

# Trends in the U.S. Forest Products Sector, Markets, and Technologies

Omar Espinoza

**Abstract:** The forest products sector plays a critical role in the economic and social well-being of the United States. The country is the top producer and consumer of forest products, and it has the highest per capita industrial wood consumption. Nevertheless, the country's forest area has not changed in over a century, owing in part to sound forest management practices and a strong tradition of wood utilization. Cyclical and long-term trends, such as the Great Recession of 2007 to 2009, changing consumer demand, globalization of manufacturing, and emergence of substitute materials, have had negative impacts on the U.S. forest products industry in the last two decades. Sustainable management of U.S. forests has in turn been negatively affected, as strong forest products markets are vital to the health and resilience of U.S. forest lands and forest-dependent communities. However, there are promising opportunities for the forest products sector, including increased interest in renewable materials and energy, increasing demand for wood-based energy products, expanding nanotechnology applications, the emergence of mass timber, and increased use of wood in large-scale construction. This paper presents the major market trends affecting the U.S. forest products sector and discusses potential scenarios over the next 20 years.

**KEY WORDS:** forest products, market trends, wood consumption, nanotechnology, cross-laminated timber, CLT

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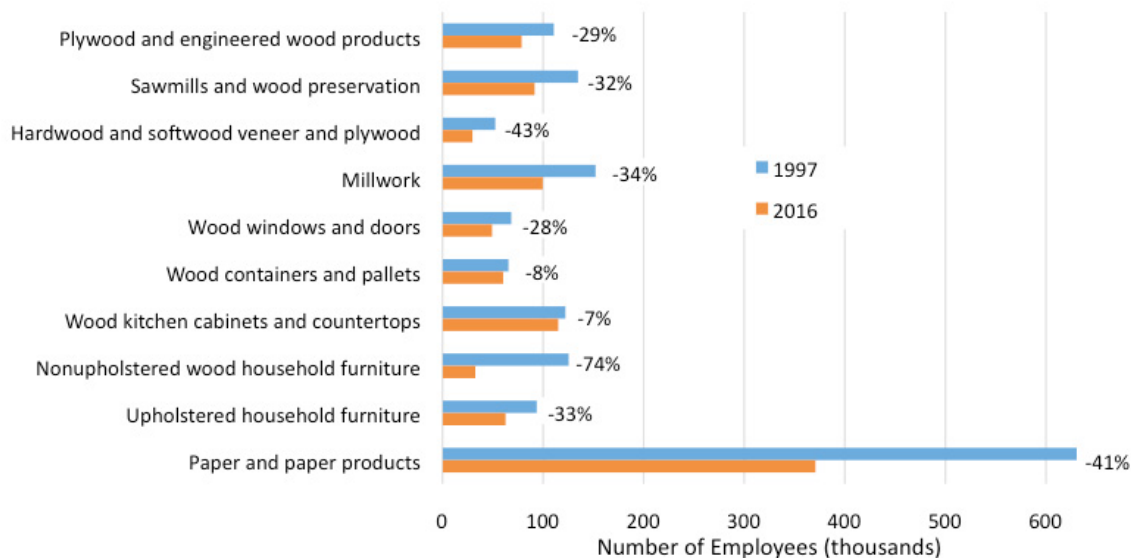
## Introduction

Over the long term, few industries have contributed more to the development of the United States as a nation than the forest products industry, and it is no exaggeration to say that wood was the foundation of American society (Youngquist and Fleischer 1977). Wood has played a central role in all aspects of the U.S. economy, from transportation to construction and from energy to communications. The forest products industry is one of the most dynamic sectors of the U.S. economy. Although the United States accounts for only 7.5 percent of total global forest area, it produces close to one-fifth of all the industrial roundwood (Food and Agriculture Organization [FAO] 2018), and Americans use five times more timber per capita than the global average (FAO 2011). However, the country's forested area has not changed significantly in more than 100 years (Oswalt et al. 2014). These trends can be attributed to several factors, including sound forest management practices, a strong wood culture, the abandonment of marginal farmlands that reverted to forest, and effective fire suppression, which all contribute to offset the loss of forest land to urbanization (Alvarez 2007). According to the American Forest and Paper Association [AF&PA], the forest products industry (excluding logging) is among the top 10 employers in 45 states, generating 4 percent of the manufacturing output (AF&PA 2017). This industry provides direct employment to over 1 million people (Golden et al. 2015). It is also the leader in biomass-based renewable energy generation, producing more than one-

fifth of the renewable energy consumed in the country (Energy Information Administration [EIA] 2015).

However, the U.S. forest products industry has been facing substantial challenges, both cyclical, such as the Great Recession of 2007 to 2009, and structural, such as globalization and the decline of printed media. Employment in the industry has not fully recovered from the last economic recession and the associated decline in the housing market, which prompted thousands of layoffs and plant closings (Buehlmann et al. 2007). Domestic manufacturers have lost market share to low-cost imports, where sectors like household furniture were particularly affected (Buehlmann and Schuler 2009, Quesada and Gazo 2006). Products traditionally made with wood, such as windows, siding, framing, and decking, are losing market share to substitute materials. In addition, considerable decrease in paper consumption has reduced the demand for fiber (Belz 2012) and caused many pulp and paper mills to close. Partly as a result of these developments, employment in the forest products industry declined considerably between 1996 and 2016 (Fig. 1). The U.S. share of global roundwood production decreased from 27 percent in 1996 to 19 percent in 2016 (FAO 2018).

This paper presents major market trends within the U.S. forest products sector that stand as key drivers of change for forestry and the forest sector. Most data presented correspond to the 1996–2016 period, but exceptions occurred when data for that period were unavailable.



**Figure 1.**—U.S. employment in selected industry subsectors, by year. Numbers to the right of the bars denote the percent change between 1997 and 2016 (Bureau of Labor Statistics 2017).

## Current Trends

### Wood Consumption in the United States

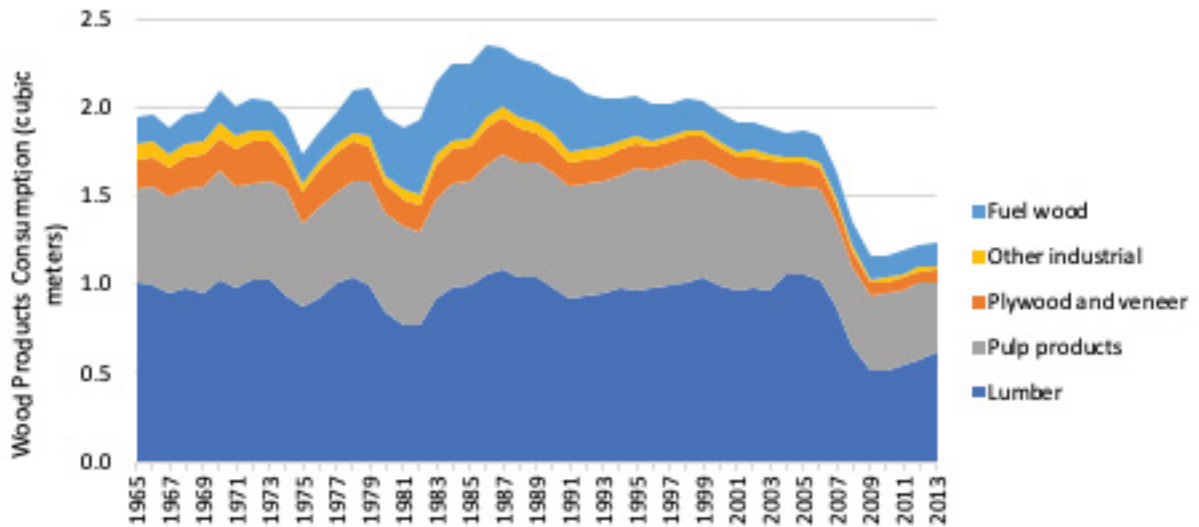
Per capita annual wood consumption in the United States was 1.24 m<sup>3</sup> (530 board feet) in 2013 (Howard and Jones 2016), the last year of available data (Fig. 2). U.S. consumption is higher than the world's average of approximately 0.5 m<sup>3</sup> (200 board feet) (FAO 2011). The distribution of this consumption is also markedly different; close to 90 percent of U.S. consumption is in industrial wood products, while in developing countries over 80 percent of wood consumption is for fuel for cooking and heating (Bruinsma 2003). U.S. consumption declined sharply from a peak in 2005 to its lowest point in over four decades in 2009, corresponding to the U.S. recession and the associated decline in the construction industry.

