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**CHARACTERIZATION OF MANUFACTURING
PROCESSES AND EMISSIONS AND
POLLUTION PREVENTION OPTIONS FOR THE
COMPOSITE WOOD INDUSTRY**

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FOREWORD

The U.S. Environmental Protection Agency is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The National Risk Management Research Laboratory is the Agency's center for investigation of technological and management approaches for reducing risks from threats to human health and the environment. The focus of the Laboratory's research program is on methods for the prevention and control of pollution to air, land, water, and subsurface resources; protection of water quality in public water systems; remediation of contaminated sites and groundwater; and prevention and control of indoor air pollution. The goal of this research effort is to catalyze development and implementation of innovative, cost-effective environmental technologies; develop scientific and engineering information needed by EPA to support regulatory and policy decisions; and provide technical support and information transfer to ensure effective implementation of environmental regulations and strategies.

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ABSTRACT

The composite wood panel manufacturing industry was included in the EPA's initial list of air toxics source categories under section 112 of the Clean Air Act Amendments of 1990.¹ The industry was defined by the EPA as "...any facility engaged in the manufacturing of plywood and/or particleboard, including, but not limited to, manufacturing of chip waferboard, strandboard, hardboard/cellulosic fiberboard, oriented strandboard, hardwood plywood, medium density fiberboard, softwood plywood, or any other wood composite product manufactured using binder (EPA, 1992)." The EPA's Office of Air Quality Planning and Standards (OAQPS) will be writing maximum achievable control technology (MACT) standards for Hazardous Air Pollutants (HAPs) as they apply to the composite wood panel manufacturing industry; the MACT regulations for this industry are scheduled to be proposed in 1999.

The Pollution Prevention Act of 1990 requires the EPA to review regulations of the Agency prior to their proposal to determine the effect of regulations on source reduction. In response to this charge, the EPA has established the Source Reduction Review Project (SRRP). The goals of the SRRP are to ensure that source reduction measures and multi-media issues are considered during the earliest stages of development of regulations under the Clean Air Act, Clean Water Act, and Resource Conservation and Recovery Act. The SRRP is focused on 17 industrial categories which will be affected by the above regulations; the composite wood panel manufacturing industry was selected as one of the 17 industrial categories.²

The EPA's National Risk Management Research Laboratory (NRMRL)/Air Pollution Prevention and Control Division (APPCD) worked in conjunction with OAQPS on the implementation of the SRRP for the composite wood panel manufacturing industry. As part of this effort, the Research Triangle Institute was contracted to characterize emissions from manufacturing processes and to identify potential pollution prevention opportunities for reducing them.

This report summarizes information gathered on emissions from the composite wood industry and potential pollution prevention options. Information was gathered through a literature search of trade association publications, journal articles, symposium presentations, university research. etc.

¹In the EPA's initial list of air toxics, the composite wood industry was called the plywood and particleboard industry.

²The composite wood panel manufacturing industry was listed in the SRRP as the plywood and particleboard industry.

Little information exists in the literature pertaining to pollution prevention. Most of the available literature focuses on ways to reduce raw material consumption and improve manufacturing processes. However, in many instances, these reductions and improvements lead to pollution prevention benefits. Some of these potential pollution prevention options are presented in this report and include: conveyor belt drying; low temperature drying; high moisture bonding adhesives; foam extrusion; and variable glue application rate. Other pollution prevention options presented in this report include alternative fiber sources such as agricultural fiber and recycled wood waste and naturally derived adhesives. These options are presented as resources that are abundant and renewable. Little emissions data exist in the literature to include with these options.

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ABBREVIATIONS AND SYMBOLS

ACGIH	American Conference of Governmental Industrial Hygienists
APA	American Plywood Association
APPCD	Air Pollution Prevention and Control Division
BACT	Best achievable control technology
Btu	British thermal unit
CARS	Constant application rate strategy
F:P	Formaldehyde to phenol
F:U	Formaldehyde to urea
FPL	Forest Products Laboratory
HAP	Hazardous air pollutants
HPVA	Hardwood Plywood & Veneer Association
HUD	Housing and Urban Development
HW	Hardwood
LVL	Laminated veneer lumber
MACT	Maximum achievable control technology
MDF	Medium density fiberboard
MDI	Methylenediphenyl diisocyanate
MeG	Methyl glucoside
MSM	Thousand square meters
MSM ₁₉	Thousand square meters on a 0.19 mm basis
MTBE	Methyl tertiary butyl ether
NCASI	National Council for Air & Stream Improvement
NIOSH	National Institute for Occupational Safety and Health
NPA	National Particleboard Association
NRMRL	National Risk Management Research Laboratory
OAQPS	Office of Air Quality Planning and Standards
OSB	Oriented strandboard
OSHA	Occupational Safety and Health Administration
PB	Particleboard
PEL	Permissible Exposure Limit
PF	Phenol-formaldehyde
ppm	Parts per million
psi	Pounds per square inch
REL	Recommended Exposure Limit
RTI	Research Triangle Institute
SARA	Superfund Amendments and Reauthorization Act
SHW	Soft hardwood
SRRP	Source Reduction Review Project
STEL	Short-term Exposure Limit
SW	Softwood

TGNMO	Total gaseous nonmethane organics
TLV	Threshold Limit Value
TWA	Time-weighted Average
UF	Urea-formaldehyde
USDA	U.S. Department of Agriculture
VARS	Variable application rate strategy
VOC	Volatile organic compound
3PHV	Three-pass high velocity

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1.0 COMPOSITE WOOD PRODUCT CLASSIFICATIONS AND INDUSTRY STATISTICS

Composite wood products are distinct from solid wood in that they are composed of wooden elements of varying sizes held together by an adhesive bond (Table 1-1). In general, the manufacturing process involves some type of wood size reduction, followed by drying (except for wet process boards), adhesive application, and pressing at elevated temperatures.

Table 1-1. Composite Wood Products

Product Type	Wood Form After Size Reduction	Primary Adhesive(s)	Manufacturing Process
Plywood panels			
- Structural plywood	veneer	PF ^a	Dry
- Hardwood plywood	veneer	UF ^b	Dry
Engineered lumber	veneer and lumber	PF	Dry
Reconstituted wood panels			
- Oriented strandboard	wood strands of uniform size	PF, MDI ^c	Dry
- Particleboard	finely ground wood particles of various sizes (fluffy, dust-like texture)	UF	Dry
- Medium density fiberboard	wood fibers of uniform size (fluffy, dust-like texture).	UF	Dry
- Cellulosic fiberboard	wood fibers of uniform size (fluffy, dust-like texture).	Starch or asphalt	Wet
- Hardboard	wood fibers of uniform size (fluffy, dust-like texture).	PF	Dry, Wet, or Wet/Dry

^aPF = Phenol-formaldehyde

^bUF = Urea-formaldehyde

^cMDI = Methylendiphenyl diisocyanate

1.1 Plywood Panels

Composite wood panels made with wood veneers are classified as plywood. Veneer is produced by cutting or peeling thin sheets of wood from a log. In plywood manufacture, veneers are bonded together with a synthetic adhesive resin to form a laminate (a laminate is any object built up of thin layers). The number of veneers or plies in a panel varies by product. The outside plies of a plywood panel are called the face and back. The center ply or plies are called cores. The center plies are layered with the grain of each sheet perpendicular to the previous one. Plywood may be made entirely of veneer, or the core materials may be lumber, particleboard (PB), plastic, metal, or other materials (Figure 1-1).

Plywood panels are classified into two groups according to end use: structural plywood and hardwood plywood. Structural plywood panels are used primarily as a sheathing product in the construction of residential homes and nonresidential buildings. Other applications include concrete forming, and construction of transportation equipment, furniture and fixtures, and materials handling. Hardwood plywood is used for decorative applications such as wall paneling and industrial applications such as furniture manufacture. The structural plywood industry is significantly larger than the hardwood plywood industry (Figure 1-2).

1.1.1 Structural Plywood

Structural plywood panels are made primarily from softwoods. Softwoods are coniferous or needleleaved trees (pine, fir, spruce, hemlock), as opposed to hardwoods which are deciduous or broadleaved trees (oak, ash, maple, walnut). The term "softwood" has only a general reference to actual wood hardness. Structural panels may use either variety, but are more commonly manufactured of softwoods (APA, 1993).

Structural plywood panels are constructed entirely of veneers (typically 2.54 millimeters (mm) thick) that are bonded with glue containing phenol-formaldehyde (PF) adhesive resins. PF adhesive resins are waterproof allowing structural panels to be used in exterior applications. Panels are typically manufactured into 1.22 meters (m) by 2.44 m sheets which may be sanded. No finishes (i.e., liquid coatings, paper coatings, etc.) are applied to the panels.

1.1.1.1 Industry Outlook

Since the mid 1980s, timber harvests from publicly owned lands have declined by more than 50 percent (Carliner, 1994). The structural panel industry attributes this decline to new land management policies enacted by the federal government which have reduced the amount of land available for harvesting. Heavy restrictions have been placed on national forests in the Pacific Northwest which contain twice as much timber as all other national forests combined (Evergreen Magazine, 1994).

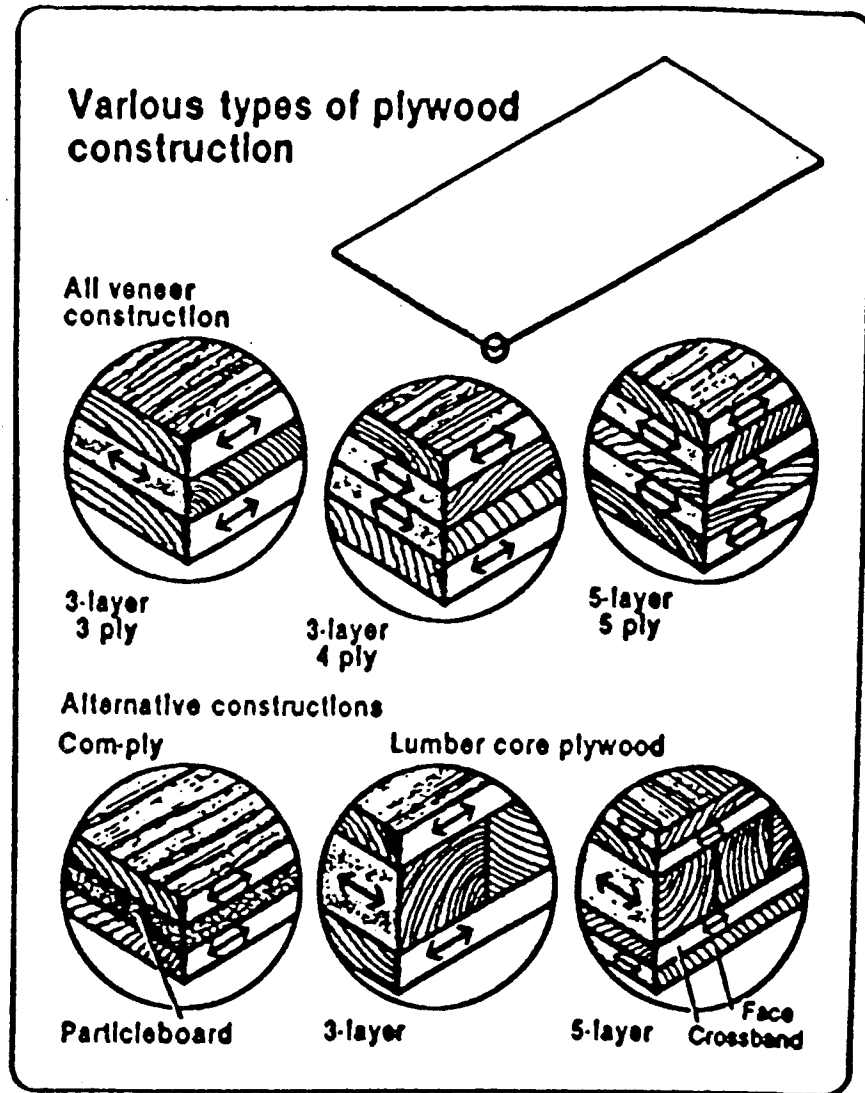


Figure 1-1. Various types of plywood construction (Haygreen and Bowyer, 1989).
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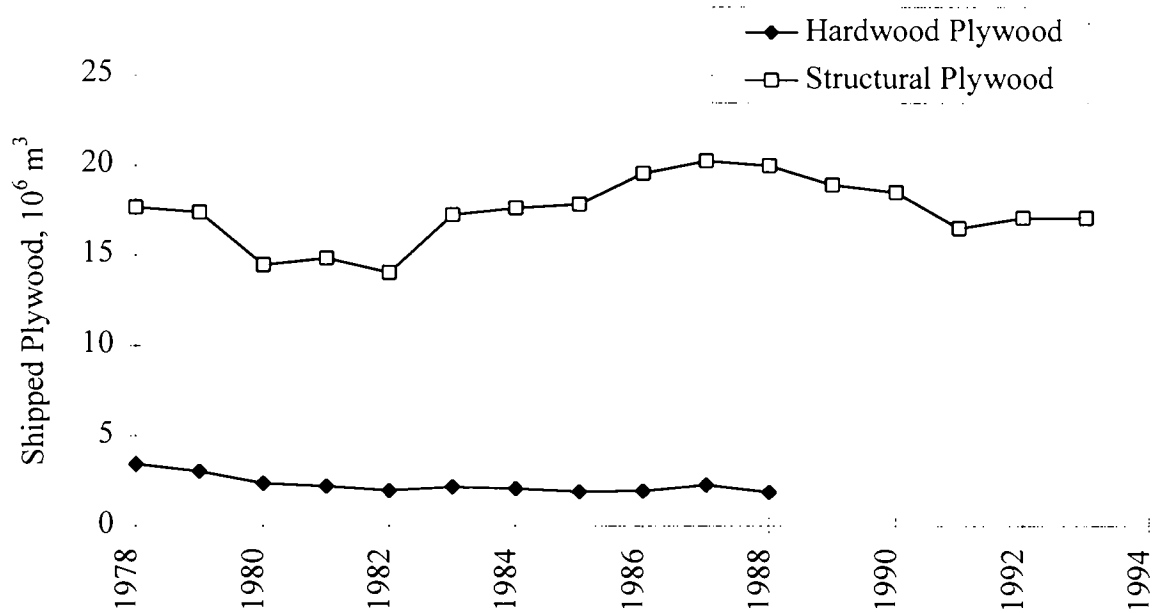


Figure 1-2. U.S. shipments of hardwood plywood and structural plywood
(Source: USDC, 1988; Adair, 1993).

Notes

1. Data unavailable on shipments of hardwood plywood after 1988.
2. Shipments of hardwood plywood are reported by the USDC as sq. ft of surface measure, irrespective of panel thickness. The present mix of hardwood plywood panels ranges in thickness from 0.313 in to 0.375 in (7.950 mm to 9.525 mm) (Groah, 1994). An average thickness of 0.344 in (8.738 mm) was used to convert surface measure to m³.
3. Shipments of structural plywood are reported by Adair as sq. ft on a 0.375 in (9.525 mm) basis; the 0.375 in basis was used to convert sq. ft to m³.

Harvesting restrictions have negatively impacted the structural plywood industry. The shortage of timber has increased log prices, resulting in increased manufacturing costs for plywood production. Rising lumber prices throughout the 1990s have also resulted in higher log costs. Lumber and plywood operations now compete for the same log. While plywood prices are held in check by substitution of oriented strandboard (OSB) (discussed in Section 1.3.2), lumber prices are more free to rise because few substitutes exist for lumber. The replacement of structural lumber is only at the beginning stages with products such as laminated veneer lumber (LVL) and glulam beams (discussed in Section 1.2). Plywood is, therefore, less able to compete with lumber for a common log resource (Roberts, 1994).

The combination of log shortages, rising manufacturing costs, and competition from OSB have resulted in plywood production curtailments and mill closures, particularly in the West. There have been 112 plywood and veneer plant closures in Washington, Oregon, and California between 1980 and the end of 1993 (Wood Technology, 1994). United States (U.S.) shipments of structural plywood from the West have decreased 53 percent since 1987 (Figure 1-3). Total U.S. shipments of structural plywood have decreased 15 percent since 1987.

1.1.2 Hardwood Plywood

Hardwood plywood is categorized into two types of products: prefinished wall paneling and industrial hardwood plywood. Both types of products are bonded with glue containing urea-formaldehyde (UF) adhesive resins which are non-waterproof (HPVA, 1991).

1.1.2.1 Wall Paneling

Hardwood plywood wall panels are primarily 3-ply and 2.82 mm to 6.35 mm thick. All wall panels are prefinished. There are two types of prefinished wall paneling: (1) naturally finished wall paneling and (2) decoratively finished wall paneling. Plywood used for naturally finished wall paneling is constructed in the U.S. from species such as oak, birch, walnut, elm, cherry, and pecan, and is finished to retain its natural look. Plywood panels used for decoratively finished wall paneling are imported from Indonesia. The imported panels are unfinished and are decorated (i.e., painted and laminated) in the U.S. (HPVA, 1991).

1.1.2.1.1 Industry Outlook

There has been a substantial decline in the use of prefinished wall paneling since the late 1970s. Total U.S. production for prefinished wall paneling has declined from around 3.11 million cubic meters (m³) in 1978 to 0.99 million m³ in 1992 (Figure 1-4). According to the Hardwood Plywood and Veneer Association (HPVA), the loss of market share by hardwood plywood wall paneling is due to the following factors:

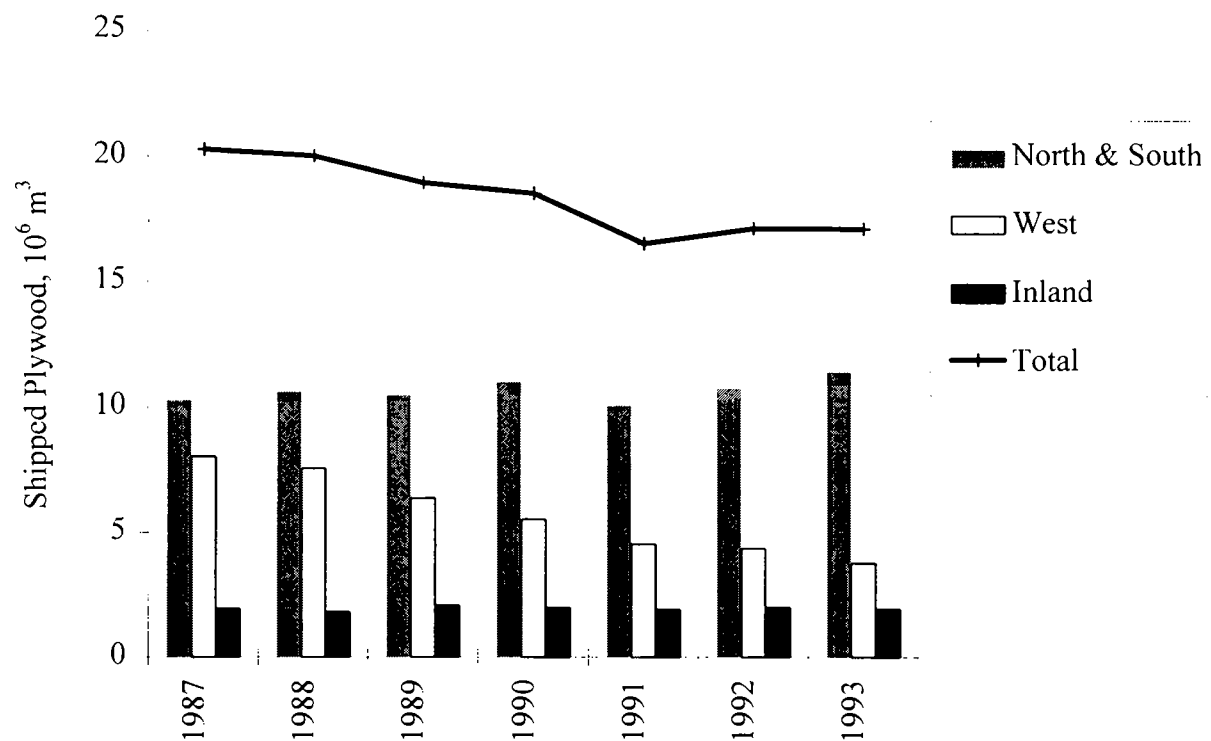


Figure 1-3. U.S. shipments of structural plywood 1987 to 1993 (Source: Adair, 1993).

Notes:

1. Shipments from the North are very small and were combined with shipments from the South to avoid disclosure.
2. Shipments of structural plywood are reported by Adair as sq. ft on a 0.375 in (9.525 mm) basis; the 0.375 in basis was used to convert sq. ft to m³.

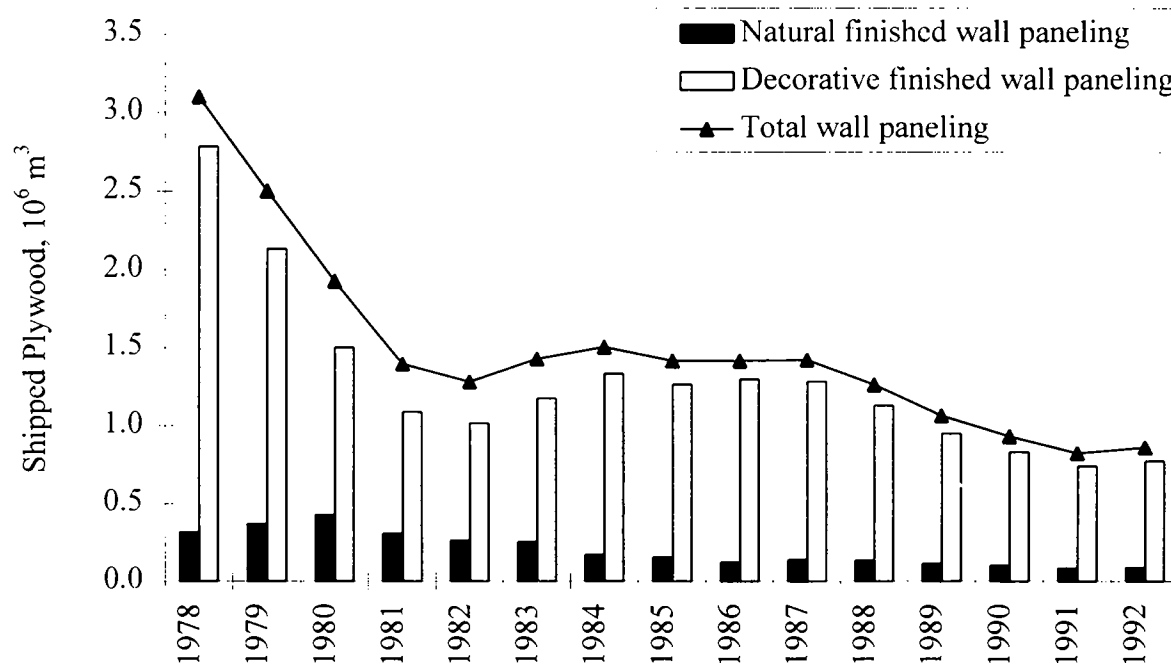


Figure 1-4. U.S. Production of natural hardwood and decorative hardwood wall paneling (Source: Groah, 1994).

Notes:

1. Shipments of hardwood plywood are reported as sq. ft of surface measure, irrespective of panel thickness. The present mix of hardwood plywood panels ranges in thickness from 0.313 in to 0.375 in (7.950 mm to 9.525 mm) (Groah, 1994). An average thickness of 0.344 in (8.738 mm) was used to convert surface measure to m³.

- Customer preference for products such as gypsum wallboard that can be repainted (in different colors, if desired) so that the appearance of a room can be more easily changed from time to time (HPVA, 1991).
- The establishment of an Indonesian cartel which has resulted in significant increases in the price of imported hardwood plywood blanks during the late 1970s and 1980s. Currently, Japan and China are the largest markets for Indonesian plywood with the U.S. a distant third (HPVA, 1991).
- A decline in promotion and advertising by some of the major manufacturers, accompanied in some cases by their withdrawal from the hardwood plywood paneling market (HPVA, 1991).
- Formaldehyde release from wall paneling, either real or perceived (HPVA, 1991).

1.1.2.2 Industrial Hardwood Plywood

Industrial hardwood plywood panels are commonly made using 3, 5, or 7 plies. The panels vary in thickness; 12.70 mm and 19.05 mm thick panels are common. Industrial hardwood plywood panels are unfinished, i.e., coatings and laminates are not applied (HPVA, 1991). The unfinished panels are used in the manufacture of furniture, cabinets and specialty panels. Some hardwood plywood industrial panels are made with a PB core (15 percent of the market) or a medium density fiberboard (MDF) core (15 percent of the market). Veneer core (65 percent of the market) is the predominant type used in industrial panels (HPVA, 1991). Unlike wall panels, production of industrial hardwood plywood panels has remained fairly constant over the years (Figure 1-5).

1.2 Engineered Lumber

As mentioned in Section 1.1.1.1, glulam beams and LVL are emerging as substitutes to lumber. Glulam is short for glued-laminated structural timber -- large beams fabricated by bonding layers of specially selected lumber with glue containing PF adhesives. End and edge jointing permit production of longer and wider structural wood members than are naturally available. Glulam timbers are used with structural wood panels for many types of heavy timber construction.

LVL is constructed of veneers that are bonded together with a PF adhesive resin to form a laminate; the veneers are layered with the wood grain along the long axis of the beam. The thickness of the veneers varies from 35 mm to 38 mm. LVL is manufactured to typical lumber sizes: 0.61 m by 1.22 m (2 ft by 4 ft), 0.61 m by 1.83 m (2 ft by 6 ft), etc. The length of the beams can be manufactured up to 9.14 m long using end joints or finger joints. Another application of LVL is in the construction of wood I-joists (an I-joist is a small beam that resembles the letter "I"). LVL is used to construct the top and bottom of the joist and OSB is used to construct the center.

