the questionnaire, email message, and cover letter. The correspondence also requested a phone interview to complete the questionnaire and to address participant questions. A second email, with attached cover letter and questionnaire, was sent to non-respondents one 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, however, chose to abstain from select questions due to 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 as they represent an important no-added-formaldehyde (NAF) option with an interesting value proposition. In fact, Isocyanate (pMDI) resins offer several key benefits versus 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 of respiratory sensitization to in-plant production workers (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”. Similar to 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) was then weighted
by company size by multiplying by the percent market share for each firm (Figure 3-1). All major IWCP types are adequately represented, with the majority of resins sold to PB and MDF manufacturers (Figure 3-1).

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. Instead, results of Student’s T-tests comparing the means for each of the nineteen product and service attributes appear in Appendix C.

**Competitive Strategy**

In an open-ended question, participants ranked, in order of importance, the top three factors that their firm employed for competitive advantages from the list of eight factors shown in Table 3-2. For each participant, their #1, #2, and #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 3-2). *Market share* was not ranked as one of the top three competitive advantages by any of the seven participating firms (Table 3-2).
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 3-2). This difference in competitive strategy may be a reflection of the increasing pressure to lower formaldehyde emissions from IWCP products. UF suppliers are 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 nineteen 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 3-3). 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, as four of the five top-ranked attributes are service-oriented (Table 3-3). 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 (Table 3-3). This underscores the results from the previous section (shown in Table 3-2). *Vendor managed inventory* was the least important attribute perhaps because of fluctuating downstream demand and the IWCP producer’s desire to control their own inventory.
PMDI suppliers perceived *low cost* as more important to IWCP customers than UF suppliers (Table 3-3). Since the 95 percent confidence interval around the mean for pMDI suppliers does not include the midpoint value of three on the five-point scale (Table 3-3), we conclude that pMDI suppliers view *low cost* as important. Alternatively, the midpoint of three 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 relative to traditional UF systems is likely responsible for this discrepancy. UF resin suppliers perceived *viscosity on specification* higher versus pMDI resin suppliers (Table 3-3), perhaps due to 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 3-3). For all participants, *low formaldehyde emissions from the finished panel product* and *reduced VOC emissions during pressing* were perceived as the two most important green resin attributes (Table 3-3). 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 three not included in 95 percent confidence interval); whereas at least some UF participants may not view this attribute as important to their IWCP customers (Table 3-3). 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 (i.e., soy protein, lignin additives, etc.) 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 non-renewable resources. Finally, two participants included references to green rating systems such as the U.S. 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 remaining questions.

Participants then answered the following: “what are the three most important resin product and/or service attributes (in your opinion) to your IWCP customers for ‘green’ resins.” Responses were weighted as follows: 1st choice = 3 points; 2nd choice = 2 points; and 3rd 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 (Figure 3-2). These findings support the fixed response attribute question (shown in Table 3-3) 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: (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 (Figure 3-3). 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 (Figure 3-3). 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 seven-point scale from 1=unimportant to my company, to 4=somewhat important to my company, to 7=critically important to my company (Figure 3-4).

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 resin market development highly (between 5.7/7 – 6.0/7) over all time periods whereas pMDI suppliers show a trend of increasing importance from today (4.7/7), to the next two years (5/7), to the next 5 years (5.7/7), to the next 10 years (6/7) (Figure 3-4). 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 interior wood composite panel (IWCP) industry, consisting of PF, 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...
out 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 out of 5) 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.

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 U.S. IWCP industry over the past 25 years. With the newly enacted CARB regulation and the potential for EPA action, reduction of formaldehyde emissions will likely be the predominant issue within the U.S. 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 emissions limits are enacted. Regulations are forcing IWCP manufacturers to drop traditional UF resins, and may eventually mandate a switch to no-added formaldehyde (NAF) options such as pMDI, polyvinyl acetate (PVAc), or soy-based resins. Over the past five years, a growing number of IWCP manufacturers have added NAF panels to their product mix (Surak, 2009). Perhaps these manufacturers are attempting to get ahead of tightening emissions regulations or are trying to capitalize on the growing green building market. The U.S. Green Building Council’s LEED program specify NAF resins for certain composite wood products (LEED® EQ Credit 4.4 – Low-Emitting Materials, <www.buildinggreen.com>).

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

ACKNOWLEDGEMENTS

The authors would like to 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.
Figure 3-1: Respondents’ Estimates of Percentage of Resin Sold to the Four Primary Panel Types in 2007 by Sales\(^1\) (\(n = 7/8\))\(^2\)

\(\text{MDF} 29\%\)

\(\text{PB} 56\%\)

\(\text{HWPW} 6\%\)

\(\text{Hardboard} 9\%\)

\(^1\)Responses 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.

\(^2\)One firm in the UF category choose to abstain from answering this question due to company policies making the response rate for this question 7/8.
Figure 3-2: Respondents' Opinion of the Most Important Green Product Attributes
(open-ended responses; 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?