### Trends in Raw Materials

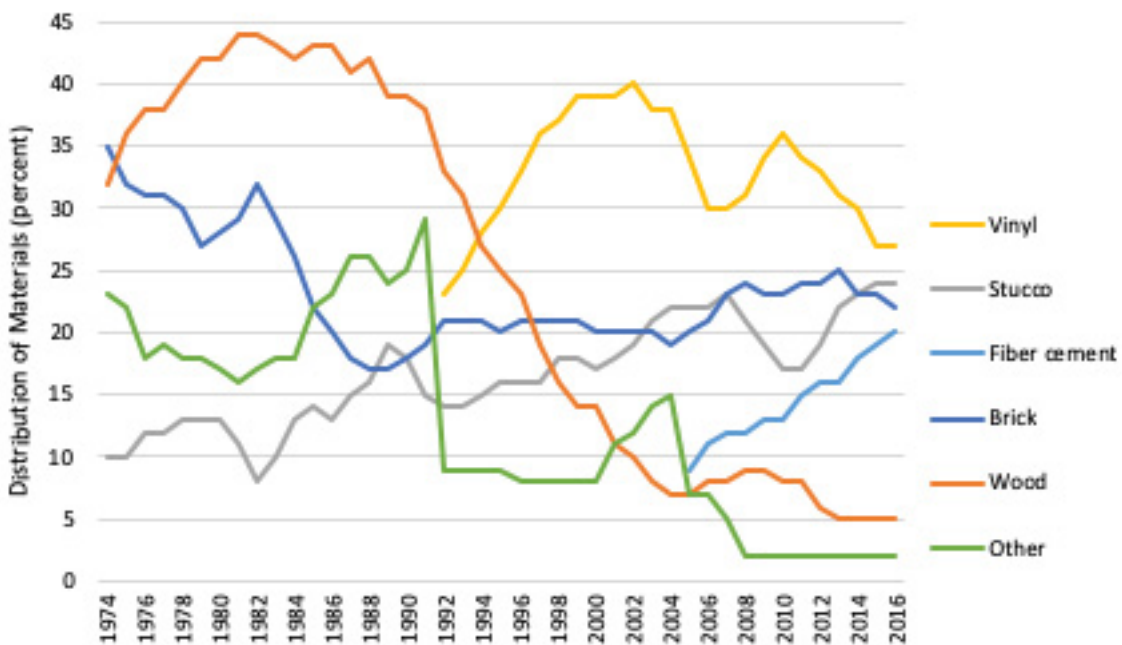
One important trend in raw materials of recent decades that affects demand for wood fiber is the growth of substitute materials. Substitute materials continue to reduce the market share of wood as raw material for

several product categories. For example, siding, which was once overwhelmingly made of wood (usually naturally durable species), now has a market share of 5 percent in the single-family residential market, with vinyl and fiber cement overtaking this segment (Fig. 3). Regional differences do exist; for example, vinyl is prevalent in the Northeast and Midwest (71 percent and 60 percent of homes in 2016, respectively) while brick and stucco have a considerable market share in the South (35 percent and 22 percent, respectively). Stucco and fiber cement have a large presence in the West (52 percent and 37 percent, respectively) (U.S. Census Bureau 2017b).

Other industries where substitutes have taken significant market share from wood-based products are outdoor decking and windows. In decking products, wood had a comfortable 97 percent share of the market in 1995 (Ganguly et al. 2010), which dropped to 62 percent in 2016 (Biobased News 2017), largely due to losses to wood-plastic composites and plastic decking (32 percent and 6 percent of the market in 2016, respectively). Wood windows, once dominant, are now limited to the traditional and luxury segments, and vinyl is the market



**Figure 2.**—U.S. per capita wood consumption, by year (Howard and Jones 2016). Data for 2013 are the latest available.



**Figure 3.**—Distribution of primary type of exterior wall material of new single-family houses completed in the United States, by year (U.S. Census Bureau 2017b). "Other" includes concrete block, stone, aluminum siding, and other minor types. "Other" included fiber cement before 2005 and vinyl siding before 1992 (thus the large drops in those years).

leader (Thompson 2017). Wood has held its own against substitute materials in markets such as pallets, residential construction, and kitchen cabinets. Wood framing is still used in more than 90 percent of single-family construction (U.S. Census Bureau 2017a), and it was estimated that more than 90 percent of pallet units are made of wood (National Wooden Pallet and Container Association 2018, Trebilcock 2013).

### Lumber

From 1996 through 2016, about 75 percent of lumber produced was in softwood species and 25 percent, hardwoods (Fig. 4). Production of both softwood and hardwood lumber reached all-time highs in 2005: 69.2 million m<sup>3</sup> (29.3 billion board feet) and 27.8 million m<sup>3</sup> (11.8 billion board feet), respectively. Lumber production dropped during the Great Recession to its lowest level in 2009, and as of 2016, it had not yet recovered to the levels of the 1990s and early 2000s.

### Hardwood Lumber

During the last two decades, there has been a considerable change in U.S. hardwood lumber markets. Industrial and export markets have grown in importance, while the participation of high value-added uses, such as furniture and cabinets, decreased between 1999 and 2015, particularly in furniture markets (Fig. 5). If only “grade” hardwood lumber is considered (excluding industrial uses such as pallets; crane mats, which are large wood platforms that provide ground stabilization for heavy machinery in several industries, such as oil drilling and exploration operations; railroad ties; and others), participation of exports is even larger, growing from 14 percent in 1999 to 41 percent in 2014 (Snow 2016). China’s share of total U.S. hardwood lumber export shipments by volume jumped from 8 percent of exports in 1999 to 46 percent in 2014. It is estimated that one in five grade lumber boards sawn in the United States was shipped

to China as of 2016 (Snow 2016). Canada, the second largest export market for U.S. hardwood, decreased its market share from 34 percent to 16 percent in the same period. China also shifted from primarily a manufacturer of hardwood products (using imported lumber and logs to manufacture goods for export) to a consumer of those goods, as its middle and upper classes grow. Another important trend has been some decoupling of housing construction activity and hardwood lumber prices. Historically lumber prices traced the trends in housing starts closely; however, starting shortly after the Great Recession, hardwood lumber prices have been increasing at a higher rate than housing starts, and exports have become a major driver of price (Snow 2016).