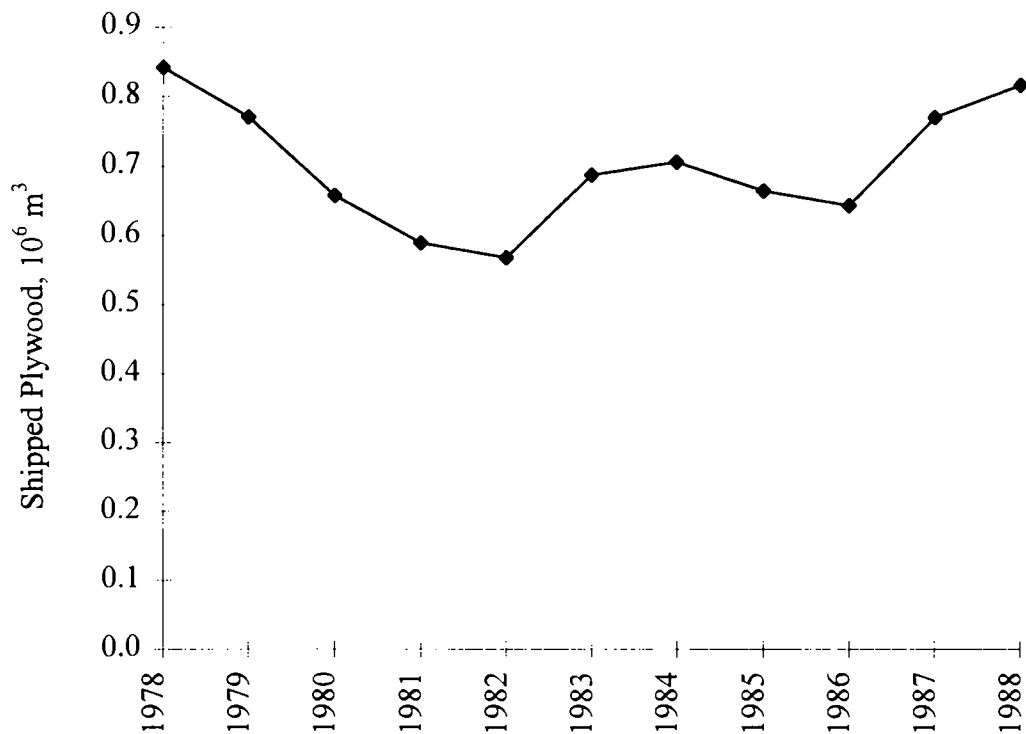


Figure 1-5. U.S. shipments of industrial hardwood plywood (Source: USDC, 1988).

Notes

1. Shipments of hardwood plywood are reported by the USDC as sq. ft of surface measure, irrespective of panel thickness. The present mix of hardwood plywood panels ranges in thickness from 0.313 in to 0.375 in (7.950 mm to 9.525 mm) (Groah, 1994). An average thickness of 0.344 in (8.738 mm) was used to convert surface measure to m^3 .

1.2.1 Industry Outlook

As seen in Table 1-2, the production of glulam beams, I-joists, and LVL is increasing rapidly and is expected to continue. By 2003, the North American output of LVL is expected to reach 2.78 million m³ (Blackman, 1994).

Table 1-2. U.S. Production Estimates of Engineered Lumber^a

	1992	1993	1994	1995	1996	1997
Glulam beams (million board meters)	83	88	94	107	119	119
I-joists (million lineal meters)	69	107	117	134	151	137
Laminated veneer lumber (million cubic meters)	0.51	0.71	0.82	0.93	1.10	1.05

Source: Adair, 1993

^aProduction figures for 1993 to 1997 are estimated

1.3 Reconstituted Wood Panels

Composite wood panels made with wood strands, particles, and fibers are classified as reconstituted wood panels. Reconstituted wood panels include PB, OSB, cellulosic fiberboard, MDF, and hardboard. Table 1-3 lists shipments of reconstituted wood panels by U.S. manufacturers on a volume basis (m³ of board) from 1985 to 1993. PB, OSB, and MDF represented 84 percent of reconstituted panel shipments by U.S. manufacturers in 1993.

Table 1-3. U.S. Shipments of Reconstituted Wood Panel (million m³) 1985 to 1993

	PB	OSB	MDF	Hardboard	Cellulosic Fiberboard
1983	5.33	1.19	1.07	na ^a	na
1984	5.66	1.81	1.12	na	na
1985	5.89	2.36	1.21	1.86	na
1986	6.38	3.11	1.38	1.72	na
1987	6.56	3.61	1.59	1.61	1.39
1988	6.78	4.07	1.66	1.53	1.40
1989	6.83	4.52	1.72	1.48	1.41
1990	6.74	4.79	1.68	1.44	1.45
1991	6.68	4.97	1.70	1.56	1.32
1992	7.04	5.89	1.89	1.55	1.53
1993	7.51	6.20	2.85	1.55	1.52

Source: (NPA, 1994b); (Wagner, 1994)

^ana = Not available

1.3.1 Particleboard

PB is a panel product made from finely ground wood particles of various sizes that are bonded together with a synthetic adhesive resin under heat and pressure in a hot press. Other materials may also be added during manufacturing to improve certain properties such as fire resistance and dimensional stability. The wood particles come primarily from planer shavings, sawdust, plywood trimmings, and other wood process residuals. Most PB in the U.S. is bonded with UF adhesive resins. PB panels bonded with UF adhesive resins are used for interior applications that do not require water resistance.

PB panels are manufactured in a variety of sizes and densities, depending on the specific end use application. Panel sizes range from 0.91 m to 2.74 m in width; 6.35 mm to 51 mm in thickness; and almost any length that is transportable. PB panels are used for industrial applications, floor underlayment, mobile home decking, door core, shelving, and stair treads. The most common use of PB panels is for industrial applications. Industrial grade panels represented 80 percent of PB shipments by U.S. manufacturers in 1993. In comparison, PB used for floor underlayment was 7 percent of the 1993 shipments, mobile home decking (4 percent), door core (3 percent), shelving (2 percent), and stair treads (0.3 percent). A large volume of industrial grade PB is used as a core stock material for furniture (domestic, institutional, office); kitchen and vanity cabinets (sides, backs, drawers, doors); doors (solid core flush doors, bifolds, sliding doors); games (table tennis, pool tables) and other goods. Industrial grade PB is also used as a substrate for laminated panel construction such as countertops, desktops, wall paneling, and shelving. High-pressure laminates, thermofused, resin-saturated papers, vinyl films, hot transfer films, decorative papers, and wood veneers comprise the types of overlay materials most commonly applied to PB substrates (NPA, 1994a).

1.3.1.1 Industry Outlook

Shipments of industrial PB by U.S. manufacturers have been increasing steadily since the early 1980s and in 1993 were at record levels (Figure 1-6). Statistics for PB panels manufactured in the U.S. are compiled by the National Particleboard Association (NPA). The NPA also compiles statistics for MDF panels manufactured in the U.S. Statistics are compiled from member companies who represent more than 85 percent of the total U.S. manufacturing capacity for U.S. PB and MDF. Most of the PB manufactured by NPA members is unfinished, i.e., coatings, laminates, etc., are not applied to the board at the plant; of the 7.50 million m³ of PB shipped in 1993, 3 percent was laminated and 1 percent was coated (NPA, 1994b). Most PB is finished by end users such as furniture and cabinet manufacturers or by companies that sell finished PB to end users.

1.3.2 Oriented Strandboard

OSB is made from strands of wood bonded together with a synthetic adhesive resin under heat and pressure in a hot press. The strands of wood are sliced from small diameter, fast growing trees; tree species used are generally aspen in the northern U.S. and pine and soft hardwoods in

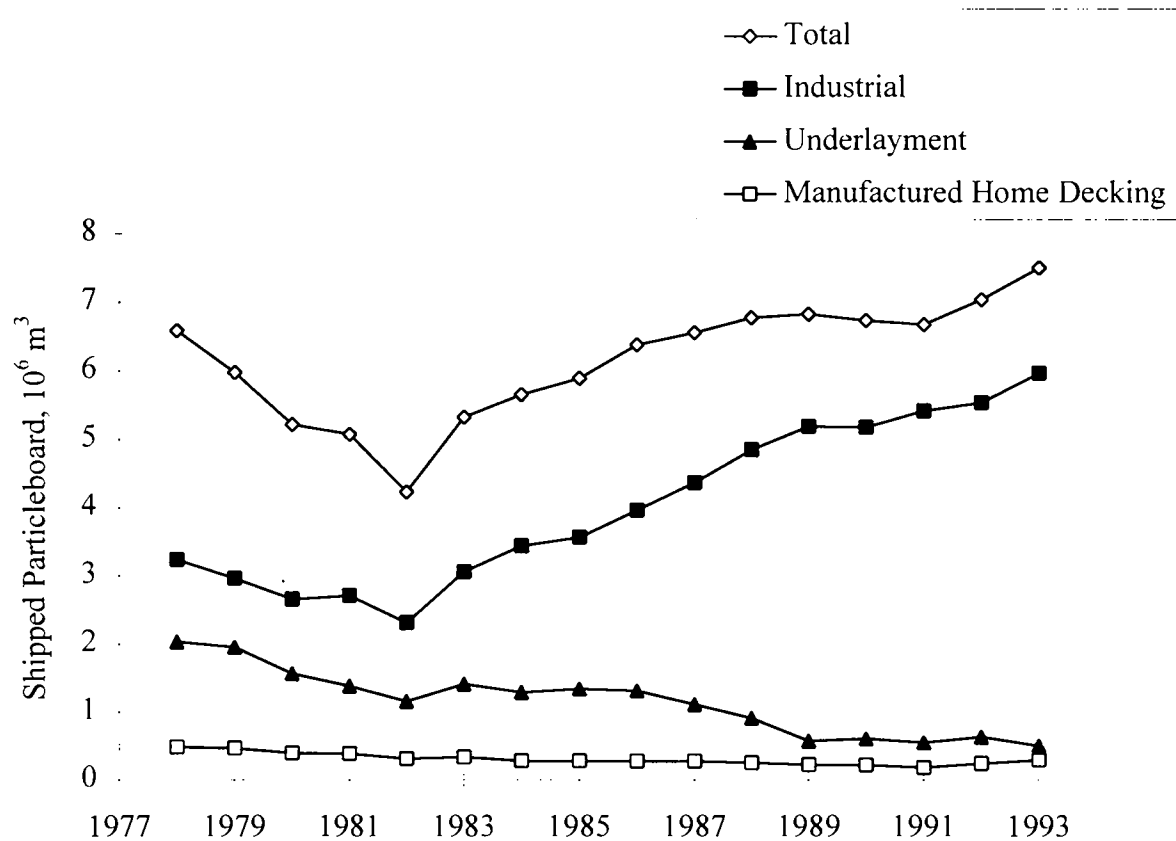


Figure 1-6. U.S. industry shipments of particleboard 1978 to 1993 (Source: NPA, 1994b). Reprinted with permission.

Notes

1. Shipments of medium density fiberboard are reported by NPA as sq. ft on a 0.75 in (19.05 mm) basis; the 0.75 in basis was used to convert sq. ft to m^3 .

the southern U.S. Strand dimensions vary depending on the slicing machinery and wood species. Typical strand dimensions are 76 mm long, 4.52 mm to 51 mm wide, and 0.51 mm to 0.71 mm thick (about the thickness of a business card). The strands of wood in the surface layers are aligned in the long panel direction, while the inner layers are randomly or cross aligned. The OSB process developed in the early 1980s as an improvement to the waferboard process in which strands of wood were randomly distributed throughout the panel. Two-thirds of the U.S. production of OSB is made with waterproof PF adhesive resins; the remaining third is made with methylenediphenyl diisocyanate (MDI) adhesive resins which are also waterproof.

OSB is used in structural applications as a replacement for sheathing grade plywood. The most common applications are for wall and roof sheathing and floor decking in wood frame construction. Other applications include materials handling (crates and pallets), web material for wood I-joists, siding, and other specialty products. The strength of OSB comes from the uninterrupted wood fiber, interleaving of the long strands, and degree of orientation of the strands in the surface layers. The waterproof adhesives combined with the strands provide internal strength, rigidity, and moisture resistance.

1.3.2.1 Industry Outlook

As illustrated in Figure 1-7, OSB has been rapidly increasing its share of the U.S. structural panel market. By late 1996, the capacity of OSB is expected to increase by 45 percent in the U.S. and by 130 percent in Canada -- total North America capacity is expected to rise by 70 percent (Roberts, 1994). A key factor in the growing OSB demand is the continuing decline of structural plywood production. The substitution of OSB for structural plywood has been relatively easy since it competes on price at equal or nearly equal performance (Roberts, 1994). In the future, the falling price of OSB due to new capacity will also play a key role in encouraging its use.

1.3.3 Hardboard

Hardboard is made with wood fibers bonded with a synthetic adhesive resin under heat and pressure in a hot press. PF adhesive resins are used to bind hardboard in the U.S. Hardboard is manufactured by a wet, dry, or wet/dry process (discussed in Section 2.2.4). Raw materials used to generate wood fibers in the dry hardboard process are primarily dry planer shavings from lumber operations. Green chips are used to generate wood fibers for wet and wet/dry hardboard processes (green means that the wood has never been dried). Most green chips are chipped from forest harvesting residues, such as branches and tops, and lumber slabs. (In the lumber process, logs are peeled and then cut to length with squared sides; lumber slabs are the other part of the tree which remains after the lumber has been cut.) A small amount of green chips are chipped from roundwood.

Hardboard has a density ranging from 641 to 1,121 kilograms per cubic meter (kg/m^3) and is categorized into three product groups: basic hardboard, hardboard siding, and prefinished wall paneling. Basic hardboard and siding make up the largest volume of hardboard products. Basic hardboard is used in the manufacture of floor underlayment, furniture, case goods, truck and head

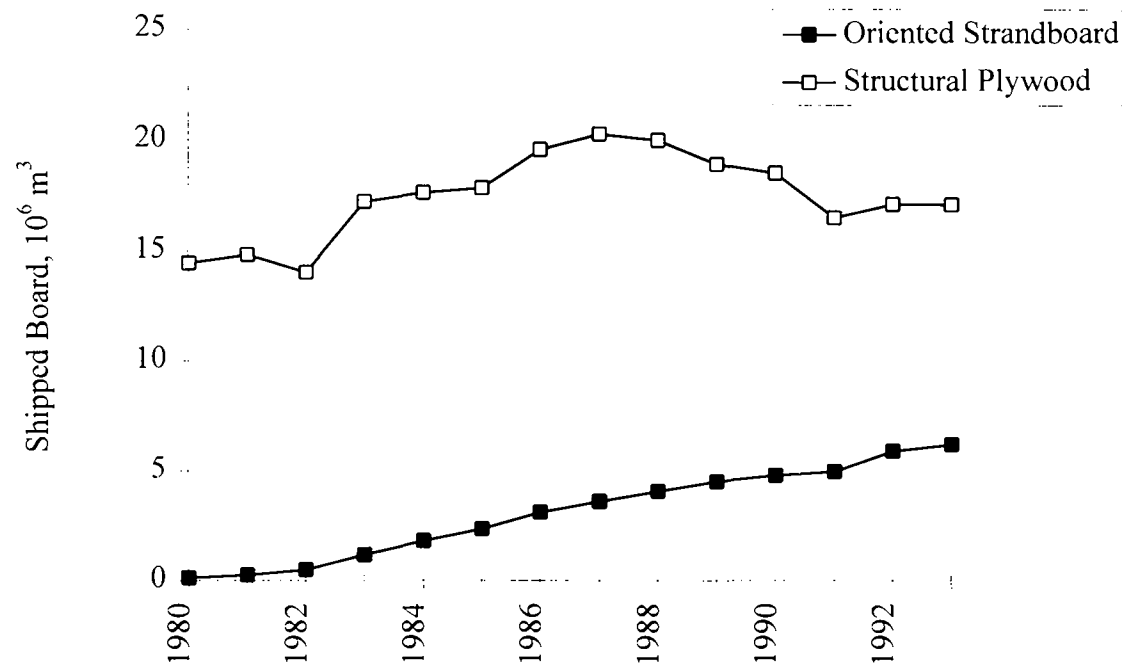


Figure 1-7. U.S. structural panel market (Adair, 1993).

Notes

1. Shipments of structural plywood and oriented strandboard are reported by Adair as sq. ft on a 0.375 in (9.525 mm) basis; the 0.375 in basis was used to convert sq. ft to m³.

liners, and door skins and faces; door skins and faces are the fastest growing market for basic hardboard (Wagner, 1994).

1.3.4 Medium Density Fiberboard

MDF is made with wood fibers bonded together with a synthetic adhesive resin under heat and pressure in a hot press. UF adhesive resins are the primary type of resin used to manufacture MDF in the U.S. Raw materials used to generate the fibers come from dry planer shavings, plywood trim, and sawdust. The density of MDF ranges from 641 to 961 kg/m³.

MDF is used in the manufacture of furniture, cabinets, and general millwork applications. It is increasingly being used as a substitute for kiln-dried dressed lumber in applications such as window frames, door jambs, and decorative moldings. Due to the fine texture and homogeneous nature of MDF, it machines cleanly and is easily painted to produce high quality finishes. Since MDF is made and sold as a panel, many furniture and cabinet components can be made from a single piece. The same components made from natural wood require labor intensive jointing and assembly operation. While nearly all MDF is made with non-waterproof UF adhesives aimed at interior applications, interest is growing in the development of PF bonded MDF panels for exterior applications (Roberts, 1994).

1.3.4.1 Industry Outlook

The MDF industry is growing rapidly; U.S. shipments of MDF were at record levels in 1993 (Figure 1-8). The U.S. currently accounts for about 90 percent of North America's MDF capacity (Roberts, 1994). By late 1996, U.S. capacity is expected to increase by 30 percent, while Canadian capacity is expected to increase to over five times its current level. Total North American capacity is expected to rise by 75 percent (Roberts, 1994).

1.3.5 Cellulosic Fiberboard

Cellulosic fiberboard is composed of wood fibers bonded together with either starch or asphalt. The raw materials used to generate the wood fibers are primarily green chips. A few plants in the U.S. manufacture cellulosic fiberboard from bagasse and newsprint. Cellulosic fiberboard is a low density board ranging from 160 to 481 kg/m³. Ninety percent of the 1993 shipments of cellulosic fiberboard were comprised of exterior wall sheathing, roofing or other specialized exterior panels; the remaining 10 percent were used in a variety of industrial applications (Wagner, 1994).

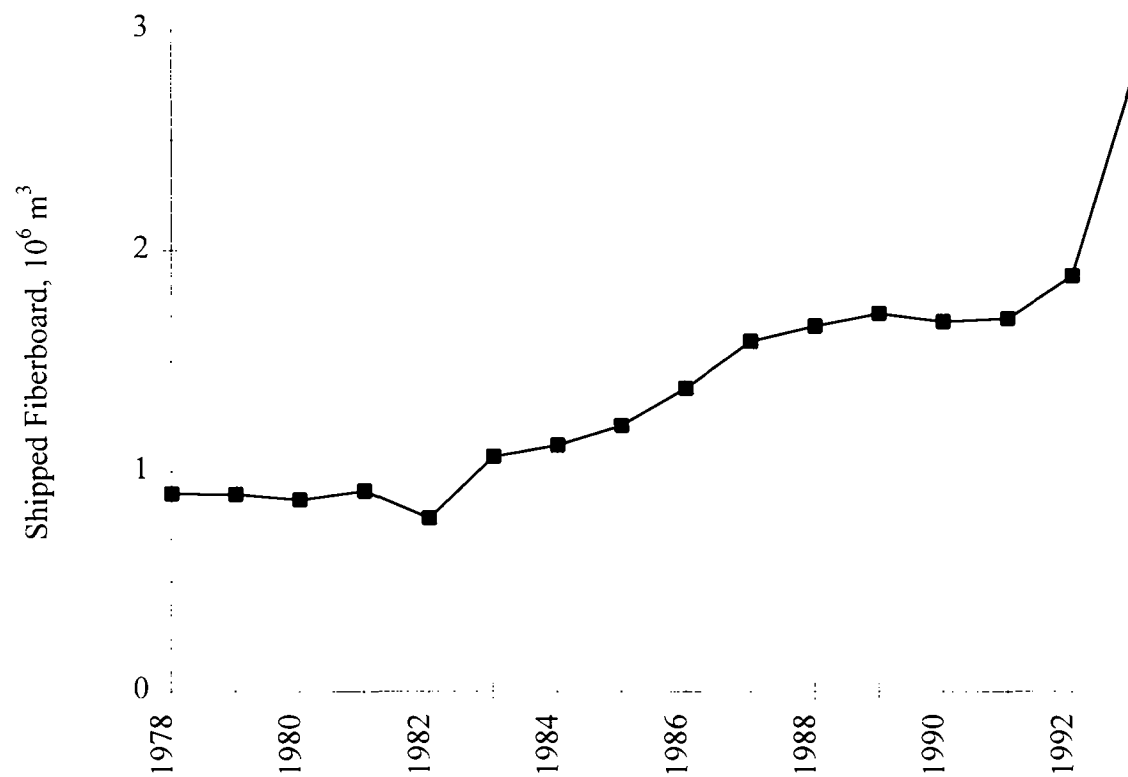


Figure 1-8. U.S. shipments of medium density fiberboard (NPA, 1994b).

Notes

1. Shipments of medium density fiberboard are reported by NPA as sq. ft on a 0.75 in (19.05 mm) basis; the 0.75 in basis was used to convert sq. ft to m^3 .

2.0 COMPOSITE WOOD MANUFACTURING PROCESS DESCRIPTIONS

2.1 Plywood Manufacture¹

The following sections describe the manufacturing processes involved in making plywood. The major steps include the following:

1. Debarking
2. Heating the blocks
3. Cutting veneer
4. Veneer storage and clipping
5. Veneer drying
6. Lay-up and pressing
7. Finishing

2.1.1 Debarking

The most widely used type of debarker in medium to large mills is the ring debarker. In this machine the log passes through a rotating ring that holds a number of pressure bars. These press against the log and tear off the bark. Large units of this type can debark logs at speeds of up to 200 lineal ft/min.

A rossing head type of debarker is sometimes used in mills where high production rates are not needed. The rossing head is a rotating cutterhead, similar to the head on a lumber planer, that rides along the log and cuts off the bark as the log is rotated. This debarker is also suited to situations where crooked or stubby logs must be debarked.

2.1.2 Heating the Blocks

When logs are cut to the length required for rotary veneer cutting, they are called blocks. Almost all hardwood and many softwood blocks are heated prior to cutting the veneer. Heating softens the wood and knots, making it easier to cut. It also improves surface quality, reducing roughness. Some of the dense hardwoods must be heated to produce satisfactory veneer. Softwood veneer from some species can be produced from cold logs because of their lower density and because the roughness limitations are less critical than for high-quality hardwoods. However, even in the softwood industry the advantages of heating the blocks generally outweigh the cost of the process. Baldwin (1975) lists four advantages of heating softwood logs:

1. Higher yields of veneer can be obtained from the logs. The reduction of cutting imperfections increases the yield an average of 3 - 5 percent.
2. The grade of the veneer is improved. Studies by Lutz (1960), Grantham and Atherton (1959), and the American Plywood Association have found that grades of veneer are upgraded from 4 to 25 percent.

¹Sections 2.1.1 through 2.1.6 were reprinted with permission from Haygreen and Bowyer, 1989.

3. Labor costs are reduced. Veneer from heated peeler blocks tends to hang together in a more continuous ribbon as it comes from the lathe. This reduces handling.
4. The amount of adhesive used can be reduced. Glue spreads can be lighter because of the improved surface.

A variety of methods are used to heat logs. Steaming, soaking in hot water, spraying with hot water, or combinations of these methods are all suitable to some situation. Dense hardwoods are usually heated by soaking at temperatures up to 200°F (93°C). Regardless of the heating medium, the objective is to heat the log to a suitable temperature as deeply into the log as veneer will be cut.

2.1.3 Cutting Veneer

Two major methods for producing veneer are slicing and peeling. Most veneer is produced by peeling (rotary cutting), which is accomplished on a veneer lathe. Slicing is used for producing decorative veneers from high-quality hardwood and is seldom used with softwoods. The cutting action on a lathe and on a slicer are very similar and are illustrated in Figure 2-1. In either case, the wood is forced under a pressure bar that slightly compresses the wood as it hits the cutting edge of the knife.

On the veneer slicer a cant of wood called the flitch is rigidly dogged, i.e., clamped, to a carriage that oscillates, cutting on the down stroke. Before each cutting stroke the knife and pressure bar move forward the thickness of the veneer to be cut. In a rotary lathe they move forward continuously as the block rotates.

2.1.4 Veneer Storage and Clipping

In modern mills the green veneer must be handled gently and rapidly as it comes from the lathe. The veneer is peeled at from 300 to 800 lineal ft/min. A series of trays is used in many softwood plywood plants to handle these long ribbons of wood. Trays are often about 120 ft long, long enough to handle the veneer that comes from a typical 15-in. block.

Clippers are high-speed knives that chop the veneer ribbons to usable widths. In hardwood veneer mills, clipping may be done manually to obtain the maximum amount of clear material from the flitch. In softwood mills and in some hardwood mills, clipping is often done automatically at speeds of up to 1500 lineal ft/min. The clipper will cut the veneer to about 54 in. (the panel width plus an allowance for shrinkage and panel trimming) if possible. However, if open defects are present, the veneer may be clipped to less than full panel width. Automatic clippers detect open defects with scanners that can be overridden by the operator when it is desirable to do so.

2.1.5 Veneer Drying

Veneer driers consist of a means of conveying the veneer through a heated chamber where temperatures range from 150 to 260°C. In older roller driers, air is circulated in a manner similar to that in a dry kiln. This type of drier is still in wide use for hardwood veneer (Figure 2-2). Most plants built in recent years utilize jet driers. These are also called impingement driers since a curtain of air at velocities of 2000-4000 fpm is directed against the surface of veneer (Figure 2-3). The high velocity produces turbulent air on the surface of the veneer.