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Weighted Responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low/no formaldehyde emissions</td>
<td>10</td>
</tr>
<tr>
<td>Low cost</td>
<td>9</td>
</tr>
<tr>
<td>Process friendly</td>
<td>7</td>
</tr>
<tr>
<td>Fast cure</td>
<td>5</td>
</tr>
<tr>
<td>Maintains board properties (I.B.)</td>
<td>3</td>
</tr>
<tr>
<td>Renewable resource based</td>
<td>2</td>
</tr>
<tr>
<td>On-site technical support</td>
<td>1</td>
</tr>
</tbody>
</table>

1 Responses were weighted as follows: 1st choice = 3 points; 2nd choice = 2 points; and 3rd choice = 1 point.
Figure 3-3: Respondents' Perception of Factors Driving Their Firm's Green Resin Program (n = 7/8)\(^1\)

Question: My firm’s green resin program is driven by: (please indicate your best estimate of the percentage attributed to the following factors)

- The regulatory environment (CARB)
- Customer demand (IWCP mfg.)
- Market demand (homeowner, builder, distributor)
- Reaction to competitors products
- Our company's marketing dept.

\(^1\) One firm in the UF category chose to abstain from answering this question due to company policies making the response rate for this question 7/8.
Figure 3-4: 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  1= unimportant to my company
Table 3-1: 2007/2008 North American IWCP Production (thousand sq ft ¼” basis)

<table>
<thead>
<tr>
<th></th>
<th>Quantity (thousand square feet)</th>
<th>Value (thousands of US $)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2007</td>
<td>2008</td>
</tr>
<tr>
<td>Particleboard</td>
<td>4,748,699 (54%)</td>
<td>3,961,847 (54%)</td>
</tr>
<tr>
<td>MDF</td>
<td>2,711,825 (31%)</td>
<td>2,220,681 (30%)</td>
</tr>
<tr>
<td>HW plywood</td>
<td>736,213* (8%)</td>
<td>631,857* (9%)</td>
</tr>
<tr>
<td>Hardboard</td>
<td>637,772 (7%)</td>
<td>513,184 (7%)</td>
</tr>
<tr>
<td>Totals</td>
<td>8,834,509 (100%)</td>
<td>7,327,569 (100%)</td>
</tr>
</tbody>
</table>


* Estimated by standardizing all panels to ¾” basis
Table 3-2: Competitive Advantages Utilized by IWCP Resin Manufacturers (open-ended)  
\( (n = 7/8)^1 \)

Question: Of the eight comparative factors listed in question #3, please rank (in order of importance) the top three factors that your firm employs for competitive advantages

<table>
<thead>
<tr>
<th>Competitive Advantage</th>
<th>All Firms(^3) ((n = 7))</th>
<th>UF(^4) ((n = 3))</th>
<th>pMDI ((n = 3))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Research and Development work</td>
<td>31.0</td>
<td>50.0</td>
<td>11.1</td>
</tr>
<tr>
<td>Technical Support</td>
<td>26.2</td>
<td>27.8</td>
<td>33.3</td>
</tr>
<tr>
<td>Customer Relationships</td>
<td>16.7</td>
<td>16.7</td>
<td>16.7</td>
</tr>
<tr>
<td>Green Product Development</td>
<td>14.3</td>
<td>0</td>
<td>16.7</td>
</tr>
<tr>
<td>Competitive Prices</td>
<td>4.7</td>
<td>0</td>
<td>11.1</td>
</tr>
<tr>
<td>Intensive Personal Selling</td>
<td>4.7</td>
<td>0</td>
<td>11.1</td>
</tr>
<tr>
<td>Effective Marketing</td>
<td>2.4</td>
<td>5.5</td>
<td>0</td>
</tr>
<tr>
<td>Market Share</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>Total (100%)</strong></td>
<td><strong>100</strong></td>
<td><strong>100</strong></td>
<td><strong>100</strong></td>
</tr>
</tbody>
</table>

\(^1\) One firm in the UF category choose to abstain from answering this question due to company policies making the response rate for this question 7/8.

\(^2\) Responses were weighted as follows: 1\(^{st}\) choice = 3 points; 2\(^{nd}\) choice = 2 points; 3\(^{rd}\) choice = 1 point. Results were standardized by setting the total points for each of the three categories equal to 100%, with each factor representing a percent of the total.

\(^3\) “All Firms” includes data from one firm that did not sell UF or pMDI resin in 2007

\(^4\) UF category is composed of approximately 99 percent UF resins and 1 percent other (PVAc, EPI, PF, MUF, PUF, soy) resins
### Table 3-3: Resin Suppliers’ Perception of the Relative Importance of Nineteen Product and Service Attributes to Their IWCP Customers (n=8/8)