The United States has been historically the leading hardwood lumber exporting country in the temperate region, and the importance of export markets has been growing in the last two decades (Fig. 6). However, its market share declined from 34 percent in 1990 to 23 percent in 2011 (Bumgardner et al. 2014).

### Softwood Lumber

The United States has historically led the world in softwood lumber consumption. In 2016, the United States consumed 81.7 million m<sup>3</sup> (34.6 billion board feet) of softwood, followed by China with 56.3 million m<sup>3</sup> (23.9 billion board feet) (FAO 2018).

The primary driver for softwood lumber consumption is residential and nonresidential construction, which has been trending upward during the last few years (Fig. 7). It is expected that new applications, such as engineered wood products, mass timber, and increased share in some markets (e.g., commercial construction, mid- and high-rise construction, pallets, and containers) will boost demand for softwood lumber. Softwood lumber has remained competitive with substitute materials, such as steel and plastic, in markets like dimension lumber, doors, and windows.

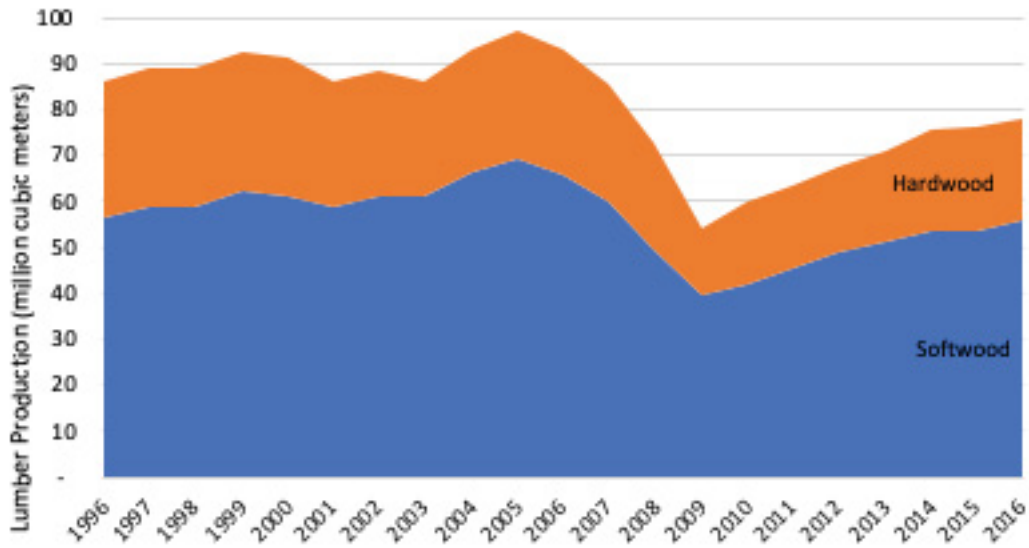


Figure 4.—U.S. softwood and hardwood lumber production, by year (FAO 2018).

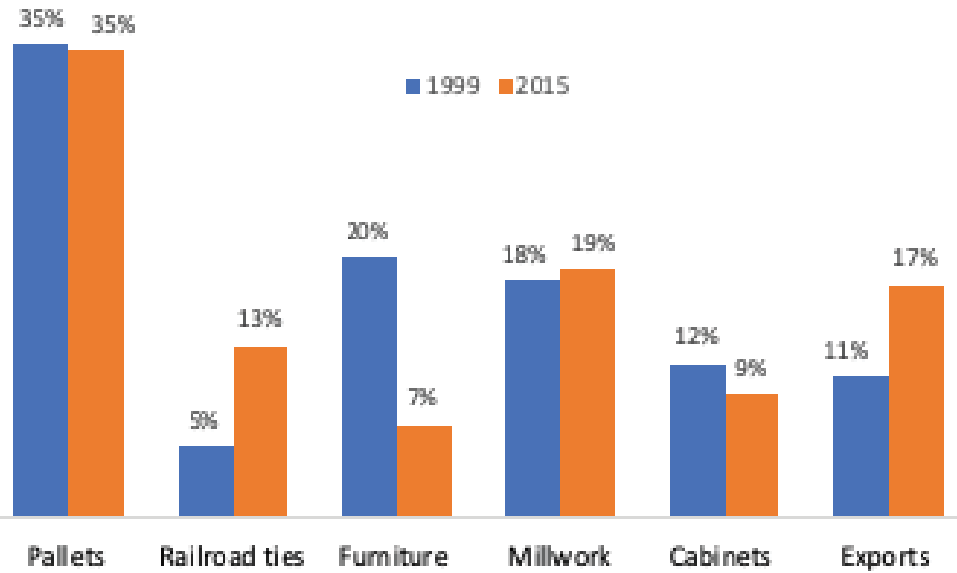


Figure 5.—Distribution of markets for U.S. hardwood lumber by volume, by year (Bumgardner 2016).

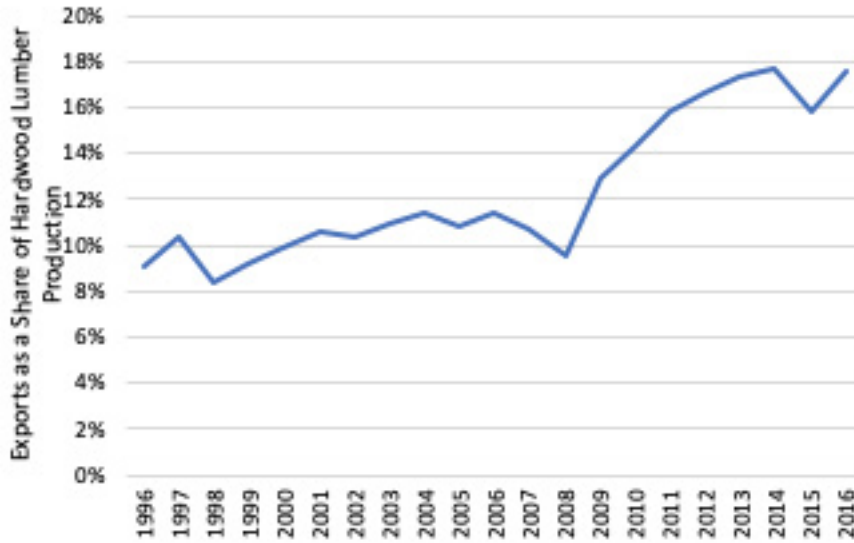


Figure 6.—Exports as a percentage of production for U.S. hardwood lumber, by year (FAO 2018).