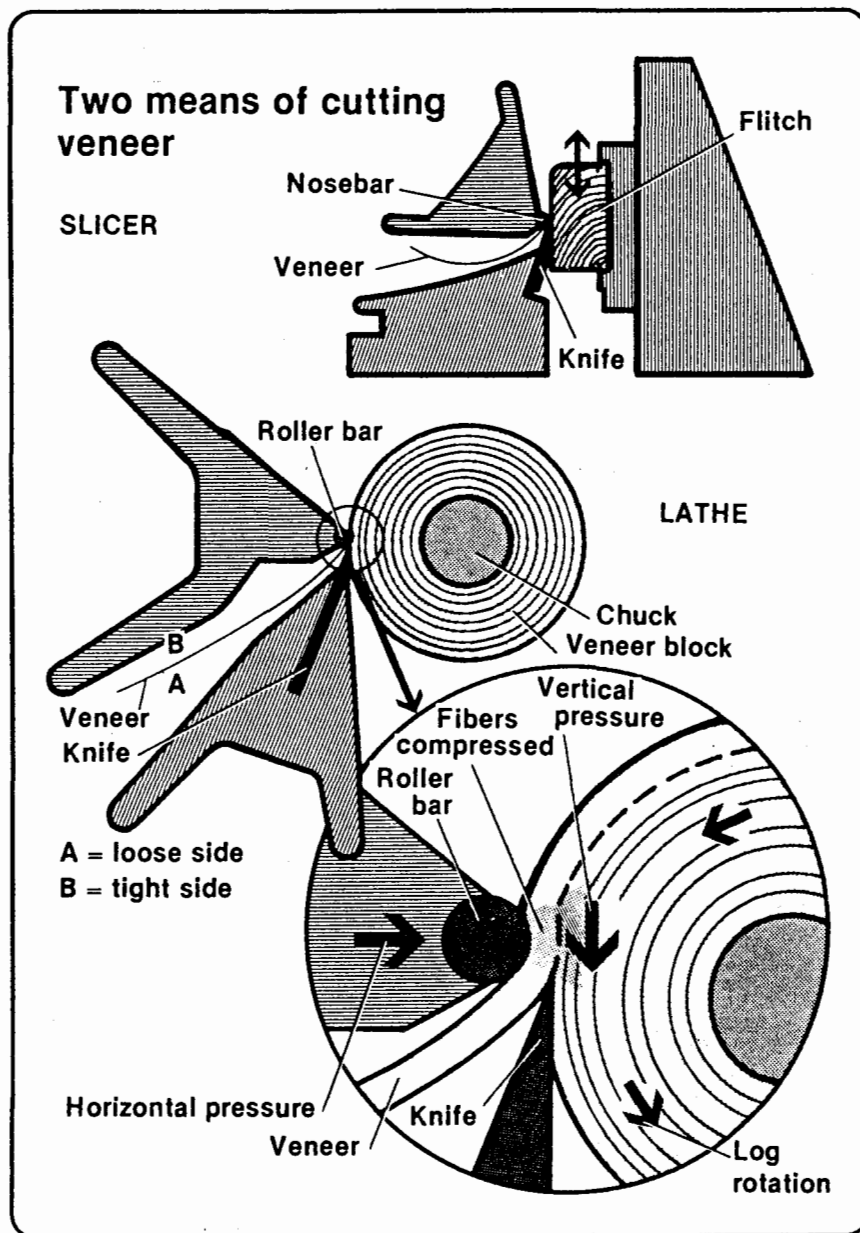


Figure 2-1. Cutting action on a lathe and slicer (Haygreen and Bowyer, 1989).
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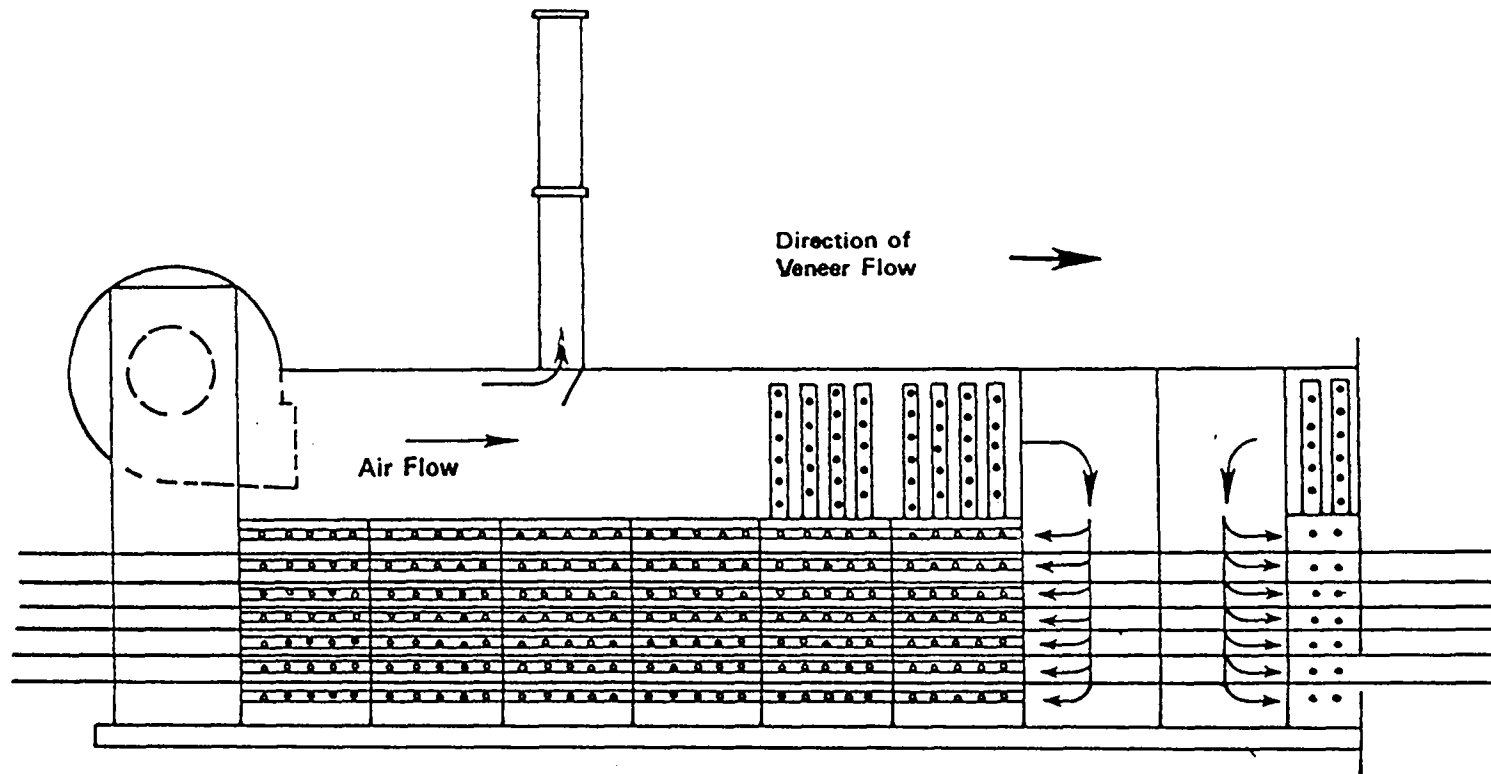


Figure 2-2. Longitudinal-flow dryer (NCASI, 1983). Reprinted with permission.

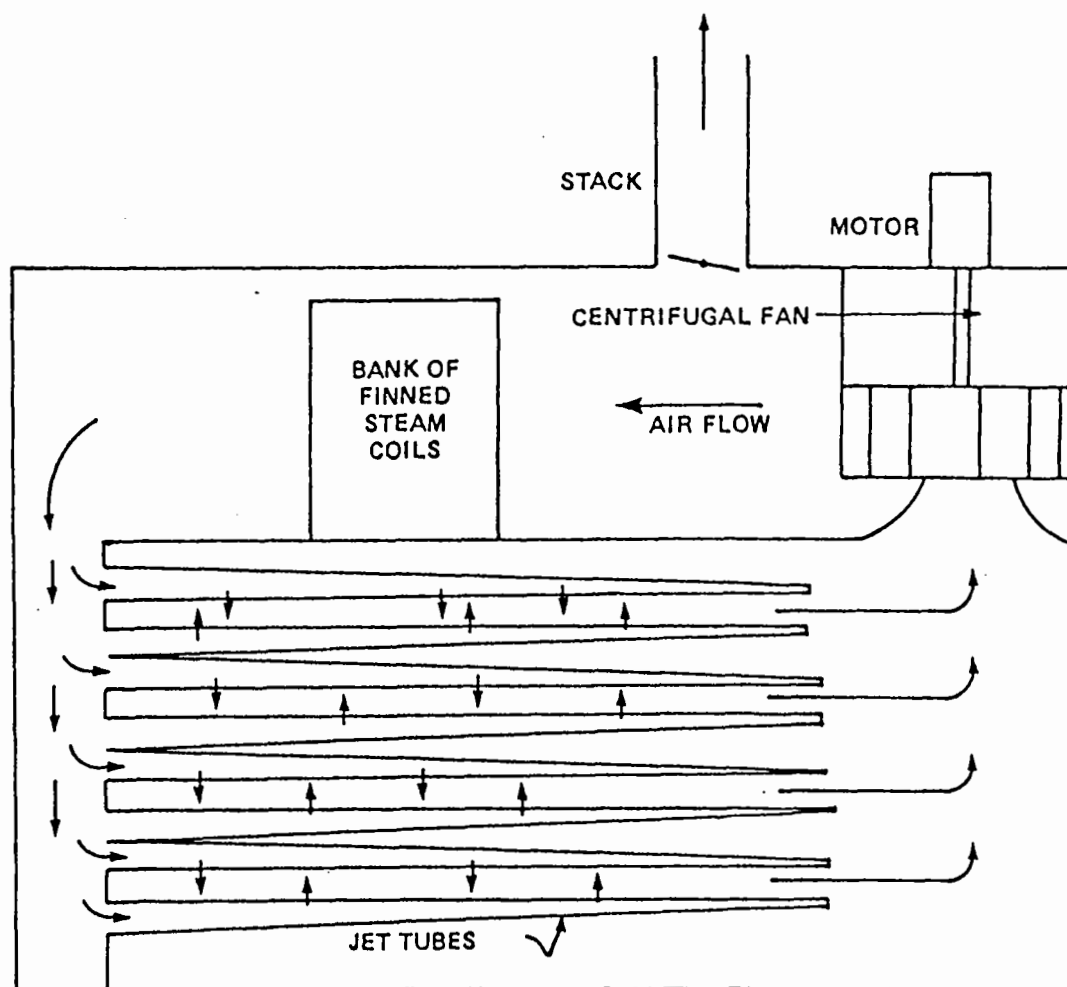


Figure 2-3. Cross section of a steam-heated jet dryer (NCASI, 1983). Reprinted with permission.

This eliminates the laminar boundary that slows down heat and moisture transfer under ordinary drying conditions.

Developments such as the use of microwave energy, use of high temperature preheaters, and increased drying temperature (up to 800°F, or 427°C) may find use for some types of veneer drying. In most softwood veneers, however, temperatures over about 400°F (204°C) have adverse effects on glueability.

2.1.6 Lay-up and Pressing

Almost all adhesives used in the plywood industry in the United States today are thermosetting (cured by heat) synthetic resins. These have almost completely replaced the blood and soybean flour protein glues that were used in the past for interior (nonwaterproof) grades of plywood. The two most important types of resins used are phenol-formaldehyde, which is used for interior and exterior grades of softwood plywood and for exterior grades of hardwood plywood, and urea-formaldehyde, which is used to manufacture interior grades of hardwood plywood. The basic components of these resins are formaldehyde, which is derived from methanol, urea, and phenol.

Only rarely are pure or “neat” resins used as adhesives for plywood. In most cases they are mixed with fillers or extenders such as Furafile and fine flour produced from wood, bark, or nutshells. Furafile is a chemical lignocellulose by-product of furfuryl alcohol production that can be produced from corn cobs, rice hulls, and oat hulls. Starch and animal blood are also used as extenders to modify the viscosity, control the penetration into the wood, and control other characteristics of the adhesive mix such as the tack (stickiness).

The process of applying adhesives to the veneers, assembling veneers into a panel, and moving the panels in and out of the press are often the most labor-intensive steps in manufacture. Veneer is highly variable in width, length, and quality, which makes it a difficult material to handle with automated systems. Yet major advances have been made to increase automation in this stage of manufacture.

One advancement has been in the application of adhesive to the veneer. The old method is to pass veneer through rubber-faced grooved rollers that apply glue by contact to the top and bottom surfaces. One person is required to feed the roller glue spreader while an offbearer places the veneer onto the panel being laid up. If veneer is extremely rough, the glue spread will not be uniform and skips may occur.

Newer means of glue application, spray and curtain-coaters, have distinct advantages in terms of uniformity of the glue spread and are suited to automated lay-up systems. These methods overcome the problem of poor glue spread on rough stock. In these systems the veneers travel on a belt conveyor under the spray or curtain. A curtain-coater consists essentially of a box with a slot in the bottom through which the adhesive flows in a continuous sheet or curtain. Glue not deposited on a piece of veneer passing through the curtain is pumped back up into the box.

Recently, two new methods of adhesive application, liquid extrusion and foamed resin extrusion, have been used successfully. These systems lay down continuous beads of resin on the veneer.

The actual assembly of veneer into plywood panels can also be mechanized — at least in larger plants producing standard-size panels. Although equipment has been developed to do this almost automatically, most mills use systems that are partially manual and partially mechanized. For example, the full-size 4 × 8-ft veneers for the two faces may be handled by machine, but the narrower strips of veneer used in the core may be assembled manually.

Most softwood plywood plants prepress the loads of laid-up panels prior to final pressing in the hot-press. This is done in a cold press at lower pressure. The purpose is to allow the wet adhesive to “tack” the veneer together. This permits easier loading of the hot-press and helps prevent shifting of the veneers during loading.

Pressing of the panels is usually done in the multiopening presses. Such presses can produce 20 - 40 4 × 8-ft panels at each pressing cycle, which may take 2 - 7 minutes. The purpose of the press is twofold: to bring the veneers into close contact so that the glue line is very thin and to heat the resin to the temperature required for the glue to polymerize. Adhesives made from phenol-formaldehyde resins typically require temperatures of 240°F (115.5°C) in the innermost glue line for approximately 90 seconds to cure properly. Resin systems must be carefully tailored to the specific conditions in a plant. Press time and temperature can be modified; i.e., a shorter press time may be possible if press temperature is increased.

2.1.7 Finishing

2.1.7.1 Structural Plywood and Industrial Hardwood Plywood

Stationary circular saws trim up to 1 in from each side of the pressed plywood, producing even-edged sheets. About 20 percent of annual plywood production is sanded. Sanding depth varies with product type. Those that are sanded may be sanded on both sides or only one. Sheets move through enclosed automatic sanders while pneumatic collectors above and below the plywood continuously remove the sanderdust. Sawdust in trimming operations is also removed by pneumatic collectors. The plywood trim and sawdust are burned as fuel or sold to reconstituted panel plants.

2.1.7.2 Hardwood Plywood Wall Paneling

As discussed in Section 1.1.2.1, hardwood plywood used for wall paneling is a finished product, i.e, liquid coatings and paper coatings are applied. Process descriptions of these finishing techniques are beyond the scope of this report. However, the following is noteworthy regarding decorative wall paneling made from unfinished plywood imported from Indonesia. The imported plywood is often treated with a formaldehyde scavenger (frequently a urea solution) and dried before further finishes, such as paper laminates, and veneers are added (Semeniuk, 1994). This scavenging step is often necessary for the panel product to meet U.S. Department of Housing and Urban Development (HUD) standards for formaldehyde (Semeniuk, 1994).

2.2 Reconstituted Panel Manufacture

The following sections describe the major process steps involved in manufacturing reconstituted wood panels. Figure 2-4 is a schematic of the overall process which includes:

1. Wood reduction
2. Drying
3. Adhesive application
4. Mat forming
5. Hot pressing
6. Finishing

The drying and pressing steps are not required by all products.

2.2.1 Wood Reduction

The wooden elements used to manufacture reconstituted panels include strands, particles, and fibers. Below is a description of how each of these wooden elements are processed.

2.2.1.1 Oriented Strandboard

The strands used to manufacture OSB are specially produced from green roundwood at the plant. Logs entering OSB plants are cut to 2.54 m lengths by a slasher saw. The logs are debarked and carried to stationary slasher saws, where they are cut into 0.84 m lengths called blocks. The blocks are then sent to a waferizer which slices them into strands approximately 0.71 mm thick (Vaught, 1990). The strands are then conveyed to a storage bin to await processing through the dryers.

2.2.1.2 Particleboard

The wood particles used to manufacture PB are processed from residues of green or dry wood operations (green refers to wood that has not been dried). Residues from green operations include planer shavings from surfacing green lumber, sawdust from cutting green logs, and green veneer wastes such as clippings, edgings, and trimmings. Dry process residues include shavings from planing of kiln-dried lumber, mill ends from kiln-dried lumber, sawdust, sanderdust, and plywood trim. The wood residues are ground into particles of varying sizes using mechanical refiners and hammermills.

2.2.1.3 Fiberboard (Cellulosic Fiberboard, MDF, and Hardboard)

The wood fibers used to manufacture fiberboards are also processed from residues of green and dry wood operations. Fibers are generated by first cooking the wood residues in a moderate pressure steam vessel (digester). During this step, the wood changes both chemically and

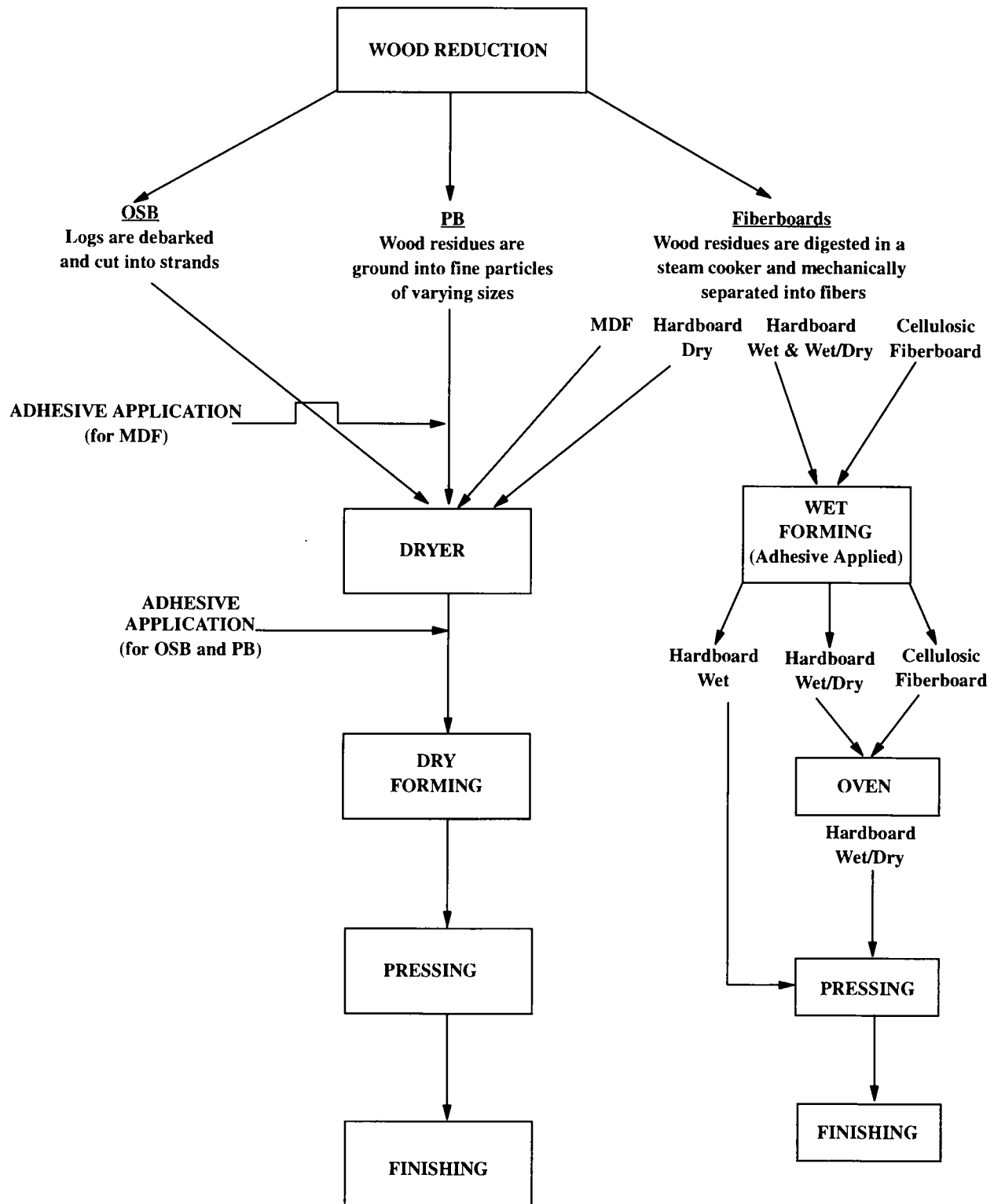


Figure 2-4. Reconstituted wood panel process flow.

physically; becoming less susceptible to the influences of moisture and less brittle as lignin softens. This semi-plastic wood is then "rubbed" apart into fiber bundles instead of being mechanically "broken" apart as in the PB process. The fibers are all the same size, therefore, they need no screening.

2.2.2 Drying

The wooden elements used to manufacture a reconstituted panel are referred to as the "furnish." In the manufacture of cellulosic fiberboard and wet and wet/dry process hardboard, the furnish is not dried because the forming process uses water (described in Section 2.2.4). In the manufacture of OSB, PB, MDF, and dry process hardboard, the furnish is dried to a very low moisture content to allow for moisture gained by adding resins and other additives. The furnish is not dried further after blending, except that some evaporation may occur from the heat in the furnish as it comes from the dryer and from air exposure when conveyed from the blender to the forming station. Furnishes are generally no warmer than 311 Kelvin (K) when blended to avoid precuring and drying out the resin (Maloney, 1977).

Most dryers currently in operation use high volumes of air to convey material of varied size through one or more passes within the dryer. Rotating drum dryers requiring one to three passes of the furnish are most common. The use of triple-pass dryers predominates in the U.S. Figure 2-5 shows a conventional triple-pass drum dryer. Dryer inlet temperatures may be as high as 1,144 K with a wet furnish. However, dry planer shavings require that dryer inlet temperatures be no higher than 533 K because the ignition point of dry wood is 503 K (Haygreen and Boyer, 1989; Maloney, 1977).

Many dryers are heated by wet or dry fuel suspension burners. Others are heated by burning oil or natural gas. The dry fuel suspension burner is the most common type of burner used to heat dryers. Cyclonic and register-style suspension burners are the two classes of dry fuel suspension burners presently in use (O'Quinn, 1991).

Cyclonic suspension burners require a fuel moisture content of less than 15 percent. Fuel must be finely divided wood particles of 3.175 mm in any dimension or smaller (usually fines and shredded edge trim). These burners require an auxiliary fuel source, such as natural gas, for warmup and startup (O'Quinn, 1991).

Register-style suspension burners are fueled by wood particles that must be less than 1.600 mm in any direction, with 90 percent of the particles being less than 0.787 mm in any dimension (usually fines, shredded panel trim, and sanderdust). Wood fuel moisture content must be less than 10 percent. Register-style burners require an auxiliary fuel source such as natural gas for warmup and startup. They also require a continuous sustaining flame of 5 to 10 percent of the rated burner output during normal operation.

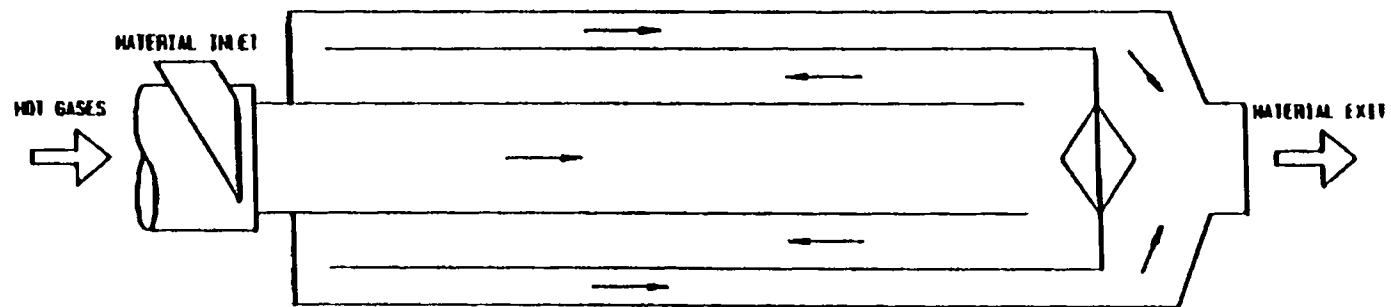


Figure 2-5. Schematic of conventional triple-pass drum dryer (Vaught, 1990).

Wet fuel burners are designed to burn high-moisture fuels such as bark and sawdust. They are used in reconstituted panel mills that use green roundwood as a raw material. These burners can burn both wet fuel and a limited amount of dry fuel, but the dry fuel must be mixed with the wet fuel at a constant rate. Some plants mix wastewater with dry fuel and burn it as a method of liquid waste disposal.

The vertical pile burner is the most common wet fuel burner used to heat rotary drum dryers in the U.S. Another wet fuel burner, the reciprocating grate burner, has been used for dryers in Europe and for thermal oil heaters in the U.S.

Fuel moisture content for both the vertical pile burner and the reciprocating grate burner must be less than 50 percent. Fuel particles for each should be no larger than 76 mm in any dimension, with typical particles being about 25 mm in any dimension (usually green shredded bark). Auxiliary fuels are not necessary but can be provided.

2.2.2.1 Screening and Air-Classifying

In PB manufacture, screening removes the fines (which would absorb too much resin if not removed) from the dryer exhaust and classifies particles by size for face and core layers (Haygreen and Boyer, 1989). The PB industry commonly uses inclined or horizontal vibrating screens or gyratory screens (Moslemi, 1974).

Air classifiers, which separate particles by particle surface area and weight, may be used alone or in conjunction with screening equipment. Air classifiers perform best if the feed is limited to particles with uniform widths and lengths. The classifier can then efficiently separate particles of different thicknesses due to the weight difference among particles of approximately equal surface area (Maloney, 1977). Undesired material is sent to a fuel preparation system for the dryer burner. The screened particles are stored in dry bins until they are conveyed to the blender (Vaught, 1990).

2.2.3 Adhesive Application

After drying, the furnish is blended with an adhesive resin, wax, and other additives added via spray nozzles, simple tubes, or atomizers. Waxes are added to the furnish to retard the adsorption of water into the board. The wax, a mixture of petroleum hydrocarbons, is typically added to the furnish as an emulsion (wax emulsions are dispersions of very small wax particles in water). The dispersion is stabilized with various chemicals known as emulsifiers. The amount of wax added to the furnish ranges from 0.25 to 1 percent or more of the dry board weight. Resin may be added to the furnish as received (usually an aqueous solution); mixed with water, wax emulsion, catalyst, or other additives; or added as a spray-dried or finely divided powder (Maloney, 1977). The amount of resin added to the furnish varies anywhere from 2 to 14 percent, depending on the type of product, and its specific end use.