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

<table>
<thead>
<tr>
<th>Attribute:</th>
<th>All Firms&lt;sup&gt;1&lt;/sup&gt; (n=8)</th>
<th>UF&lt;sup&gt;2&lt;/sup&gt; (n=4)</th>
<th>pMDI&lt;sup&gt;2&lt;/sup&gt; (n=3)</th>
<th>95% C.I. for UF</th>
<th>95% C.I. for pMDI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fast resolution of customer complaints</td>
<td>4.5</td>
<td>4.5</td>
<td>4.7</td>
<td>(3.93, 5.07)</td>
<td>(4.01, 5.32)</td>
</tr>
<tr>
<td>Support during resin trials</td>
<td>4.3</td>
<td>4.3</td>
<td>4.3</td>
<td>(3.76, 4.74)</td>
<td>(3.68, 4.99)</td>
</tr>
<tr>
<td>On-time delivery</td>
<td>4.2</td>
<td>4.5</td>
<td>4.2</td>
<td>(3.93, 5.07)</td>
<td>(3.84, 4.49)</td>
</tr>
<tr>
<td>Wide operating window</td>
<td>4.1</td>
<td>4.0</td>
<td>4.3</td>
<td>(3.20, 4.80)</td>
<td>(3.68, 4.99)</td>
</tr>
<tr>
<td>Support customer’s new product development at the vendor’s research and development facility</td>
<td>4.0</td>
<td>4.4</td>
<td>3.7</td>
<td>(3.93, 4.94)</td>
<td>(3.01, 4.32)</td>
</tr>
<tr>
<td>High internal bond strength</td>
<td>4.0</td>
<td>4.3</td>
<td>3.7</td>
<td>(3.76, 4.74)</td>
<td>(3.01, 4.32)</td>
</tr>
<tr>
<td>Low cost</td>
<td>3.9</td>
<td>3.5</td>
<td>4.7</td>
<td>(2.52, 4.48)</td>
<td>(4.01, 5.32)</td>
</tr>
<tr>
<td>Fast cure</td>
<td>3.9</td>
<td>4.3</td>
<td>4.3</td>
<td>(3.76, 4.74)</td>
<td>(3.68, 4.99)</td>
</tr>
<tr>
<td>Viscosity on spec.</td>
<td>3.8</td>
<td>4.3</td>
<td>3.3</td>
<td>(3.76, 4.74)</td>
<td>(2.68, 3.99)</td>
</tr>
<tr>
<td>Long storage life</td>
<td>3.6</td>
<td>3.8</td>
<td>3.7</td>
<td>(3.26, 4.24)</td>
<td>(3.01, 4.32)</td>
</tr>
<tr>
<td>Assistance in new production equipment set-up at customer’s production facility</td>
<td>3.6</td>
<td>3.8</td>
<td>3.7</td>
<td>(2.52, 4.98)</td>
<td>(1.94, 5.40)</td>
</tr>
<tr>
<td>Resin does not discolor finished panel product</td>
<td>3.5</td>
<td>3.0</td>
<td>4.0</td>
<td>(2.20, 3.80)</td>
<td>(2.87, 5.13)</td>
</tr>
<tr>
<td>Geographic proximity of resin mfg. facility to the customer</td>
<td>3.3</td>
<td>3.0</td>
<td>3.3</td>
<td>(1.61, 4.39)</td>
<td>(2.68, 3.99)</td>
</tr>
<tr>
<td>Vendor-managed inventory</td>
<td>2.5</td>
<td>2.5</td>
<td>2.7</td>
<td>(1.93, 3.07)</td>
<td>(2.01, 3.32)</td>
</tr>
</tbody>
</table>

**Green IWCP resin product attributes ranked by importance**

<table>
<thead>
<tr>
<th>Attribute:</th>
<th>All Firms&lt;sup&gt;1&lt;/sup&gt; (n=8)</th>
<th>UF&lt;sup&gt;2&lt;/sup&gt; (n=4)</th>
<th>pMDI&lt;sup&gt;2&lt;/sup&gt; (n=3)</th>
<th>95% C.I. for UF</th>
<th>95% C.I. for pMDI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low formaldehyde emissions from finished panel product</td>
<td>4.8</td>
<td>4.8</td>
<td>4.7</td>
<td>(4.26, 5.24)</td>
<td>(4.01, 5.32)</td>
</tr>
<tr>
<td>Reduced VOC emissions during panel pressing</td>
<td>4.3</td>
<td>4.5</td>
<td>3.7</td>
<td>(3.93, 5.07)</td>
<td>(2.36, 4.97)</td>
</tr>
<tr>
<td>Low energy requirements for composite panel pressing</td>
<td>3.3</td>
<td>3.0</td>
<td>3.7</td>
<td>(2.20, 3.80)</td>
<td>(3.01, 4.32)</td>
</tr>
<tr>
<td>Environmentally friendly adhesive synthesis processes</td>
<td>3.0</td>
<td>3.3</td>
<td>2.3</td>
<td>(2.31, 4.19)</td>
<td>(1.03, 3.64)</td>
</tr>
<tr>
<td>“Green” resin components (i.e. soy protein, lignin additives, etc.)</td>
<td>3.0</td>
<td>3.5</td>
<td>1.7</td>
<td>(2.93, 4.07)</td>
<td>(0.93, 2.97)</td>
</tr>
</tbody>
</table>

Scale: 1 = Not at all important  3 = Neither important nor unimportant  5 = Extremely important

<sup>1</sup> “All Firms” includes data from one firm that did not sell UF or pMDI resin in 2007

<sup>2</sup> UF category is composed of approximately 99 percent UF resins and 1 percent other (PVAc, EPI, PF, MUF, PUF) resins
References


Chapter 4

Research Summary

This research investigated the impact of formaldehyde emissions regulations on 1) adhesive development in North America and 2) within the context of existing national and international formaldehyde emissions regulations for wood composite panels. A summary of relevant findings and conclusions is presented here for each objective of this study. Final thoughts and considerations for future research are also discussed.