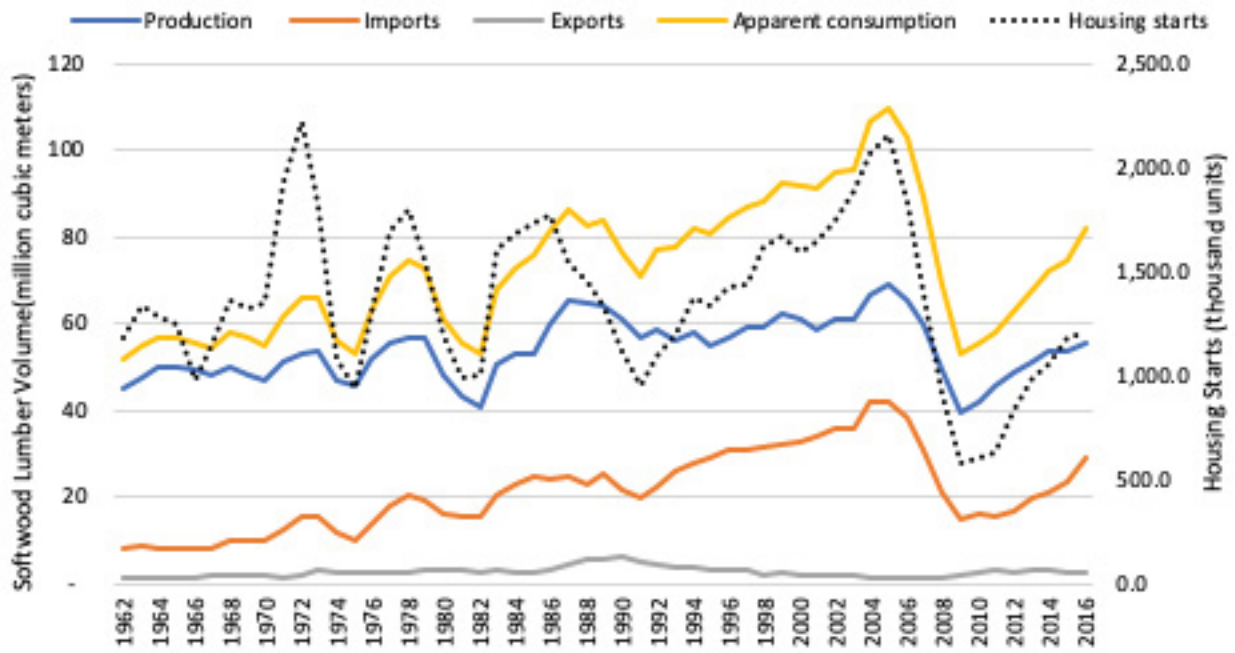


Figure 7.—U.S. softwood lumber production, imports, exports, and apparent consumption (FAO 2018). Housing starts are also represented (U.S. Census Bureau 2018b). Apparent consumption is calculated as production plus imports minus exports.

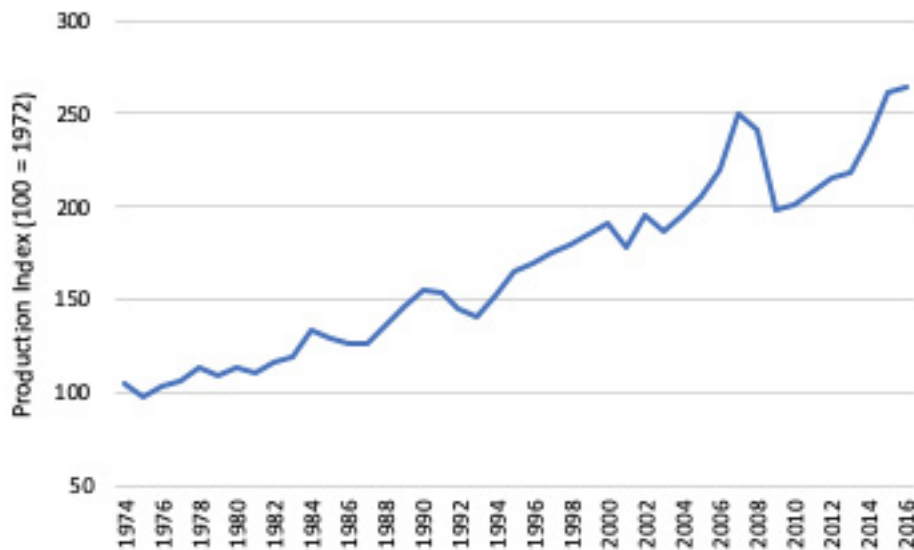
Moreover, improvements in process efficiency, such as the use of small diameter logs as raw material, will contribute to maintaining the competitive position of softwood lumber over substitute materials.

## Industrial Wood Products

Industrial wood products support transportation and logistics operations as well as communications and energy infrastructure. Major industrial wood products are pallets and containers, railroad ties, wood utility poles, mining supplies, crane mats, and road construction products (e.g., sound barriers, guardrail posts, retaining walls, signposts, and trail and road bridges). These products are gaining importance as logistics operations become more global, U.S. oil and gas industries prosper, and outlets for lower-grade hardwoods shrink.

Pallets are a critical component of logistics infrastructure, as they reduce material handling time and costs. More than 90 percent of pallets are made of wood, primarily

hardwood species (Sanchez Gomez 2011). However, there are continued efforts to use competing materials (metal, plastic) to capture market share from wood. Pallets and containers, as well as railroad ties, are important for hardwood timber utilization, as they provide an outlet for the lower-grade material from lumber manufacturing. Pallets are the single most important outlet for low-grade hardwood, and their production consumes over 40 percent of all hardwood produced in the United States (Hardwood Market Report 2014). Some pallet industry trends include the steady growth of pallet recycling, an increasing market share of pallet rental systems, phytosanitation requirements for invasive species and exports, and increased use of softwoods for pallet manufacturing. Pallet production has grown steadily during the last four decades but had a notable downturn in 2007 through 2008, associated with the Great Recession (Fig. 8). Wood railroad ties are an important outlet for wood; in 2016, more than 19 million new wood crossties were installed in the United States (Railway Tie Association 2018).



**Figure 8.**—U.S. wood pallet and container production index, scaled to an index of 100 in 1972, by year (Federal Reserve Bank of St. Louis 2017).



### Value-added Products

Value-added wood products are manufactured by using the outputs such as lumber, veneer, and wood-based panels obtained from primary processing operations. Value-added products include furniture, kitchen cabinets, millwork, wood flooring, decking, railings, windows, and doors. Production of value-added wood products has declined in the United States over the past three decades because of the Great Recession, increased competition from imports, market penetration from substitute materials, and other factors. For example, more than 70 percent of the nonupholstered furniture consumed in the United States is now imported (Fig. 9). There have been changes in the sourcing of those imports as distributors look for lower-cost suppliers. For example, in 2015 China accounted for 59 percent of total imports of household and institutional furniture and cabinets, by value, down from 61 percent in 2010. Meanwhile, Vietnam has been steadily increasing in market share (Bumgardner 2016), mostly due to Vietnam's lower costs. Imports from China grew only 3 percent in 2016, while those from Vietnam grew 30 percent in the same period (American Plywood Association 2017). The decline in U.S. manufacturing of value-added products has led to a decrease in domestic demand for grade lumber (Fig. 5). Other market segments, such as flooring and millwork, have shown similar trends.

### Engineered Wood Products

Engineered wood products (EWPs) are generally made by breaking down wood into smaller pieces or particles, which are then bonded with adhesive. These products reduce wood product variability and help to utilize the raw material more efficiently. They are designed to meet precise standards and specifications (Fig. 10).

In general, trends of engineered wood products follow those of the housing market (Fig. 11). After a large drop during the Great Recession,

production of laminated veneer lumber (LVL), I-joists, and glulam has increased steadily.

One engineered wood product that has received considerable attention during the last decade is cross-laminated timber (CLT), a relatively new engineered wood product made of multiple layers of wood boards oriented perpendicularly to the adjacent layers (Karacabeyli and Douglas 2013). These panels are manufactured in large dimensions to form entire wall and floor systems. The cross-laminated configuration of CLT (Fig. 10) results in excellent mechanical properties, and the prefabricated nature of CLT allows for high precision and a construction process characterized by faster completion and little disruption to the neighboring areas. In the United States, CLT panels for structural use are certified by the American National Standards Institute (2018), which specifies requirements and test procedures for quality assurance. One early study estimated that a CLT market in North America could generate need for 1.2 million to 3.6 million m<sup>3</sup> (0.51 billion to 1.5 billion board feet) of wood, depending on market penetration (Crespell and Gaston 2011). In the United States, as of the time of this writing, two firms manufacture CLT panels approved for structural use (American Plywood Association 2018), two firms produce noncertified panels, and the construction of four plants has been announced (Dalheim 2017, Esler 2017).