2.2.3.1 Particleboard and Oriented Strandboard

Particles are blended in short retention time (i.e., seconds) blenders. The blenders consist of a small horizontal drum with high-speed, high shear impellers and tangential glue injection tubes. As the wood furnish enters the drum, resin is injected, and the impellers hurl the furnish at high speeds which effectively mixes it with the resin.

Strands are blended in long retention time (i.e., minutes) blenders. The blenders are very large rotating drums that are tilted on their axes. As the strands are fed into the drums, they are sprayed with resin. The tumbling action of the strands through the drums serves to blend them with the resin.

2.2.3.2 Medium Density Fiberboard and Dry Process Hardboard

After refining, the fibers are discharged through a blowvalve into a blowline. In the blowline, the fibers are sprayed with a resin. The resin can be injected immediately after the blow valve or anywhere along the blowline (Figure 2-6).

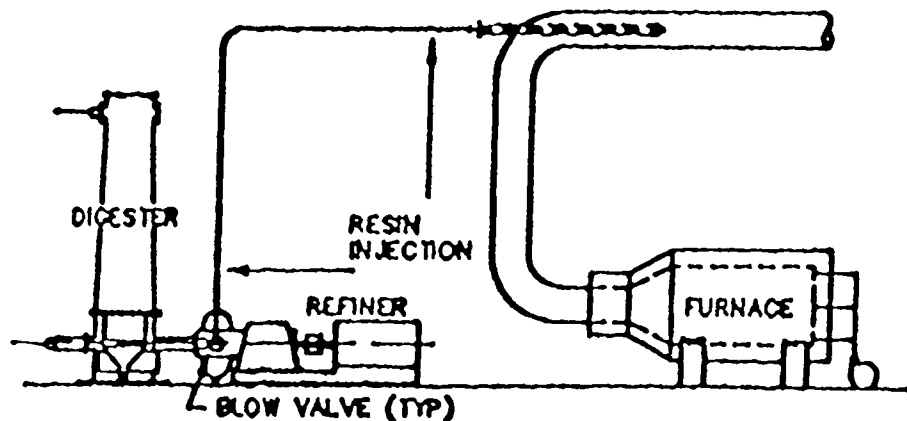


Figure 2-6. MDF blowline blending (Frashour, 1990). Reprinted with permission.

2.2.4 Mat Forming

Mat forming is the spreading of the furnish particles into a uniform mat. Mat formation may be a wet or dry process.

2.2.4.1 Wet Forming

Wet and wet/dry process hardboard and cellulosic fiberboard are formed by a wet process. In the wet forming process, fibers are mixed with water and adhesive and this water-fiber mixture is then metered onto a wire screen. Water is drained away with the aid of suction applied to the underside of the wire, and the fiber mat along with the supporting wire is moved to a prepress where excess water is squeezed out.

2.2.4.2 Dry Forming

PB, OSB, MDF, and dry process hardboard are formed by a dry process. The dry forming process uses air to distribute the furnish onto a moving caul (tray), belt, or screen (Figure 2-7). PB mats are often formed of layers of different sized particles, with the larger particles in the core, and the finer particles on the outside of the board (Figure 2-8). In PB and fiberboard manufacture, the particles and fibers are distributed in a random orientation. OSB is produced by deliberate mechanical or electrostatic orientation of the strands. In mechanical orientation processes, mats are produced by dropping long slender flakes between parallel plates or disks. In electrostatic orientation, particles align with an electrical field when dropped between charged plates (Haygreen and Boyer, 1989).

2.2.5 Hot Pressing

All reconstituted wood panels, except for cellulosic fiberboard, are hot pressed to increase their density and to cure the resin. For cellulosic fiberboard, the mat is simply brought to desired thickness using a press roll and then dried in an oven. Wet/dry process hardboard is also dried in an oven before being hot pressed.

Most plants use multi-opening platen presses (Figure 2-9). Typical multi-opening presses have 14 to 18 openings (Maloney, 1977). The last 10 years has seen the introduction of the continuous press (Figure 2-10). Though more popular in Europe, the continuous press is currently being used in two PB and two MDF plants in the U.S.

Steam generated by a boiler that burns plant residuals runs through a platen passageway to provide the heat in most hot presses. Hot oil and hot water can also be used to heat the platens. Direct heating by gas flames has also been used (Maloney, 1977).

The press temperature required to cure the adhesive resin varies, depending on adhesive type. Press temperatures are typically 478 ± 266 K for PF adhesives, and 450 ± 266 K for UF adhesives (Price, 1995). The press time needed to compress the mat varies depending on the final mat thickness, platen temperature, mat moisture content, and adhesive type. Press times are typically 15 to 20 seconds for every 1.600 mm in thickness for PF adhesives and 10 to 25 seconds for every 1.600 mm in thickness for UF adhesives (Price, 1995).

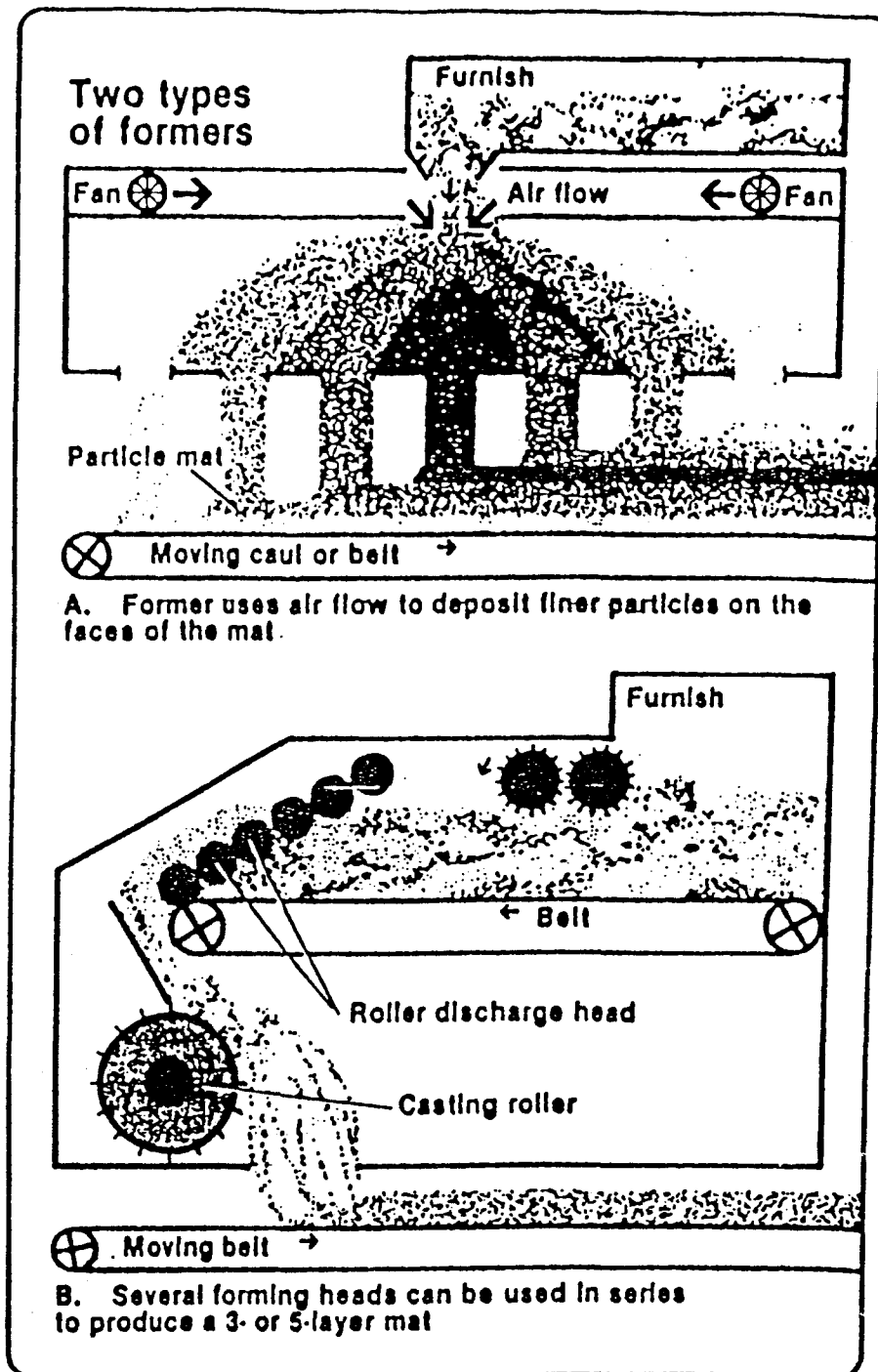
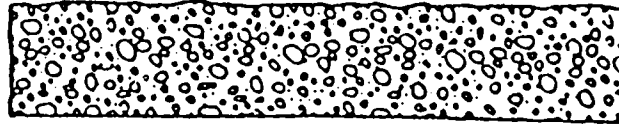
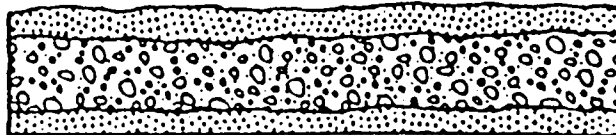


Figure 2-7. Two types of mat forming machines (Haygreen and Bowyer, 1989).
Reprinted with permission.

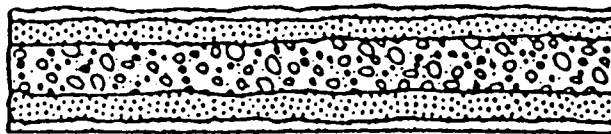
A. SINGLE LAYER



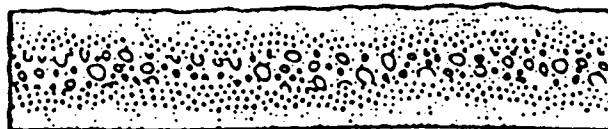
B. 3-LAYER



C. 5-LAYER



D. GRADUATED



**Figure 2-8. Various types of mat construction (Moslemi, 1974).
Reprinted with permission.**

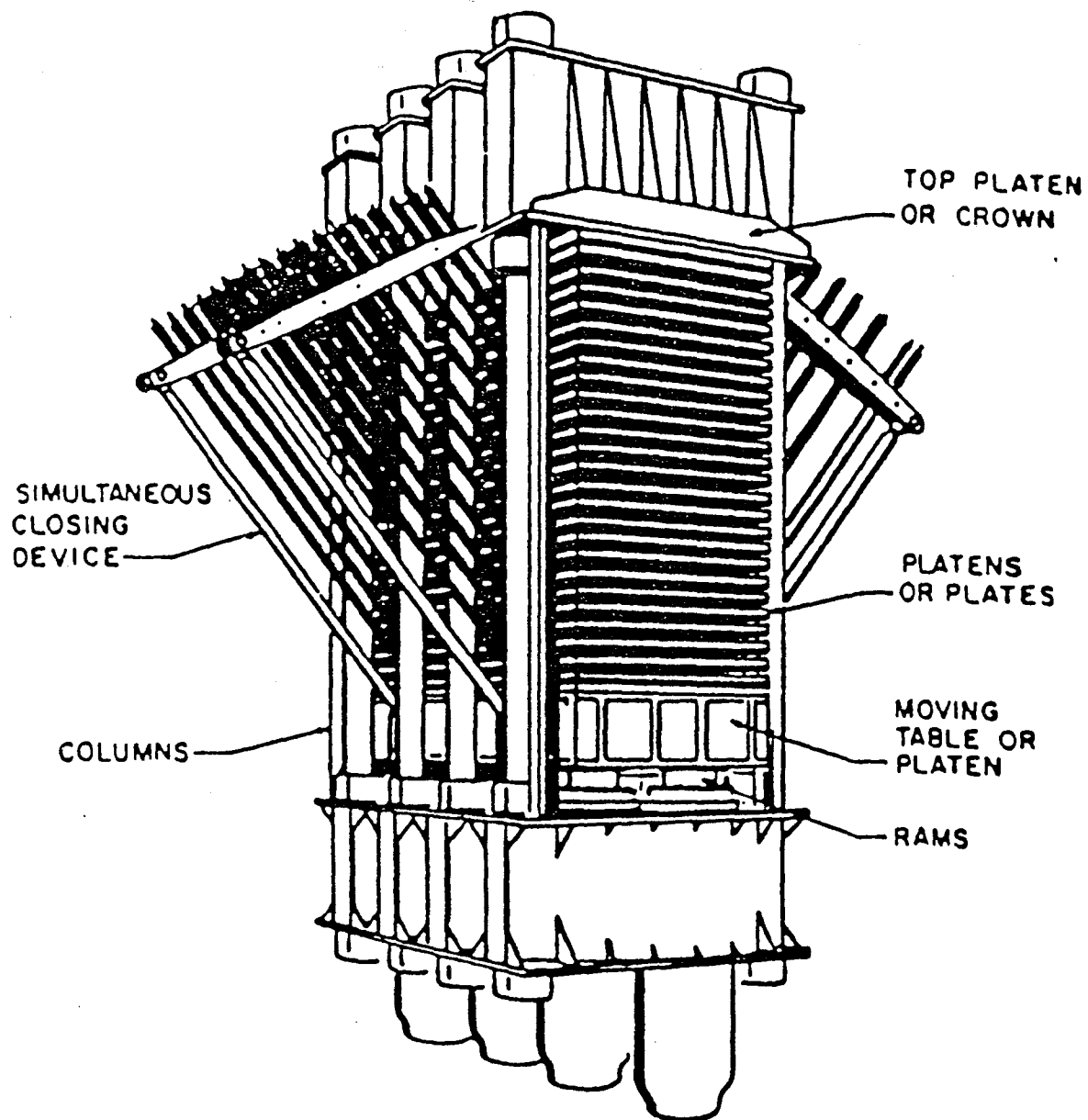


Figure 2-9. Schematic of multiopening board press (Suchsland and Woodson, 1987).

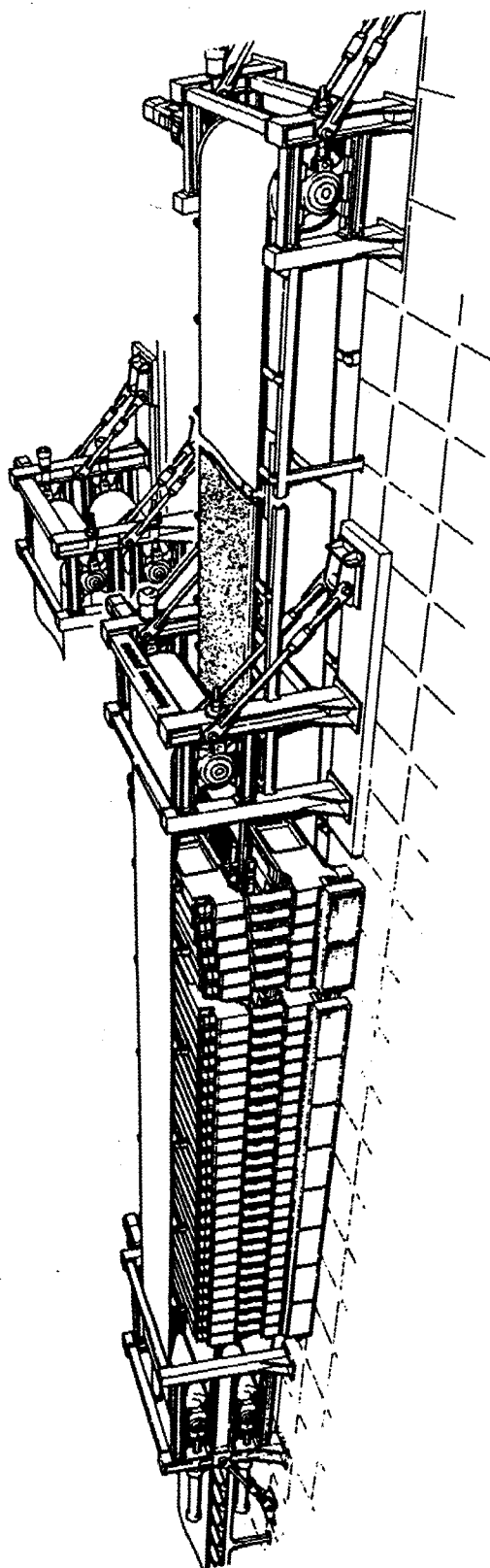


Figure 2-10. Continuous press (Wolff, 1996). Reprinted with permission.

2.2.6 Finishing

Primary finishing steps include cooling or hot stacking, grading, trimming/cutting, sanding, and shipping. Cooling is important for UF-resin-cured boards since the resin degrades at high temperatures after curing. Boards bonded using PF resins may be hot-stacked to give additional curing time (Maloney, 1977). Secondary finishing steps include filling, painting, laminating, and edge finishing (Maloney, 1977). However, the vast majority of reconstituted panel manufacturers do not apply secondary finishes to their panels. Panels are primarily finished by end users such as cabinet and furniture manufacturers. Panels are also finished by laminators who sell finished panels to furniture and cabinet manufacturers.

3.0 PROCESS EMISSIONS AND WASTES

In accordance with Section 313 of Title III in the Superfund Amendments and Reauthorization Act of 1986 (SARA), many industrial manufacturing facilities are required to annually report releases to land, water and air, and off-site transfers for treatment, storage or disposal of over 300 individual chemicals. Reconstituted and plywood panel plants are among the facilities required to report their releases. Tables 3-1 and 3-2 are reported releases of SARA section 313 chemicals from plywood and reconstituted panel plants for 1991. At both plants, air releases were much greater than releases to water or land. At reconstituted panel plants, formaldehyde releases to the air exceeded the releases of all other compounds combined.

3.1 Solid Wastes

Solid wastes at plywood plants consist of wastes from wood preparation, such as bark, log trimmings and sawdust and wastes from panel operations such as edge trimmings, off-spec panels, and sanderdust. Most of the wood preparation wastes are burned as fuel at the plant, although some green sawdust may be sold to reconstituted panel plants. Edge trimmings and off-spec panels are ground and sold to reconstituted panel plants (Price, 1995).

Solid wastes at reconstituted panel plants consist of wastes from panel operations such as edge trimmings, off-spec panels, and sanderdust. Edge trimmings and off-spec panels are ground and reused in the process. Sanderdust is burned as fuel at the plant (Price, 1995).

3.2 Adhesive Wastes

Adhesive wastes at plywood and reconstituted panels plants are the result of adhesive spills or leaks in the glue line. Although adhesive overspray is generated by plywood glue lines that use spray applicators, the overspray is collected in a bin beneath the line and reused. In general, if adhesive waste is generated during adhesive application (plywood or reconstituted panel manufacture), it is collected and reused. Adhesive waste is collected and reused because adhesives are a significant portion of the panel manufacturing cost (Price, 1995).

Table 3-1. Reported Releases of SARA Section 313 Chemicals from Reconstituted Wood Panel Plants for 1991^a

Compound	Total Releases (10 ³ kg)			Total Transfers (10 ³ kg)	
	Air	Water	Land	POTW ^b	Other Off-Site
acetone	129	0	0	0	1
ammonia	35	45	23	29	<0.5
ammonium nitrate solution	<0.5	0	0	0	0
ammonium sulfate solution	0	<0.5	0.5	0	2
asbestos	0	0	8	0	0
barium compounds	<0.5	0	1	0	0
chlorine	0	<0.5	0	0	0
ethyl benzene	26	0	0	0	7
ethyl glycol	12	0	0	0.5	0
formaldehyde	1590	<0.5	23	<0.5	2
glycol ethers	18	0	0	0	5
lead	0	0	<0.5	0	0
manganese compounds	0	0	0	22	0
methanol	282	0	0	0	0
methylenediphenyl diisocyanate	2	0	<0.5	0	0
methyl ethyl ketone	167	0	0	0	18
methyl isobutyl ketone	53	0	0	0	13
n-butyl alcohol	50	0	0	0	1
nitric acid	<0.5	0	0	0	0
phenol	83	<0.5	1	0	0
polychlorinated biphenyls	0	0	0	0	10
styrene	0	0	<0.5	0	1
sulfuric acid	13	0	0	0	0
tetrachloroethylene	<0.5	0	0	0	0
toluene	362	0	0	0	10
1,1,1-trichloroethane	0	0	0	0	1
1,2,4-trimethylbenzene	6	0	0	0	0.5
xylene	195	0	0	0	34
zinc compounds	0	0	<0.5	0	0

Source: NCASI, 1993. Reprinted with permission.

^aSARA = Superfund Amendments and Reauthorization Act

^bPOTW = Publicly owned treatment works

Table 3-2. Reported Releases of SARA Section 313 Chemicals from Plywood Plants for 1991^a

Compound	Total Releases (10 ³ kg)			Total Transfers (10 ³ kg)	
	Air	Water	Land	POTW ^b	Other Off-site
acetone	171	0	0	0	2
ammonium sulfate solution	0	0	0	0	0
barium compounds	<0.5	0	2	0	0
dichlormethane	0	0	0	0	1
formaldehyde	39	0	1	<0.5	0
glycol ethers	11	0	0	0	0
methanol	164	0	0	0	<0.5
diphenylmethane diisocyanate	5	0	0	0	0
methyl ethyl ketone	36	0	0	0	1
methyl isobutyl ketone	6	0	0	0	7
phenol	15	0	2	<0.5	0
sulfuric acid	<0.5	0	0	0	0
toluene	46	0	0	0	2
xlenes	34	0	0	0	3

Source: NCASI, 1993. Reprinted with permission.

^aSARA = Superfund Amendments and Reauthorization Act

^bPOTW = Publicly owned treatment works

3.3 Water Wastes

As seen in Tables 3-1 and 3-2, water releases from plywood plants and reconstituted panel plants are minimal. Water wastes are generated at these plants, however, the water is reused, instead of discharged. Below is a brief description of water usages at reconstituted panel and plywood panel plants.

Although some hardboard plants use water in the forming process, the majority of reconstituted panel plants are dry processes. Water is primarily used at reconstituted panel plants for rinsing equipment such as blenders and glue lines. The spent water is kept in a holding tank and added back into the adhesive (Price, 1995).

Plywood plants use water in a variety of applications. During the summer, southern plywood plants spray water on log piles to prevent blue stain. Blue stain is a discoloration caused by a certain type of fungus; spraying the logs with water prevents the growth of the fungus. The water that is sprayed on the logs drains into a pond; this water is then reused to spray the logs.

A second use of water at plywood plants is for soaking logs. Most plants soak logs in heated water (339 to 355 K) prior to peeling the veneer. The logs are soaked in either vats or ponds. The soaking water contains natural constituents from the wood, and sodium hydroxide and fungicide which are added by the plant. Sodium hydroxide is added to the water to maintain a PH of 7. This prevents corrosion of the vats and allows maximum penetration of water into the wood (Price, 1995).

A third use of water at plywood plants is for rinsing glue applicators. This is typically done on a daily or weekly basis, depending on a plant's schedule. The spent water is collected in a tank and is added back into the adhesive formulation at the plant or sent to a resin plant which uses the spent water in formulating adhesive (Price, 1995).

3.4 Air Emissions

At reconstituted panel and plywood panel plants, air emissions are generated from dryers and presses. The following describes the emissions from these sources.

3.4.1 Reconstituted Panel Dryers

3.4.1.1 Emissions Stream Characteristics

Reconstituted panel dryers process strands, fine particles, and fibers. As mentioned in Section 2.2.2, the most common type of furnish dryer is a three-pass rotary drum dryer that is direct heated by dry fuel suspension burners.²

Compounds in wood dryer emissions can be classified into several categories: (1) terpenes and isoprenes, (2) pitch, (3) wood pyrolysis products, and (4) energy source combustion products. Terpenes are natural constituents of softwoods. Isoprenes are found in hardwoods. The amount of terpenes and isoprenes present in the wood will vary with wood species and previous drying history of the furnish. Green wood contains the most terpenes or isoprenes. The amount of these materials in the furnish will decrease as the wood dries. Wood residues obtained from other wood products operations that dry the raw material will have low terpene content because volatile materials are lost in the first drying process. Storage of raw wood will also result in loss of volatile wood components. Terpenes and isoprenes evaporate from wood or chips at low temperatures; nearly all that is present in the wood entering a dryer is

²The remaining portion of 3.4.1.1 is reprinted with permission from Dallons, 1991 and Emery, 1991 .

probably released and emitted. Terpenes and isoprenes will remain in a vapor state in the atmosphere. Hence they contribute only to VOC [volatile organic compounds] emissions from dryers.

Resin and fatty acids, more commonly referred to as pitch, are also natural constituents of wood. They can be vaporized from the wood during drying. Vaporization rates vary with drying temperature, airflow through the dryers, and the pitch content of the wood. The amount of pitch in the wood varies with species. When dryer emissions enter the atmosphere and cool, these materials condense to form an aerosol that is responsible for the blue haze associated with wood product dryer's emissions.

If wood is heated to sufficiently high temperatures, it decomposes. This process is called pyrolysis. The exact temperatures at which various degradation products are formed are not known with certainty; however, it is generally accepted that wood will begin to decompose somewhere between 212 and 392 °F, giving off acetic acid, formic acid, and possibly some carbon dioxide. Decomposition continues with increases in temperature, and wood will burst into flames somewhere around 523 °F in the presence of oxygen. The process of pyrolysis is literally an explosive breaking apart of the chemical structure of the wood. Hundreds, perhaps thousands, of chemical compounds are formed during pyrolysis. In the absence of sufficient oxygen to ensure complete combustion, this decomposition is manifested by the formation of smoke.

One important chemical formed during pyrolysis is formaldehyde. Formaldehyde appears to be much more prevalent for hardwoods than for softwoods. Other VOCs, as well as particulates (smoke), are also formed during pyrolysis, and the amounts and types depend upon drying temperature, wood species, size and residence times of the wood particles, and possibly other variables.

Combustion products from direct fired burners can contribute VOC emissions. The burners used for direct firing dryers are efficient units and little volatile organics are expected to be released by them. Thus, VOCs from combustion are expected to be a minor portion of the total VOCs emitted from dryers.

Ash from combustion of sanderdust or other wood residue fuels will contribute to the particulate emissions. Much of the ash is small in size and contributes to PM₁₀.