Literature Review

The first objective of this work was to review, compare, and contrast domestic and international formaldehyde emissions standards for interior wood composite panel products. A thorough search of the scientific literature and public documents was conducted to develop a profile of each emission standard. Domestic and international experts were identified and consulted to confirm our understanding and interpretation of each standard.

The “ceiling” emission limits in the second phase of the CARB regulation will be the most stringent emission limits in the world. While CARB regulations require documentation throughout the value chain, plus deconstructive testing on finished products, comparable international emission standards do not contain such provisions. CARB regulations are likely to influence the development and implementation of a national formaldehyde emission standard for wood composite panel products.
North American IWCP Resin Industry Profile

The second objective of this study was to develop a profile of the North American interior wood composite panel (IWCP) industry in 2007. A survey questionnaire was developed and administered to eight key IWCP resin suppliers to determine their product positioning strategies, markets, and green resin product development strategies. The effect of formaldehyde emissions regulations on green IWCP resin development was of particular interest.

In 2007, the North American IWCP resin industry was highly concentrated and dominated by urea-formaldehyde resins (~98%). Results show that key differences exist between UF and pMDI resin suppliers in the areas of company positioning strategy, green resin program development, and green resin market development. Overall, results indicate that formaldehyde emissions regulations are driving changes within the North American IWCP resin industry. Survey respondents ranked low formaldehyde emissions from the finished panel product (4.9 out of 5) and reduced VOC emissions during pressing (4.3) as the most important green resin product attributes to their IWCP customers. Additionally, survey respondents rated low/no formaldehyde emissions as the most important green product attribute to their IWCP customers in an open-ended question, underscoring the importance of low emission resin products. Finally, results indicate that the regulatory environment (i.e. CARB) was the most important driver of green resin programs.
**Combined Results**

Overall results from this study indicate that formaldehyde emissions regulations are driving major changes within the North American IWCP industry and the resin industry that supplies it. The newly enacted CARB regulation contains some of the most stringent emission limits and is the only emission standard in the world to require chain-of-custody documentation and deconstructive testing of finished products. With increasing awareness of indoor air quality issues and subsequent pressure from environmental groups, the prospect of national formaldehyde emissions regulations for IWCPs remains high. Perhaps the U.S. Environmental Protection Agency will combine elements of the CARB regulation with other existing emission standards such as the HUD standard or the Japanese emission standards. Whether national regulations are enacted or not, the CARB regulation is already viewed by many to be a de-facto national standard with serious implications for IWCP manufacturers, resin manufacturers, fabricators, and retailers.

Results of this study demonstrate the effect of the CARB standard as a driver for green adhesive development within the IWCP resin industry. Going forward, the CARB regulation will likely be a challenge and an opportunity for the IWCP resin industry. The regulation has challenged UF resin manufacturers to develop new ultra-low emitting products that can meet CARB phase II limits. Alternatively, the regulation offers resin manufacturers an opportunity to differentiate through new product development in an industry that has traditionally been dominated by commodity products. Finally, the available CARB exemptions for no-added formaldehyde resins and potentially higher cost of low emission formaldehyde-based systems, may allow no-added formaldehyde
resin systems such as pMDI and soy-based resins to compete in an industry that has been dominated by lower cost UF resins.

Future Work

The CARB regulation and impending national regulation have renewed interest in the formaldehyde emissions arena and created numerous opportunities for research. Future work may investigate the effect of deconstructive testing on formaldehyde emissions from the core panel product. Additionally, future work may include a longitudinal survey of the North American IWCP resin industry to determine how the industry has changed with the implementation of CARB phase one and two.
Appendix A

Formaldehyde Emission Limits by Standard

*Table A-1: CARB Phase I and II Emission Limits and Effective Dates*

<table>
<thead>
<tr>
<th>Effective Date</th>
<th>Phase I (P1) and Phase II (P2) Emission Limits (ppm)</th>
<th>HWPW-VC&lt;sup&gt;2&lt;/sup&gt;</th>
<th>HWPW-CC&lt;sup&gt;3&lt;/sup&gt;</th>
<th>PB</th>
<th>MDF</th>
<th>Thin MDF&lt;sup&gt;4&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/1/2009</td>
<td>P1: 0.08</td>
<td>-------</td>
<td>P1: 0.18</td>
<td>P1: 0.21</td>
<td>P1: 0.21</td>
<td></td>
</tr>
<tr>
<td>7/1/2009</td>
<td>-------</td>
<td>P1: 0.08</td>
<td>-------</td>
<td>-------</td>
<td>-------</td>
<td></td>
</tr>
<tr>
<td>1/1/2010</td>
<td>P2: 0.05</td>
<td>-------</td>
<td>-------</td>
<td>-------</td>
<td>-------</td>
<td></td>
</tr>
<tr>
<td>1/1/2011</td>
<td>-------</td>
<td>-------</td>
<td>P2: 0.09</td>
<td>P2: 0.11</td>
<td>-------</td>
<td></td>
</tr>
<tr>
<td>1/1/2012</td>
<td>-------</td>
<td>-------</td>
<td>-------</td>
<td>-------</td>
<td>P2: 0.13</td>
<td></td>
</tr>
<tr>
<td>7/1/2012</td>
<td>-------</td>
<td>P2: 0.05</td>
<td>-------</td>
<td>-------</td>
<td>-------</td>
<td></td>
</tr>
</tbody>
</table>

