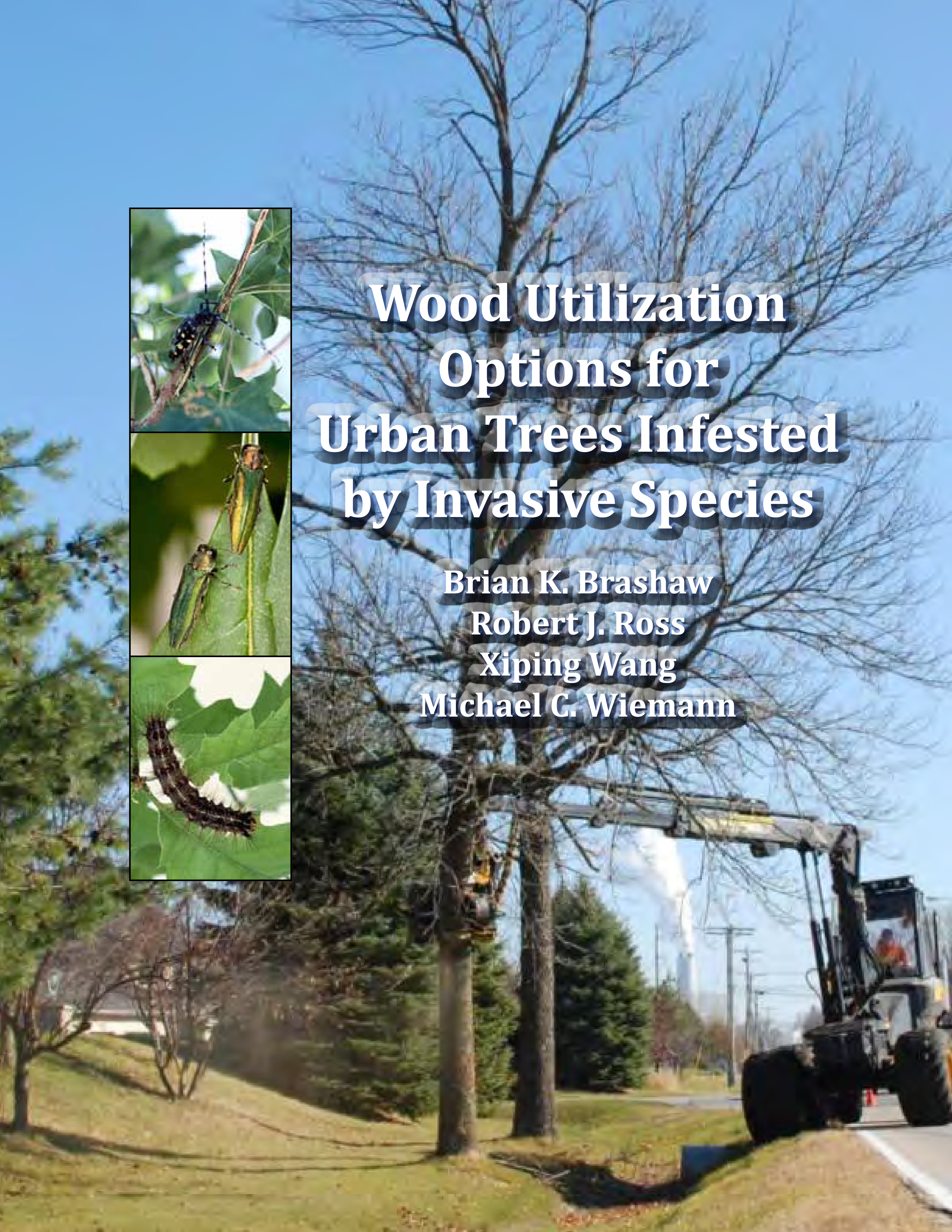

Wood Utilization Options for Urban Trees Infested by Invasive Species

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University of Minnesota Duluth
Natural Resources Research Institute

Forest Service, U.S. Department of Agriculture

Forest Products Laboratory
Research Working For You

WERC
Wood Education and Resource Center

Cover photo taken by Don Peterson.
Insect photos (from top to bottom): Asian longhorned beetle photo courtesy of Michael Smith, USDA Agricultural Research Service; emerald ash borer photo courtesy of Stephan Ausmus, USDA Agricultural Research Service; and gypsy caterpillar photo courtesy of Scott Bauer, USDA Agricultural Research Service.

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Preface

This publication is a compilation of information on the properties, processing characteristics, and potential products that can be manufactured from hardwoods that have been attacked by various invasive species.

Part One provides background information and outlines the magnitude of the problem in the United States.

Part Two provides basic information for many U.S. hardwood species that grow in urban areas. Scientific and common names, physical and mechanical property data, machining characteristics, and other important information are summarized. Micrographs of the cross sections of several species or representative specie for a species grouping are included.

Part Three provides summaries that highlight a wide range of product options for wood from these species.

Part Four summarizes results from a recently completed, extensive research program focused on providing detailed, practical heat sterilization options for treating firewood obtained from these trees.

This publication was designed to serve as a primary reference on the topic for land management professionals, arborists, utilization specialists, and other natural resource professionals who are at the forefront of dealing with invasive species and their devastating effect on our forest resources.

About the Authors

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Brian Brashaw is Director of the Wood Materials and Engineering Program at the Natural Resources Research Institute (NRRI), University of Minnesota Duluth. His broad-based research focuses on nondestructive testing and evaluation methods for wood materials and structures, applied product development, resource utilization, renewable energy, and technology transfer. He coordinates NRRI's Physical and Mechanical Testing Laboratory. He is the author or co-author of more than 300 technical reports and publications including the popular *Wood and Timber Condition Assessment Manual*, published by the Forest Products Society. Brian holds BS and MS degrees from the University of Wisconsin Stevens Point and Washington State University, respectively, and is currently a PhD candidate at Mississippi State University.

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Dr. Robert Ross is a Project Leader at the USDA Forest Products Laboratory (FPL), Madison, WI. His research focuses on the development and use of nondestructive evaluation technologies for wood products and structures. Bob has worked on a variety of projects, including in-place assessment of members of the USS Constitution. He has written or co-authored more than 200 technical reports and articles, and jointly holds 29 U.S. and foreign patents. He was Technical Editor for the Centennial Edition of the *Wood Handbook: Wood as an Engineering Material* and is a Fellow in the International Academy of Wood Science. He holds BS and MS degrees from Michigan Technological University, and a PhD from Washington State University.

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Dr. Xiping Wang is a Research Forest Products Technologist at the USDA Forest Products Laboratory (FPL), Madison, WI. His work at FPL focuses on nondestructive testing and evaluation of wood products, condition assessment of wood structures, and urban tree hazard assessment. He has worked on numerous structural inspection projects, including those for industrial buildings, timber bridges, and historic wooden sailing vessels. He recently completed an extensive effort focused on developing heat sterilization procedures for wood products infected by invasive species. He is the Associate Editor of the *Journal of Materials in Civil Engineering* (published by the American Society of Civil Engineers), jointly holds six U.S. and foreign patents, and has published more than 100 technical reports and publications. Xiping holds BS and MS degrees in Mechanical Engineering and Forest Engineering, respectively, from Beijing Forestry University, and a PhD from Michigan Technological University.

Michael C. Wiemann

Dr. Michael Wiemann is a Research Botanist at the USDA Forest Products Laboratory (FPL), Madison, WI. His research specialty is examining and defining the relationship of ecology and growth conditions to wood properties and quality. His primary research goals are to explore the effects of climate, geography, and silvicultural treatments on wood anatomy and properties. He is especially interested in the similarities and differences among species of tropical America and Africa, both in their properties and in methods that can be used to differentiate between similar woods. Mike has prepared numerous publications that summarize his research findings and authored *Characteristics and Availability of Commercially Important Woods*, one of the most widely used chapters from FPL's flagship publication, *Wood Handbook: Wood as an Engineering Material*. Mike holds the following degrees: AAS (Forestry from Paul Smith's College), BS (North Carolina State University), MS (SUNY College of Environmental Science and Forestry), and PhD (Louisiana State University).

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Finally, we would like acknowledge the outstanding efforts of our colleagues in the field who are fighting the battle against invasive species and their detrimental effects on our natural resources.

Part One – Overview of Invasive Species and Utilization Options for Hardwoods

by Brian K. Brashaw

Introduction

The introduction and spread of non-native invasive species are causing significant ecological and economic damage to U.S. urban and rural forests. The National Invasive Species Management Plan (2008) defines invasive species as a "species that is non-native to the ecosystem under consideration and whose introduction causes or is likely to cause economic or environmental harm or harm to human health." As a result of infestation from invasive species, particularly emerald ash borer (EAB) but also Asian longhorned beetle (ALB), gypsy moth, and thousand canker disease, tremendous numbers of infested trees are being killed and removed each year for control and ultimate eradication of the pests (USDA APHIS 2006). Proper utilization and safe disposal of woody biomass from these trees present considerable challenges to many local communities and landowners. Urban forestry professionals are increasingly faced with the task of selecting appropriate utilization options for the materials and locating the necessary technical information for making such decisions. Although many studies and wood utilization projects have been conducted for wood from trees attacked by invasive species, much of the basic information on wood materials, product options, and corresponding manufacturing requirements is published in numerous technical reports prepared by universities and other research organizations. While there are a number of agency websites available, there is not a single location which provides comprehensive information on wood technology, markets, and technical information for hardwoods affected by invasive species.

The University of Minnesota Duluth's Natural Resources Research Institute and the USDA Forest Products Laboratory have developed this book as a primary reference on these topics. The target audiences are land management professionals, arborists, utilization specialists, and other natural resource professionals who are at the forefront of dealing with invasive species and their devastating effect on our forest resources. The primary sections of the book are:

1. Overview of Invasive Species and Utilization Options for Hardwoods
2. Basic Wood Properties of Hardwoods Affected by Invasive Species
3. Market and Utilization Options for Ash Logs, Lumber, and Other Products
4. Heat Treatment of Wood for Invasive Forest Pests

While these chapters are available as a printed book, they are also available under the utilization options tab on the EAB website: www.emeraldashborer.info. This web portal is a collaborative effort of the USDA Forest Service, Michigan State University, Purdue University, and Ohio State University to provide comprehensive, accurate, and timely information on the emerald ash borer to the site's visitors. The site was created with support from the USDA Forest Service and is administered through Michigan State University (USDA et al. 2012). In addition, an electronic version of this book is available online at the Wood Education and Resource Center (WERC) website: www.na.fs.fed.us/werc/.

Another important source of information on the invasive species affecting the United States can be found at the National Invasive Species Information Center (NISIC). The NISIC was established in 2005 and manages the www.invasivespeciesinfo.gov website, a reference gateway to information, organizations, and services about invasive species (USDA National Agricultural Library 2012).

Background Information

Emerald Ash Borer

In 2002, the emerald ash borer (EAB), *Agrilus planipennis* Fairmaire, was discovered in southeastern Michigan. At that time, ash trees near Detroit were exhibiting top-down crown dieback, dense sprouting from trunks, and other signs of distress stress usually attributed to ash yellow (USDA APHIS 2010). After positive identification as being caused by EAB, aggressive quarantines were issued in southeastern Michigan and Windsor, Ontario, in June 2002. Extensive surveys were completed in neighboring areas, and EAB was identified in Ohio in 2003; northern Illinois and Maryland in 2006; western Pennsylvania and West Virginia in 2007; Wisconsin, Missouri, and Virginia in summer 2008; Minnesota, New York, and Kentucky in spring 2009; Iowa in spring 2010; and Tennessee in summer 2010.