### Wood-based Panels

Wood-based panels can be structural or nonstructural. Structural wood-based panels are used in construction as sheathing for roofs, floors, and walls. The two basic types of structural panels are plywood and oriented strand board (OSB). Structural plywood is made mostly from softwood species. Nonstructural wood-based panels have countless applications, such as furniture and kitchen cabinets, laminated flooring, millwork, doors, wall paneling, car parts, and

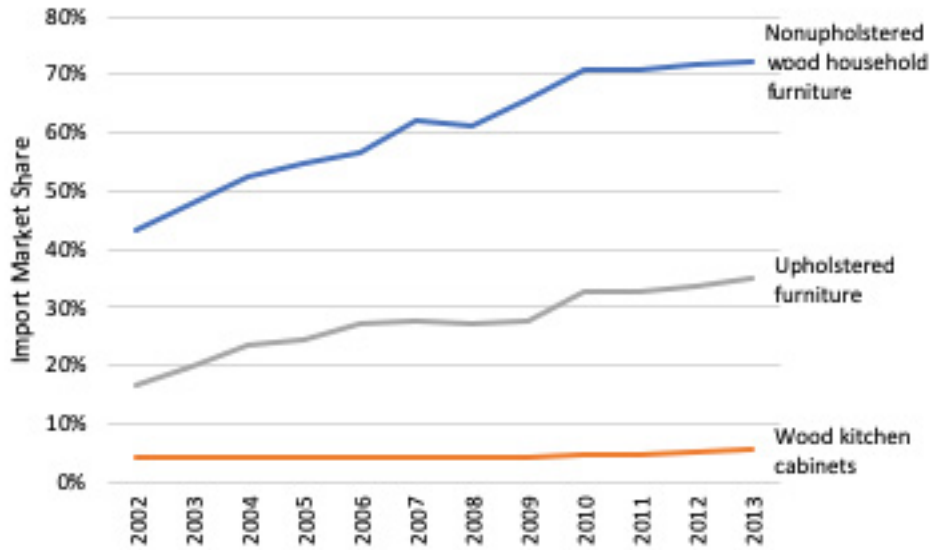


Figure 9.—Market share estimates of imports of kitchen cabinets and furniture in the United States (Nicholls and Bumgardner 2018).



Figure 10.—Examples of engineered wood products. From left: parallel strand lumber, I-joists, and cross-laminated timber (Photo credit: Maria Fernanda Laguarda Mallo, University of Minnesota, used with permission).

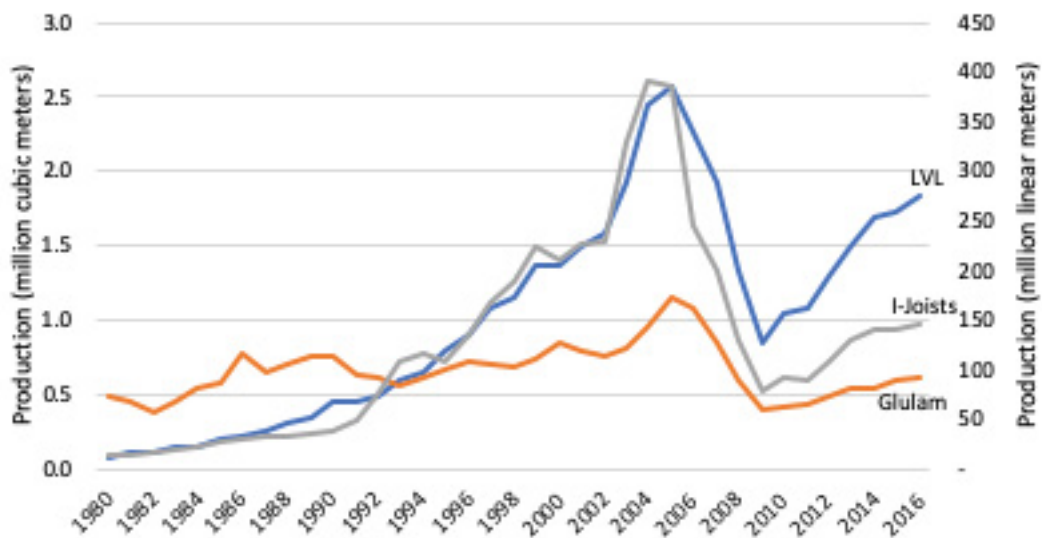


Figure 11.—U.S. production of laminated veneer lumber (LVL), I-joists, and glulam, by year (American Plywood Association 2017, Howard and Jones 2016).

siding. Common nonstructural wood-based panels are plywood (often hardwood plywood), particleboard, medium density fiberboard (MDF), and hardboard. During the last few decades U.S. production of wood-based panels has shown a sustained shift from plywood to other panel products (Fig. 12). In residential construction, OSB has overtaken a large part of the plywood market share. Plywood's largest market is now in the industrial sector (United Nations European Forestry Commission/Food and Agriculture Organization 2017). Oriented strand board is also used for siding, and about 600 million square feet (3/8 inch basis) (56 million m<sup>2</sup>; 1 centimeter basis) was produced on average from 2012 through 2016 (American Plywood Association 2018).

In secondary wood products manufacturing, the use of composites, such as particleboard and MDF, has increased. However, an increasing percentage of consumption has been covered by imports, while domestic production has decreased. For example, the average production volume of MDF between 1996 and 2016 decreased at an average annual rate of 3 percent, while imports grew 19 percent annually (calculated with data from FAO 2018). U.S. imports of OSB panels, almost exclusively from Canada, grew by more than 11 percent from 2010 to 2017 (calculated with data from American Plywood Association 2017), while plywood imports came primarily from China and Canada.