<sup>1</sup>Limits based on primary test method (ASTM E 1333-96 Large Chamber Method)

<sup>2</sup>Hardwood plywood veneer core

<sup>3</sup>Hardwood plywood composite core

<sup>4</sup>MDF 8mm or less in thickness

### Table A-2: European E1 Emission Limits

<table>
<thead>
<tr>
<th>Panel Product</th>
<th>Unfaced</th>
<th>Unfaced</th>
<th>Coated, overlaid, or veneered</th>
</tr>
</thead>
<tbody>
<tr>
<td>PB</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OSB</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MDF</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plywood</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solid wood panels</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LVL</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PB</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OSB</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MDF</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plywood</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solid wood panels</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LVL</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Initial type testing</th>
<th>Test method</th>
<th>Emission limit</th>
<th>Factory production control</th>
<th>Test method</th>
<th>Emission limit</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Release ≤ 0.124 mg/m³ air</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>EN 717-1 ³</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>EN 717-2 ⁴</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Test method</th>
<th>Emitting limit</th>
<th>Release ≤ 3.5 mg/m³/h or ≤ 5 mg/m³/h within 3 days after production</th>
</tr>
</thead>
<tbody>
<tr>
<td>EN 120 ³</td>
<td>Contain ≤ 8 mg/100g oven dry board</td>
<td></td>
</tr>
</tbody>
</table>

¹For established products, initial type testing may also be done on the basis of existing data with EN 120 or EN 717-2 testing, either from factory production control or from external inspection

²European large chamber method

³Perforator method

⁴Gas analysis method

Table A-3: European E2 Emission Limits

<table>
<thead>
<tr>
<th>Panel Product</th>
<th>Unfaced</th>
<th>Unfaced</th>
<th>Coated, overlaid, or veneered</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PB OSB MDF</td>
<td>Plywood Solid wood panels LVL</td>
<td>PB OSB MDF Plywood Solid wood panels Fiber boards (wet process) Cement bonded PB LVL</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Initial type testing</th>
<th>Test method</th>
<th>Emission limit</th>
<th>Factory production control</th>
<th>Test method</th>
<th>Emission limit</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>EN 717-1(^1)</td>
<td>Release &gt; 0.124 mg/m(^2) air(^2)</td>
<td></td>
<td>EN 120(^3)</td>
<td>Release &gt; 3.5 mg/m(^3) h to ≤ 8 mg/m(^3) h or &gt;5 mg/m(^3) h to ≤ 12 mg/m(^3) h within 3 days after production</td>
</tr>
<tr>
<td></td>
<td>EN 717-2(^4)</td>
<td></td>
<td></td>
<td>EN 120(^3)</td>
<td>Release &gt; 3.5 mg/m(^3) h to ≤ 8 mg/m(^3) h or &gt;5 mg/m(^3) h to ≤ 12 mg/m(^3) h within 3 days after production</td>
</tr>
</tbody>
</table>

\(^1\)European large chamber method
\(^2\)The corresponding upper emission limits can be found from the EN 120 or EN 717-2 factory production/external control tests.
\(^3\)Perforator method
\(^4\)Gas analysis method

Table A-4: Japanese Formaldehyde Emission Classes

<table>
<thead>
<tr>
<th>Name</th>
<th>Emission Class</th>
<th>Formaldehyde Emission Limit (mg/m²h)</th>
<th>Restrictions on Interior Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type 1</td>
<td>Equivalent to old E₂, Fc₂ standards under JIS, JAS, unclassified</td>
<td>0.12 &lt; X</td>
<td>Use prohibited</td>
</tr>
<tr>
<td>Type 2</td>
<td>F** under JIS, JAS, or ministerial approval</td>
<td>0.02 ≤ X ≤ 0.12</td>
<td>Limited area of use</td>
</tr>
<tr>
<td>Type 3</td>
<td>F*** under JIS, JAS, or ministerial approval</td>
<td>0.005 ≤ X ≤ 0.02</td>
<td></td>
</tr>
<tr>
<td>Type 4</td>
<td>F**** under JIS, JAS, or ministerial approval</td>
<td>X ≤ 0.005</td>
<td>No restrictions</td>
</tr>
</tbody>
</table>