Figure 1.1. ~ *EAB insect. Photo courtesy of Stephan Ausmus, USDA Agricultural Research Service.*

This non-native pest has caused significant problems for regions where it has been detected. EAB kills all species of ash trees, often within 2 or 3 years after they have been infested. The adult beetle (**Fig. 1.1**) lays eggs in bark crevices, which hatch within 7 to 10 days. The larvae (**Fig. 1.2**) then bore through the bark into the phloem, where they create long galleries. This damage affects the tree's ability to transport water and nutrients. The larvae develop into pupae, which transform into beetles in the spring. The beetles then emerge from the tree, leaving recognizable D-shaped holes in the bark. Symptoms of EAB infestation include (USDA APHIS 2010):

- Thinning of the foliage or crown dieback
- Possible epicormic sprouting on declining trees
- Damage from woodpeckers as small patches of bark are stripped away when the birds search for EAB
- D-shaped emergence holes, approximately 3 mm in diameter
- Larval galleries, typically S-shaped, meandering and packed with EAB frass.

Figure 1.2. ~ *EAB larvae. Photo courtesy of David Cappaert, Michigan State University, www.Bugwood.org.*

Since its discovery, EAB has (USDA et al. 2012):

- Killed tens of millions of ash trees in southeastern Michigan alone, with tens of millions more lost in Illinois, Indiana, Kentucky, Minnesota, Missouri, New York, Ohio, Ontario, Pennsylvania, Quebec, Tennessee, Virginia, West Virginia, and Wisconsin.

- Caused regulatory agencies and the U.S. Department of Agriculture (USDA) to enforce quarantines and fines to prevent potentially infested ash trees, logs, or hardwood firewood from being transported out of areas where EAB occurs. Regulated areas include: Illinois, Indiana, Iowa, Kentucky, Maryland, Michigan, Minnesota, Missouri, New York, Ohio, Ontario, Pennsylvania, Tennessee, Virginia, West Virginia, and Wisconsin.

- Cost municipalities, property owners, nursery operators, and forest products industries tens of millions of dollars.

Figure 1.3 is a map of the locations of EAB in the United States and Canada. This map provides detail on the locations where EAB was initially detected within each state, the federal EAB quarantine zones, state quarantine zones, and the location of Canadian EAB regulated areas. Dated September 5, 2012, the map represents the most accurate information available. When revised, updated versions can be accessed on the web portal: www.emeraldashborerinfo.org.

Detailed information on the locations of EAB within each state, including the ability to use interactive GIS, can be found on the website: www.emeraldashborer.info/surveyinfo.cfm.

Federal and State Initiatives for EAB

Since its discovery in 2002, there have been significant efforts to detect, control, and eradicate EAB; understand the biology of EAB; educate the public about the dangers of transporting

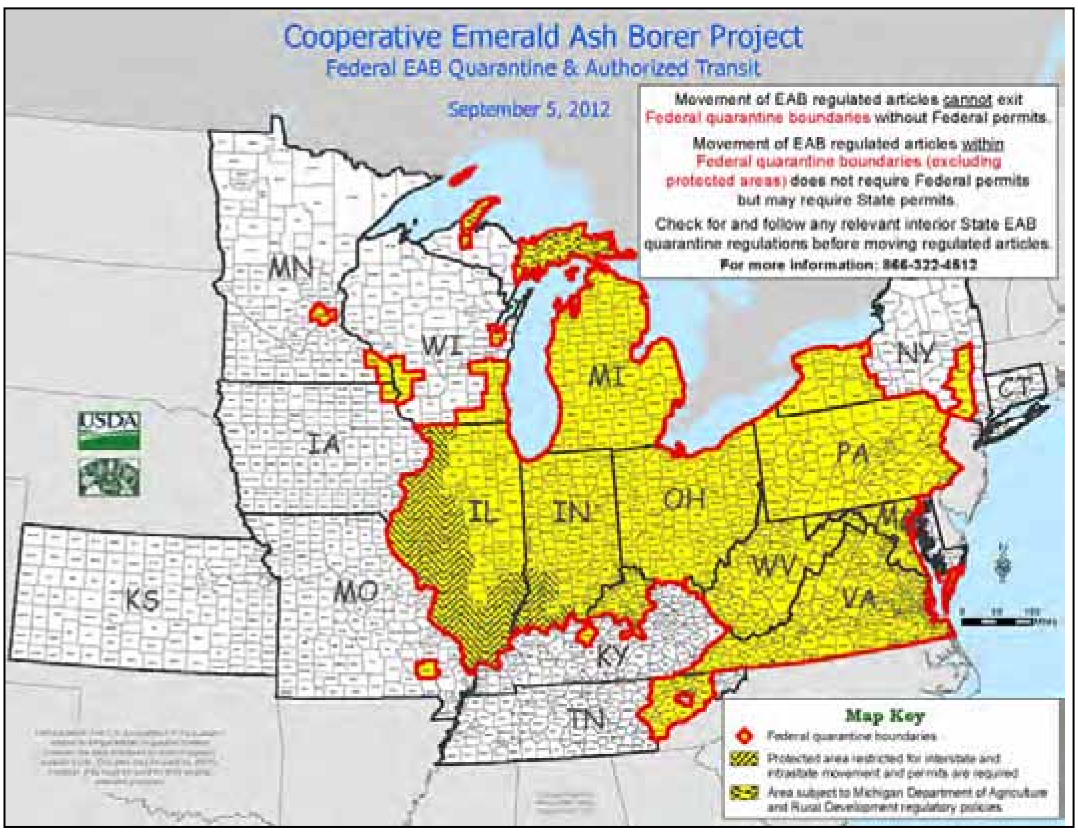

Figure 1.3. ~ *EAB locations and quarantines in North America (USDA APHIS 2012a).*

logs and firewood; and create markets for harvested trees. The following section summarizes several important activities that have been undertaken by a number of agencies and organizations since the discovery of EAB.

USDA Animal and Plant Health Inspection Service

The U.S. Department of Agriculture Animal and Plant Health Inspection Service (USDA APHIS) has had significant responsibilities in dealing with EAB. Initially, APHIS worked with state cooperators to develop and implement strategies to detect, control, and eradicate EAB. It has participated in research with other government agencies and university partners to better understand the biology of EAB. As a means to limit the travel of the insect, APHIS has developed regulatory programs that include federal quarantines and inspections of firewood and other wood products produced. Additionally it has focused significant efforts on developing outreach programs, such as the "Don't Move Firewood" campaign aimed at the general public. All of these activities were conducted in partnership with state and federal agencies. APHIS has a comprehensive list of EAB information, quarantine maps, program manuals, biological control plans, survey guidelines, and regulatory information available on its web portal: www.aphis.usda.gov/plant_health/plant_pest_info/emerald_ash_b/index.shtml.

USDA Forest Service

The USDA Forest Service (Northeastern Area, Northern Research Station and Wood Education and Resource Center [WERC]) has conducted and sponsored significant research into the risk, detection, and spread; biology and ecology; control and management; effects and impacts of EAB; and utilization and market options for tree removals infested with EAB. In addition, it has focused on utilization and marketing of ash logs, lumber, and materials. Comprehensive research with links to key information on these topics can be found on the Forest Service's website: www.nrs.fs.fed.us/disturbance/invasive_species/eab/.

The U.S. Forest Service Northeastern Area has developed an "*Integrated Program Strategy for Reducing the Adverse Impacts of Emerald Ash Borer Throughout North America*" (Cesa et al. 2010). The top five priorities as identified by the Northeastern Area Executive Team are:

1. Prevent the spread of EAB and prepare for EAB outbreaks and infestations by helping state and local governments, homeowners, forest landowners, Federal partners, and tribal governments prepare for EAB and its adverse effects.

2. Manage EAB infestations that will not be eradicated by developing effective management tools and strategies.

3. Manage EAB infestations that will not be eradicated by reducing EAB-induced impacts in high-value areas and unique ecosystems.

4. Rehabilitate and restore forest ecosystems altered by the loss of ash trees by promoting and restoring healthy, sustainable urban and rural forests and unique ecosystems affected by EAB.

5. Prevent the spread of EAB and prepare for EAB outbreaks and infestations by minimizing artificial movement of EAB to non-infested areas.

The USDA Forest Service WERC has also supported research activities focused on phytosanitary treatment of hardwoods and the utilization and marketing of ash materials and logs. WERC is administered by the Northeastern Area State and Private Forestry of the Forest Service. WERC's mission is to facilitate networking and information exchange throughout the forest products industry in order to enhance opportunities that sustain forest products production.

WERC's programs provide training, technology transfer, and applied research and support managerial and technical innovation that keep businesses competitive. The center consists of offices, training facilities, and a rough mill in Princeton, West Virginia and serves the 35 U.S. states in the eastern hardwood region. Information on WERC-funded projects can be found at: www.na.fs.fed.us/werc/eab.shtm.

From 2005 to 2011, WERC conducted an annual competitive grants program that provided funding to numerous urban wood utilization and marketing projects. The results of these projects can be viewed online by using the query box and entering "urbanwood": www.spfnic.fs.fed.us/werc/p_search.cfm.

Southeast Michigan Resource Conservation and Development Council

One of the major efforts to address ash utilization through demonstration projects, training sessions, and research has been conducted through the Southeast Michigan Research Conservation and Development (RC&D) Ash Utilization Options Project. Funded in part through the WERC, this program has helped Michigan communities and businesses develop products and utilization options for urban trees removed due to EAB.

Specifically, the effort has helped fund demonstration projects using EAB wood including the Ann Arbor District Library, Traverwood Branch, in which harvested ash trees from the building site were milled into flooring, wall and ceiling paneling, and shelving. Some of the harvested trees were used intact as support beams and columns. In the Urbanwood Project, small businesses recovered serviceable logs from landscape tree removals and manufactured them as lumber and flooring for the Southeast Michigan Reclaimed Wood Marketplace (www.urbanwood.org). The Ann Arbor, Michigan Urbanwood market is shown in **Figure 1.4**. Additional details on the Urbanwood Project can be found in Part 3 of this book.

Figure 1.4. ~ *The Michigan Urbanwood market.*

The Southeast Michigan RC&D Council has also provided training to numerous city foresters, tree service companies, city maintenance staff, park superintendents, road commission tree crews, arborists, city planners, economic developers, wood processors, and entrepreneurs in Michigan. The training focused on the availability of urban forest resources, "waste wood" recycling opportunities, wood products manufacturing and marketing options, and natural resource-based business development strategies.

A wide range of research and demonstration projects and training opportunities have been funded and completed through the Southeast Michigan RC&D Ash Utilization Options Project. The initial focus of these research projects was treatment of EAB-infested logs. Other studies focused on waste wood processing and utilization and the potential for using material in woody biomass energy production. Comprehensive information, potential product applications, completed research, and additional resources are available at: www.semircd.org/ash/.

Illinois Emerald Ash Borer Wood Utilization Team

Following the identification of EAB in Illinois in 2006, the Illinois Emerald Ash Borer Wood Utilization Team was formed in 2007 to concentrate on encouraging the harvesting and use of wood from urban and community trees felled in Illinois as a result of EAB. The Team has focused on developing an understanding of EAB infestation and opportunities for wood utilization across the entire spectrum of the wood use chain. Arborists, sawyers, woodworkers, intermediaries, and end-users were the targeted groups.