3.4.1.2 Variables Affecting Emissions from Reconstituted Panel Dryers

As discussed above, two variables that affect the composition of dryer emissions are dryer temperature and wood species. The effects of these variables on specific types of dryer emissions are presented below. The discussion is based entirely on various emissions test reports published by the National Council of the Paper Industry for Air and Stream Improvement (NCASI). The reports summarize emissions data measured at various reconstituted panel plants.

Dryer emissions are described in terms of total gaseous nonmethane organics (TGNMO) and formaldehyde³.

3.4.1.2.1 Effects of Dryer Inlet Temperature on TGNMO Emissions

NCASI reported that at dryer inlet gas temperatures greater than 588 K, the concentration and emissions rate of the condensable portion of TGNMO increased as functions of temperature (Figures 3-1 and 3-2) (NCASI, 1986c). Little correlation was seen between emissions of the noncondensable portion of TGNMO and the inlet dryer temperature (Figure 3-3) (NCASI, 1989). The emissions in Figure 3-3 are from drying green material only (Dallons, 1991). Materials that had been pre-dried in other processes, such as planer shavings or sawdust from kiln dried lumber, had lower emissions of noncondensables than drying green furnish (Dallons, 1991). When pre-dried material was processed, VOC emissions ranged between 0.36 and 0.54 gram per kilogram (g/kg) of product. However, because the raw material had been partially dried in other processes, it contained fewer terpenes. The material also required less heat to dry which resulted in lower dryer temperatures (Dallons, 1991).

3.4.1.2.2 Effects of Dryer Inlet Temperature on Formaldehyde Emissions

NCASI reported that the concentration of formaldehyde in the dryer exhaust was a function of the dryer inlet temperature (Figure 3-4) (NCASI, 1986c). The formaldehyde concentration at dryer inlet temperatures below 810 K was less than 20 parts per million (ppm). At inlet temperatures above 810 K, the formaldehyde emission rates were as high as 110 ppm.

3.4.1.2.3 Effects of Wood Species on Formaldehyde Emissions

Formaldehyde emissions from drying different wood species are shown in Figure 3-5 (NCASI, 1989). Based on the data shown in Figure 3-5, NCASI concluded that dryers processing hardwood or a mixture of hardwood and softwood species had a moderate to dramatic increase in formaldehyde emissions at dryer inlet gas temperatures greater than 699 K, but dryers processing softwood species had only a slight increase in formaldehyde emissions with increasing temperatures (NCASI, 1989).

³Measurement of TGNMO is not recognized by EPA as a measurement of VOC.

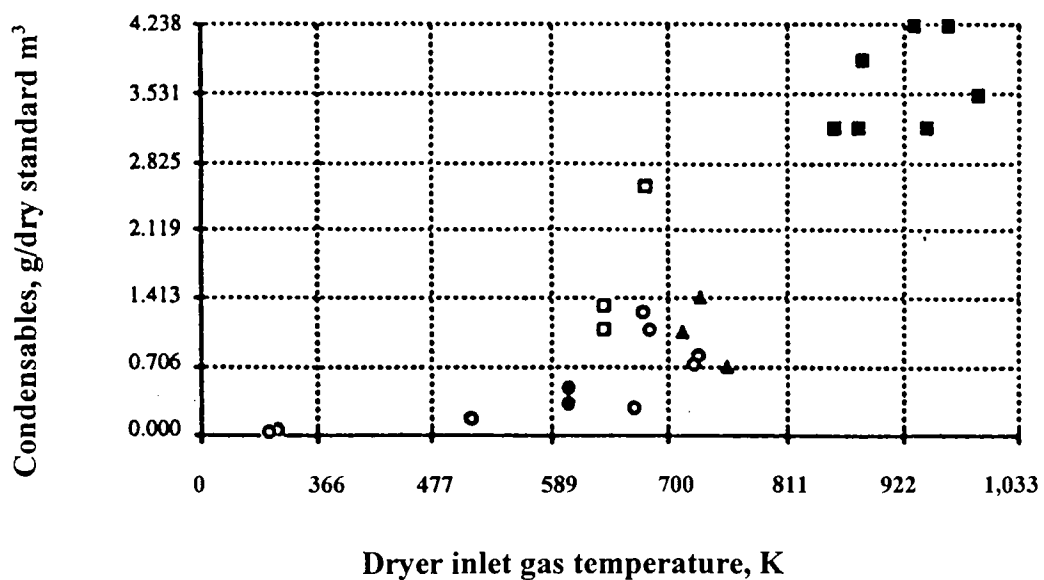


Figure 3-1. Concentration of condensable organics vs. dryer inlet temperature (NCASI, 1986c) (Symbols refer to different mills). Reprinted with permission.

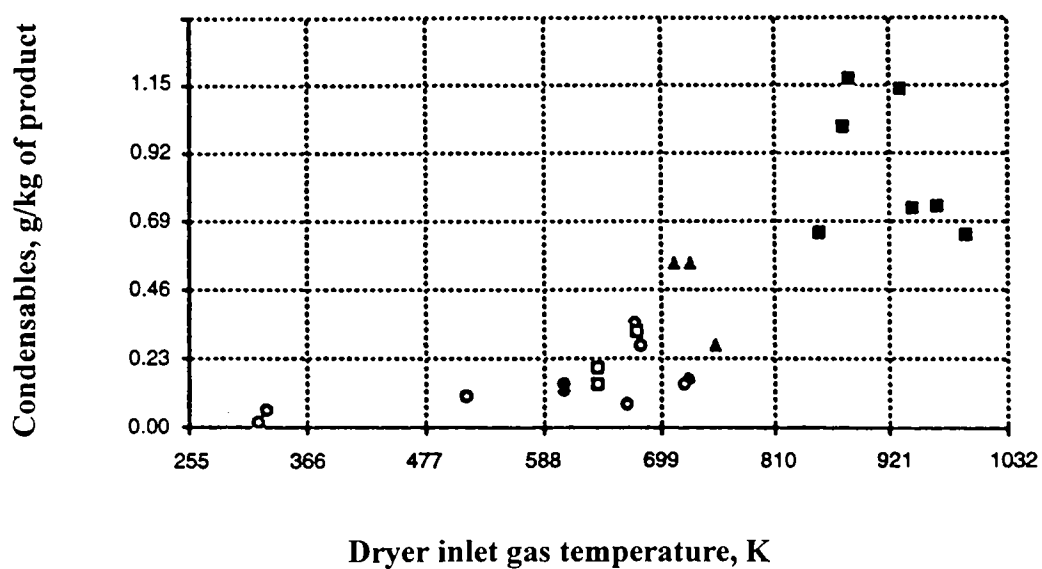


Figure 3-2. Emission rate of condensable organics vs. dryer inlet temperature (NCASI, 1986c) (Symbols refer to different mills). Reprinted with permission.

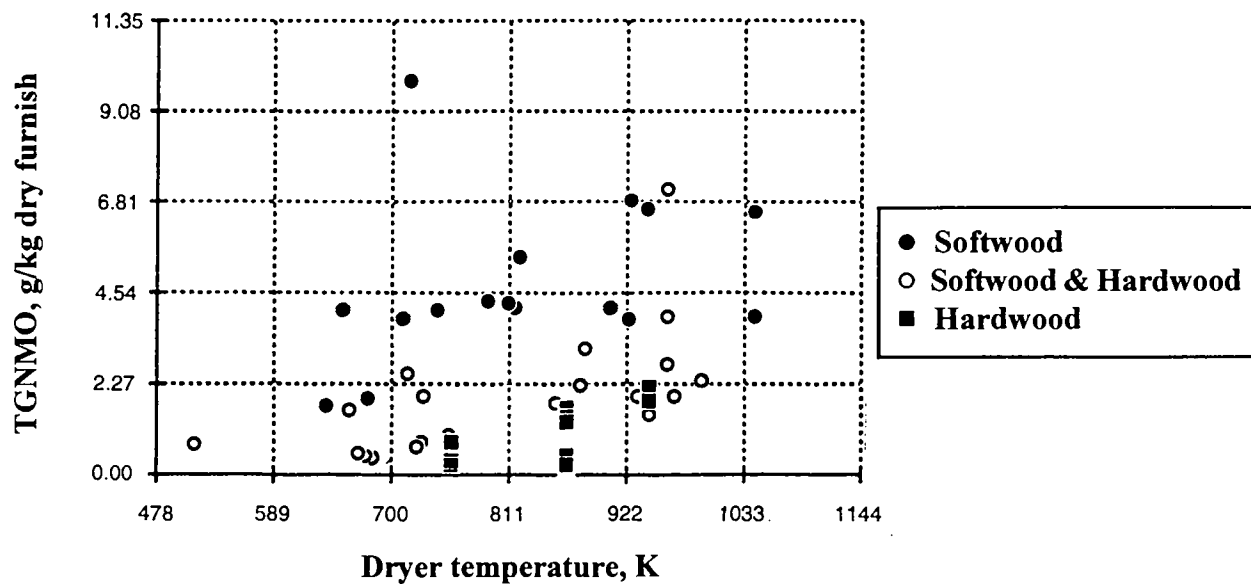


Figure 3-3. Noncondensable portion of total gaseous nonmethane organics (TGNMO) vs. dryer inlet temperature (NCASI, 1989). Reprinted with permission.

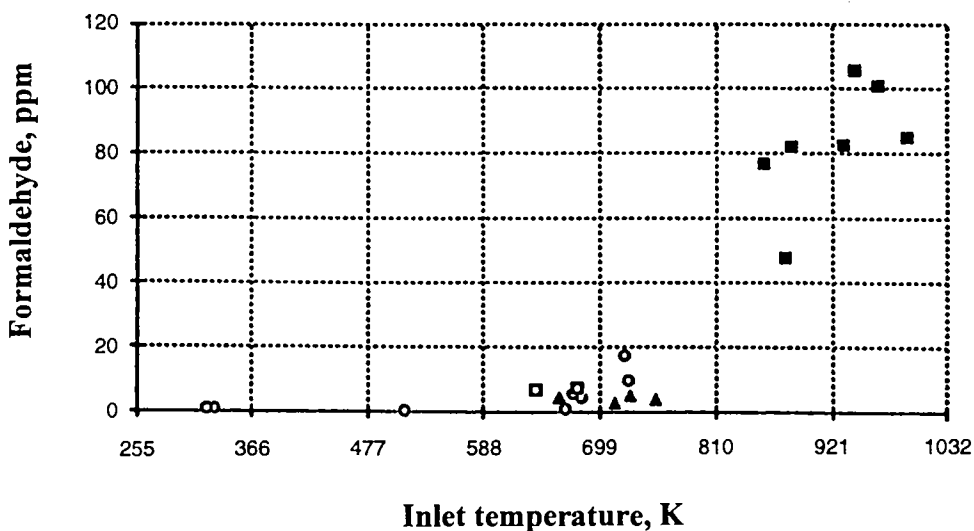


Figure 3-4. Concentration of formaldehyde in dryer exhaust as a function of the dryer inlet temperature (NCASI, 1986c) (Symbols refer to different mills). Reprinted with permission.

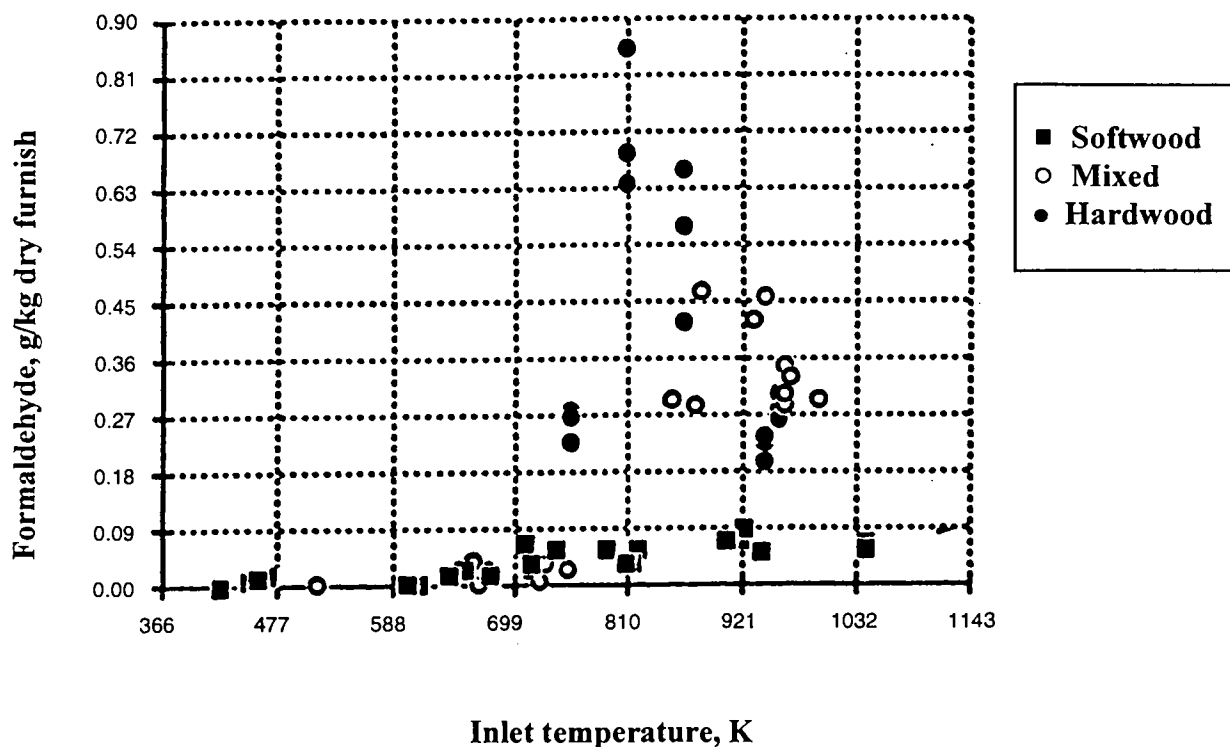


Figure 3-5. Formaldehyde emissions associated with drying different wood species (NCASI, 1989). Reprinted with permission.

3.4.2 Veneer Dryers

3.4.2.1 Emissions Stream Characteristics

Uncontrolled veneer dryer emissions at stack gas temperatures above 89 K contain particulates and gaseous organics (NCASI, 1983). Particulate emissions from steam-heated dryers consist of wood fibers from the veneer. Particulate emissions from wood-residue fired direct-heated dryers contain wood fibers as well as ash from the combustion process. Gaseous organics released from veneer when it dries consist primarily of non-structural wood components that are commonly termed “extractives.” Extractives are wood constituents which can be removed with “neutral” solvents, i.e., solvents which do not significantly affect the strength of the wood, such as water, alcohol, benzene, and ether (Emery, 1991). Most extractives are of low molecular weight and therefore, volatilize from the veneer as it dries. Upon entering the atmosphere, some of the gaseous extractives remain VOC while others condense to form aerosols.

3.4.2.2 Variables Affecting Veneer Emissions

The effects of dryer type, dryer temperature, wood species, and other variables on veneer emissions are presented below. The discussion is based entirely on an emission test report published by NCASI. The report summarizes emissions data measured at several plywood plants on the West Coast and in the South.

3.4.2.2.1 Factors Affecting Noncondensable Organics

The NCASI report concluded that emissions of noncondensable organic compounds were related to the turpentine content of the veneer dried and to the dryer type. Average noncondensable organic compound emissions from steam heated dryers were 10.7 kg per thousand square meters (MSM) for lodgepole pine, 3.9 kg/MSM for Douglas fir, and 3.4 kg/MSM for hemlock. Average noncondensable organic compound emissions from wood-residue-fired direct-heated dryers were 11.7 kg/MSM for Douglas fir and 4.4 kg/MSM for hemlock (lodgepole pine was not tested).

The report's conclusion that noncondensable organic compounds were related to the turpentine content of the veneer to be dried does not coincide with a table in the report that listed the turpentine content of various wood species (part of this table is reproduced in Table 3-3). As seen in Table 3-3, the turpentine content of all three species of hemlock is nondetectable yet noncondensable emissions of hemlock from steam-heated dryers were almost the same as noncondensable emissions of Douglas fir. The study does not indicate which species of Douglas fir were tested; however, lodgepole pine emissions from steam-heated dryers were higher than Douglas fir emissions from these dryers. The latter suggests that the Washington specie of Douglas fir was tested (since it has a lower turpentine content than the lodgepole pine).

Table 3-3. Turpentine Content of Wood Species	
Specie	Turpentine (m ³ /million kg of dry wood)
Douglas Fir (Washington)	3.91
Douglas Fir (Canada)	0.71
Hemlock, Eastern	nondetectable
Hemlock, Mountain	nondetectable
Hemlock, Western	nondetectable
Lodgepole pine	2.01

Source: NCASI, 1983. Reprinted with permission.

3.4.2.2.2 Factors Affecting Particulated and Condensable Organics

Particulate and condensable organic emissions from steam-heated dryers were found to be a function of the veneer specie, dryer temperature, and the amount of air passed through the dryer. Particulate and condensable emissions from steam-heated dryers ranged between 0.3 and 9.9 kg/MSM. Wood-residue fired direct-heated dryers were found to have particulate and condensable organic emissions ranging between 2.4 and 7.8 kg/MSM; according to the report, these emissions appeared to be independent of wood specie due to the greater influence of ash in the exhaust gas from the combustion of wood (NCASI, 1983).

3.5 Press Emissions

Press emissions from plywood and reconstituted panels consist of VOCs and particulates. VOCs are generated from the wood and the adhesive that binds the wood. Particulates are primarily wood dust that is generated in the manipulation of the panels and unpresse mats (O'Quinn, 1991).

3.5.1 Wood Related Emissions

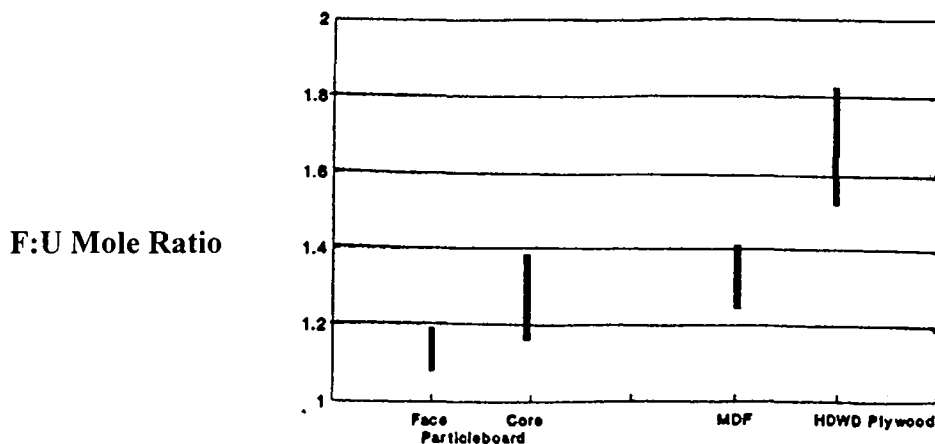
At elevated press temperatures, various extracts may be driven from wood as VOCs (O'Quinn, 1991). VOC formation is higher in woods with higher extract content; i.e., softwoods. However, hardwoods tend to release more secondary formaldehyde from the pyrolysis of extracts (O'Quinn, 1991).

3.5.2 Adhesive Related Emissions

Both UF and PF adhesives involve polymerization with formaldehyde. The high press temperatures required to promote the reaction drive off part of the unreacted formaldehyde (O'Quinn, 1991). The cyanates contained in MDI are of such low volatility that polymerization is complete, resulting in no detectible emissions (O'Quinn, 1991). The following sections describe in more detail, press emissions associated with UF, PF, and MDI resins.

3.5.2.1 Press Emissions from Curing UF Resins

The formaldehyde to urea (F:U) mole ratio is the ratio of the number of moles of formaldehyde to number of moles of urea in UF adhesive resins. For example, a F:U mole ratio of 1.15 has 1.15 moles of formaldehyde for each mole of urea. As seen in Figure 3-6, a wide range of mole ratios are used in UF bonded products: for PB, when a single resin is used throughout the board, the F:U mole ratio can fall anywhere within the range set by the face/core systems; MDF products use resins with F:U mole ratios higher than PB resins; hardwood plywood products use the highest F:U mole ratios. The nature of the product and process dictates the F:U mole ratio of



**Figure 3-6. Urea-formaldehyde resin mole ratios (Rammon, 1990).
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resin used. The mole ratio directly impacts the ultimate strength the resin will produce in the board, i.e., certain products require higher mole ratio resins to attain an adequate level of bond strength (Rammon, 1990).

The F:U mole ratio in UF resins is related to formaldehyde board and press emissions; the higher the mole ratio, the higher are formaldehyde emissions and vice versa (Gollob, 1990). Table 3-4 presents data from a NCASI study which measured press emissions at four PB mills where UF adhesives were used. According to the study, a direct relationship between F:U ratios and press emissions was observed at these mills, in particular, Mill B. At Mill B, two types of PB products were produced: commercial grade and door core. The amount of resin used in each product was the same (8.8 percent), however, resins with different F:U mole ratios were used to make each product. A F:U mole ratio of 1.25 was used to make the commercial grade PB and a F:U mole ratio of 1.5 was used to make the door core. For the commercial grade PB, the formaldehyde emission rate was 3.86 kg/MSM on a 19 mm thickness basis (MSM₁₉); for the door core PB, the formaldehyde was 5.86 kg/MSM. According to the study, the formaldehyde emission rate increased in proportion to the increase in the F:U mole ratio of the resin. The study also reported that data from Mill A illustrated a relationship between increasing formaldehyde emission rates with increasing resin usage and that data from Mill D illustrated a relationship between increasing formaldehyde emissions rates with increasing press temperatures. The data in Table 3-4 do not seem to be sufficient to draw these conclusions. At most, they suggest a trend between these variables and press emissions. The effect of variables such as furnish moisture

Table 3-4. Press Emissions from Particleboard Mills using UF Resins							
Mill	Product	Wood Species	Press Temp., K	Percent Resin in Board	F:U Mole Ratio	CH ₂ O ^a	TGNMO kg/MSM
						19 mm Basis	
A	Commercial	Douglas fir	433	5.8	- - ^b	1.76	4.20
A	Industrial	Douglas fir	433	7.1	- -	2.15	--
B	Commerce	Aspen/pine	455	8.4	1.25	3.66	6.35
B	Door Core	Aspen/pine	466	8.4	1.50	5.86	9.28
C	Commercial	Douglas fir/pine	433	8.8	- -	1.51	9.77
C	Industrial	Douglas fir/pine	433	10	- -	1.76	11.23
D	Commercial	Pine	430	6.9	- -	1.46	--
D	Commercial	Pine	469	6.9	- -	1.76	--

Source: NCASI, 1986b. Reprinted with permission.

^a CH₂O = chemical formula of formaldehyde

^b Not reported

^c TGNMO = total gaseous nonmethane organics

^d MSM = thousand square meters

^e UF = urea-formaldehyde

^f F:U = formaldehyde to urea

content and wood species on press emissions was not examined. The study also failed to mention the use of formaldehyde scavengers or the influence that scavengers would have on emissions (see section 6.3).

3.5.2.2 Press Emissions from Curing Phenol-Formaldehyde Resins

The data in Table 3-5 are from a NCASI study that measured press emissions at two OSB mills (NCASI, 1986a). Based on this data, the study concluded that emissions of formaldehyde and phenol were not related to any of the operating parameters monitored, but were instead affected by different resin compositions. At Mill A, three types of liquid PF resins were used along with an unspecified type of wax. The resin application rate was 5.0 percent in the core, and 4.75 percent in the surface material. At Mill B, a powdered PF resin and an unspecified type of wax were used. The resin application rate was 2.0 percent in both the core and surface material. The study stated that the different resin compositions used at Mill A were unknown because it was kept confidential by the manufacturer of the resin. Consequently, the lack of information about the resin composition precluded development of relationships to resin properties (NCASI, 1986a).

Table 3-5. Press Emissions From OSB^a Mills Using PF^b Resins					
Mill	Wood Species	Press Temp. K	Percent Resin in Board	Formaldehyde kg/MSM ^{c,d}	Phenol kg/MSM
A	Aspen	478	4.8	1.61	>0.10
A	Aspen	478	4.8	2.73	>0.68
A	Aspen	478	4.8	2.59	>0.78
B	Lodgepole pine	478	4.2	0.83	>0.25

Source: NCASI, 1986a. Reprinted with permission.

^a OSB = oriented strandboard

^b PF = phenol-formaldehyde

^c MSM = thousand square meters

^d Study did not indicate thickness basis

3.5.2.3 Press Emissions from Curing MDI Resins

NCASI compiled press vent emissions measured at four mills using MDI resins. Table 3-6 summarizes the measured emissions. The average formaldehyde emissions rate from the three mills using MDI ranged between 0.05 and 0.34 kg/MSM₁₉. One mill used a combination of MDI and PF resins to bind the board; press vent emissions of formaldehyde were the highest at this mill.

Table 3-6. Press Emissions from MDI^a Resins		
Resin	Formaldehyde kg/MSM ^b ₁₉	MDI kg/MSM ₁₉
MDI	0.05	0.049
MDI	0.10	0.103
MDI	0.34	0.0000
MDI (core) & PF ^c (face)	0.54	

Source: NCASI, 1989. Reprinted with permission.

^a MDI = methylene diphenyl diisocyanate

^b MSM = thousand square meters

^c PF = phenol-formaldehyde

4.0 POLLUTION PREVENTION

Sections 5.0 through 8.0 present potential pollution prevention options for reducing manufacturing emissions from composite wood manufacturing processes. These options were found through a literature search of journal articles, symposium publications, company brochures, phone inquiries, etc. Most of the available literature focused on reducing costs and improving manufacturing processes. As a result, this report contains little information on quantitative emissions reduction. The intent of this report is to provide the reader with potential pollution prevention options. The inclusion of any particular technique or technology does not imply best achievable control technology (BACT), MACT, or any other regulatory required technology. In addition, life-cycle assessments on potential pollution prevention options were beyond the scope of work for this report. Consequently, whether or not the options presented in this report are pollution prevention will require further investigation.