### Table A-5: Chinese E1 and E2 Emission Limits

<table>
<thead>
<tr>
<th>Product</th>
<th>Test Method</th>
<th>Emission Limit</th>
<th>Use Restriction</th>
<th>Emission Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>MDF, PB, OSB, High-density fiberboard&lt;sup&gt;1&lt;/sup&gt;</td>
<td>Perforator</td>
<td>≤ 9mg/100g</td>
<td>Direct indoor use</td>
<td>E1</td>
</tr>
<tr>
<td></td>
<td>Perforator</td>
<td>≤ 30mg/100g</td>
<td>Indoor applications only after surface finish application</td>
<td>E2</td>
</tr>
<tr>
<td>Plywood and plywood with a decorative surface veneer&lt;sup&gt;1&lt;/sup&gt;</td>
<td>9-11L Desiccator</td>
<td>≤ 1.5 mg/L</td>
<td>Direct indoor use</td>
<td>E1</td>
</tr>
<tr>
<td></td>
<td>9-11L Desiccator</td>
<td>≤ 5.0 mg/L</td>
<td>Indoor applications only after surface finish application</td>
<td>E2</td>
</tr>
<tr>
<td>Surface decorated/treated wood-based panels</td>
<td>Chamber</td>
<td>≤ 0.12 mg/m&lt;sup&gt;3&lt;/sup&gt;</td>
<td>Direct indoor use</td>
<td>E1</td>
</tr>
<tr>
<td>(laminated wood, solid wood composite flooring, bamboo flooring,</td>
<td></td>
<td>≤ 1.5 mg/L</td>
<td></td>
<td></td>
</tr>
<tr>
<td>impregnated paper decorated wood-based panels)&lt;sup&gt;2&lt;/sup&gt;</td>
<td>9-11L Desiccator</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>


Appendix B

Resin Supplier Email, Questionnaire, and Cover Letter

Figure B-1: Resin Supplier Email

Mr. Ruffing,

I am writing to ask for your participation in an important survey of resin development for the North American Interior Wood Composite Panel (IWCP) industry. I have attached a cover letter explaining the survey and the importance of this study. The survey will be conducted in a phone interview that should only take 15-20 minutes of your valuable time. A copy of the survey is attached for your convenience in preparing for the phone interview.

You were identified as a contact person through the XYZ corporate web site. If you are not the best person to complete this marketing survey, please reply to this message with the contact information for the appropriate marketing person within your organization.

Thank you in advance for your participation,

Sincerely,

Tom Ruffing
Graduate Research Assistant
Pennsylvania State University
Figure B-2: Resin Supplier Questionnaire

Manufacturer’s Perspectives of Resin Development for the Interior Wood Composite Panel Industry

Administered by:
The Pennsylvania State University Wood Products Marketing Program

This survey will focus exclusively on resins/adhesives used in the Interior Wood Composite Panel (IWCP) industry. Please omit any information on resin sales or marketing of other products.

1) Please estimate the percentage of your 2007 resin sold to the following IWCP customers:

   Interior panel type
   - Medium density fiberboard (MDF) ________%
   - Hardwood plywood ________%
   - Hardboard ________%
   - Particleboard ________%
   TOTAL = 100%

Company Positioning:

2) When compared to other suppliers of interior wood composite panel resins, how would you say your company is positioned on the following eight comparative factors?

<table>
<thead>
<tr>
<th>Comparative Factors</th>
<th>Clearly in a more advantageous/better position</th>
<th>Equal position</th>
<th>Clearly in a more disadvantageous/worse position</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Effective marketing</td>
<td>5</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>B. Customer relationships</td>
<td>5</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>C. Intensive personal selling</td>
<td>5</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>D. Market share</td>
<td>5</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>E. Competitive prices</td>
<td>5</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>F. Research and Development work</td>
<td>5</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>G. Technical support</td>
<td>5</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>H. Green product development</td>
<td>5</td>
<td>4</td>
<td>3</td>
</tr>
</tbody>
</table>
3) Of the eight factors listed in question #3, please rank (in order of importance) the top three factors that your firm employs for competitive advantages (please place the letter of the factor above in the appropriate space parenthesis below):

   #1. (   )
   #2. (   )
   #3. (   )

**Corporate Strategy:**

4) Using the descriptions provided below, please classify the type that best matches the strategy employed by your firm’s interior panel resin sales force in 2007.

Type 1.
- **Cost leadership** through economies of large-scale production. Minimization of production cost is the main objective. Product and customer differentiation is avoided. Product development and marketing costs are minimized.

Type 2.
- **Differentiation** of products or services. Uniqueness is the main objective. Differentiation can be based on customer service, product attributes, distribution, or a reputation as an innovator in developing new products.

Type 3.
- **Focus** on a certain customer group, market area or product group. The company, or a product/market area-group inside the company, builds its strategy to serve a certain target group as well as possible- better than competitors that are serving a broader area. (The company can thereby achieve a cost or differentiation advantage within a chosen target group.)

   Our company’s strategy corresponds most closely to type (___).

   If there are components in your strategy from more than one type, how is it divided between the described types?

   Type 1 _____%
   Type 2 _____%
   Type 3 _____%

   Total 100%
Product Positioning Strategy:

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

<table>
<thead>
<tr>
<th>Product (resin) Attributes:</th>
<th>Extremely Important</th>
<th>Neither Important nor Unimportant</th>
<th>Not At All Important</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Cost</td>
<td>5</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Viscosity on spec.</td>
<td>5</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Fast cure</td>
<td>5</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Resin does not discolor finished panel product</td>
<td>5</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Long Storage Life</td>
<td>5</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Resin PH within spec.</td>
<td>5</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>High internal bond strength</td>
<td>5</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Wide operating window</td>
<td>5</td>
<td>4</td>
<td>3</td>
</tr>
</tbody>
</table>