To teach urban foresters how to remove trees in ways that preserve their timber value, the Wood Utilization Team sponsors Urban Timber Harvesting for Hardwood Lumber Utilization and Recovery (UTiH2LzR) training sessions. Municipal managers learn how to grade trees and logs for timber value, negotiate removal contracts, and market urban and community wood through the Municipal Managers UTiH2LzR training sessions. To help promote milling of urban logs into lumber, a primary wood manufacturers directory of custom sawyers was created and several sawing demonstrations were held. To support woodworkers, the brochure, "Emerald Ash Board", was created and a cabinet trade show was held. Intermediary architects, interior designers, wholesalers, and retailers were targeted through student projects at the Illinois Institute of Technology and partnerships with Tri-State Marketing and Branding Cooperative. To create understanding and market pull by end-users, creative, high profile projects were designed, including using baseball bats and state rest stop kiosks and presenting an ash "key" to Chicago for an American Idol show finalist. Detailed information on events, news, resources, and contacts can be found at: www.illinoisurbanwood.org.

www.emeraldashborer.info

The USDA Forest Service and Michigan State University (MSU) created a national clearinghouse website for EAB information. While the site is managed by MSU, the content undergoes a peer-review approval process prior to being added to the website. Emeraldashborer.info is the leading source of information on EAB. The website contains key information on a wide variety of critical EAB topics and has received over 1 million site visits (Usborne 2012) since its launch in 2004. The home page of the website is shown in **Figure 1.5**, with key topics shown in the menu on the left.

Figure 1.5. ~ *www.emeraldashborer.info website home page (May 2012).*

Other Invasive Species

Gypsy Moth

Originating in Europe and Asia, the gypsy moth (*Lymantria dispar*) was introduced into the United States in 1869 near Boston, Massachusetts. Since then the insect has moved north to Maine, west to Wisconsin, and south to North Carolina. Currently infesting 19 U.S. states and Canada, the gypsy moth continues to expand beyond its current range. To reproduce a female moth lays a massed cluster of eggs on or near a tree, as shown in **Figure 1.6**. Each egg mass can then hatch thousands of caterpillars that feed on leaves or needles for 6 to 8 weeks. Then, they pupate, resulting in an adult gypsy moth emergence in approximately 2 weeks, starting the cycle

Figure 1.6. ~ *Gypsy moth. Photo courtesy of Daniel Herms, Ohio State University, www.Bugwood.org.*

Figure 1.7. ~ *Gypsy caterpillar. Photo courtesy of Scott Bauer, USDA Agricultural Research Service.*

again. Gypsy moths produce one egg mass generation per year (USDA APHIS 2003).

The gypsy moth larvae (**Fig. 1.7**) feed on tree leaves, with a preference for oak and aspen. The primary impact of this insect is successive years of defoliation, which may ultimately result in tree mortality (Forest Service 2003). For the forest products industry, the primary concern is the loss of the economically important oak species (*Quercus*).

The gypsy moth has been studied intensively over the last 100 years in North America. There are numerous publications detailing the biology, ecology, and management of the insect. An excellent source of information on these topics can be found on the USDA Forest Service Northeast Area's website: www.fs.fed.us/ne/morgantown/4557/gmoth/. Regulatory information can be found on the USDA APHIS's website: www.aphis.usda.gov/plant_health/plant_pest_info/gypsy_moth/index.shtml. The goal of the regulatory program is to control the spread of gypsy moths by minimizing the human-assisted movement of host material from infested areas to other parts of the United States. Additionally, comprehensive sampling and spraying control programs are in existence in areas with or adjacent to gypsy moth quarantined areas (**Fig. 1.8**).

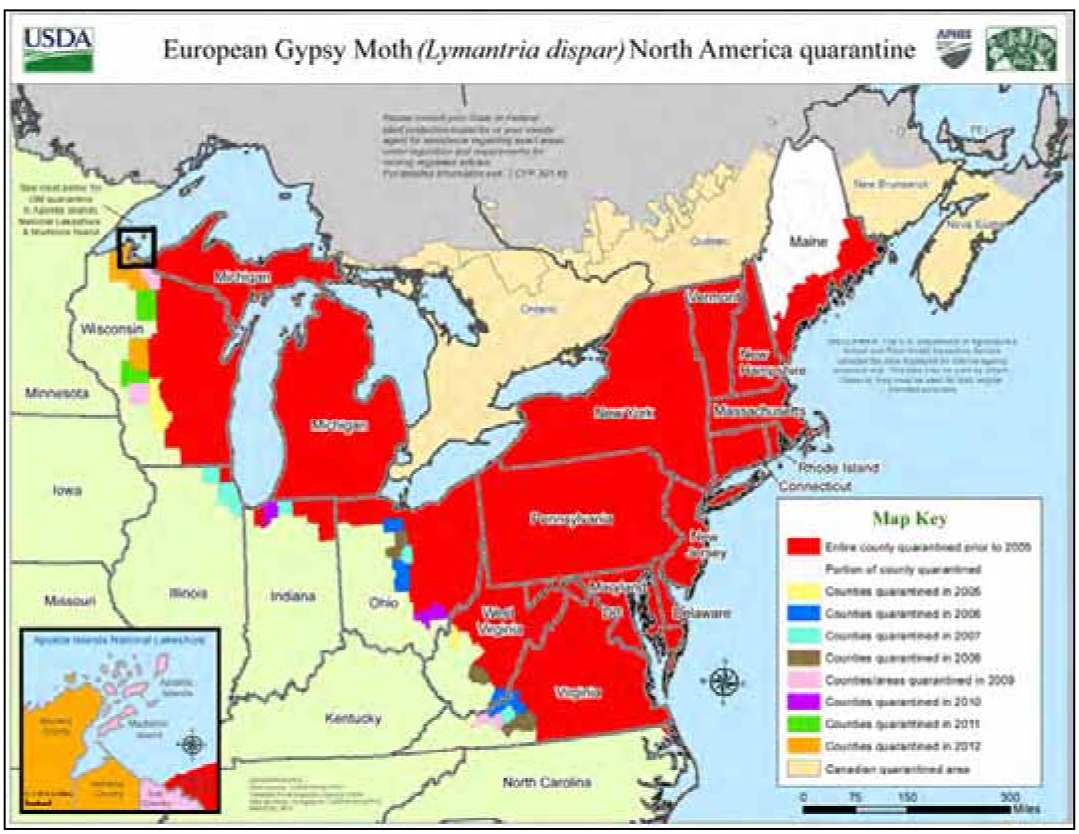

Figure 1.8. ~ *Gypsy moth locations and quarantines in North America (USDA APHIS 2012c).*

Asian Longhorned Beetle

The Asian longhorned beetle (ALB) *Anoplophora glabrinpennis* (Motschulsky) entered the United States among wood packaging or crating materials from China (USDA APHIS 2012c). The ALB is 1 to 1.5 inches long with a black shiny body and white spots (**Fig. 1.9**). The adult beetle lays eggs in tree bark. After hatching, the larvae bore into the tree and feed on living tree tissue. After pupating, they exit the tree during the spring. Similar to other invasive species, the beetle larvae can be transported in logs, lumber with bark, or firewood.

Figure 1.9. ~ *ALB beetle. Photo courtesy of Michael Smith, USDA Agricultural Research Service.*

This invasive species is a serious threat to deciduous hardwood trees. In the United States, the beetle prefers maple species (*Acer* spp.), including box elder, Norway, red, silver, and sugar maples. Other preferred hosts are birches, Ohio buckeye, elm, horse chestnut, and willow. Occasional to rare hosts include ashes, European mountain ash, London plane tree, mimosa, and poplars (USDA Forest Service 2008). The insect eventually kills infested trees. The initial ALB infestation was found in 1996 in New York, followed by Chicago, Illinois in 1998. Additional infestations have been found in Massachusetts, New Jersey, and Ohio. The USDA APHIS has accelerated efforts since ALB's identification through the use of tree removal efforts with resulting chip and burn techniques and quarantines.

Detailed information on ALB infestations, news, and quarantines is available on the USDA APHIS's website: www.aphis.usda.gov/plant_health/plant_pest_info/asian_lhb/index.shtml.

Thousand Cankers Disease

The Thousand Cankers Disease (TCD) poses a significant new threat to eastern black walnut (*Juglans nigra*) in the eastern United States. TCD is caused by the walnut twig beetle (*Pityophthorus juglandis*) and a fungus it vectors (*Geosmithia morbida*). The twig beetle is considered native to the southwestern United States and Mexico, while the origin of the fungus is unknown. TCD is considered an invasive species in the eastern United States, as it has the potential to kill significant numbers of economically important eastern black walnut.

Figure 1.10. ~ *Walnut twig beetle on black walnut trunk. Photo courtesy of Whitney Cranshaw, Colorado State University, www.Bugwood.org.*

The beetle carries the fungal spores on its body, and the spores are introduced into the tree by adult beetles during gallery construction. The fungus then invades the phloem tissue below the bark, resulting in canker development that disrupts the flow of nutrients, ultimately resulting in the death of the tree (NIFA 2012). **Figure 1.10** shows the adult beetle, and **Figure 1.11** shows the visual evidence of the cankers formed that kill the tree.

Figure 1.11. ~ *Thousand cankers disease showing walnut twig beetle galleries and Geosmithia morbida cankers on black walnut. Photo courtesy of Karen Snover-Clift, Cornell University, www.Bugwood.org.*

TCD had been confined to the western states until 2010, when it was identified in Knoxville, Tennessee. Since that identification, it has also been confirmed in Pennsylvania and Virginia. Confirmation of the disease within the native range of eastern black walnut has created significant concern for urban foresters, forest managers, and the wood products industry. Quarantines have been established in a number of states. Typically, these quarantines restrict the entrance of walnut materials from areas where TCD has become established. Several states, including Minnesota, however, have more restrictive exterior quarantines. In 2011, the Minnesota Agriculture Commissioner signed a permanent exterior quarantine restricting movement of products that could be harboring TCD from those states known to have TCD and from other potentially infested areas into Minnesota. The list of walnut products covered by the quarantine includes: live walnut trees, walnut logs, walnut lumber, walnut nursery stock, wood chips and mulch made from walnut wood, walnut branches and roots, and packaging materials made from walnut wood. The quarantine also applies to all hardwood firewood. It does not apply to walnut nuts, nutmeat, walnut hulls, finished products made from walnut wood without bark, or processed lumber that is 100 percent bark-free and kiln-dried with square edges (Minnesota Department of Agriculture 2012).

Detailed information on the status of TCD infestations, news, and quarantines is available at www.thousandcankers.com, a web portal created by Purdue University (Department of Forestry and Natural Resources and the Hardwood Tree Improvement and Regeneration Center), in cooperation with the USDA Forest Service Northeast Area and Northern Research Station and the Walnut Council.

Wood Utilization Options for Trees Affected by Invasive Species

Ash and other species affected by EAB, ALB, and gypsy moth can be utilized in a wide range of products. This includes primary wood products such as lumber that can be further processed into housing products, sporting goods, tools, bioenergy products, and residues for wood composites, wood pellets, or paper. Since the emphasis of this book is ash affected by EAB, **Figure 1.12** shows examples of ash used in various product applications. Detailed information on each application noted can be found in Part 3, Market and Utilization Options for Ash Logs, Lumber, and Other Products. Information will include detailed sections on production considerations, quality specifications, market opportuities, and key trade associations.