5.0 ALTERNATIVE FIBER SOURCES

As discussed in Section 1.1.1, harvesting restrictions from publicly owned lands have curtailed production of plywood and lumber, particularly in the West. Production of PB and MDF has also been affected by the harvesting restrictions. Over 80 percent of the wood used to manufacture PB and MDF are residuals from lumber or plywood manufacturing such as chips and shavings (McCredie, 1993). Curtailment of the production of plywood and lumber affects the supply of chips and shavings available for the production of PB and MDF. Western board manufacturers have been especially hard hit by the drop in timber supply. Oregon alone has 11 PB/MDF plants that account for more than 25 percent of the U.S. production of these products. The shut-down of plywood and lumber mills has put a premium on the remaining supply of wood residuals (McCredie, 1993). PB and MDF manufacturers that were historically able to satisfy their wood supply requirements within a 161-kilometer (km) radius of the plant now routinely go out 322 km to 483 km (McCredie, 1993). This results in increased competition for available supplies and increased transportation costs (McCredie, 1993). While no Oregon PB or MDF mills have been permanently shut down for lack of wood, some production curtailments have occurred (McCredie, 1993).

Two potential alternative fiber sources for composite panels are recycled wood waste and agricultural fibers. In an interview regarding the shortages of wood for manufacturing composite panels and the use of recycled wood waste as an alternative raw material source, Rich Margosian, executive director of the NPA, predicted that in the next five to ten years more manufacturers will be using alternate fiber sources. "I think we're at the beginning of this," he stated. "Board producers are having to do research in two different directions--looking for alternate resources such as recycled wood waste and economizing on material needed to make board" (Plantz, 1994).

5.1 Recycled Wood Waste

In 1993, Willamette Industries initiated a program to recycle wood waste into chips for PB production (Plantz, 1994). This wood waste includes construction site debris, discarded household items, crates, and pallets that had been burned or put into landfills. Willamette's Eugene PB and Duraflake mills now use up to 15 percent recycled material, and its Korpine mill is developing sources and starting to use recycled material.

Medite Corporation is another board producer that is using waste wood at its New Mexico MDF mill. Recycling was something that in past years was not economically feasible for the company; however, increased prices for wood have now made it possible.

Recycling wood waste requires a different mind set for raw material acquisition -- instead of looking to the forests, a company has to look to urban areas. That can work to a mill's advantage. Medite has made arrangements with trucking companies to develop equipment that can haul finished board to the user and bring raw material back from the city to the mill. Medite is currently hauling material from Oklahoma City, Denver, and Albuquerque. Willamette has also invested time, training, and money to develop their suppliers. An example is Wood Recycling, Inc., in Eugene, Oregon. Willamette purchased the operation's equipment and leases it back to Wood Recycling, which sells all its product to Willamette.

Beyond finding sources, extensive training and research is required on what materials will and will not work, careful control of the quality of recycled materials, and cleaning of the material to remove any foreign matter. The mills must make sure the mix of material and resins is correct. There are many hurdles in cleaning the material, especially with being able to adjust the process to run different kinds of material, while still maintaining a quality product. It is not simply a matter of taking discarded wood and grinding it up. From a product standpoint, if the wood waste is clean it makes good PB (Plantz, 1994).

By late 1995, CanFibre hopes to start up its first plant to produce MDF using 100 percent post consumer waste and PF adhesives. The plant (the first of its kind in North America) will be located near Toronto, Ontario. Approximately 34,000 m³ per year of structural MDF will be produced from recycled urban waste such as waste wood, cardboard, drink containers, and newspaper (Wood Technology, 1994). The plant will have two significant cost advantages over conventional MDF plants: (1) the cost of post-consumer waste is currently negative and (2) savings in freight costs due to the plant's location near an urban site (most existing MDF plants are remotely located and the cost of hauling wood waste back to these mills is high). The net mill cost for the process used by CanFibre's Toronto plant is estimated to be \$893/MSM versus \$1,113/MSM for a conventional plant (Roberts, 1994). The company plans to build a total of nine plants in North America: six in the U.S. and three in Canada. All plants will use 100 percent post consumer waste and PF adhesives.

5.2 Agricultural Fiber

Agricultural fiber comes from two main sources: agricultural crops grown for fiber (e.g., kenaf) and residues of crops grown for other purposes (e.g., wheat, cotton). Agricultural fiber is used in many countries to manufacture composite panel products such as cellulosic fiberboard, PB, MDF, and hardboard. A worldwide literature search conducted at the U.S. Department of Agriculture (USDA) Forest Service's Forest Products Laboratory (FPL) in Madison, Wisconsin, found 1,039 citations on the use of agricultural fibers for manufacturing composite panels (Youngquist et al., 1993). Many of these applications are in developing countries where there is not enough wood to cover the needs for fuelwood, industrial wood, sawn wood, and wood-based composite panels (Youngquist et al., 1993). Recently, a plant was built in North Dakota which manufactures particleboard from wheat straw and MDI resins (Galbraith, 1995).

Large volumes of agricultural fiber are generated each year in the U.S. Sources of this fiber include bagasse, cereal straw, corn stalks and cobs, cotton stalks, kenaf, rice husks, rice straw, and sunflower hulls and stalks (Youngquist et al., 1993). The volume of agricultural fiber generated in the U.S. is so great that if 75 reconstituted wood panel plants were to switch entirely to agricultural fiber and, on average, each plant required 135 billion kg of fiber annually, more than 30 times as much agricultural fiber would be available as would be consumed (Youngquist et al., 1993). The above calculation is based only on agricultural residues, except for bagasse, and does not account for agricultural fibers from nonresidue sources like kenaf. Thus, in terms of potential availability, the amount of residues generated by U.S. agriculture far exceeds present and future composite panel fiber requirements (Youngquist et al., 1993).

Although there is more than enough agricultural fiber in the U.S. to supplant wood in composite panel manufacture, the feasibility of such a substitution depends on many factors such as product quality, cost, current uses of agricultural residues, and others. Whether this substitution is pollution prevention requires a comparison of the total environmental impacts (air, water, and soil) associated with manufacturing composite panels using agricultural fibers versus wood. An abundance of information is available on the feasibility of using agricultural fiber for composite panel manufacture (as stated above, the FPL literature search found 1,039 citations). However, information on the environmental impacts associated with agricultural fiber use was not found during the literature search for this report. Despite not knowing if agricultural fiber is a pollution prevention option for wood composite panels, it is included in this report as a raw material substitute for wood; the discussion, however, is limited to feasibility issues regarding its use in composite panel manufacture.

5.2.1 Product Quality

In North America, available agricultural fiber for composite panel manufacture includes bagasse, cereal straw, corn stalk, cotton stalks, kenaf, rice husks, rice straw, and sunflower hulls and stalks (Youngquist et al., 1993). Many of these fibers have been used to construct composite panels which meet or exceed standards for PB (Figure 5-1). Fewer of these composite panels meet the

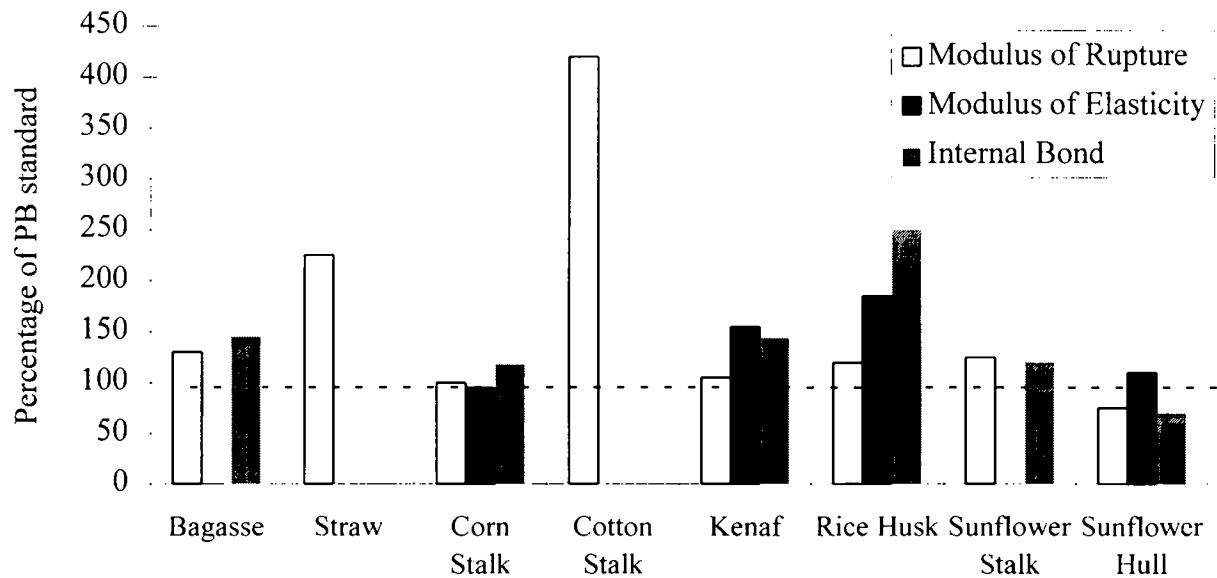


Figure 5-1. Properties of composite panels made with agricultural fibers compared to properties required for particleboard panels (Youngquist et al., 1993).

Notes

Properties not indicated in the table were unspecified in the Youngquist et al. source

Composition of Panels

Bagasse: 92 % bagasse; 8 % urea-formaldehyde (UF) resin ; 0.74 specific gravity (SG); 0.3 in thickness

Straw: 97 % pulped rice straw; 3 percent UF resin; 0.98 SG; 0.08 in thickness

Corn Stalk: 92 % hammermilled and depithed corn stalks; 7 percent UF resin; 1 % wax; 0.74 SG; 0.5 in thickness

Cotton Stalk: 97 % refined debarked cotton stalk; 3 percent phenol-formaldehyde (PF) resin; 0.82 SG; 0.08 in thickness

Kenaf: 92 % depithed kenaf bast fiber; 7 % UF resin; 1 % wax; 0.74 SG; 0.5 in thickness

Rice: 0.94 SG; 0.2 in thickness

Sunflower Stalk: 90 % depithed sunflower stalks; 10 % PF resin; 0.74 SG; 0.4 in thickness

standards for hardboard (Figure 5-2 - note that thickness swell and water absorption values below the dotted line are desirable).

Although some composite panels made from agricultural fibers possess properties adequate for PB and hardboard use, they may not be adequate to meet the structural requirements of OSB panels. Whereas PB and hardboard panels are composed of finely ground wood residues, OSB panels are constructed of specially cut wood strands. The uninterrupted wood fiber of the strands, interleaving of the strands, and degree of orientation of the strands in the panel imparts structural properties to OSB panels. The composite panels in Figures 5-1 and 5-2 are composed of ground up agricultural residues that may not provide the necessary strength required for OSB panels. While adequate structural properties may be developed by increasing panel thickness, this will increase both the amount of fiber needed and the manufacturing cost of the product (Bigbee, 1994). Further investigations are required to determine the suitability of agricultural fibers for OSB (Bigbee, 1994).

5.2.2 Bulk Density

A major difference between wood and non-wood fibers is bulk density. One obstacle to agricultural fiber utilization is low bulk density. Low bulk density can increase transportation costs significantly. A standard cord of wood has a bulk density (dry basis) of 240 to 320 kg/m³. Processing and transportation costs limit the practical procurement of cords to a radius of about 64 km (Vaagen, 1991). In contrast, annual fiber stems of plants such as kenaf or straw cannot be compacted much beyond 135 kg/m³. The procurement range for these fibers is about 24 to 32 km (Sandwell and Associates, 1991).

5.2.3 Price

Price estimates for various types of wood species and agricultural fiber are presented in Table 5-1 (Youngquist et al., 1993). As shown, pulpwood prices range from \$41 to \$60/1000 kg and agricultural fiber prices range from \$25 to \$90/1000 kg. Among the agricultural fibers, kenaf is generally the highest in estimated price because all cultivation and harvest costs are born by the fiber component of the output (Youngquist et al., 1993). Straw and corn generally cost less than do crops grown specifically for their fiber content because the grain portion of the output bears the expense (Youngquist et al., 1993). An exception to this is where the fiber has value for other uses, such as animal bedding. In those cases, straw prices can be almost twice as high as pulpwood and not currently within economic reach of PB producers. For example, in Wisconsin and Pennsylvania where animal bedding needs are high, baled straw is priced from \$50 to \$90/1000 kg (Youngquist et al., 1993). In North Dakota, straw is generally left on the ground; the small amount of straw that is baled markets for only \$25 to \$35/1000 kg (Youngquist et al., 1993).

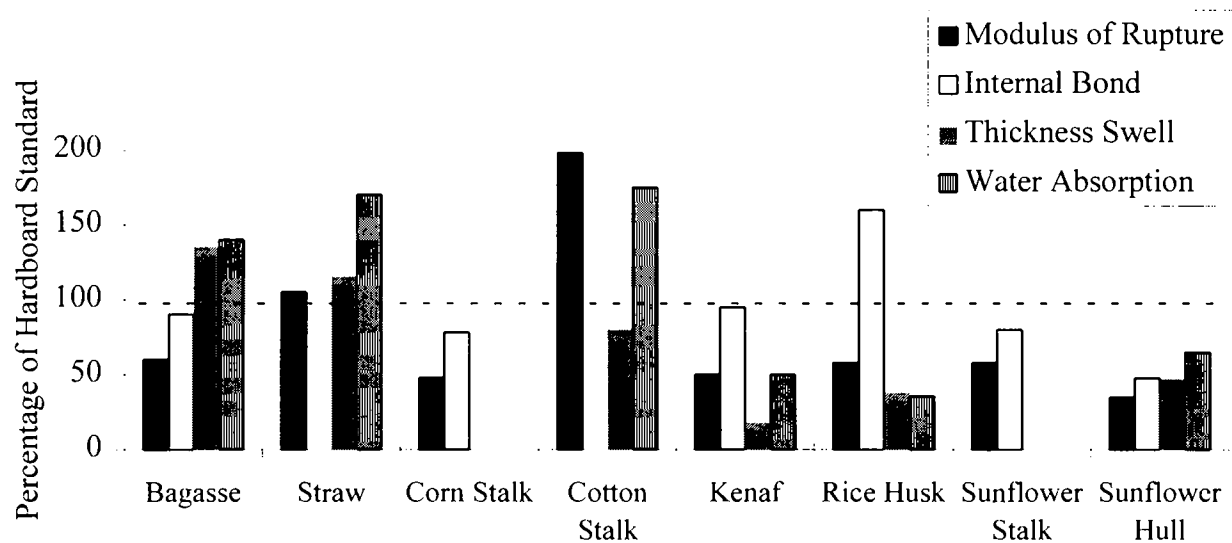


Figure 5-2. Properties of composite panels made with agricultural fibers compared to properties required for hardboard panels (Youngquist et al., 1993).

Notes

Properties not indicated in the table were unspecified in the Youngquist et al. source

Thickness swell and water absorption values below dotted line are desirable

Composition of Panels

Bagasse: 92 % bagasse; 8 % urea-formaldehyde (UF) resin ; 0.74 specific gravity (SG); 0.3 in thickness

Straw: 97 % pulped rice straw; 3 percent UF resin; 0.98 SG; 0.08 in thickness

Corn Stalks: 92 % hammermilled and depithed corn stalks; 7 percent UF resin; 1 % wax; 0.74 SG; 0.5 in thickness

Cotton Stalks: 97 % refined debarked cotton stalk; 3 percent phenol-formaldehyde (PF) resin; 0.82 SG; 0.08 in thickness

Kenaf: 92 % depithed kenaf bast fiber; 7 % UF resin; 1 % wax; 0.74 SG; 0.5 in thickness

Rice: 0.94 SG; 0.2 in thickness

Sunflower Stalks: 90 % depithed sunflower stalks; 10 % PF resin; 0.74 SG; 0.4 in thickness

Sunflower Hulls: 92 % sunflower hulls; 7 % UF resin; 1 % wax; 0.78 SG; 0.3 in thickness

Table 5-1. Estimated Prices of Wood and Agricultural Fibers (\$/1000 kg)

Pulpwood & Agricultural Fiber	Stumpage ^a	Harvested and Delivered	Total
Southern pine ^b	16	25	41
Southern hardwood ^b	8	31	39
Aspen ^c	13	34	47
Hybrid poplar ^d	40	20	60
Kenaf ^e	36	19	55
Cereal straw ^f	5 to 70	20	25 to 90
Corn stalks ^f	5	20	25

Source: Youngquist et al., 1993. Reprinted with permission.

^aStumpage is growing cost plus return to land and farmer; for kenaf, straw, and corn, cost of harvest is included in stumpage

^bPrices from Timber Mart South (1992)

^cAspen prices from Wisconsin and Minnesota state forestry officials

^dHybrid poplar based on Turhollow (1991)

^eKenaf based on Sandwell and Associates (1991)

^fBased on partial survey of state agricultural extension economists

5.2.4 Fiber Availability

Not all the gross potential supply of agricultural fiber in the U.S. is freely available. For instance, to participate in Federal farm programs, all farms must have an approved conservation plan by 1995 (Youngquist et al., 1993). In some cases, this entails leaving some portion of the residue mass on the ground as cover for soil protection. In other instances, fiber by-products are used for animal bedding. In addition, fibers are available only on a seasonal basis and only in certain geographical areas, therefore shipping and storage issues must be considered as well.

5.3 Recycled Textile Fibers

Professor Chris Pastore at North Carolina State University has developed a process that converts wasted textile fibers into composite panels. The process uses thermoplastic fibers such as nylon and polyester and some glass fiber. The fibers are formed into a mat and then cured to melt the thermoplastic fibers (adhesives are not necessary to bind the fibers). After curing, the fibers solidify into a mat. A veneer laminate can also be applied to the mat prior to curing; adhesive is not required to attach the laminate since the fibers melt onto the veneer.

The textile composite can be used in traditional MDF and OSB applications; it actually outperforms OSB structurally (Pastore, 1995). Currently, a small business in Raleigh, N.C is purchasing the material instead of OSB because it is cheaper (Pastore, 1995). The pollution prevention benefits of this product are: (1) it reuses a wasted material; (2) it reduces the use of green roundwood (OSB manufacture); (3) manufacturing emissions associated with adhesives are nonexistent; and (4) indoor air emissions may be reduced since adhesives are not contained in the product.

6.0 ALTERNATIVE ADHESIVES

6.1 Background

In the U.S., composite wood panels are manufactured primarily with UF, PF, and MDI adhesive resins (Table 6-1). The use of these adhesives depends on many factors including product end use, manufacturing issues such as process emissions, worker safety, process adaptability, and consumer safety (associated with product emissions).

6.1.1 Product End Use

The selection of an adhesive is dictated by whether the product is used for interior or exterior applications. Composite wood used for exterior applications requires a waterproof adhesive such as PF or MDI. Composite wood used for interior applications requires an adhesive that is moisture resistant, but not necessarily waterproof. Most composite wood used in interior applications is bonded with UF resins; UF resins are moisture resistant, however, they will not withstand continuous cycles of wetting and drying and will begin to degrade at about 333 K and 60 percent relative humidity. Wood moisture content of 15 to 20 percent accelerates UF resin degradation at temperatures lower than 333 K (Sellers et al., 1988).

6.1.2 Manufacturing Issues

Many manufacturing issues exist regarding the selection of an adhesive. The first issue is cost. As seen in Table 6-1, UF resins are lowest in cost among the three resins, however, these adhesives are limited to interior applications. For exterior purpose resins, the cost of MDI is twice as high as that for liquid PF resins and almost one and a half times as high as that for powdered PF resins on a solids basis. Based on price alone, manufacturers have no incentive to select MDI adhesives. However, since the early eighties, one third of the OSB industry has switched from using PF adhesives to MDI adhesives. According to the U.S. manufacturer of MDI adhesives (ICI Americas), manufacturers have switched to MDI resins because of several pollution prevention benefits associated with using them. The first advantage is reduced VOC emissions associated with low temperature drying. As will be discussed in detail in Section 6.2, MDI adhesives are capable of bonding wood flakes with a moisture content as high as 12 percent. Conventional PF adhesives are only capable of bonding wood flakes with a moisture content of around seven percent. More dryer energy at a higher temperature is required to dry

Table 6-1. Adhesives Commonly Used in Manufacturing Composite Wood

Adhesive resin	Characteristics	Typical applications	Price solid basis ^a \$ per 1000 kg	Spread range ^b
Urea-formaldehyde	Hot setting and cold setting; acid curing with heat and/or catalyst accelerated fast cure; cold-water resistant; colorless; may emit formaldehyde in use	Hardwood plywood, PB ^d , and MDF ^e	400	220-317 (PB 5-8%) ^c
Phenol-formaldehyde	Hot setting; normally cured above 220°F (105°C); usually highly alkaline for rapid cure; waterproof; dark in color	Structural plywood, and OSB ^f	800 (liquid) 1100 (powder)	171-244 (plywood) (OSB 3.5-6%, liquid PF) (OSB 2-3%, spray-dried PF)
MDI ^g	Hot setting; water and heat accelerate cure, waterproof under severe conditions; neutral in color (press release agent tans wood surfaces).	OSB	1600	(OSB 2-4.5%, PB 4-5 %)

Source: Sellers et al., 1988, and Sellers, 1994.

^aMarch 1994; prices can vary by $\pm 25\%$ depending on type and quantity ordered.

^bSpreads are shown on a weight-per-area basis (kg/1000 m² of joint area) merely for comparison purposes.

^cPB 5-8% denotes 5 to 8 percent resin solids applied to board on a weight basis

^dPB = particleboard

^eMDF = medium density fiberboard

^fOSB = oriented strandboard

^gMDI = methylene diphenyl diisocyanate

wood to seven percent versus 12 percent. Thus, because less dryer energy is required to dry flakes suitable for MDI bonding, fewer VOC emissions may be generated (ICI, 1993). Additional advantages to using MDI adhesives are lower press temperatures and shorter press cycles, both of which may lead to reduced press emissions (ICI, 1993). In the past, a manufacturing disadvantage in the use of MDI has been its characteristic of sticking to the pressing equipment. For this reason, the development of release agents to prevent costly buildup of the adhesive on the equipment has been an important factor in the increased use of MDI. Two types of release agents can be used: those which are sprayed onto the surfaces of the pressing equipment and those which are added to the resins (either at the resin manufacturing facility, or at the composite wood plant).

Another manufacturing issue which influences the selection of an adhesive is occupational safety. MDI adhesives are an example of how occupational safety concerns factor into adhesive selection. Although MDI adhesives may offer pollution prevention benefits in terms of manufacturing emissions, some companies are opposed to using them for reasons such as worker toxics exposure, potential acute impacts of possible spills, and inconsistency with toxic use reduction objectives (Correl, 1994). Table 6-2 is a comparison of exposure limits and health

Table 6-2. Exposure Limits and Health Hazards Described in MSDS for MDI, UF, and PF Wood Adhesives

Exposure limits	Methylenediphenyl diisocyanate (hazard contained in MDI adhesives)	Formaldehyde (hazard contained in PF and UF adhesives)
OSHA PEL	0.02 ppm ceiling	0.75 ppm TWA; 2 ppm STEL (15 min)
ACGIH TLV	0.005 ppm TWA	0.3 ppm ceiling; A2 (suspected human carcinogen)
NIOSH REL	0.005 ppm TWA; 0.020 ppm ceiling (10-min)	Carcinogen; 0.016 ppm TWA; 0.1 ppm ceiling
Health Hazards	Irritating to eyes, respiratory system and skin. Risk of serious damage to respiratory system. May cause sensitization by inhalation and skin contact. Repeated inhalation of aerosol at levels above the occupational exposure limit could cause respiratory sensitization. The onset of respiratory symptoms may be delayed for several hours after exposure. A hyper-reactive response to even minimal concentration of MDI may develop in sensitized persons.	Skin absorption: no hazards to be known to Borden (manufacturer); Ingestion: no hazards to be known to Borden; Inhalation: not expected to be harmful under normal conditions of use. However, if allowed to become airborne, may cause irritation of nose, throat and lungs; Skin: may cause irritation on prolonged or repeated contact; Chronic exposure: potential carcinogen.

Source: ICI, 1995 and Borden, 1995.

Abbreviations used in this table are: OSHA = Occupational Safety and Health Administration; PEL = Permissible Exposure Limit; ACGIH = American Conference of Governmental Industrial Hygienists; TLV = Threshold Limit Value; NIOSH = National Institute for Occupational Safety and Health; REL = Recommended Exposure Limit; TWA = Time-weighted Average; STEL = Short-term Exposure Limit; MSDS = Material Safety Data Sheet; PF = Phenol-formaldehyde; UF = Urea-formaldehyde; MDI = Methylenediphenyl diisocyanate

hazards associated with MDI and formaldehyde (formaldehyde is the chemical hazard associated with use of PF and UF adhesives resins). As seen in Table 6-2, exposure limits to MDI are much lower than exposure limits to formaldehyde. Manufacturers of MDI state that safe exposure levels are obtainable through good engineering controls which include making sure that blenders are sealed well and that the blending and forming areas are well ventilated (Galbraith, 1995).

6.1.3 Consumer Safety

Product emissions are another issue regarding adhesive selection. The most frequently measured compound emitted from composite wood products is formaldehyde. One source of formaldehyde is the UF adhesives that bond composite wood products such as PB and MDF. Formaldehyde emissions from composite wood bonded with PF and MDI adhesives are minimal (Graves, 1993). In 1984, HUD passed a standard requiring that all PB used in manufactured homes emit less than 0.3 ppm formaldehyde under standard conditions. To meet this standard, manufacturers of UF bonded composite wood switched to reformulated UF adhesives and/or formaldehyde scavenging systems. Today, PB and MDF manufactures have a voluntary standard of 0.2 ppm for all products. As progress is made to reduce formaldehyde emissions associated with wood adhesives, research is focussing on other board emissions associated with adhesives such as VOCs.

6.2 High Moisture Bonding Adhesives

Phenol-formaldehyde and UF adhesives cure by a condensation reaction, i.e., water is released. Consequently, furnish that is bonded with conventional PF and UF adhesives must be dried to a very low moisture content (a few percent) for these resins to cure properly. Switching to an adhesive that is capable of bonding a high moisture furnish eliminates the need to dry wood to a very low moisture content. Dryer energy and temperature can be reduced because less water must be removed from the wood. Press temperatures can also be lowered since heat transfer is more efficient in high moisture furnish (Phillips et al., 1991).

The pollution prevention advantage to using a high moisture bonding adhesive is the potential to reduce VOC emissions from both dryers and presses. Figure 6-1 shows drying temperatures required for specific furnish moisture contents. Significantly lower temperatures are adequate to dry furnish to a 12 percent moisture content instead of a six percent moisture content. Because VOC emissions increase with increasing dryer temperature, these emissions should be reduced by drying at lower temperatures (Chelak and Newman, 1991).