Environmental / “Green” Attributes

<table>
<thead>
<tr>
<th>That affect our customer’s business</th>
<th>Extremely Important</th>
<th>Neither Important nor Unimportant</th>
<th>Not At All Important</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low formaldehyde emissions from finished panel product</td>
<td>5</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Reduced VOC emissions during panel pressing</td>
<td>5</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Low energy requirements for composite panel pressing</td>
<td>5</td>
<td>4</td>
<td>3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>That affect our business</th>
<th>Extremely Important</th>
<th>Neither Important nor Unimportant</th>
<th>Not At All Important</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environmentally friendly adhesive synthesis processes</td>
<td>5</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>“Green” resin components (i.e. soy protein, lignin additives etc.)</td>
<td>5</td>
<td>4</td>
<td>3</td>
</tr>
</tbody>
</table>

Service Attributes:

<table>
<thead>
<tr>
<th>Service Attributes:</th>
<th>Extremely Important</th>
<th>Neither Important nor Unimportant</th>
<th>Not At All Important</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fast resolution of customer complaints</td>
<td>5</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Vendor managed inventory</td>
<td>5</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>On-time delivery</td>
<td>5</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Geographic proximity of resin mfg. facility to the customer</td>
<td>5</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Support during resin trials</td>
<td>5</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Assistance in new production equipment set up at customer’s production facility</td>
<td>5</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Supporting customer’s new product development at the vendor’s R&amp;D facility</td>
<td>5</td>
<td>4</td>
<td>3</td>
</tr>
</tbody>
</table>

6) How would you personally define “green” as it relates to IWCP resins?

________________________________________________________________________
________________________________________________________________________
________________________________________________________________________.
Green Adhesive Product Development:

7) Is your company currently selling any “green” (environmentally-friendly) resins for IWCPs?

➢ Yes ( )
➢ No ( )

If yes, please estimate the percentage of your 2007 IWCP resin sales that you promoted as “green”

____________% 

What are the three most important resin product and/or service attributes (in your opinion) to your IWCP customers, for these “green” interior wood composite panel resins?

#1__________________
#2__________________
#3__________________

8) Please rate your level of agreement with the following statements regarding your firm’s level of commitment to the following “green” strategies/objectives:

<table>
<thead>
<tr>
<th>Statement</th>
<th>Strongly Agree</th>
<th>Neither Agree nor Disagree</th>
<th>Strongly Disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td>Implementing environmentally friendly/“green” production strategies is very important to my firm</td>
<td>7</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>My firm is striving to make existing resin products “greener”</td>
<td>7</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>My firm is striving to be an industry leader in the development of new “green” resin products</td>
<td>7</td>
<td>6</td>
<td>5</td>
</tr>
</tbody>
</table>
9) Please rate the level of importance your firm places on green resin product market development over the four time periods listed below.

<table>
<thead>
<tr>
<th></th>
<th>Critically Important to my Company</th>
<th>Somewhat Important to my Company</th>
<th>Unimportant to my Company</th>
</tr>
</thead>
<tbody>
<tr>
<td>Today</td>
<td>7</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>Within the next 2 years</td>
<td>7</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>Within the next 5 years</td>
<td>7</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>Within the next 10 years</td>
<td>7</td>
<td>6</td>
<td>5</td>
</tr>
</tbody>
</table>

If your company is currently promoting green resin products please answer the following two questions. If not, please skip to question # 11.

10) My firm’s green resin program is driven by: (Please indicate your best estimate of the percentage attributed to the following factors)

Customer demand (IWCP mfrs.)   ______
Market demand (homeowner, builder, distributor)   ______
The regulatory environment (CARB)   ______
Our company’s marketing department   ______
Reaction to competitor’s products   ______
Other (please specify): _____________________    ______
Total   100%

11) When developing new “green” resin products, please indicate your best estimate of the percentage of your firm’s effort attributed to the following factors:

Resin product performance   ______
Finished resin product cost   ______
“Greenness” of resin product   ______
Other (Please specify): _____________________    ______
Total   100%
Reminder: Your answers will be held confidential and used only in combination with other responses for statistical analysis and reporting. Your responses will never be associated with you, or your firm.

12) Please provide an estimate of your 2007 sales of interior wood composite panel resins in pounds.

________________ lbs
Figure B-3: Resin Supplier Cover Letter

18 March, 2009

Mr. Ruffing:

I am writing to ask for your participation in an important survey of resin development for the North American Interior Wood Composite Panel (IWCP) industry. Detailed information on development and marketing of interior wood composite panel resins is lacking; therefore, we are conducting this survey as part of a graduate research project in the wood products program at the Pennsylvania State University. The results of this survey will provide important insights into the drivers of interior resin development and marketing within your industry.

Due to the limited number of resin manufacturers serving this market, completion of every interview is important to achieve meaningful results that truly represent the industry. The survey is designed for easy completion through a phone interview process that will only take a few minutes of your valuable time.

This survey is voluntary and completely confidential. Your answers will be held confidential and used only in combination with other responses for statistical analysis and reporting. Your responses will never be associated with you, or your firm.

As a token of our appreciation for completing the survey, we will provide a complete summary of the results to all responding firms.

Please respond to this message (e-mail) with a date and time when you are available to complete the survey and a phone number where you can be reached. If your firm did not sell resin products to the North American IWCP industry in 2007 please respond via e-mail and we will remove your firm from our list.