Figure 1.12. ~ *Products produced from ash and other species affected by invasive species include: lumber, veneer, furniture, flooring, cabinetry, millwork, structural columns, pallets, bats, snowshoes, tool handles, craft items, mulch, pellets, and firewood. Collage produced by UMD NRRI Trish Sodahl from courtesy photos and UMD NRRI images.*

Trade Associations for Wood Products

There are a wide range of relevant trade associations specializing in lumber and products that can be manufactured from ash and other species affected by invasive species. The following national associations serve as key resources for technical, quality, and marketing information. Regional and state associations are also important sources of information. For an up-to-date list, contact the state's department of natural resources or forestry.

National Associations

American Hardwood Export Council — The America Hardwood Export Council (AHEC) (www.ahec.org) is the leading international trade association for the American hardwood industry, representing companies and trade associations engaged in the export of a full range of U.S. hardwood products, including lumber, veneer, plywood, flooring, molding, and dimension materials.

American Institute of Architects — The American Institute of Architects (AIA) (www.aia.org) has been the leading professional membership association for licensed architects, emerging professionals, and allied partners since 1857.

American Walnut Manufacturers Association — The American Walnut Manufacturers Association (AWMA) (www.walnutassociation.org) is an international trade association representing manufacturers of walnut lumber, dimension lumber, veneer, walnut squares, and gunstock blanks. Organized in 1912, the purpose of the association is to help the industry build and maintain better markets for walnut and lead in efforts to ensure proper management and sustainability of the timber supply of all fine hardwoods, especially walnut.

Hardwood Distributors Association — The Hardwood Distributors Association (www.hardwooddistributors.net) was formed to obtain recognition of wholesale hardwood distributing yards as an important segment within the lumber industry. The purpose of the Association today is to maintain this recognition and to protect and promote the interests of its members.

Hardwood Manufacturers Association — The Hardwood Manufacturers Association (HMA) (www.hmamembers.org) is the only national trade organization with membership limited to hardwood sawmills and lumber concentration yards located in the United States. The HMA created the American Hardwood Information Center (www.HardwoodInfo.com) as the authoritative resource for consumers and professionals seeking information about American hardwoods. With the goal of promoting the use of American hardwood products ranging from flooring, cabinetry, and furniture to millwork and building materials in both residential and commercial applications, the Center offers advice from industry experts on design trends, care and maintenance, installation, finishing, and professional specifying.

Hardwood Plywood & Veneer Association — The Hardwood Plywood & Veneer Association (HPVA) (www.hpva.org) represents the interests of the hardwood plywood, hardwood veneer, and engineered hardwood flooring industries. HPVA offers a wide variety of valuable information and resources on hardwood plywood, veneer, and engineered flooring.

Kitchen Cabinet Manufacturers Association — The Kitchen Cabinet Manufacturers Association (KCMA) (www.kcma.org) was founded to represent companies that manufacture kitchen, bath, or other residential cabinets or produce decorative laminates and their suppliers. KCMA works to advance the industry through advocacy, setting standards, sponsoring research, and providing management tools and educational programs.

National Hardwood Lumber Association — The mission of the National Hardwood Lumber Association (NHLA) (www.nhla.com) is to serve members engaged in commerce in the North American hardwood lumber industry by: maintaining order, structure, rules, and ethics in the changing global hardwood marketplace; providing member services unique to the hardwood lumber industry; driving collaboration across the hardwood industry to promote demand for North American hardwood lumber and advocate for the interest of the hardwood community in public/private policy issues; and building positive relationships within the global hardwood community.

National Wood Flooring Association — The mission of the National Wood Flooring Association (www.woodfloors.org) is to help advance and promote the wood flooring industry, while bringing valuable resources and information to its members.

National Wooden Pallet & Container Association — The National Wooden Pallet & Container Association (NWPCA) (www.palletcentral.com) is the largest organization of wood packaging professionals in the world, focused on advocacy and educational issues for the wood packaging industry.

Wood Component Manufacturers Association — The Wood Component Manufacturers Association (WCMA) (www.woodcomponents.org) represents manufacturers of dimension and wood component products that can supply any component needed for cabinetry, furniture, architectural millwork, closets, flooring, staircases, building materials, or decorative/specialty wood products made from hardwoods, softwoods, or a variety of engineered wood materials. The objectives of WCMA are to develop and promote a general demand for the industry's products and services; collect and distribute useful economic and technical information concerning industry trends and developments; and serve as a business referral clearinghouse by responding to inquiries from dimension and component buyers and sharing this information with its members.

Wood Floor Covering Association — The Wood Floor Covering Association (WFCA) (www.wfca.org) is dedicated to providing consumers with the information, service, and support needed to ensure a successful carpet, hardwood flooring, laminate flooring, vinyl flooring, ceramic tile, area rug, natural stone, cork flooring, or bamboo flooring purchase experience.

Wood Products Manufacturers Association — The mission of the Wood Products Manufacturers Association (WPMA) (www.wpma.org) is to provide its members with the tools to help their businesses succeed. WPMA also acts as a clearinghouse for solving problems of mutual concern and assists members in controlling costs.

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Part Two – Basic Wood Properties of Hardwoods Affected by Invasive Species

by Robert J. Ross and Michael C. Wiemann

Introduction

This chapter summarizes basic property information for several hardwood species. After a discussion of the common and scientific names, micrographs of the cross sections of several species or a representative specie for a species grouping are presented. The physical and mechanical property data, machining characteristics, and other important information are summarized. The information was taken directly from the references listed at the end of this chapter.

Common and Scientific Names

The use of scientific (botanical) names is key to obtaining accurate information about the properties of the wood. Most trees and their woods have a number of common names, and unrelated species can often share the same common name. Common names can be given in reference to the form, use, or a characteristic of the tree, and common names vary from region to region. The scientific name, however, is a two-part identifier that provides a unique name. The first part of the name is the genus and the second part is the species. When written, the genus is capitalized and both the genus and species are underlined or placed in italics type. This naming system dates back to 1753 when Carl von Linne, Linnaeus, wrote *Species Plantarum*. The use of scientific names prevents confusion and the incorrect identifications that can result when using common names. Because anatomical and other characteristics of the wood influence its utilization potential, correctly identifying the wood is crucial. **Table 2.1** lists the common and scientific names of several hardwood species.

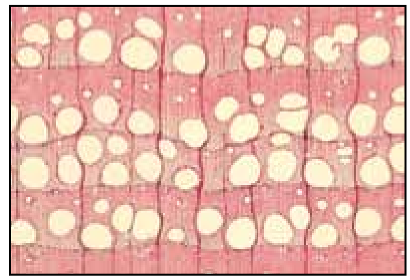
Table 2.1. ~ *Common and scientific names of several hardwood species.*

Common Name	Scientific Name
Ash	*Fraxinus*
Black ash	*Fraxinus nigra*
Green ash	*Fraxinus pennsylvanica*
White ash	*Fraxinus americana*
Birch	*Betula*
Gray birch	*Betula populifolia*
Paper birch	*Betula papyrifera*
River birch; red birch	*Betula nigra*
Sweet birch; black birch	*Betula lenta*
Yellow birch	*Betula alleghaniensis*
Elm	*Ulmus*
American elm; white elm	*Ulmus americana*
Rock elm; cork elm	*Ulmus thomasii*
Slippery elm; red elm	*Ulmus rubra*
Horse-chestnut	*Aesculus*
Ohio buckeye; fetid buckeye	*Aesculus glabra*
Yellow buckeye	*Aesculus octandra*
Maple	*Acer*
Black maple	*Acer nigrum*
Boxelder	*Acer negundo*
Red maple	*Acer rubrum*
Silver maple	*Acer saccharinum*
Sugar maple	*Acer saccharum*
Oak	*Quercus*
Black oak	*Quercus velutina*
Northern red oak	*Quercus rubra*
Pin oak	*Quercus palustris*
Southern red oak	*Quercus falcata*
White oak	*Quercus alba*
Willow	*Salix*
Black willow	*Salix nigra*

Species Descriptions

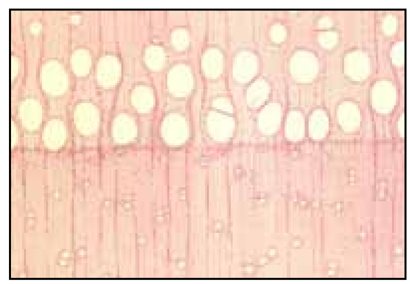
Each species or group of species is described in terms of its principal location, characteristics, and uses. More detailed information on the properties of these and other species is given in various tables throughout this book. Information on historical and traditional uses is provided to illustrate their utility. Accompanying each description is a low-magnification micrograph of a representative cross section of each species or species group. The slides for these micrographs are from the Forest Products Laboratory collection. The micrographs are reproduced at magnifications of approximately 15X. Their color is a consequence of the stains used to accentuate anatomical features and is not indicative of the actual wood color.

Ash (Black Ash)



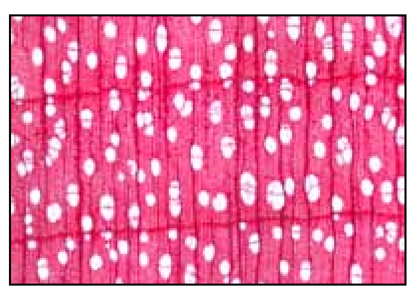
Black ash (*Fraxinus nigra*) grows in the northeast and midwest. The heartwood of black ash is a darker brown than that of American white ash; the sapwood is light-colored or nearly white. The wood of the black ash group is lighter in weight (basic specific gravity of 0.45 to 0.48) than that of the white ash group (basic specific gravity greater than 0.50). Principal uses for black ash are decorative veneer, cabinets, millwork, furniture, cooperage, and crates.

Ash (White Ash Group)



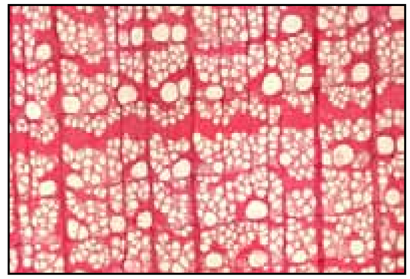
Important species of the white ash group are American white ash (*Fraxinus americana*) and green ash (*F. pennsylvanica*). These species grow in the eastern half of the United States. The heartwood of the white ash group is brown, and the sapwood is light-colored or nearly white. Second-growth trees are particularly sought after because of the inherent qualities of the wood from these trees: it is heavy, strong, hard, and stiff, and it has high resistance to shock. American white ash is used principally for nonstriking tool handles, oars, baseball bats, and other sporting and athletic goods. For handles of the best grade, some handle specifications call for not less than 2 nor more than 7 growth rings per centimeter (not less than 5 nor more than 17 growth rings per inch). The additional weight requirement of 690 kg/m^3 (43 lb/ft^3) or more at 12% moisture content ensures high-quality material. Principal uses for the white ash group are decorative veneer, cabinets, furniture, flooring, millwork, and crates.