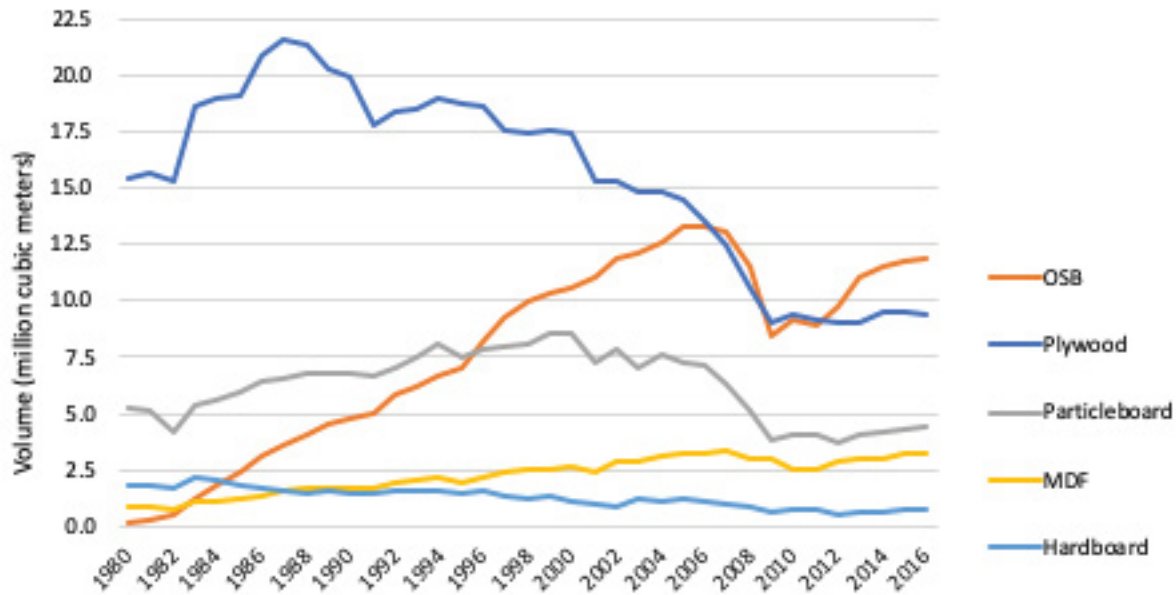
### Pulp and Paper Products

Pulp and paper products include a wide variety of goods, such as communication papers (e.g., printing paper, newsprint), packaging and paperboard products, and tissue. There is also high diversification in terms of raw materials, channels of distribution, and final uses. Many of the pulp and paper industry's outputs are raw materials for other industries. Important structural changes have affected the global paper industry during the last three decades. Electronic communications have

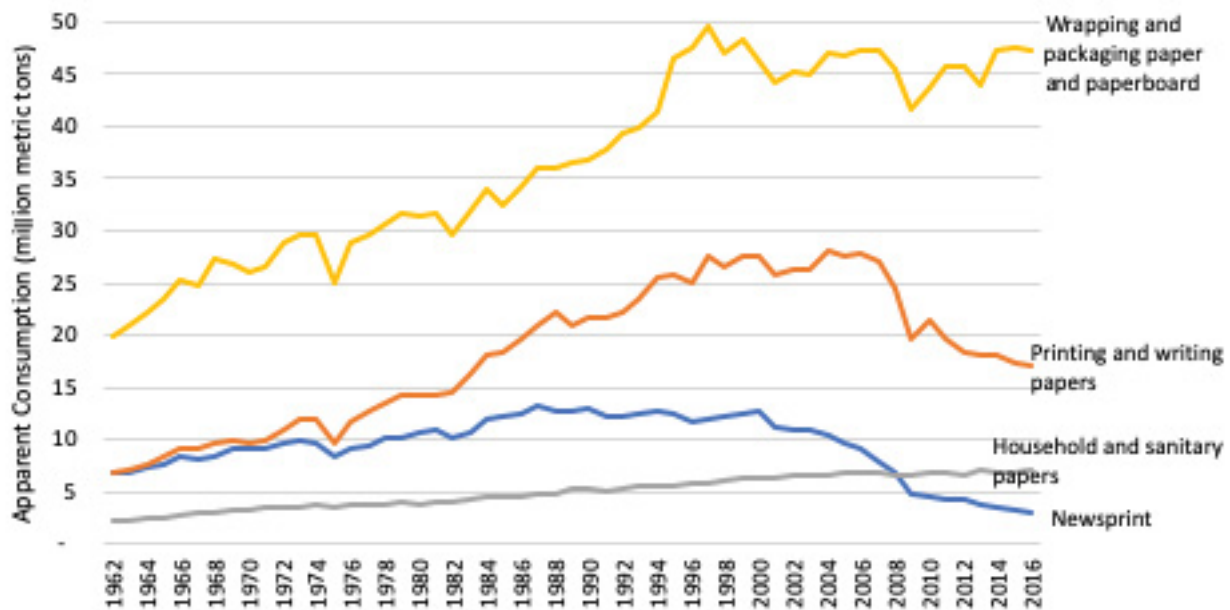
greatly reduced consumption of newsprint, writing paper, and printing paper, especially in developed countries. The sharp growth in electronic commerce has increased parcel shipping, reflected in increased demand for paperboard and wrapping and packaging paper—a trend that is expected to continue in the United States (Fig. 13) and elsewhere. Consumption of household and sanitary paper products has kept pace with population growth, but an emerging trend is a shift in consumption; people in lower income countries are rapidly increasing their use of household paper goods. Low-income countries were projected to surpass higher income countries in the use of household and sanitary paper products in 2014 (Hansen et al. 2014). Last, there has been a considerable increase in the share of recovered paper as input to paper production in the United States; recovery rates almost doubled, from 34 percent in 1990 to 66 percent in 2017 (AF&PA 2018).

In the United States, the pulp and paper industry has experienced consolidation and plant closings. The number of establishments decreased from just under 7,000 in 2001 to 5,500 in 2016, and employment fell from 630,000 to 368,000 between 1997 and 2016 (Bureau of Labor Statistics 2017). Likewise, there was a decline in capacity, from 62.0 million metric tons (air dry; 68.3 million tons) to 53.5 million metric tons (air dry; 59.0 million tons) between 1997 and 2016 (FAO 2017). Consumption and production of paper and paperboard are expected to continue to decline in North America. According to at least one projection, consumption in 2030 may be half of what it was in 2000 (Hansen et al. 2014). These changes have profound implications for wood fiber demand.

Another important development in the pulp and paper industry is the diversification toward new products, such as biorefining and bioenergy. Research and development efforts in the industry are focused on innovations in biochemicals, biofuels, biocomposites,



**Figure 12.**—Wood-based panel production in the United States, by year (FAO 2018, Howard and Jones 2016, Howard and McKeever 2016, Howard et al. 2017). Values for 2016 are estimates. OSB: oriented strand board; MDF: medium density fiberboard. Plywood figures include hardwood and softwood plywood.



**Figure 13.**—Apparent consumption of paper and paper products in the United States, by year (FAO 2018). Some data for 2016 are estimates.

nanotechnology, and others. Industry and research communities have proposed the concept of “biorefinery,” which is a production facility that can use different raw materials (forest or agricultural biomass, or municipal and industrial solid wastes) to produce a wide variety of outputs. These products include biofuels, electricity, chemicals, and conventional products like paper, lumber, and composites (Hansen et al. 2014). Biorefineries will take years to become an economically viable option, but they can have an important effect on demand for fiber.

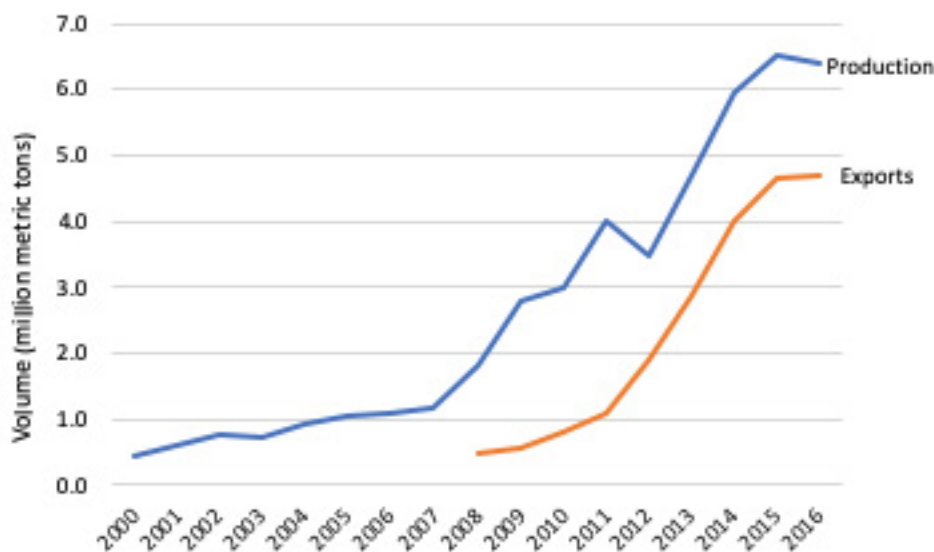
### Wood Energy

Markets for heat and electricity generation from wood biomass have grown during the last decade. In 2016, wood represented over 40 percent of the total biomass energy consumed in the United States and 20 percent of the total renewable energy (EIA 2017). Wood-based energy represented 2 percent of total U.S. energy consumption and 10 percent of industrial energy consumption as of July 2018

(EIA 2018b). The major use of wood biomass is for heat and electric energy generation (combined heat and power, or cogeneration) by the forest products industry, mostly pulp and paper.