Thank you in advance for your participation in this important study.

Sincerely,

[Signature]

Mr. Thomas Ruffing
Graduate Research Assistant
Pennsylvania State University
Dr. Paul M. Smith  
Professor of Wood Products Marketing  
Chemistry  
Pennsylvania State University  
University

Dr. Nicole R. Brown  
Asst. Professor of Wood  
Pennsylvania State
**Appendix C**

**Summary Statistics for Nineteen Product and Service Attributes**

*Table C-1: Resin Suppliers’ Perception of the Relative Importance of Nineteen Product and Service Attributes to Their IWCP Customers – summary statistics (n=8/8)*

<table>
<thead>
<tr>
<th>Attribute:</th>
<th>All Firms $^1$ (n=8)</th>
<th>UF $^2$ (n=4) (95%CI)</th>
<th>pMDI (n=3) (95%CI)</th>
<th>P-value UF v pMDI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fast resolution of customer complaints</td>
<td>4.5</td>
<td>4.5 (3.93,5.07)</td>
<td>4.7 (4.01,5.32)</td>
<td>0.721</td>
</tr>
<tr>
<td>Support during resin trials</td>
<td>4.3</td>
<td>4.3 (3.76,4.74)</td>
<td>4.3 (3.68,4.99)</td>
<td>0.846</td>
</tr>
<tr>
<td>On-time delivery</td>
<td>4.2</td>
<td>4.5 (3.93,5.07)</td>
<td>4.2 (3.84,4.49)</td>
<td>0.408</td>
</tr>
<tr>
<td>Wide operating window</td>
<td>4.1</td>
<td>4.0 (3.20,4.80)</td>
<td>4.3 (3.68,4.99)</td>
<td>0.576</td>
</tr>
<tr>
<td>Support customer’s new product development at the vendor’s research and development facility</td>
<td>4.0</td>
<td>4.4 (3.93,4.94)</td>
<td>3.7 (3.01,4.32)</td>
<td>0.121</td>
</tr>
<tr>
<td>High internal bond strength</td>
<td>4.0</td>
<td>4.3 (3.76,4.74)</td>
<td>3.7 (3.01,4.32)</td>
<td>0.211</td>
</tr>
<tr>
<td>Low cost</td>
<td>3.9</td>
<td>3.5 (2.52,4.48)</td>
<td>4.7 (4.01,5.32)</td>
<td>0.135</td>
</tr>
<tr>
<td>Fast cure</td>
<td>3.9</td>
<td>4.3 (3.76,4.74)</td>
<td>4.3 (3.68,4.99)</td>
<td>0.846</td>
</tr>
<tr>
<td>Viscosity on spec.</td>
<td>3.8</td>
<td>4.3 (3.76,4.74)</td>
<td>3.3 (2.68,3.99)</td>
<td>0.074</td>
</tr>
<tr>
<td>Long storage life</td>
<td>3.6</td>
<td>3.8 (3.26,4.24)</td>
<td>3.7 (3.01,4.32)</td>
<td>0.846</td>
</tr>
<tr>
<td>Assistance in new production equipment set-up at customer’s production facility</td>
<td>3.6</td>
<td>3.8 (2.52,4.98)</td>
<td>3.7 (1.94,5.40)</td>
<td>0.940</td>
</tr>
<tr>
<td>Resin does not discolor finished panel product</td>
<td>3.5</td>
<td>3.0 (2.20,3.80)</td>
<td>4.0 (2.87,5.13)</td>
<td>0.203</td>
</tr>
<tr>
<td>Geographic proximity of resin mfg. facility to the customer</td>
<td>3.3</td>
<td>3.0 (1.61,4.39)</td>
<td>3.3 (2.68,3.99)</td>
<td>0.721</td>
</tr>
<tr>
<td>Vendor-managed inventory</td>
<td>2.5</td>
<td>2.5 (1.93,3.07)</td>
<td>2.7 (2.01,3.32)</td>
<td>0.721</td>
</tr>
</tbody>
</table>

**Green IWCP resin product attributes ranked by importance**

| Low formaldehyde emissions from finished panel product                     | 4.8                  | 4.8 (4.26,5.24)       | 4.7 (4.01,5.32)     | 0.846             |
| Reduced VOC emissions during panel pressing                                | 4.3                  | 4.5 (3.93,5.07)       | 3.7 (2.36,4.97)     | 0.259             |
| Low energy requirements for composite panel pressing                      | 3.3                  | 3.0 (2.20,3.80)       | 3.7 (3.01,4.32)     | 0.286             |
| Environmentally friendly adhesive synthesis processes | 3.0 | 3.3 (2.31,4.19) | 2.3 (1.03,3.64) | 0.301 |
| “Green” resin components (i.e. soy protein, lignin additives, etc.) | 3.0 | 3.5 (2.93,4.07) | 1.7 (0.36,2.97) | 0.039 |

Scale: 1= Not at all important  3= Neither important nor unimportant  5= Extremely important

1 “All Firms” includes data from one firm that did not sell UF or pMDI resin in 2007
2 UF category is composed of approximately 99 percent UF resins and 1 percent other (PVAc, EPI, PF, MUF, PUF) resins