Birch



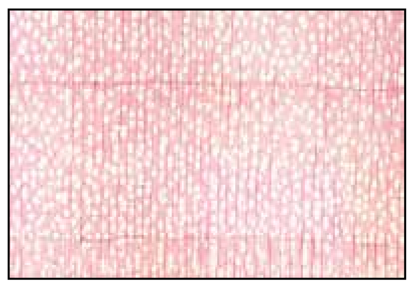
The three most important species are yellow birch (*Betula alleghaniensis*), sweet birch (*B. lenta*), and paper birch (*B. papyrifera*). These three species are the source of most birch lumber and veneer. Other birch species of some commercial importance are gray birch (*B. populifolia*) and river birch (*B. nigra*). Paper birch is transcontinental, whereas yellow, sweet, and paper birch grow principally in the northeast and the Lake States; yellow and sweet birch also grow along the Appalachian Mountains to northern Georgia. Yellow birch has white sapwood and light reddish-brown heartwood. Sweet birch has light-colored sapwood and dark brown heartwood tinged with red. For both yellow and sweet birch, the wood is heavy, hard, and strong, and it has good shock-resisting ability. The wood is fine and uniform in texture. Paper birch is lower in weight, softer, and lower in strength than yellow and sweet birch. Birch shrinks considerably during drying. Yellow and sweet birch lumber are used primarily for the manufacture of furniture, boxes, baskets, crates, wooden ware, cooperage, interior woodwork, and doors; veneer plywood is used for doors, furniture, paneling, cabinets, aircraft, and other specialty uses. Paper birch is used for toothpicks, tongue depressors, ice cream sticks, and turned products, including spools, bobbins, small handles, and toys.

Elm



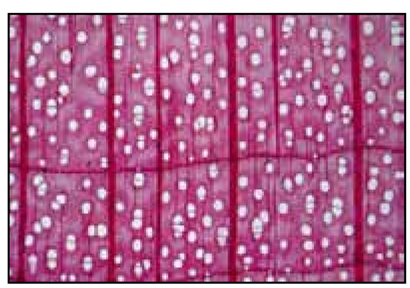
Elm grows in the eastern United States and includes American elm (*Ulmus americana*), slippery elm (*U. rubra*), and rock elm (*U. thomasii*). American elm is also known as white elm, slippery elm as red elm, and rock elm as cork elm. American elm is threatened by two diseases, Dutch Elm disease and phloem necrosis, which have killed hundreds of thousands of trees. Sapwood of elm is nearly white and heartwood light brown, often tinged with red. Elm may be divided into two general classes, soft and hard, based on the weight and strength of the wood. Soft elm includes American elm and slippery elm. It is moderately heavy, has high shock resistance, and is moderately hard and stiff. Rock elm is somewhat heavier than soft elm. Elm has excellent bending qualities. Historically, elm lumber was used for boxes, baskets, crates, slack cooperage, furniture, agricultural supplies and implements, caskets and burial boxes, and wood components in vehicles. Today, elm lumber and veneer are used mostly for furniture and decorative panels. Hard elm is preferred for uses that require strength.

Horse Chestnut (Buckeye)



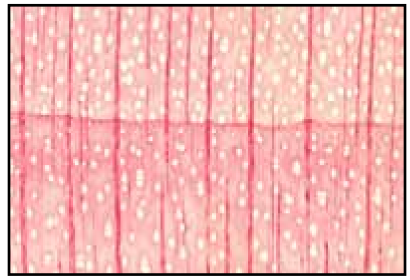
Buckeye consists of two species, yellow buckeye (*Aesculus octandra*) and Ohio buckeye (*A. glabra*). These species range from the Appalachians of Pennsylvania, Virginia, and North Carolina westward to Kansas, Oklahoma, and Texas. The white sapwood of buckeye merges gradually into the creamy or yellowish white heartwood. The wood is uniform in texture, generally straight grained, light in weight, soft, and low in shock resistance. It is rated low on machinability such as shaping, mortising, boring, and turning. Buckeye is suitable for pulping for paper. In lumber form, it has been used principally for furniture, boxes and crates, food containers, wooden ware, novelties, and planing mill products.

Maple (Hard Maple Group)



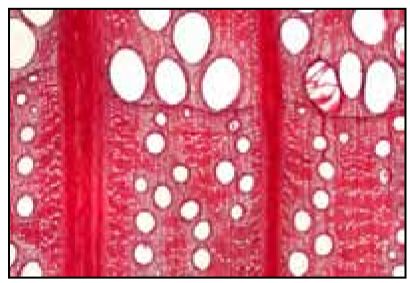
Hard maple includes sugar maple (*Acer saccharum*) and black maple (*A. nigrum*). Sugar maple is also known as rock maple, and black maple as black sugar maple. Maple lumber is manufactured principally in the Middle Atlantic and Great Lake States, which together account for about two-thirds of production. The heartwood is usually light reddish-brown but sometimes considerably darker. The sapwood is commonly white with a slight reddish-brown tinge. It is usually 8 to 12 cm (3 to 5 in.) wide. Hard maple has a fine, uniform texture. It is heavy, strong, stiff, hard, resistant to shock, and has high shrinkage. The grain of sugar maple is generally straight, but birdseye, curly, or fiddleback grain is often selected for furniture or novelty items. Hard maple is used principally for lumber and veneer. A large proportion is manufactured into flooring, furniture, cabinets, cutting boards and blocks, pianos, billiard cues, handles, novelties, bowling alleys, dance and gymnasium floors, spools, bobbins, and bowling pins.

Maple (Soft Maple Group)



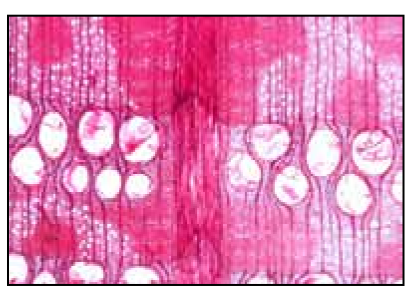
Soft maple includes red maple (*Acer rubrum*), silver maple (*A. saccharinum*), and boxelder (*A. negundo*). Silver maple is also known as white, river, water, and swamp maple; red maple as soft, water, scarlet, white, and swamp maple; and boxelder as ash-leaved, three-leaved, and cut-leaved maple. These species are found in the eastern United States. Heartwood and sapwood are similar in appearance to hard maple. Heartwood of soft maple is somewhat lighter in color than the sapwood and somewhat wider. The wood of soft maple, primarily silver and red maple, resembles that of hard maple but is not as heavy, hard, and strong. Soft maple is used for railroad crossties, boxes, pallets, crates, furniture, veneer, wooden ware, novelties, and is also used as a less expensive alternative to hard maple in architectural millwork.

Oak (Red Oak Group)



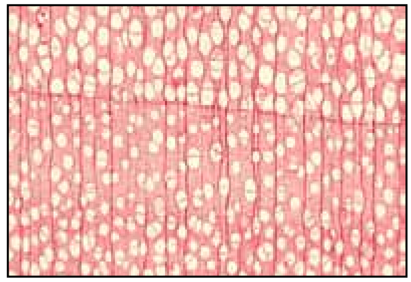
Most red oak comes from the Eastern States. The principal species are northern red oak (*Quercus rubra*), black oak (*Q. velutina*), southern red oak (*Q. falcata*), and pin oak (*Q. palustris*). The sapwood is nearly white and roughly 2 to 5 cm (1 to 2 in.) wide. The heartwood is brown with a tinge of red. Sawn lumber of the red oak group cannot be separated by species on the basis of wood characteristics alone; however, northern red oak lumber from the Lake States has a higher value because of tighter growth rings and uniformity of color than Appalachian or Southern red oak. This is true with other hardwood species and is due to slower growth caused by a shorter growing season. Red oak lumber can be separated from white oak by the size and arrangement of pores in latewood and because it generally lacks tyloses in the pores. The open pores of red oak make this species group unsuitable for tight cooperage, unless the barrels are lined with sealer or plastic. Quartersawn lumber of the oaks is distinguished by its broad and conspicuous rays. Wood of the red oaks is heavy. Rapidly grown, second-growth wood is generally harder and tougher than finer textured, old-growth wood. The red oaks have fairly high shrinkage upon drying. The red oaks are primarily cut into lumber, railroad crossties, mine timbers, fence posts, veneer, pulpwood, and fuelwood. Ties, mine timbers, and fence posts require preservative treatment for satisfactory service. Red oak lumber is remanufactured into flooring, furniture, general millwork, boxes, pallets and crates, agricultural implements, caskets, wooden ware, and handles. It is also used in railroad cars and boats.

Oak (White Oak)



White oak lumber comes chiefly from the South, South Atlantic, and Central States, including the southern Appalachian area. The principal species is *Quercus alba*. The sapwood of white oak is nearly white and roughly 2 to 5 cm (1 to 2 in.) wide. The heartwood is generally grayish brown. Heartwood pores are usually plugged with tyloses, which tend to make the wood impenetrable to liquids. Consequently, white oak is suitable for tight cooperage such as for barrels. The wood of white oak is somewhat heavier than the wood of red oak. Its heartwood has good decay resistance. White oak is usually cut into lumber, railroad crossties, mine timbers, fence posts, veneer, fuelwood, and many other products. High-quality white oak is especially sought for tight cooperage. An important use of white oak is planking and bent parts of ships and boats; heartwood is often specified because of its decay resistance. White oak is also used for furniture, flooring, pallets, agricultural implements, railroad cars, truck floors, furniture, doors, and millwork.

Willow (Black)



Black willow (*Salix nigra*) is the most important of the many willows that grow in the United States. It is the only willow marketed under its own name. Most black willow comes from the Mississippi Valley, from Louisiana to southern Missouri and Illinois. The heartwood of black willow is grayish brown or light reddish brown and frequently contains darker streaks. The sapwood is whitish to creamy yellow. The wood is uniform in texture, with somewhat interlocked grain, and is light in weight. It has exceedingly low strength as a beam or post, is moderately soft, and is moderately high in shock resistance. It has moderately high shrinkage. Black willow is principally cut into lumber, which is then remanufactured into boxes, pallets, crates, caskets, and furniture. Small amounts are used for slack cooperage, veneer, excelsior, charcoal, pulpwood, artificial limbs, and fence posts.

Characteristics

All wood is composed of cellulose, lignin, hemicelluloses, and minor amounts (usually less than 10%) of extraneous materials contained in a cellular structure. Variation in the characteristics and proportions of these components and differences in cellular structure make woods heavy or light, stiff or flexible, and hard or soft. The properties of a single species are relatively constant within limits; therefore, selection of wood by species alone may sometimes be adequate. To use wood to its best advantage and most effectively in engineering applications, however, specific characteristics or physical properties must be considered.

Grain and Texture

The terms grain and texture are commonly used rather loosely in connection with wood. Grain is often used in reference to the relative sizes and distribution of cells, as in fine grain and coarse grain. But, grain is also used to indicate the direction of fibers, as in straight grain, spiral grain, and curly grain. Wood finishers refer to wood as open grained and close grained, which are terms reflecting the relative size of the pores, which determines whether the surface needs a filler. Earlywood and latewood within a growth increment usually consist of different kinds and sizes of wood cells. The difference in cells results in difference in appearance of the growth rings, and the resulting appearance is the texture of the wood. Coarse texture can result from wide bands of large vessels, such as in oak. “Even” texture generally means uniformity in cell dimensions. Fine-textured woods have small, even-textured cells. Woods that have larger even-sized cells are considered medium-textured woods. When the words grain or texture are used in connection with wood, the meaning intended should be made clear.

Plainsawn and Quartersawn

Lumber can be cut from a log in two distinct ways:

a. tangential to the annual rings, producing flatsawn or plainsawn lumber in hardwoods and flatsawn or slash-grained lumber in softwoods, and

b. radially from the pith or parallel to the rays, producing quartersawn lumber in hardwoods and edge-grained or vertical-grained lumber in softwoods (**Fig. 2.1**).