A bioenergy application of wood that has grown rapidly is wood pellets (Fig. 14). As of July 2018, there were 83 facilities producing densified biomass in the United States, with a production capacity of 12 million metric tons (13 million tons) per year (EIA 2018a). Although pellet production started in the Northeast and Northwest, most of the growth in pellet production capacity has been in the Southeast (Dale et al. 2017). The major raw material sources for wood pellet manufacturing in the United States are mill residues and pulpwood (both softwood and hardwood).

Exports of wood pellets account for 80 percent of total sales, with close to 100 percent going to Europe (80 percent to the United Kingdom) to replace coal for power generation (EIA 2018a). European targets to reduce greenhouse



**Figure 14.**—U.S. wood pellet production and exports, by year (Lamers et al. 2012, Thrän et al. 2017, United Nations European Forestry Commission/Food and Agriculture Organization 2017).

gas emissions drive this demand in great part as Europe strives to meet 20 percent of its energy needs from renewable sources by 2020 (European Commission 2018b). Demand for wood pellets is likely to increase as countries in Europe and other regions move away from coal for power generation (Beeler and Morrison 2018).

The major driver for U.S. domestic consumption of wood pellets has been the competitiveness of wood biomass with heating oil and propane, coupled with very little industrial demand for pellets (Thrän et al. 2017). In the United States, wind and solar are the preferred renewable energy sources (Motyka et al. 2018). Growth of wood pellet production in the United States also responded to declines in the pulp and paper industry. However, wood biomass for pellets accounts for a small percentage of removals (e.g., only 2 percent of 2014 removals in the Southeast) (Dale et al. 2017). Currency exchange rates will greatly influence the future of U.S. pellet exports; a strong dollar will benefit suppliers in other countries. New environmental policies in the United Kingdom may negatively affect imports of U.S. wood pellets. However, new subsidies in the Netherlands may offset such losses (Tovey-Fall 2016). The European Commission publishes European and national biomass action plans (European Commission 2018a).

An emerging wood energy application is torrefaction, where wood biomass (as chips or pellets) is “roasted” in a low oxygen environment, increasing its energy density (Fosnacht 2018). Torrefied wood can be co-fired with coal in power generation, increasing renewable energy output and reducing emissions. Recent tests in several power plants yielded promising results (Fosnacht 2018, HM3 Energy 2018).

## Other Products and Trends

### Nanotechnology

Nanotechnology is the manipulation of materials at dimensions of less than 100 nanometers (Atalla et al. 2005). For perspective, 100 nanometers is approximately one-thousandth the thickness of a sheet of paper. At this scale, material properties change significantly from those of materials at a macroscale, allowing for new and unique applications. For example, some forms of nanocellulose exhibit high strength, transparency, and electroactive behavior (Hansen et al. 2014). It is believed that nanotechnology will be an important driver of economic growth, and it is expected to transform the forest products industry by opening new and commercially important areas for innovation. Significant investments are being made on nanoscience and nanotechnology research, such as the P3Nano Public-Private partnership (U.S. Endowment for Forestry and Communities 2018), the nanocellulose pilot plants at the USDA Forest Service’s Forest Products Laboratory (Forest Products Laboratory 2018), and the University of Maine’s nanomaterial pilot plant (University of Maine 2018). Some potential applications of nanocellulose technologies that are being investigated are in mining and drilling rheology agents, concrete additives, wood preservation, energy efficiency, drug delivery, tissue engineering and scaffolding, automobile parts manufacturing, food packaging, self-sterilizing surfaces, coatings, bioremediation, and computer chips (Bowyer et al. 2016, Laks and Heiden 2004, Moon et al. 2006, Wei et al. 2014).

### Wood-based Chemicals and Biofuels

Deriving chemicals from wood is not a new industry. Exudates from pine (*Pinus* species) trees were used to obtain turpentine and rosin in North America beginning in the early 1700s, and these products had many applications in the “naval stores” industry

(Williams 1992). Wood hydrolysis, which converts wood polymers into simple sugars, has been understood for well over a century and has been used to create commercial quantities of rayon and cellophane since the early 1900s (Goldstein 1978). There is renewed interest in using wood biomass as raw material for chemicals traditionally derived from petroleum and other commodity compounds, as the chemical industry explores a transition from hydrocarbon-based products to carbohydrate-based products. Processes such as gasification, extraction, and fermentation seem promising for the commercial production of chemicals from wood biomass. For example, lactic acid, a very versatile platform chemical, is industrially derived from starch crops, but it is possible to use sugars from wood as raw material (Abdel-Rahman et al. 2011, Parajo et al. 1996). Other chemicals from wood with commercial application are acetic acid, furfural, succinic acid, methanol, itaconic acid, and hydrogen (MacKay et al. 2009).

Wood biochar, a product of thermal decomposition under conditions of low oxygen and low temperature, is commonly used as a soil conditioner (Lehmann and Joseph 2009) but has potential for carbon sequestration, for energy generation, and as a low-cost alternative to activated carbon (Groot et al. 2016). There are about 135 producers of biochar in the United States, with estimated production between 35,000 and 70,000 tons (32 to 64 teragrams; 1 Tg = 1 billion grams) per year (U.S. Biochar Initiative 2018). Future “forest biorefineries” could produce fuels and chemicals from wood biomass derived from a number of sources, including roundwood, short-rotation woody crops, harvest residues, small diameter thinnings, wood residues from manufacturing operations, demolition debris, or black liquor from pulp mills (Golden et al. 2018, MacKay et al. 2009).

Second-generation biofuels, based on cellulosic feedstock, were highly anticipated.

Wood biomass is considered an attractive feedstock, due to its abundance (making up four-fifths of the total global biomass [Badger 2002]), relatively low cost, greater energy balance than starch-based ethanol (Morey et al. 2006), long storage life, high bulk density, high sugar content, and established collection systems (Roberts 2008). When harvested sustainably, forest biomass can be a source for renewable energy with low greenhouse emissions, minimum impacts on biodiversity, and carbon mitigation benefits (Bowyer et al. 2011a, 2011b; FAO 2010). However, cellulosic biofuels markets today have fallen short of the expectations. The 2016 Renewable Fuel Standard anticipated 17.0 billion liters (4.5 billion gallons) of cellulosic biofuel produced, and the actual production was only 0.6 billion liters (0.16 billion gallons) (most of it biogas) (Lynd 2017). Some of the causes are technological readiness, underinvestment, the large amounts of biomass and land required, balance between economies of scale and logistics, and the fall in oil prices. As investment in biofuels has dwindled, most of it has been directed toward biochemicals development (Lynd 2017).