Many OSB plants are switching to high moisture bonding adhesives with the primary goals of reducing dryer emissions and possibly reducing wood drying costs (Phillips et al., 1991). Efforts have been made to improve phenolic resin technology to allow better bonding in the presence of water. Highly pre-reacted (advanced) PF adhesives and catalyzed PF resins are capable of bonding OSB furnish with six or seven percent moisture content (Chelak and Newman, 1991). An even better adhesive for bonding high moisture furnish is MDI. MDI adhesives do not

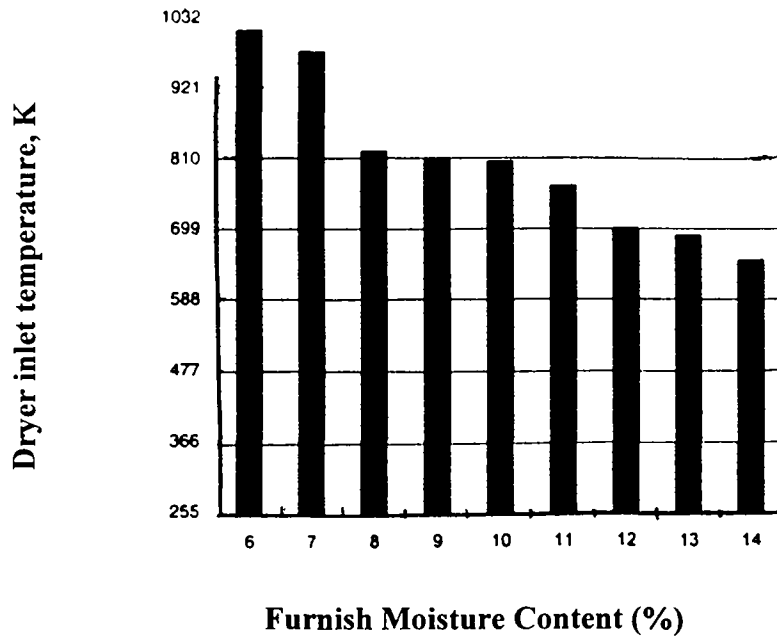


Figure 6-1. Dryer inlet temperature versus furnish moisture content (Chelek and Newman, 1991). Reprinted with permission.

produce water when they cure so they are not inhibited if water is present. They can utilize the moisture in wood to cure. As a result, MDI adhesives are capable of bonding OSB furnish with moisture contents as high as 12 percent (Chelak and Newman, 1991).

The gluing of high moisture content wood has become an established practice in manufacturing plywood (Phillips et al., 1991). The primary incentive for bonding high moisture veneer is a reduction in adhesive consumption. As discussed in Section 7.3, gluing high moisture veneer requires less adhesive than gluing low moisture veneer because there is less chance of dryout. In the southern plywood industry where dryout is a problem, a dramatic reduction in glue application rate has been achieved by gluing high moisture veneer; reduced dryer emissions and savings in dryer cost have also been achieved as a result of gluing high moisture veneer (Phillips et al., 1991).

6.3 Reformulated Urea-Formaldehyde Resins

As mentioned in Section 3.5.2.1, formaldehyde emissions are related to the F:U mole ratio in UF resins; the higher the mole ratio, the higher are formaldehyde emissions and vice versa (Gollob, 1990). Switching to a low mole ratio UF resin is one way panel manufacturers can lower formaldehyde emissions from the press and board (Figure 6-2). Often, however, the use of a low mole ratio UF resin results in significant losses of resin efficiency or productivity. To avoid these problems, many plants use formaldehyde scavengers in conjunction with their regular UF

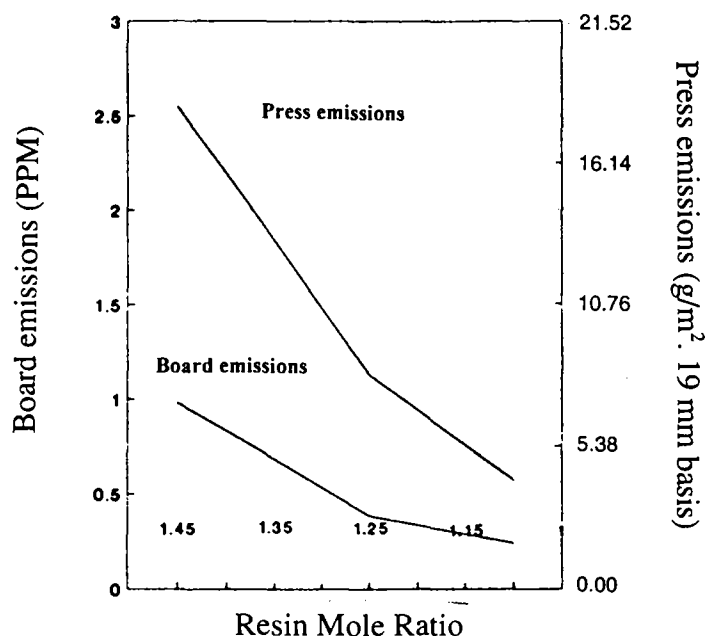


Figure 6-2. Resin mole ratio vs. board emissions and press emissions (Outman, 1991). Reprinted with permission.

resins to reduce emissions. Two common types of formaldehyde scavengers are urea scavengers and scavenger resins. The basic principle behind their uses is essentially the same; both allow the use of a high mole ratio UF resin with all its attendant benefits while achieving acceptable emissions by scavenging the excess formaldehyde (Graves, 1993). Urea scavengers have been widely used by North American panel manufacturers for a number of years. The urea is used as a solution or as a dry chemical and is added to the raw material before pressing. Application rates generally are 0.25 to 1.0 percent urea based on dry wood weight. These levels usually result in formaldehyde reductions of 15 to 50 percent depending on many plant characteristics.

Figure 6-3 shows the effect on formaldehyde emissions of various levels of urea scavenger with three different mole ratio resins; for the same level of urea scavenger, the emission reductions were more dramatic with the higher resin mole ratios (Graves, 1990).

The use of scavenger resins, commonly called combi-blending, has recently become popular among panel manufacturers as a way to reduce board and press emissions of formaldehyde. With combi-blending, a normal UF resin is used in conjunction with an ultra-low mole ratio UF resin to yield a composite mole ratio low enough to yield acceptable emissions. One advantage to using combi-blending versus a urea scavenger is that, unlike the urea, the scavenger resin has adhesive properties and contributes to bonding. Figure 6-4 shows the results from a plant trial where resin substitution levels up to 30 percent were employed; the data show that formaldehyde concentrations were reduced almost 50 percent at the 30 percent substitution level (Graves, 1993).

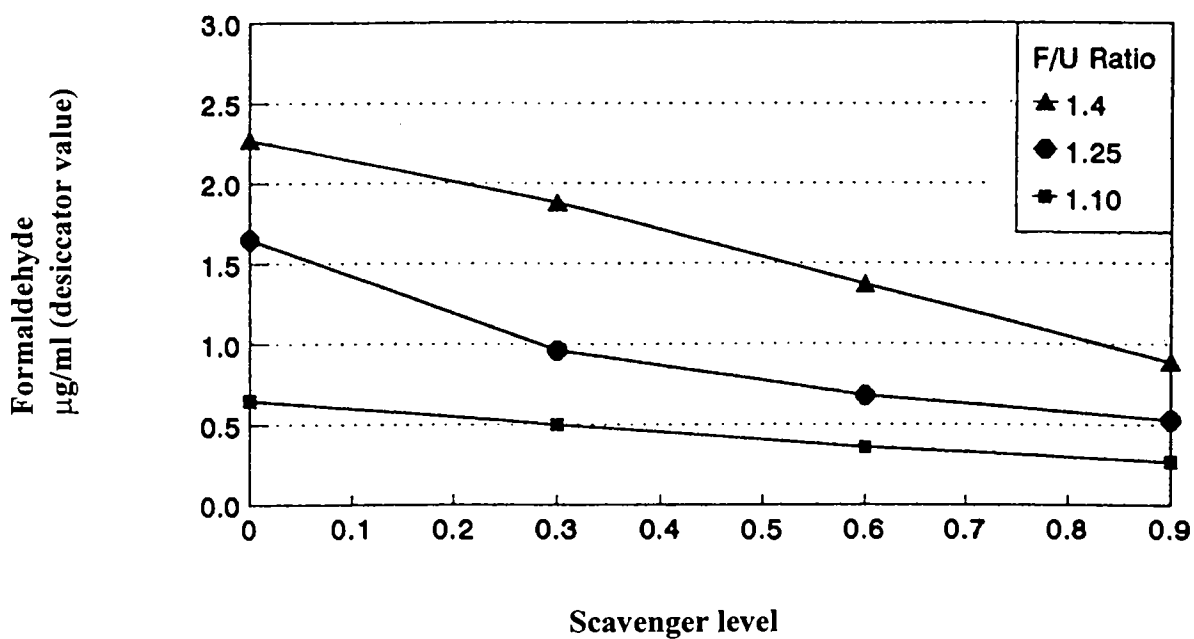


Figure 6-3. Effect of urea scavenger on formaldehyde emissions when used with various mole ratio UF resins (Graves, 1990). Reprinted with permission.

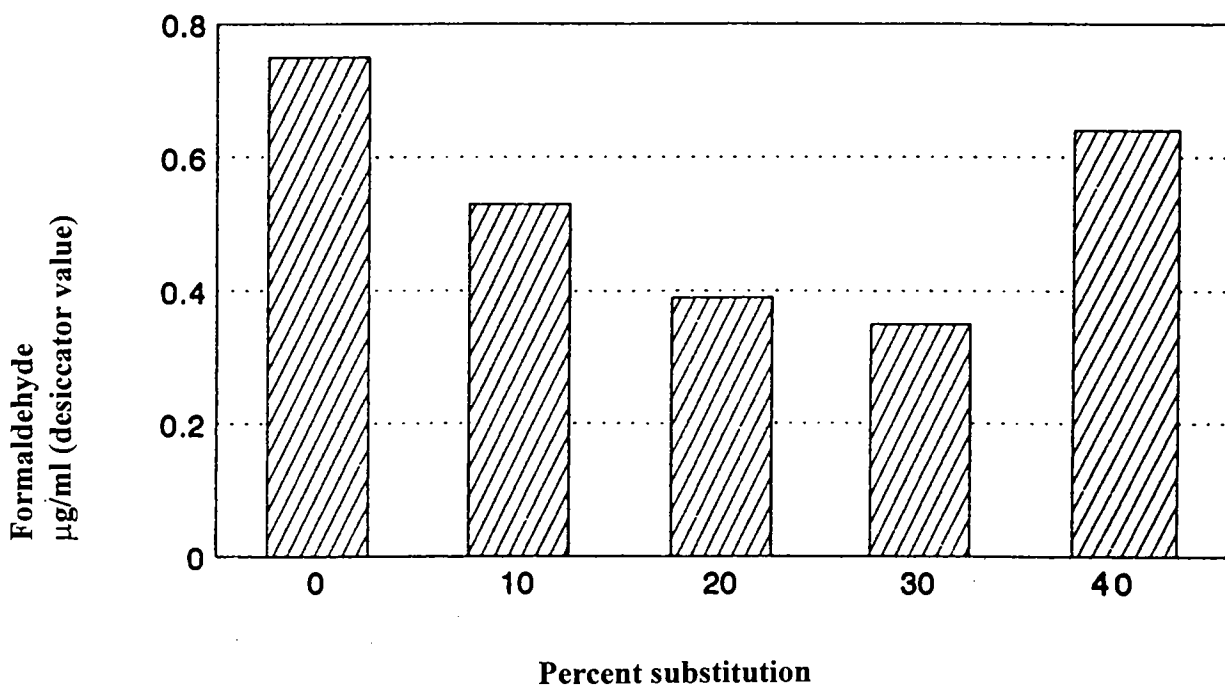


Figure 6-4. Formaldehyde emissions results from panels made during a production trial of scavenger resin (Graves, 1993). Reprinted with permission.

6.4 Naturally Derived Adhesives

The three major adhesives used in the wood panel industry (UF, PF, and MDI) are all synthesized from petroleum-derived chemicals. The wood panel industry consumes about 25 percent of the total U.S. adhesives production (Koch et al., 1987). Over the past decade, the price of the raw materials used in these adhesives has been growing rapidly. The price of phenol, for example, has more than doubled since 1985 (in 1990 it was \$0.99/kg compared to \$0.42/kg in 1985). The price of methanol (the basic raw material used to produce formaldehyde) jumped from \$0.18/liter (l) in June of 1994, to \$0.34/l in October 1994 (Wellons, 1994). The rapid price increases are a result of increased competition for these raw materials.

The major competition for phenol has come from demand for bisphenol A and caprolactam. Bisphenol A is the feedstock component for polycarbonates which are used to produce automotive plastics, compact discs, and computer discs. Caprolactam is a basic raw material for the production of Nylon 6™ which is used in the fast growing stain resistant carpet market. Phenol demand for both bisphenol A and caprolactam is expected to exceed PF resin by 1995 (White, 1990). In addition to causing higher prices for PF adhesives, the demand for phenol is reaching world capacity. In 1988, the consumption of phenol equaled 96 percent of the world capacity (White, 1990).

The increase in demand for methanol has been fueled both by general economic improvement in the U.S. and abroad, and most importantly, by the growth of methyl tertiary butyl ether (MTBE) as an oxygenate and octane booster in gasoline (Wellons, 1994). The MTBE market is forecasted to grow from the 1993 level of 4400 million kg to over 8000 million kg in 1997 (Wellons, 1994). Other major methanol markets, formaldehyde and acetic acid, are forecasted to grow equal to or above the rate of the gross national product (Wellons, 1994).

The significant price increases and potential scarcity of raw material supplies for UF, PF, and MDI adhesives have created interest in renewable raw material sources. Research and development funds are being expended by chemical raw material suppliers, forest products companies and wood adhesive/binder suppliers to search for renewable raw material sources to replace entirely, or least partially, petroleum-derived chemicals in the manufacture of wood adhesives. Some of the current research is presented below. Naturally derived adhesives are included in this report as pollution prevention because of their potential to use renewable resources, which in many cases are by-products of other processes. An effort was made to collect information on availability, cost, properties, composition, environmental effects, and stage of product development for each product. Any information found on these topics is included with each adhesive. However, for most of the adhesives, the above information was not found.

6.4.1 FAREZ® Resin

FAREZ® resin is manufactured from furfuryl alcohol, a derivative of corn. The resin is being evaluated at the University of New Brunswick, in Canada, as an alternative low VOC binder to substitute for PF resins used for glass fiber insulation products and wood products (Rude, 1994).

6.4.1.1 Environmental Effects

Unlike PF resins, the FAREZ® resin is storage stable at ambient temperatures, without refrigeration. As delivered, the FAREZ® resin contains very low amounts of volatile components. Upon curing, especially heat curing, the FAREZ® resin liberates 80 to 90 percent less total VOC emissions and 80 to 90 percent less emissions of materials on the HAP list (Rude, 1994). The FAREZ® system offers the same relative speed of cure as the PF resin systems. Various acidic catalyzation options are available that allow either ambient temperature or heat curing capability.

6.4.1.2 Availability

The FAREZ® resin is manufactured by the Quaker Oats Company and is currently in the experimental stage of development. The insulation and wood products industries have shown little interest in the resin because of its high cost; the cost of the resin is twice that of a PF resin. However, cost analyses have been performed for the insulation industry which show that using the resin to meet future HAP standards would be cheaper than purchasing and operating control devices such as scrubbers. The same is likely to hold true for the wood products industry (Rude, 1994).

6.4.2 Methyl Glucoside

Plywood glue contains PF adhesive resins. Conventional PF resins typically have formaldehyde to phenol (F:P) ratios ranging from 1.7 to 2.1. Lower F:P ratios are not used because the cure rate is too slow. Higher F:P ratios are not used because the cure rate is too fast which causes the glue to dry out before the veneer is pressed together. Higher F:P ratios also lead to high levels of residual formaldehyde that can be emitted during curing as well from the product during use (Drury et al., 1990).

PF resins are synthesized in regional plants and shipped to individual plywood mills. At the mills, the PF resins are combined with proteinaceous extenders, lignocellulosic fillers, and caustic to make a glue mixture. The extenders, fillers, and caustic are added to modify the viscosity of the adhesive to be compatible with the method of glue application (curtain, roll, spray, foam); allow better distribution of the adhesives; faster cure; and lower costs. A typical proteinaceous extender is soft wheat flour; a typical lignocellulosic filler is pecan flour (Sellers et al., 1988).

Researchers at the University of Illinois have been investigating the use of methyl glucoside (MeG), a corn-derived monosaccharide, in the manufacture of plywood adhesives. Researchers have incorporated MeG into plywood adhesives as both an additive and as a partial replacement for phenol in PF resins used in plywood adhesives.

MeG can be incorporated into plywood adhesives either by adding it to the glue mix used at a mill or cooking it into the PF resins manufactured at regional plants. At the mill, MeG can be added to the glue mix as an additional ingredient or it can replace part of the PF resin in glue mix. (Details about the incorporation of MeG into glue mixes is published in Sellers and Bomball [1990].) Laboratory studies and large-scale mill trials indicate several positive properties from the incorporation of MeG into glue mixes including lower adhesive cost, better dry-out resistance, and better flow properties of the glue. The improved dry-out resistance allows spread reductions of up to 12 percent, resulting in significant cost savings (Drury et al., 1990).

A more direct and easier way to incorporate MeG into plywood adhesives is to cook it into the PF resins which are manufactured at regional distribution plants. The modified PF resins can then be distributed to individual plywood mills, as opposed to attempting to optimize MeG in every plywood mill's glue mix. Laboratory studies have shown that MeG can replace up to 50 percent of the phenol in a base 1.7 to 2.1 F:P mole ratio resin, resulting in a resin with a F:P mole ratio of up to 4.2. Wood failure and tensile strengths comparable or superior to conventional resins were achieved with no increases in free formaldehyde or loss in storage stability (Drury et al., 1990).

One pollution prevention benefit of adding MeG to PF resins is that the modified resin can bond high moisture veneer (veneer with 9 percent moisture was bonded in the above studies). As discussed in Section 8.4, the pollution prevention advantage to using an adhesive that is capable of bonding high moisture wood is the potential to reduce VOC emissions from both dryers and presses. Another pollution prevention benefit of adding MeG to the PF resin is that phenol consumption is reduced, which in turn may reduce phenol emissions at the press (emissions data were not found in the literature to confirm this).

6.4.2.1 Future Availability

MeG is made from corn. As the drought of the summer of 1988 demonstrated, even when yields of corn are almost halved, there remain corn surpluses sufficient for all current needs (Drury et al., 1990). In normal years, American farmers, produce nearly twice what is needed in the U.S. or can be exported (Drury et al., 1990).

The incorporation of MeG into PF resins (the easier and more direct way of incorporating MeG into plywood adhesives) has yet to be scaled-up to resin producers/plywood mills. But if the modified resins can be demonstrated on a plant scale, incorporation of MeG into plywood adhesives will proceed at a much faster pace than at present. The long term goal after successful

commercialization of this technology in the plywood industry is to extend this approach to other structural panels such as OSB. OSB panels use a much higher amount of PF resin adhesive because of the higher surface area of the wood strands being glued compared to plywood. The use of MeG in the OSB industry could lead to greater cost savings and pollution prevention benefits through reduction of adhesives use.

6.4.3 Lignin Adhesives

Lignin is an aromatic polymer made up from phenylpropane units. Lignin makes up one of the three major components of wood, along with cellulose and hemicellulose. In chemical paper processes, such as kraft pulping, lignin is transformed into a soluble form and removed. In 1980, an estimated 20 billion kg of lignin (in the form of spent liquor) were produced from kraft pulping in the U.S. Only 40 million kg (0.20 percent) of this lignin was recovered from the spent liquor and used in manufacture of by-products (Zhao et al., 1994).

6.4.3.1 Adhesive Utilization

Lignin can be used as a feedstock for aromatic-based chemicals. Consequently, the abundance of lignin as a waste product in pulp mills has made it a desirable raw material alternative to nonrenewable petroleum-derived chemicals in the production of wood adhesives. Research into utilizing lignin for adhesive production has been ongoing for years. A large portion of the research has focused on the substitution of lignins for PF adhesives. While 100 percent lignin substitution has yet to be achieved, there has been industrial success with partial substitution of lignins into PF adhesives. Substitution of 20 to 30 percent of kraft lignin into PF resins is common in plywood applications. Until recently, no more than 20 to 30 percent of lignin could be substituted into PF resins because cure times increased as the amount of lignin increased. Another drawback has been that lignin adhesives have low cross-linking and strength. However, recently, a new approach has been developed that can substitute large amounts of kraft lignin for PF adhesives, while actually increasing the cure speed, as well as board strength (Stephanou and Pizzi, 1993). According to research published by Stephanou and Pizzi (1993), a different, and up to now, unknown chemical reaction mechanism has been developed to give “truly competitive kraft lignin-based wood adhesives of good exterior grade performance.” The new approach, which utilizes MDI resins, has been demonstrated on a lab scale level; exterior grade PB panels with excellent strength properties were prepared from adhesives containing 46 to 63 percent kraft lignin resin solids, at press times much faster than those used for traditional synthetic PF resins (Stephanou and Pizzi, 1993). The results of this research “...clearly indicate that excellent lignin-based adhesives for exterior grade panel products can be manufactured. These adhesives have none of the drawbacks which have been the main stumbling blocks in the effective industrial utilization of lignin for panel binders, namely low cross-linking and strength, and particularly, far too slow pressing times. The adhesives produced gave panels of excellent strength, good durability and very fast press times” (Stephanou and Pizzi, 1993).

6.4.3.2 Availability

Currently, Westvaco is the only company in the U.S. that operates a commercial lignin extraction facility. In early 1990, the selling price of kraft lignin was approximately \$0.71/kg to \$0.75/kg, and the selling price of phenol was approximately \$0.99/kg (White, 1990). Although an adhesive manufacturer can purchase kraft lignin at a cheaper cost than phenol, additional processing is required to make the lignin appropriate for adhesive production; the additional processing results in the cost of lignin being equal to that of phenol (White, 1990). However, if the price of phenol continues to rise and exceed the total manufacturing cost of lignin, and assuming sufficient quantities of extracted commercial lignin could be made available, lignin could compete as a partial raw material coreactant with phenol in PF wood adhesives (White, 1990). For there to be sufficient quantities of extracted lignin, additional lignin extraction facilities must be built. The capital cost of a new commercial lignin extraction facility compared to the capital cost of a new phenol plant is estimated to be almost equal per kg of product produced.

6.4.4 Tannin

Tannin refers to a widely occurring group of substances derived from plants. In their most common usage, these substances are capable of rendering raw hides into leather. Common tannin or tannic acid is found in a variety of nuts, tea, sumac, and bark. It is a complex, dark polyhydroxy PF compound.

As a bark product, tannins are readily available. Large quantities of bark are available at mill sites where bark is a waste product of sawmilling and other panel making processes. On average, bark contains 15 to 30 percent polyphenols, 20 to 30 percent lignin, 30 to 45 percent carbohydrates and 1 to 3 percent fats and waxes (Koch et al., 1987). These values are dependent upon wood species, location, age, and exposure.

6.4.4.1 Adhesive Utilization

The use of tannin adhesives for the manufacture of exterior grade weatherproof PB has been gaining increasing industrial and technical acceptance during the last twenty years (Pizzi, 1983; Pizzi, 1989). Until recently, all industrial formulations have been based on tannins such as wattle (mimosa extract of commerce) and quebracho (Pizzi 1983; Pizzi, 1989). In countries where these tannins are produced, wattle and quebracho tannins have been progressively displacing synthetic PF adhesives for manufacturing exterior PB, due to their lower cost and excellent performance (Pizzi 1983; Pizzi, 1989). However, the total worldwide production of these two tannins is only 150 million kg per year. This is coupled with the fact that the tannin producers do not make more than 20 to 30 percent of their total production available for adhesives application (the rest being reserved for their traditional market, leather). For these reasons these materials, although industrially and commercially very successful, have had little chance to influence the PF adhesives market.

A tannin that can easily be extracted and rendered available in most countries is pine tannin, extracted from the bark of the most diffuse worldwide forestry crop, pine trees (Pizzi et al., 1993). Significant amounts, well into the billions of kg, of this tannin could be rendered available if a successful wood adhesive system based on it could be proven industrially (Pizzi et al., 1993). Recently in Chile, a small industrial producer of native and sulphated pine tannins has developed an adhesive consisting of MDI, tannin, and formaldehyde for exterior grade PB. Industrial results of extended plant production runs of this adhesive system showed "very encouraging results" (Pizzi, 1993) .

7.0 REDUCING ADHESIVE CONSUMPTION

In the plywood industry, spray-line layup systems are commonly used to apply adhesives. These systems generate a lot of overspray. Although most of the overspray is collected and reused, some waste is generated. Applying adhesives more efficiently and/or reducing the amount of adhesive required in the panel can reduce this waste. As discussed throughout Section 3.5.2, reducing the amount of resin in the panel may also reduce press emissions.

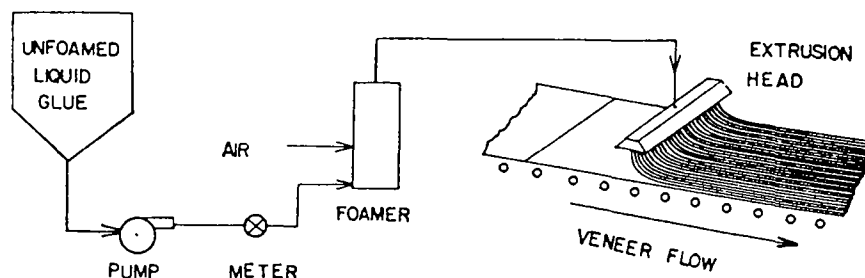
7.1 Foam Extrusion

An efficient way of applying adhesive to veneer is by foam extrusion (a typical foam adhesive mix for gluing plywood is shown in Table 7-1). In the extrusion process, strands of glue are deposited precisely on the panel thus eliminating over application (Figure 7-1). The layup line consists of multiple extrusion stations similar to the one in Figure 7-1. At each station, mixed glue is pumped from a central storage tank (not shown in Figure 7-1), into a holding tank. From the holding tank, the glue is pumped at a controlled rate to the foaming unit. The foamed adhesive is then forced under pressure to the extrusion head. The extrusion head converts the large incoming stream of foamed glue into 160 small round streams through a series of branches. The extrusion head consists of three plastic plates: an intake plate, a center plate which contains

Table 7-1. Typical Foam Adhesive Mix for Gluing Plywood

Water	792 (kg)
Blood	82
Wheat Flour	204
Caustic Soda	61
Resin (43% solids)	1588
Surfactant	4
Total	2731

Source: Nylund, 1985.