Quartersawn lumber is not usually cut strictly parallel with the rays. In plainsawn boards, the surfaces next to the edges are often far from tangential to the rings. In commercial practice, lumber with rings at angles of 45° to 90° to the wide surface is called quartersawn, and lumber with rings at angles of 0° to 45° to the wide surface is called plainsawn. Hardwood lumber in which annual rings form angles of 30° to 60° to the wide faces is sometimes called bastard sawn. For many purposes, either plainsawn or quartersawn lumber is satisfactory. Each type has certain advantages that can be important for a particular use. Some advantages of plainsawn and quartersawn lumber are given in **Table 2.2**.

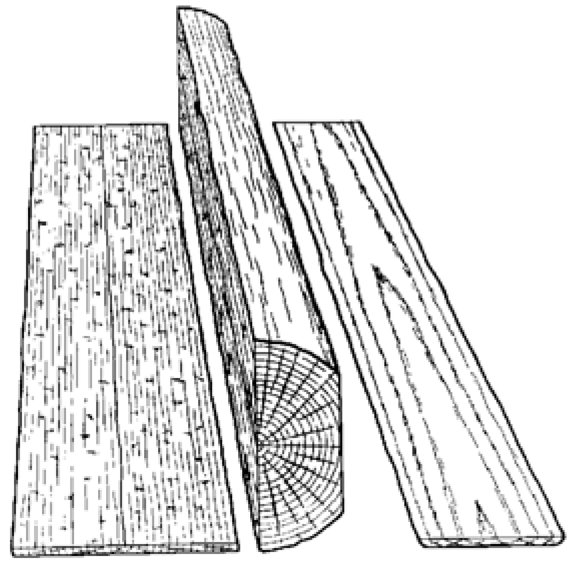


Figure 2.1. ~ *(A) Quartersawn and (B) plainsawn boards cut from a log.*

Table 2.2. ~ *Some advantages of plainsawn and quartersawn lumber.*

Plainsawn	Quartersawn
Shrinks and swells less in thickness	Shrinks and swells less in width
Round or oval knots affect surface appearance less than spike knots in quartersawn boards; boards with round or oval knots are not as weak as boards with spike knots	Cups, surface checks, and splits less in seasoning and use
Shakes and pitch pockets, when present, extend through fewer boards	Does not allow liquids to pass through readily in some species
Figure patterns resulting from annual rings and some other types of figure brought out more conspicuously	Figure patterns resulting from pronounced rays, interlocked grain, and wavy grain are brought out more conspicuously
Is less susceptible to collapse in drying	Raised grain caused by separation in annual rings does not become as pronounced
Costs less because it is easier to obtain	Holds paint better in some species
	Sapwood appears in boards at edges and its width is limited by the width of the log

Decorative Features

The decorative value of wood depends upon its color, figure, and luster, as well as the way in which it bleaches or takes fillers, stains, and transparent finishes. Because of the combinations of color and the multiplicity of shades found in wood, it is impossible to give detailed color descriptions of the various kinds of wood. Sapwood of most species is light in color; in some species, sapwood is practically white.

White sapwood of certain species, such as maple, may be preferred to the heartwood for specific uses. In most species, heartwood is darker and fairly uniform in color. In some species, such as basswood, cottonwood, and beech, there is little or no difference in color between sapwood and heartwood. **Table 2.3** describes the color and figure of several common hardwoods.

On the surface of plainsawn boards and rotary-cut veneer, the annual growth rings frequently form elliptic and parabolic patterns that make striking figures, especially when the rings are irregular in width and outline on the cut surface.

On quartersawn surfaces, these rings form stripes, which are not especially ornamental unless they are irregular in width and direction. Relatively large rays sometimes appear as flecks that can form a conspicuous figure in quartersawn oak and sycamore. When oak is used for furniture, the wood is cut to minimize the broad rays. With interlocked grain, which slopes in alternate directions in successive layers from the center of the tree outward, quartersawn surfaces show a ribbon effect, either because of the difference in reflection of light from successive layers when the wood has a natural luster or because cross grain of varying degree absorbs stains unevenly. Much of this type of figure is lost in plainsawn lumber.

In open-grained hardwoods, the appearance of both plainsawn and quartersawn lumber can be varied greatly by the use of fillers of different colors.

Knots, pin wormholes, bird pecks, decay in isolated pockets, birds-eye, mineral streaks, swirls in grain, and ingrown bark are decorative in some species when the wood is carefully selected for a particular architectural treatment.

Table 2.3. ~ *Color and figure of several common hardwood species.*

Common species name	Color of dry heartwood[a]	Type of figure	
		Plainsawn lumber or rotary-cut veneer	Quartersawn lumber or quarter-sliced veneer
Ash, black	Moderately dark grayish brown	Conspicuous growth rings; occasional burl	Distinct, inconspicuous growth ring stripes; occasional burl
Ash, white	Grayish brown, sometimes with reddish tinge	Conspicuous growth rings; occasional burl	Distinct, inconspicuous growth ring stripes; occasional burl
Birch, paper	Light brown	Faint growth rings	None
Birch, sweet	Dark reddish brown	Distinct, inconspicuous growth rings; occasionally wavy	Occasionally wavy
Birch, yellow	Reddish brown	Distinct, inconspicuous growth rings; occasionally wavy	Occasionally wavy
Elm, American and rock	Light grayish brown, usually with reddish tinge	Distinct, inconspicuous growth rings with fine wavy pattern	Faint growth ring stripes
Elm, slippery	Dark brown with shades of red	Conspicuous growth rings with fine patterns	Distinct, inconspicuous growth ring stripes
Maple: black, bigleaf, red, silver, and sugar	Light reddish brown	Faint growth rings, occasionally birds-eye, curly, and wavy	Occasionally curly and wavy
Oaks, all red oaks	Light brown, usually with pink or red tinge	Conspicuous growth rings	Pronounced flake; distinct, inconspicuous growth ring stripes
Oaks, all white oaks	Light to dark brown, rarely with reddish tinge	Conspicuous growth rings	Pronounced flake; distinct, inconspicuous growth ring stripes

[a] Sapwood of all species is light in color or virtually white unless discolored by fungus or chemical stains.

Moisture Content

Moisture content of wood is defined as the weight of water in wood expressed as a fraction, usually a percentage, of the weight of ovendry wood. Weight, shrinkage, strength, and other properties depend upon the moisture content of wood.

In trees, moisture content can range from about 30% to more than 200% of the weight of wood substance. In hardwoods, the difference in moisture content between heartwood and sapwood depends on the species. The average moisture content of heartwood and sapwood of several species is given in **Table 2.4**. These values are considered typical, but there is considerable variation within and between trees. Variability of moisture content exists even within individual boards cut from the same tree.

Table 2.4. ~ *Average moisture content of green wood, by species.*

Common species name	Moisture content (%)	
	Heartwood	**Sapwood**
Ash, black	95	--
green	--	58
white	46	44
Birch, paper	89	72
sweet	75	70
yellow	74	72
Elm, American	95	92
rock	44	57
Maple, silver	58	97
sugar	65	72
Oak, northern red	80	69
southern red	83	75
white	64	78

Green Wood

Moisture can exist in wood as free water (liquid water or water vapor in cell lumens and cavities) or as bound water within cell walls. Green wood is often defined as freshly sawn wood in which the cell walls are completely saturated with water; however, green wood usually contains additional water in the lumens. The moisture content at which both the cell lumens and cell walls are completely saturated with water is the maximum possible moisture content. Specific gravity is the major determinant of maximum moisture content. Lumen volume decreases as specific gravity increases, so maximum moisture content also decreases as specific gravity increases because there is less room available for free water.

Shrinkage

Wood is dimensionally stable when the moisture content is greater than the fiber saturation point. Wood changes dimension as it gains or losses moisture below that point. It shrinks when losing moisture from the cell walls and swells when gaining moisture in the cell walls. This shrinking and swelling can result in warping, checking, splitting, and loosening of tool handles, gaps in strip flooring, or performance problems that detract from the usefulness of the wood product. Therefore, it is important that these phenomena be understood and considered when they can affect a product in which wood is used.

With respect to shrinkage characteristics, wood is an orthropic material. It shrinks most in the direction of the annual growth rings (tangentially), about half as much across the rings (radially), and only slightly along the grain (longitudinally). The combined effects of radial and tangential shrinkage can distort the shape of wood pieces because of the difference in shrinkage and the curvature of annual rings. The major types of distortion as a result of these effects are illustrated in **Figure 2.2**.

Transverse and Volumetric

Data have been collected to represent the average radial, tangential, and volumetric shrinkage of numerous species by methods described in American Society for Testing and Materials (ASTM) D143—Standard Method of Testing Small Clear Specimens of Timber (ASTM 1997). Shrinkage values, expressed as a percentage of the green dimension, are listed in **Table 2.5**.

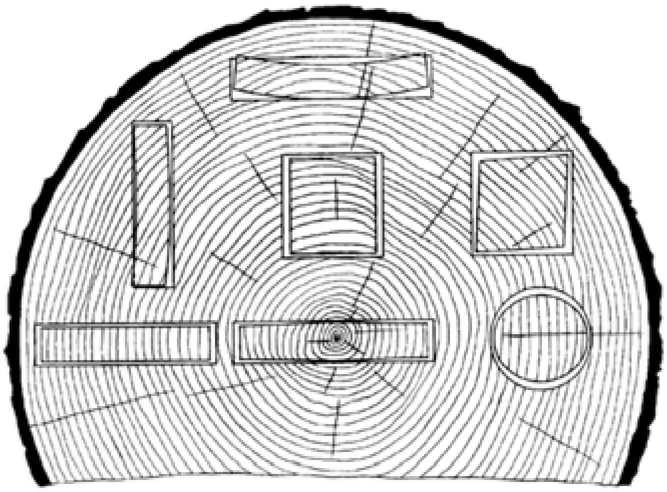


Figure 2.2. ~ *Characteristic shrinkage and distortion of flat, square, and round pieces as affected by direction of growth rings. Tangential shrinkage is about twice as great as radial.*

Table 2.5. ~ *Shrinkage values of several hardwood species.*

Common species name	Shrinkage[a] (%) from green to ovendry moisture content		
	Radial	Tangential	Volumetric
Ash, black	5.0	7.8	15.2
blue	3.9	6.5	11.7
green	4.6	7.1	12.5
Oregon	4.1	8.1	13.2
pumpkin	3.7	6.3	12.0
white	4.9	7.8	13.3
Birch, Alaska paper	6.5	9.9	16.7
gray	5.2	--	14.7
paper	6.3	8.6	16.2
river	4.7	9.2	13.5
sweet	6.5	9.0	15.6
yellow	7.3	9.5	16.8
Buckeye, yellow	3.6	8.1	12.5
Elm, American	4.2	8.5	14.6
cedar	4.7	10.2	15.4
rock	4.8	8.1	14.9
slippery	4.9	8.9	13.8
winged	5.3	11.6	17.7
Maple, bigleaf	3.7	7.1	11.6
black	4.8	9.3	14.0

(Table continued on next page.)

The shrinkage of wood is affected by a number of variables. In general, greater shrinkage is associated with greater density. The size and shape of a piece of wood can affect shrinkage, and the rate of drying for some species can affect shrinkage. Transverse and volumetric shrinkage variability can be expressed by a coefficient of variation of approximately 15%.