### Wood Composites

Many research and development efforts have been carried out to enhance wood properties by combining components of wood with other substances. For example, in fiber cement siding, cellulose fibers were incorporated into cement as a safer alternative to asbestos. This product has had market success since its introduction in the early 1980s, doubling its market share in the residential housing market during the last decade (see Figure 3). Wood-plastic composites (WPCs), which incorporate wood fiber into thermoplastics, are another successful alternative to solid wood, especially in market segments such as outdoor decking, siding, molding, and window manufacturing. Further development of WPCs may include the incorporation of nanomaterials, such as

nanotubes, to enhance performance (Omar and Matuana 2008) and the advancement of structural applications, for example, by extruding WPC on solid wood.

### Wood Modification Treatments

Some of the same forces driving the development of chemicals and composites derived from wood explain the expanding interest in chemical-free treatments to enhance wood's durability for both residential and industrial uses. Interest in treatments with lower impacts on the environment and human health has encouraged researchers and industries to develop treatments such as thermal and chemical modification of wood. In thermal modification, wood is heated to very high temperatures (Kocaefe et al. 2008), thus altering its chemical and physical properties (Esteves and Pereira 2009). As a result, dimensional stability and resistance to rot and decay are improved (International ThermoWood Association 2003, Leitch 2009, Rapp and Sailer 2000).

Thermally modified wood has been successfully marketed for nonstructural exterior applications, such as decking and siding (International ThermoWood Association 2003). Although it is still in its early stage of adoption in the United States, it is believed to have market potential as a high-end substitute for tropical tree species and WPCs (Gamache et al. 2017). In chemical modification, the basic chemistry of the cell wall polymers is changed to obtain the desired improved properties, often to reduce the hydrophilic nature of the cell wall or to improve dimensional stability. One chemical treatment that has had some market success is acetylation, where wood is treated with acetic anhydride, resulting in the esterification of the hydroxyl groups in the cell wall (Rowell 2013). Acetylated wood has shown improved dimensional stability and decay resistance (Ohkoshi et al. 1999, Rowell et al. 2009).

### Chemicals-based Wood Preservation

A more traditional way to enhance the durability of wood has been to treat it with chemical preservatives. There are many preservative formulations, with the choice depending on the required protection, exposure, health and safety, and expected service life of the structure (Ross 2010). Wood preservatives are broadly classified in two groups: oil-borne preservatives and waterborne preservatives. Examples of oil-borne preservatives are creosote, copper naphthenate, and pentachlorophenol; and in the waterborne group commonly used preservatives are ACQ (alkaline copper quaternary), CCA (chromated copper arsenate), and ACC (acid copper chromate) (Vlosky 2009). In 2016, the wood preservation industry employed 10,600 and had a total value of shipments of \$7.8 billion (U.S. Census Bureau 2018a). Currently heavy-duty preservatives, namely creosote, pentachlorophenol, and heavy metal systems, have the largest share of the wood preservation market for industrial uses. For the residential market, CCA, which was the predominant chemical, was discontinued due to environmental and health concerns and replaced by alkaline copper systems; more recently, micronized copper options have dominated residential applications (Morrell 2017). In the future, it is expected that the use of metal-free options, nonbiocidal treatments, coatings, and barriers will be expanded, after technical and economic limitations are overcome.

### The Environmental Movement

Concern for the sustainability of natural resources and human health has given rise to market-based initiatives such as forest certification and green building rating systems (Espinoza and Dockry 2014, Espinoza et al. 2012). These systems are aimed at creating a market incentive for forest managers and companies to adopt sustainable construction standards. In the United States at the time of



this writing, there are currently 14 million hectares (35 million acres) of forest certified under the Forest Stewardship Council system (Forest Stewardship Council 2018) and 33 million hectares (82 million acres) under the Programme for the Endorsement of Forest Certification (which, in turn, includes the Sustainable Forest Initiative and the American Tree Farm System) (Programme for the Endorsement of Forest Certification 2018). Green building systems promote the use of environmentally preferable materials in buildings, for example, by favoring the use of environmentally certified wood products (Espinoza et al. 2012). More than 63,000 projects achieved LEED (Leadership in Energy and Environmental Design) certification, the leading green building system in the United States, by 2018 (U.S. Green Building Council 2018). Other green building systems include Green Globe (Green Globe Ltd. 2018) and the Living Building Challenge (International Living Future Institute 2018).

### Changing Demographics of the Labor Force

Demographic trends are likely to affect the forest products industry in the next two decades. An aging workforce and difficulty attracting new employees in some sectors can have negative effects on the industry. For example, the logging industry has been particularly affected; the median age of workers in the industry was approaching 50 years in 2017 and a workforce contraction of 13 percent is projected over the next decade (Bureau of Labor Statistics 2017). Added to the growing driver shortage in the trucking industry (Raphelson 2018), this shrinking of the labor force will make timber harvesting the most fragile link in the forest products supply chain. Innovations in timber harvesting technology such as automation, robotics, and precision forestry (Goulding 2016) are unlikely to offset labor shortages in this sector for the next two decades. Similar trends can be observed in other sectors, which makes

it important to update recruitment and educational efforts (Espinoza 2015, Sharik and Bal 2018).

## A Look 20 Years Ahead and Implications for the Forest Sector

The forest products industry will continue to play a critical role in the economic, social, and environmental development of the United States during the next two decades and beyond. However, several trends will affect the structure of the industry and the nature of its contributions to the economy and forest health. These trends include the globalization of the economy, export opportunities in fast-growing economies, increased interest in renewable materials and energy, changing demographics in the population, and technological developments. Some of these changes will increase the demand for wood fiber or shift its use to new applications, while others will reduce the need for wood. Potential scenarios are discussed next.

- Sustainability concerns, architectural and engineering considerations, and changes to building codes may lead to the increased use of timber in commercial and mid- and tall-rise building construction, including an increased use of prefabrication of building elements.
- The increased use of engineered wood products could lead to further improvements in wood utilization, particularly the use of small diameter and low-value trees.
- Production of wood-based energy products (e.g., biofuels, pellets) could increase, driven, in part, by demand in European and Asian countries. Increased production would benefit mostly producers in coastal areas. Greater demand for wood-based energy products could intensify competition for wood feedstocks with other sectors, such as wood-based panels and pulp and paper, potentially leading to higher fiber prices. A

growing wood energy industry could benefit forest landowners, but it could diminish profits in the manufacturing sector. However, small or no increases in wood energy consumption are likely in the United States in the medium term.

- Use of wood biomass as raw material for industrial chemicals and pharmaceuticals may increase. The concept of “forest biorefineries” could turn into an important source of demand for wood fiber. At the same time, nanotechnology applications of wood biomass may become available at a commercial scale.
- Demand for newsprint, printing, and writing paper is likely to continue to decline, while the use of recycled fiber in paper manufacturing is likely to increase further, resulting in reduced demand for wood fiber. The increasing demand for paperboard and packaging materials will offset part of the declining demand for communication paper.
- The expanding purchasing power in fast-growing economies could increase demand for forest products. As the gap between forest harvest and growth widens in these regions, greater imports will probably be needed to help meet growing demand in those countries. As a result, U.S. exports of logs, lumber, and some value-added products may increase during the next two decades.

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