**Figure 7-1. Flow diagram of foam extrusion apparatus (Cone, 1969).
Reprinted with permission.**

the 160 extrusion orifices spaced about 21 mm apart, and a defoam plate. If the line stops, the glue is diverted to the defoam plate. Inside the defoam plate are branching channels through which the glue flows into a central stream to a defoamer. The defoamed glue is sent back to the holding tank where it mixes with fresh incoming glue. From there, it will be refoamed and sent back to the extruder when the line restarts. Sheets of veneer are laid up either by hand or by vacuum system. After the last sheet is placed on the panel, the panel passes through a mashout press.

The mashout press consists of two rolls that apply pressure to the laid up panel to flatten out the glue strands, providing glue coverage between the strands and intimate contact between the glue and both veneer surfaces. The panel then travels to the prepress and hot press as in a conventional lay up line.

In addition to reducing adhesive waste, foam extrusion also reduces the chance of dryout. When wet glue comes into contact with dry veneer, the water in the glue migrates into the veneer, which causes a loss of fluidity in the glue. The drier the veneer, the faster is the migration of the water. If too much water migrates into the wood, the glue film no longer has sufficient fluidity to make intimate contact under pressure with the opposing veneer surface, resulting in poor bonding. This condition is referred to as dryout. In spray-line applications, dryout is prevented by increasing the amount of adhesive applied to the panel. Applying excess adhesive is not necessary in the foam extrusion process. Foaming the glue and applying it in the form of rods, slows down the migration of water, thereby impeding dryout. Foaming, by increasing the thickness of the glue layer, forces the water contained in the glue to travel farther in order to reach the wood. Depositing the foamed glue onto the veneer surface in the form of rods that are spaced apart reduces the area where glue and wood make contact and therefore, reduces the opportunity for water to migrate.

The combination of less waste and lower glue application rates when using foam extruders can reduce adhesive costs by 20 to 31 percent, depending on the type of equipment being compared to the foam extruder (Nylund, 1985). In 1985, seven plywood plants were using the foam extrusion process. Foam extrusion appears to be the future of adhesive application in the plywood industry (Nylund, 1985).

7.2 Variable Glue Spread for Veneer Layup

The amount of adhesive/glue required to bond veneer varies with moisture content. For example, high moisture veneer requires less glue than low moisture veneer because there is less migration of water from the glue into the veneer. Although the moisture content of veneer varies at a plywood mill, glue is applied at a constant rate to prevent dryout of low moisture veneer. As a result, an excess amount of adhesive is applied to high moisture veneer. When this happens, the glueline contains too much moisture. As a result, the glue penetrates too deeply into the veneers when they are pressed together and a poor bond forms because not enough glue remains between the veneers. This condition is referred to as washout.

In a study by Faust and Borders (1992), variable and constant glue rates were used to bond plywood and bond quality was compared. The variable application rate strategy (VARS) adjusted the glue application rate for each individual plywood panel according to its moisture content. For instance, when conditions for dryout were present, the glue application rate was increased to provide additional moisture to the glueline and increase glue penetration during hot-pressing. When conditions for washout were present, a lower glue application rate was used to reduce the moisture in the glueline and retard glue penetration during hot-pressing. Essentially, the application rate was adjusted to control the rate of penetration of glue into the wood substrate. With constant rate application strategy (CARS), the glue application rate was held constant for all veneer moisture contents.

The Faust and Borders study investigated the effect of VARS on bond quality and glue mix consumption in manufacturing southern pine plywood. When compared to CARS, VARS improved overall wood failure by 8.3 percent while reducing glue consumption by more than 13.1 percent (see footnote for definition of wood failure).⁴ The broad range of application rates used by VARS was effective in reducing dryout problems. VARS performed extremely well in conditions that normally induce dryout and in extreme conditions of washout.

Process-sensing and control technology has been developed for the practical application of VARS. Sensor technology is currently available for on-line measurement of veneer moisture

⁴ Wood failure is a measure of how well glue bonds to veneer. To measure wood failure, two pieces of bonded veneer are pulled apart. The bond is good when the separation damages the surfaces of the veneers, i.e., the separation causes wood failure; the bond is poor when the two pieces of veneer pull apart without any damage to their surfaces. The higher the damage to the veneers when pulled apart, the higher is the wood failure rating, which is reported as a percentage. The APA sets a minimum of 70 percent wood failure for plywood.

content and temperature. The accurate on-line adjustment and measurement of application rate has also been investigated and has been commercially implemented for spray applicator systems.

From a manufacturing standpoint, the greatest benefit of implementing VARS is to compensate for problem bonding conditions that occur unexpectedly during production, i.e., when there is a shortage of dry veneer and hot veneer is used directly on the layup line causing dryout problems; when high moisture content veneer is used in a veneer shortage situation causing washout or steam blows; when there is a shortage of properly conditioned peeler block and rough veneer results; when crews are unaware of problem bonding conditions due to lack of experience; and when an unexpected shutdown of the hot-press results in long assembly times. From a pollution prevention standpoint, the greatest benefit of VARS is a reduction in adhesive consumption, and consequently, a reduction in plant emissions.

8.0 PROCESS MODIFICATIONS

8.1 Low Temperature Drying

8.1.1 Recirculation of Dryer Exhaust

As discussed throughout Section 3.4, high dryer emissions of TGNMO and formaldehyde are associated with high drying temperatures. Process modifications that will lower the required dryer temperature should lower these emissions. As discussed in Section 6.2, the use of high moisture bonding adhesives is one way to lower dryer emissions. Another option for lowering dryer temperatures is to recirculate the dryer exhaust. Figure 8-1 shows the relationship between the dryer inlet temperature and the amount of water removed from dryers at four reconstituted panel mills (NCASI, 1986c). At high water removal rates (greater than 0.80 kg of water per pound of product), the dryers represented by the solid triangles and open squares operated at lower inlet temperatures than the dryers represented by the solid squares. The dryers represented by the solid triangles operated at low inlet temperatures by diluting the inlet gas stream with air. The dryers represented by the open squares operated at low inlet temperatures by recirculating exhaust gas to the burner outlet to cool the gases entering the dryer. Although both methods lowered the inlet temperature, the dryers which used dilution air required a thermal input ranging from 3,527 to 4,630 British thermal units per kilogram of water removed (Btu/kg H₂O). The dryers that recirculated their exhaust stream required about 2,866 Btu/kg H₂O. Thus, recirculation of exhaust gas is the most efficient way to lower inlet dryer temperatures.

8.2 Steam Injection Single Opening Press

As mentioned in Section 5.1, the CanFibre company is planning to build nine MDF plants in North America that will use 100 percent post-consumer waste and PF adhesives. CanFibre's plant process will be similar to traditional MDF processes, in that wood will be refined, dried, combined with adhesive, and pressed. However, there will also be unique components of the process that have potential pollution prevention benefits.

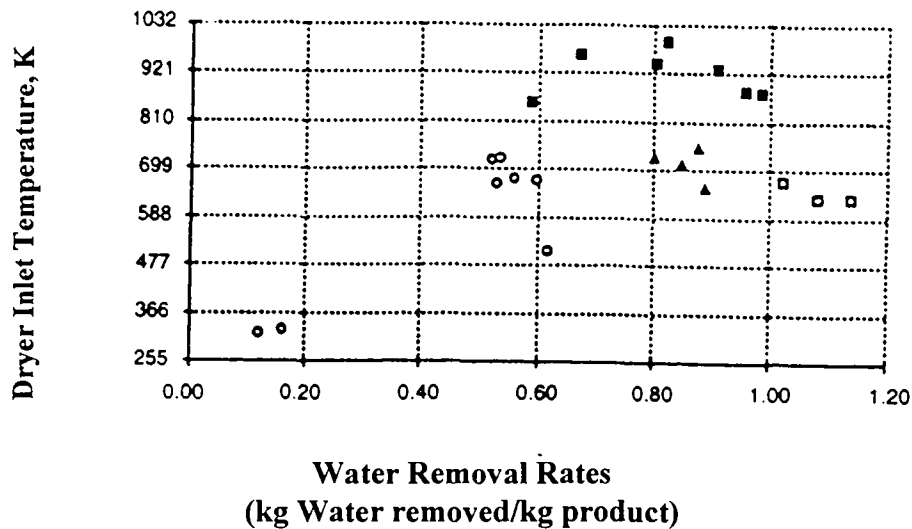


Figure 8-1. Dryer inlet temperatures as a function of the water removed per pound dry product (NCASI 1986c). Reprinted with permission.

A typical CanFibre plant will receive pre-sorted wood waste that will be free of most brick, concrete, stucco, and gypsum. A primary crusher will break down the wood into 251 mm square chips. The chips will be fed onto a vibrating feeder and go through a series of metal detectors and rock traps. A secondary crusher will break the wood chips into chips approximately 25 mm square by 6.35 mm thick. The chips will be once more screened by magnets before being washed to remove any remaining grit (Duncanson Investment Research Inc., 1993).

After cleaning, the wood chips will be processed through a high pressure steam digester and a double disc refiner (similar to traditional MDF plants). The refined fiber will be dried to approximately 4 to 6 percent moisture content. The fiber will be blended with PF resins in a high pressure steam conditioning blender. Combining the resin in this manner will result in 50 percent less adhesive being added to the board than is typically required in a standard MDF process (Duncanson Investment Research Inc., 1993). As a result, the resin content in CanFibre's MDF panel will be less than 6 percent by weight as compared to an industry average of 10 percent (Duncanson Investment Research Inc., 1993).

In standard MDF presses, adhesive coated fiber mats are "sandwiched" between hot plates called platens; the heat from the platens transfers gradually from the panel surface towards the center. The combination of heat and pressure sets off the curing of the adhesive. The heat transfer takes approximately 5 minutes for a 19.05 mm panel. The CanFibre process will use a type of press that heats panels by injecting live steam into them. The CanFibre press, recently developed by Forintek Canada Corporation, consists of a pressure bar mounted to the upper press platen, which compresses and seals the edges of the panel. Orifices located on the underside of the upper

platen intermittently inject steam into the panels and then vacuum the steam out. As the steam permeates through the panels, it drives off the moisture in the wood and adhesive. Because the curing process of the CanFibre press involves both mass and heat transfer (the curing process of a hot platen press involves only heat transfer), cure time using the CanFibre press is half that of a standard MDF press (Duncanson Investment Research Inc., 1993). Also, because the heat transfer using the Forientek press works from the interior of the panel to the surfaces, the cure is more uniform. (A major disadvantage with a hot platen press is surface overcuring, especially with thicker panels.)

In the U.S., the majority of PB and MDF are bonded with UF adhesives. UF adhesives are used to bond these panels instead of PF or MDI adhesives for various reasons. As discussed earlier, most PB and MDF are used for interior purposes, thus waterproof adhesives such as PF and MDI are not necessary. Although PF and MDI adhesives could be used to bond PB and MDF panels, UF adhesives are substantially cheaper than these adhesives (see Table 6-1) and they also cure faster and at lower temperatures than PF adhesives. Because the Forintek steam press reduces panel curing time by more than 50 percent, the CanFibre process will be able to use slower curing PF adhesives at a cost comparable to using UF adhesives (Duncanson Investment Research Inc., 1993). Manufacturing MDF panels with PF adhesives will also allow the panels to be used in exterior applications.

Production costs for the proposed CanFibre mills are projected to be 35 percent lower than those of Medite Corporation - one of the leading MDF producers in the U.S. (Duncanson Investment Research Inc., 1993). Significant cost savings will be from a negative wood cost, i.e., waste companies will pay CanFibre to dispose of construction wastes, waste paper, and other dry wastes. Significant savings will also be from low transportation costs. Most of the existing MDF plants are remotely located and the cost of hauling wood waste back to these mills is high. The proposed CanFibre mills will be located in the "urban" forest - close to post consumer waste and close to end customers. On a delivered basis, CanFibre's costs are projected to be 45-50 percent lower than those of its competitors (Duncanson Investment Research Inc., 1993).

Many pollution prevention benefits are associated with the future CanFibre process. Manufacturing emissions may be reduced (compared to a traditional MDF plant) due to: (1) the use of PF resins, (2) lower resin usage, and (3) lower energy usage. Emissions may also be reduced from consumer products (versus products made with UF-bonded MDF) (Duncanson Investment Research Inc., 1993). In terms of recycling, the entire wood supply for the CanFibre process will consist of construction wastes, waste paper, and other dry wastes which would otherwise be landfilled.

8.3 Shelter for Raw Materials

Dry wood residues such as planer shavings from kiln-dried lumber, plywood trim, etc., require little heat to reduce their moisture content to that required for panel manufacture. The energy savings are lost, however, if the dry residues are stored outside and get wet. Consequently,

shelters should be used to prevent the wood from getting wet. Even green residues should be kept under a shelter to allow air drying. It has been shown in the asphalt industry that air drying the aggregate to reduce the moisture content from 6 to 4 percent can reduce fuel consumption by 19 percent and increase production capacity by 31 percent (Foster, 1987). Protecting the aggregate from getting wet has much the same effect (Foster, 1987).

8.4 Conveyor Belt Drying

Rotary drum dryers are used in the OSB industry to dry strands. Rotary dryers are typically characterized by high drying air temperatures, short retention times, and aggressive handling of strands (Teal, 1994). The adverse effects of these characteristics include the generation and emissions of various airborne pollutants, and strand damage. Consequently, attempts have been made to utilize low-temperature air in rotary dryers. However, one limitation to this change has been the fact that as temperature is reduced, retention time and/or air flow must be increased to maintain the same evaporative load. In a rotary dryer, the air flow serves two purposes: to remove the evaporated water, and to move the product through the drum. Therefore, it has been difficult to increase retention time in order to compensate for reduced drying air temperatures (Teal, 1994). Although mechanical devices have been used in attempts to retard the flow of strands through the drum, these too have met with limited success, and often contribute to strand breakage (Teal, 1994).

Conveyor dryers offer an alternative method to drying OSB strands as well as other reconstituted wood materials. A conveyor dryer is typically constructed of sections of perforated plate, linked by continuous hinges, and attached to carrier chains. The bed moves continuously through the dryer and may be driven at varying speed, thus allowing for precise control of retention time of product within the dryer.

The drying air may be heated by various means. Natural gas or oil may be used to fire a burner, over which air is passed. Steam or thermal oil coils also frequently serve as a source of heat. Exhaust gases from a furnace may also be used and blended with ambient air to control drying air temperature.

Fans pull or push the drying air through the dryer conveyor and the product on it. As the heated air passes through the wet product, it picks up moisture, and cools. The "spent" drying air may be exhausted entirely, or partly recirculated to conserve thermal energy. Dampers are typically used to determine the portion of air recirculated.

According to Benny Teal of TSI, conveyor drying provides several pollution prevention benefits when compared to rotary drying.⁵ The first pollution prevention benefit is lower exhaust volume.

⁵TSI is located at 115 Second Ave. N., Edmonds, WA 98020/206-771-1190. TSI works with conveyor dryer manufacturer Proctor & Schwartz, which is headquartered in Horsham, PA. and has a manufacturing facility in Lexington, NC.

The volume of air exhausted from a conveyor dryer using thermal oil as a heating medium is generally one-half to one-third of the volume exhausted by a conventional three-pass rotary dryer operating at the same capacity. The lower exhaust volume reduces the capacity of any equipment which might be required to treat the spent air prior to release to the atmosphere.

Another benefit to using a conveyor dryer is its ability to adjust to variations in flow rate, wood species and moisture content (Teal, 1994). With rotary dryers, temperatures and air flows are high and retention times are short, offering little opportunity for variation and therefore adaptability to changes in demands on the dryer (Teal, 1994). Rotary dryers are slow to respond when mass flow rates vary or when evaporative load changes quickly and significantly (Teal, 1994). In contrast, conveyor dryers can independently vary temperature, retention time, and air flow. With a conveyor dryer, it is feasible to stop the dryer with partially-dried product inside, then restart several minutes, even hours later.

A third benefit associated with conveyor dryers is that they are capable of operating at temperatures below 478 K. According to Teal, the low operating temperature of the conveyor dryers reduces VOC emissions (Teal, 1994). An article by Teal presents emissions data from recent VOC tests conducted on full-size and lab-size conveyor dryers. Measurements were made at several operating temperatures. Based on the data, VOC concentrations decrease as temperatures decrease, however, the changes are not linear, implying a diminishing reduction in VOC as the temperature drops to very low levels (Teal, 1994). Additionally, lower drying temperatures result in longer drying times, so that VOC concentrations alone are not directly indicative of the comparative benefits of changes in drying temperature (Teal, 1994). The VOC data in the article were not compared to VOC concentrations from rotary dryers. Consequently, the magnitude of reduction in VOC emissions from conveyor dryers (compared to rotary dryers) could not be determined.

Proctor & Swartz, a manufacturer of conveyor dryers, was contacted for a rough cost estimate of a conveyor dryer for the OSB industry. The contact at Proctor & Swartz was unable to estimate the cost of a conveyor dryer or give any indication of the relative cost between a conveyor dryer and a rotary drum dryer. The contact stated that estimating the cost of a conveyor dryer required very specific information such as the inlet and outlet moisture content of the strands and strand throughput.

8.5 Three-Pass High Velocity Rotary Drum Dryer

The following is an excerpt from an EPA report (Vaught, 1990). The excerpt describes the three pass high velocity dryer (3PHV) manufactured by Productization, Inc., located in Independence, Kansas. The 3PHV is a new type of OSB dryer which may generate fewer emissions than conventional OSB dryers.

Another critical cause of blue haze is overloading a dryer by attempting to remove too much moisture within a given time. Overloading results in the introduction of green material to a high-temperature flame or gas stream causing a thermal shock that results in rapid and

excessive volatilizing of hydrocarbons that condense upon release to ambient air, causing the characteristic blue haze.

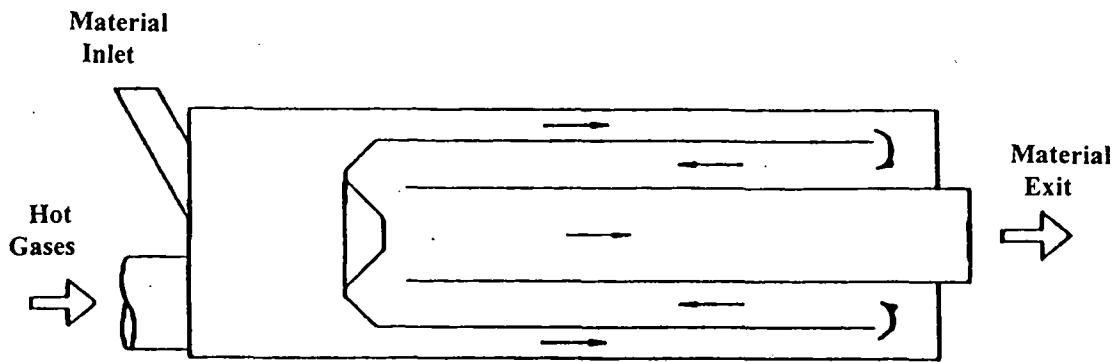
The conventional three-pass dryer is a rotating cylindrical drum that consists of three, concentric interlocked cylinders. Hot gases enter the innermost cylinder with the wet wood chips and progress through the intermediate and then the outer drum shells in a serpentine flow path while pneumatically conveying the wood chips through the dryer.

In a conventional three-pass dryer, the velocity of the air slows through the second and third passes, allowing larger particles to settle out and smaller particles to pass through; however, this is not the case at high material flow rates. Larger settled particles will interrupt the flow of the smaller, faster moving particles with the result being that all particles are traveling at a rate determined only by the forward velocity of the larger particles. When smaller particles are held at these slower velocities in the second and third passes for a prolonged period of time, volatilization of their surfaces occurs, which results in the formation of hydrocarbon and carbon monoxide emissions. Should plugging occur in the second or third passes due to the material dropping out of suspension, elevation of particle surface temperature to their flash points will result in combustion.

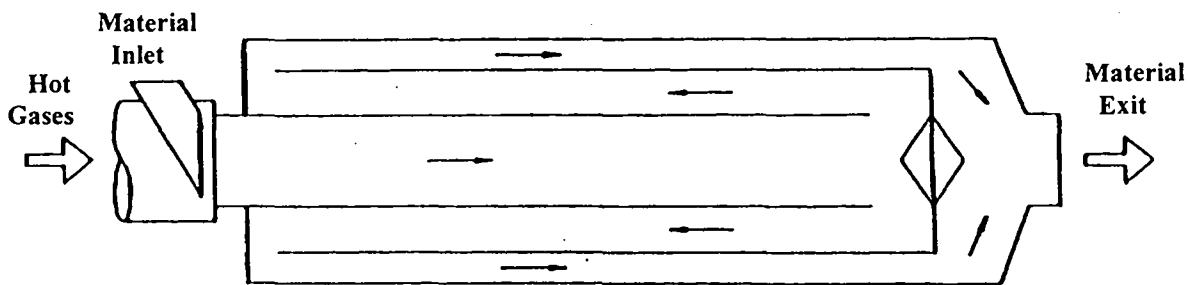
The conventional three-pass dryer is a rotating cylindrical drum that consists of three, concentric, interlocked cylinders. Hot gases enter the innermost cylinder with the wet wood chips and progress through the intermediate and then the outer drum shells in a serpentine flow path while pneumatically conveying the wood chips through the dryer.

The 3PHV rotary dryer, shown in figure 8-2, like the conventional three-pass dryer, is a rotating cylindrical drum consisting of three, concentric, interlocking cylinders. In the 3PHV dryer, hot gases enter the outermost cylinder with the wood chips and progress through the intermediate and then the inner drum shells in a serpentine flow path. This flow path direction is the opposite of that in the conventional three-pass dryer (see Figure 8-2). The reason the 3PHV should reduce emissions is described below.

A determinant in establishing a saltation (conveying) velocity for a particle is the relationship between the density of the particles to the density of the supporting gases. As wet particles dry, their density decreases, and as gases cool (due to the transfer of heat), their density increases. When the density of the particle decreases sufficiently due to its drying, and the density of the cooling gases increases sufficiently, the aforementioned relationship determining an individual particle's saltation velocity dictates that the saltation velocity will decrease. If the gas velocities are greater than the particle's saltation velocity, the particle will be pneumatically conveyed. Gas velocities in the primary and secondary passes of the 3PHV are not capable of supporting (pneumatically conveying) any but the least dense (driest) particles. The denser (still moisture laden) particles will undergo a showering action in these passes while being propelled not at conveying velocities, but at velocities determined by a combination of drag and gravity forces.



Productization, Inc. 3PHV drum dryer



Conventional triple pass drum dryer

Figure 8-2. Flow comparison of conventional triple pass dryer and 3PHV drum dryer. (Vaught, 1990)

Because small particles have a higher surface area in proportion to their mass, moisture is more rapidly evaporated from their surfaces. Also, heat and, therefore, temperature gradients traverse to the center of smaller particles more rapidly than larger ones. As the moisture is evaporated from the particle, the particle density is reduced. Once the saltation velocity of the particle is reduced below the prevailing gas velocity, the particle is picked up in the gas stream and conveyed through the remaining drums.

Larger particles are retained in the outer drum where they undergo showering action and are subjected to turbulent airflow. Once the moisture of these larger particles is reduced to the desired moisture content, particle densities are likewise reduced, which allows them to reach their own saltation velocities. Large particles will reach their respective saltation velocities in either the outer (first) pass or intermediate (second) pass depending upon their size, weight, and moisture content.

In the first pass, the 3PHV dryer allows smaller, dried particles to pass through the slower moving mass of larger, wetter particles in an area bounded by the outer and intermediate drum cylinders, which is much larger than the area of the inner drum of conventional triple-pass dryers. As the larger particles are dried, they will "catch up" with the smaller faster

moving particles in an area bounded by the intermediate (second pass) drum cylinder. Here, air flow velocities become high enough to convey the entire mass of particles out of the drying portion of the drum and into the inner (third pass) drum cylinder where they will be conveyed out of the dryer.

In summary, as particles dry, they approach their saltation velocity. As they reach saltation velocity, it is important to provide a gas velocity sufficient to pick up the particle and pneumatically convey it out of the drying environment. This action prevents the product from reaching temperatures in excess of the wet bulb temperature, thus reducing carbon monoxide and hydrocarbon emissions associated with pyrolysis and combustion of the wood chips.

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Appendix A. Metric Conversions for Cited Text

Velocity		Temperature		Length				Pressure	
feet/ minute	meters/ second	Fahrenheit	Kelvin	feet	meters	inches	milli- meter	pounds per square inch	kilo-Pascal
Sections 2.1.1 through 2.1.5									
300	2	200	366	120	37	15	37	300	2068
800	4	302	423	10	3	54	1372	200	1379
1500	8	500	533	4	1.22	1	25	110	758
4000	20			8	2.44				
Section 3.4.1.1									
		212	373						
		392	473						
		523	546						

TECHNICAL REPORT DATA <i>(Please read Instructions on the reverse before comp.)</i>		
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16. ABSTRACT The report summarizes information gathered on emissions from the composite wood industry (also called the Plywood and particleboard industry) and potential pollution prevention options. Information was gathered during a literature search that included trade association publications, journal articles, symposium presentations, and university research. Little information exists in the literature pertaining to pollution prevention. Most available literature focuses on ways to reduce raw material consumption and improve manufacturing processes. However, in many instances, these reductions and improvements lead to pollution prevention benefits. Some of these potential pollution prevention options presented in the report include: conveyor belt drying, low temperature drying, light moisture bonding adhesives, foam extrusion, and variable glue application rate. Other pollution prevention options presented in the report include alternative fiber sources (e.g., agricultural fiber and recycled wood waste) and naturally derived adhesives. These options are presented as resources that are abundant and renewable. Little emissions data exist in the literature to include with these options.		
17. KEY WORDS AND DOCUMENT ANALYSIS		
a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
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