Longitudinal

Longitudinal shrinkage of wood (shrinkage parallel to the grain) is generally quite small. Average values for shrinkage from green to ovendry are between 0.1% and 0.2% for most species of wood. Certain types of wood, however, exhibit excessive longitudinal shrinkage, and these should be avoided in uses where longitudinal stability is important. Reaction wood and wood from near the center of trees (juvenile wood) of some species shrink excessively parallel to the grain. Reaction wood and juvenile wood can shrink 2% lengthwise from green to ovendry. Wood with cross grain exhibits increased shrinkage along the longitudinal axis of a piece.

Reaction wood exhibiting excessive longitudinal shrinkage can occur in the same board with normal wood. The presence of this type of wood, as well as cross grain, can cause serious warping, such as bow, crook, or twist, and cross breaks can develop in the zones of high shrinkage.

Weight, Density, and Specific Gravity

Two primary factors affect the weight of wood products: the amount of dry wood substance and moisture content. A third factor, minerals and extractable substances, has a marked effect only on a limited number of species.

The density of wood, exclusive of water, varies greatly both within and between species. Although the density of most species falls between about 320 and 720 kg/m^3 (20 and 45 lb/ft^3), the range of density actually extends from about 160 kg/m^3 (10 lb/ft^3) for balsa to more than 1,040 kg/m^3 (65 lb/ft^3) for some other imported woods. A coefficient of variation of about 10% is considered suitable for describing the variability of density for common U.S. hardwood species.

Wood is used in a wide range of conditions and has a wide range of moisture content values in use. Moisture makes up part of the weight of each product in use; therefore, the density must reflect this fact. This has resulted in the density of wood often being determined and reported on the basis of moisture content in use.

The calculated density of wood, including the water contained in the wood, is usually based on average species characteristics. This value should always be considered an approximation because of the natural variation in anatomy, moisture content, and ratio of heartwood to sapwood that occurs. Nevertheless, this determination of density usually is sufficiently accurate to permit proper utilization of wood products where weight is important. Such applications range from the estimation of structural loads to the calculation of approximate shipping weights.

Table 2.5. ~ *(Continued.) Shrinkage values of several hardwood species.*

Common species name	Shrinkage[a] (%) from green to ovendry moisture content		
	Radial	Tangential	Volumetric
Maple *(continued)*			
red	4.0	8.2	12.6
silver	3.0	7.2	12.0
striped	3.2	8.6	12.3
sugar	4.8	9.9	14.7
Oak (red group)			
black	4.4	11.1	15.1
laurel	4.0	9.9	19.0
northern red	4.0	8.6	13.7
pine	4.3	9.5	14.5
scarlet	4.4	10.8	14.7
southern red	4.7	11.3	16.1
water	4.4	9.8	16.1
willow	5.0	9.6	18.9
Oak (white group)			
bur	4.4	8.8	12.7
chestnut	5.3	10.8	16.4
live	6.6	9.5	14.7
overcup	5.3	12.7	16.0
post	5.4	9.8	16.2
swamp, chestnut	5.2	10.8	16.4
white	5.6	10.5	16.3
Willow, black	3.3	8.7	13.9

[a] Expressed as a percentage of the green dimension.

To standardize comparisons of species or products and estimations of product weight, specific gravity is used as a standard reference basis, rather than density. The traditional definition of specific gravity is the ratio of the density of the wood to the density of water at a specified reference temperature (often 4.4°C (40°F)) where the density of water is 1.0000 g/cm^3. To reduce confusion introduced by the variable of moisture content, the specific gravity of wood usually is based on the ovendry weight and the volume at some specified moisture content.

Commonly used bases for determining specific gravity are ovendry weight and volume at:

a. green,

b. ovendry, and

c. 12% moisture content.

Ovendry weight and green volume are often used in databases to characterize specific gravity of species, which is referred to as basic specific gravity.

Working Qualities

The ease of working wood with hand tools generally varies directly with the specific gravity of the wood. The lower the specific gravity, the easier it is to cut the wood with a sharp tool. Specific gravity values can be used as a general guide to the ease of working with hand tools.

A wood species that is easy to cut does not necessarily develop a smooth surface when it is machined. Consequently, tests have been made with many U.S. hardwoods to evaluate them for machining properties. Results of these evaluations are given in **Table 2.6**.

Table 2.6. ~ *Some machining and related properties of several hardwood species.*

Common species name	Planing: perfect pieces (%)	Shaping: good to excellent pieces (%)	Turning: fair to excellent pieces (%)	Boring: good to excellent pieces (%)	Mortising: fair to excellent pieces (%)	Sanding: good to excellent pieces (%)	Steam bending: unbroken pieces (%)	Nail splitting: pieces free from complete splits (%)	Screw splitting: pieces free from complete splits (%)
Ash	75	55	79	94	58	75	67	65	71
Birch	63	57	80	97	97	34	72	32	48
Birch, paper	47	22	--	--	--	--	--	--	--
Elm, soft	33	13	65	94	75	66	74	80	74
Maple, bigleaf	52	56	80	100	80	--	-	--	--
Maple, hard	54	72	82	99	95	38	57	27	52
Maple, soft	41	25	76	80	34	37	59	58	61
Oak, red	91	28	84	99	95	81	86	66	78
Oak, white	87	35	85	95	99	83	91	69	74
Willow	52	5	58	71	24	24	73	89	62

Decay Resistance

Wood kept constantly dry does not decay. In addition, if wood is kept continuously submerged in water, even for long periods of time, it does not decay significantly by the common decay fungi regardless of the wood species or the presence of sapwood. Bacteria and certain soft-rot fungi can attack submerged wood, but the resulting deterioration is very slow. A large proportion of wood in use is kept so dry at all times that it lasts indefinitely.

Moisture and temperature, which vary greatly with local conditions, are the principal factors that affect rate of decay. Wood deteriorates more rapidly in warm, humid areas than in cool or dry areas. High altitudes, as a rule, are less favorable to decay than are low altitudes because the average temperatures at higher altitudes are lower and the growing season for fungi, which cause decay, is shorter. The heartwood of common native species of wood has varying degrees of natural decay resistance. Untreated sapwood of substantially all species has low resistance to decay and usually has a short service life under decay-producing conditions. The decay resistance of heartwood is greatly affected by differences in the preservative qualities of the wood extractives, the attacking fungus, and the conditions of exposure.

Considerable difference in service life can be obtained from pieces of wood cut from the same species, even from the same tree, and used under apparently similar conditions.

Precise ratings of decay resistance of heartwood of different species are not possible because of differences within species and the variety of service conditions to which wood is exposed. But, broad groupings of many native species, based on service records, laboratory tests, and general experience, are helpful in choosing heartwood for use under conditions favorable to decay. **Table 2.7** lists such groupings for several hardwood species, according to their average heartwood decay resistance. The extent of variations in decay resistance of individual trees or wood samples of a species is much greater for most of the more resistant species than for the slightly or nonresistant species.

Table 2.7. ~ *Grouping of several hardwood species according to average heartwood decay resistance.*

Resistant	Slightly or nonresistant
Oaks, white[a]	Ashes
	Birches
	Buckeye
	Elms
	Hickories
	Maples
	Willows

[a] More than one species included, some of which may vary in resistance from that indicated.

Where decay hazards exist, heartwood of species in the resistant or very resistant category generally gives satisfactory service, but heartwood of species in the slightly or nonresistant category will usually require some form of preservative treatment. For mild decay conditions, a simple preservative treatment—such as a short soak in preservative after all cutting and boring operations are complete—will be adequate for wood low in decay resistance.

Mechanical Properties

The mechanical properties presented in this section were obtained from tests of small pieces of wood termed "clear" and "straight grained" because they did not contain characteristics such as knots, cross grain, checks, and splits. These test pieces did have anatomical characteristics such as growth rings that occurred in consistent patterns within each piece.

Many of the tabulated mechanical properties of hardwoods were derived from extensive sampling and analysis procedures. These properties are represented as the average for that species. Variability, or variation in properties, is common to all materials. Because wood is a natural material and the tree is subject to many constantly changing influences (such as moisture, soil conditions, and growing space), wood properties vary considerably, even in clear material.

While it is beyond the scope of this chapter to list all of the mechanical properties for the hardwood species discussed, a brief description of four important mechanical properties widely used in evaluating the potential performance of a wood species in many applications is presented. **Table 2.8** provides values for modulus of rupture, modulus of elasticity, compression stress perpendicular to grain, and hardness values for various hardwood species. These clear wood properties should not be used for calculation of structural properties without consideration of growth characteristics such as location of knots and slope of grain.

Modulus of Rupture

The modulus of rupture (MOR) reflects the maximum load-carrying capacity of a member in bending. MOR is an accepted criterion of strength, although it is not a true stress because the formula by which it is computed is valid only to the elastic limit.

Modulus of Elasticity

The modulus of elasticity (MOE) obtained from a simple bending test is frequently reported for wood. Elasticity implies that deformations produced by low stress are completely recoverable after loads are reduced or removed. A high MOE value indicates that species of wood will deform less under a given load than a species that has a low MOE value.

Compressive Stress Perpendicular to Grain

Compressive stress perpendicular to grain is reported as stress at proportional limit. There is no clearly defined ultimate stress for this property.

Hardness

Hardness is generally defined as resistance to indentation using a modified Janka hardness test, measured by the load required to embed a 11.28-mm (0.444-in.) ball to one-half its diameter. Values presented are the average of radial and tangential penetrations.

Table 2.8. ~ *Strength properties of some commercially important hardwoods grown in the United States (inch-pound).*[a]

Common species name	Moisture content	Specific gravity[b]	Static bending: Modulus of rupture ($lbf\ in^{-2}$)	Static bending: Modulus of elasticity[c] ($\times10^6\ lbf\ in^{-2}$)	Compression perpendicular to grain ($lbf\ in^{-2}$)	Side hardness (lbf)
Ash, black	Green	0.45	6,000	1.04	350	520
	12%	0.49	12,600	1.60	760	850
blue	Green	0.53	9,600	1.24	810	--
	12%	0.58	13,800	1.40	1,420	--
green	Green	0.53	9,500	1.40	730	870
	12%	0.56	14,100	1.66	1,310	1,200
Oregon	Green	0.50	7,600	1.13	530	790
	12%	0.55	12,700	1.36	1,250	1,160
white	Green	0.55	9,500	1.44	670	960
	12%	0.60	15,000	1.74	1,160	1,320
Birch, paper	Green	0.48	6,400	1.17	270	560
	12%	0.55	12,300	1.59	600	910
sweet	Green	0.60	9,400	1.65	470	970
	12%	0.65	16,900	2.17	1,080	1,470
yellow	Green	0.55	8,300	1.50	430	780
	12%	0.62	16,600	2.01	970	1,260
Elm, American	Green	0.46	7,200	1.11	360	620
	12%	0.50	11,800	1.34	690	830
rock	Green	0.57	9,500	1.19	610	940
	12%	0.63	14,800	1.54	1,230	1,320
slippery	Green	0.48	8,000	1.23	420	660
	12%	0.53	13,000	1.49	820	860
Maple, bigleaf	Green	0.44	7,400	1.10	450	620
	12%	0.48	10,700	1.45	750	850
black	Green	0.52	7,900	1.33	600	840
	12%	0.57	13,300	1.62	1,020	1,180

(Table continued on next page.)

Table 2.8. ~ *(Continued.) Strength properties of some commercially important hardwoods grown in the United States (inch-pound).*[a]

Common species name	Moisture content	Specific gravity[b]	Static bending: Modulus of rupture (lbf in^{-2})	Static bending: Modulus of elasticity[c] (×10^{6} lbf in^{-2})	Compression perpendicular to grain (lbf in^{-2})	Side hardness (lbf)
Maple *(continued)*						
red	Green	0.49	7,700	1.39	400	700
	12%	0.54	13,400	1.64	1,000	950
silver	Green	0.44	5,800	0.94	370	590
	12%	0.47	8,900	1.14	740	700
sugar	Green	0.56	9,400	1.55	640	970
	12%	0.63	15,800	1.83	1,470	1,450
Oak (red group)						
black	Green	0.56	8,200	1.18	710	1,060
	12%	0.61	13,900	1.64	930	1,210
cherrybark	Green	0.61	10,800	1.79	760	1,240
	12%	0.68	18,100	2.28	1,250	1,480
laurel	Green	0.56	7,900	1.39	570	1,000
	12%	0.63	12,600	1.69	1,060	1,210
northern red	Green	0.56	8,300	1.35	610	1,000
	12%	0.63	14,300	1.82	1,010	1,290
pin	Green	0.58	8,300	1.32	720	1,070
	12%	0.63	14,000	1.73	1,020	1,510
scarlet	Green	0.60	10,400	1.48	830	1,200
	12%	0.67	17,400	1.91	1,120	1,400
southern red	Green	0.52	6,900	1.14	550	860
	12%	0.59	10,900	1.49	870	1,060
water	Green	0.56	8,900	1.55	620	1,010
	12%	0.63	15,400	2.02	1,020	1,190
willow	Green	0.56	7,400	1.29	610	980
	12%	0.69	14,500	1.90	1,130	1,460
Oak (white group)						
bur	Green	0.58	7,200	0.88	680	1,110
	12%	0.64	10,300	1.03	1,200	1,370
chestnut	Green	0.57	8,000	1.37	530	890
	12%	0.66	13,300	1.59	840	1,130
live	Green	0.80	11,900	1.58	2,040	--
	12%	0.88	18,400	1.98	2,840	--

(Table continued on next page.)

Table 2.8. ~ *(Continued.) Strength properties of some commercially important hardwoods grown in the United States (inch-pound).*[a]

Common species name	Moisture content	Specific gravity[b]	Static bending: Modulus of rupture (lbf in^{-2})	Static bending: Modulus of elasticity[c] (x10^6 lbf in^{-2})	Compression perpendicular to grain (lbf in^{-2})	Side hardness (lbf)
Oak (white group) *(continued)*						
overcup	Green	0.57	8,000	1.15	540	960
	12%	0.63	12,600	1.42	810	1,190
post	Green	0.60	8,100	1.09	860	1,130
	12%	0.67	13,200	1.51	1,430	1,360
swamp chest-nut	Green	0.60	8,500	1.35	570	1,110
	12%	0.67	13,900	1.77	1,110	1,240
swamp white	Green	0.64	9,900	1.59	760	1,160
	12%	0.72	17,700	2.05	1,190	1,620
white	Green	0.60	8,300	1.25	670	1,060
	12%	0.68	15,200	1.78	1,070	1,360
Willow, black	Green	0.36	4,800	0.79	180	--
	12%	0.39	7,800	1.01	430	--

[a] Results of tests on clear specimens in the green and air-dried conditions.
[b] Specific gravity is based on weight when ovendry and volume when green or at 12% moisture content.
[c] Modulus of elasticity measured from a simply supported, center-loaded beam, on a span depth ratio of 14/1. To correct for shear deflection, the modulus can be increased by 10%.
[d] Side hardness is measured when load is perpendicular to grain.

Literature Cited

American Society for Testing and Materials (ASTM). 1997. D143—Standard method of testing small clear specimens of timber. ASTM International, West Conshohocken, PA.

Davis, E.M. 1962. Machining and Related Characteristics of United States Hardwoods. Technical Bulletin No. 1267. USDA Forest Service, Forest Products Laboratory, Madison, WI.

Forest Products Laboratory. 2010. Wood Handbook: Wood as an engineering material. General Technical Report FPL-GTR-113. USDA Forest Service, Forest Products Laboratory, Madison, WI. 508 p.

Hardin, J.W., D.J. Leopold, and F.M. White. 2001. Textbook of Dendrology. McGraw-Hill, New York, NY. 534 p.

Part Three – Market and Utilization Options for Ash Logs, Lumber, and Other Products

by Brian K. Brashaw

Ash and other species affected by emerald ash borer (EAB), Asian longhorned beetle, gypsy moth, and thousand canker disease can be utilized in a wide range of products. Primary wood products include lumber that can be further processed into housing products, sporting goods, tools, bioenergy products, and residues for wood composites, wood pellets, or paper. Because the main focus of this book is the three primary U.S. ash species, black (*Fraxinus nigra*), white (*F. americana*), and green (*F. pennsylvanica*), affected by EAB, detailed information on production considerations, quality specifications, market opportunities, key trade associations, and additional references will be provided for the following:

- Trees,
- Lumber,
- Veneer,
- Furniture,
- Cabinetry,
- Millwork,
- Flooring,
- Biomass (firewood, chips, residues),
- Pallets,
- Sporting goods,
- Specialty products, and
- Engineered materials and components.

Trees

Architects and engineers have begun creatively using ash trees, boles, and branches in a variety of decorative, structural applications. For example, research, demonstration, and construction projects have been completed using trees as structural columns, support beams, or decorative components.

Production Considerations

Careful attention should be given to selecting straight, uniform, and defect-free trees. It is also important to minimize any impact from felling the tree as this can cause internal checking and damage to the tree's bole or branches. Following harvest, ash trees should be carefully placed to allow for drying. Typically, this would consist of placing the components under a covered structure with open ends and sides and allowing a minimum of several months to reach moisture contents of 15% to 19%. The bark should be removed from the tree or branch to allow for uniformity in drying and the minimization of any additional insect or fungal damage.

Precise engineering calculations must be completed for all applications that are considered structural. Selection of appropriate hardware and connectors will also be required. Documentation will be needed for review by local or state building code officials.

Quality Specifications

Special attention should be given when selecting trees, boles, or branches. They should be relatively straight and without evidence of damage or decay. It is important to visually assess the end grain to verify that the exterior grain is sound and that there is minimal interior decay. Interior decay could reduce the effective cross-section for structural calculations. The bark would typically be removed to minimize any potential insect damage and to allow for decorative finishes such as stains or seal coats.

Market Opportunities

Several demonstration projects have been completed using ash trees for structural columns or decorative applications. The Traverwood Branch Library in Ann Arbor, Michigan, for example, used ash trees harvested from the construction site that had been affected by EAB. Specifically, the ash trees were converted into vertical posts that supported a column in one wing of the library (**Fig. 3.1**). Ash was also used to make interior flooring, wall panels, ceilings, and table components. Further details and information on this project can be found in *Architect Magazine* (October 2009).

Figure 3.1. ~ *The Traverwood Reading Room during and after construction. Photos courtesy of the Ann Arbor District Library.*

WholeTrees, LLC, a Wisconsin company founded in 2007, has developed a variety of structural building systems using round timber obtained from harvested trees. It has completed a large number of construction projects in commercial and residential buildings. Research completed under a USDA Small Business Innovative Research grant determined that the strength of round timbers may be up to 50% greater than square timbers cut from the same tree (WholeTree 2012). It also developed customized connector technologies allowing its company to expand the use of round tree components in structural applications.

Product Summary

Materials:	Tree components including boles and branches
Diameter:	2 to 30+ inches
Grade:	Visual grading to minimize major defects
Finish:	Natural stains or topcoats

Key Trade Association

American Institute of Architects: www.aia.org

References

Architect Magazine. 2009. www.architectmagazine.com/community-projects/traverwood-branch-library.aspx. Accessed July 31, 2012.

WholeTree, LLC. 2012. www.wholetreesstructures.com. Accessed July 31, 2012.

Lumber

Production Considerations

The Forest Service definition of a hardwood sawlog is a log that is at least 8 feet long (plus 6 to 8 in. trim) and has a diameter of at least 8 inches measured inside the bark on the small end of the log (USDA Forest Service 2004). Many sawmills have their own criteria for minimum log length and diameter that may vary from the Forest Service minimums. Following harvest, sawlogs should be properly stored to prevent any staining that could occur. During winter, logs can be stored for a longer duration than in the warm summer months. Typically, hardwood logs are then sawn into lumber at a traditional sawmill or with portable band sawmills. There are a variety of sawing technologies and equipment suppliers available for processing urban hardwood logs. Special attention should be given to the grade and size of urban logs, the potential for metal or other contamination in the logs, and any log quarantines that are in effect for specific hardwood species as noted in Part 1 of this book. For more detailed information on sawing hardwood lumber, refer to the following print and web-based publications:

- *A Simplified Procedure for Developing Grade Lumber from Hardwood Logs*. Malcolm, F.B. 2000. USDA Forest Service, Forest Products Laboratory. Research Note FPL–RN–098. www.fpl.fs.fed.us/documnts/fplrn/fplrn98.pdf. 13 p.

- *Manufacturing and Marketing Eastern Hardwood Lumber Produced by Thin Kerf Band Mills*. Cassens, D. 2012. Purdue University Cooperative Extension Service. FNR-435W. www.na.fs.fed.us/pubs/werc/thin%20kerf%20band%20mills/FNR-435-manufacturing-marketing-thin-kerf.pdf. 366 p.

Following sawing, lumber should be dried to eliminate the risk of developing stain, decay, or molds. Furthermore, hardwood lumber for furniture, cabinetry, millwork, and flooring is usually dried to a recommended moisture content of 6% to 8% (Wengert 1996), resulting in minimized dimensional changes while in service. The best practice for drying lumber uses hardwood stickers to separate individual boards, resulting in good air flow around the lumber. The stickers are usually 3/4 by 3/4 inch and are consistently placed at right angles to the length direction. Located a few inches from each end, the stickers are placed about 24 inches apart (Denig et al. 2000). Once the material is stickered, it can be dried using several different methods. The most common drying methods are air drying and kiln drying. There are, however, other methods or equipment for drying hardwood lumber. These include: shed air drying, forced-air shed drying, warehouse predrying, low temperature kiln drying, dehumidification kiln drying, vacuum drying, and microwave drying. Generally, when air drying, the lumber is stacked in a well-ventilated environment and allowed to dry until the moisture content is between 6% and 8%. Kiln drying can take place in a wide variety of home-built and commercial kilns ranging from very small (300 board feet) to very large (>100,000 board feet). For more detailed information on drying hardwood lumber, refer to the following web-based publications:

- *Dry Kiln Operator's Manual*. Simpson, W.T., Ed. 1991. USDA Forest Service, Forest Products Laboratory, Madison, WI. www.fpl.fs.fed.us/documnts/usda/ah188/ah188.htm. 274 p.

- *Drying Hardwood Lumber.* Denig, J., E.M. Wengert, and W.T. Simpson. 2000. USDA Forest Service, Forest Products Laboratory. General Technical Report FPL-GTR-118. www.fpl.fs.fed.us/documnts/fplgtr/fplgtr118.pdf. 138 p.

- *Air Drying of Lumber*. 1999. USDA Forest Service, Forest Products Laboratory. General Technical Report FPL-GTR-117. www.fpl.fs.fed.us/documnts/fplgtr/fplgtr117.pdf. 62 p.

- *Operation and Cost of a Small Dehumidification Dry Kiln*. Bergman, R. 2008. USDA Forest Service, Forest Products Laboratory. Technical Note FPL–RN–0310. www.fpl.fs.fed.us/documnts/fplrn/fpl_rn310.pdf. 20 p.

- *Dehumidification Drying for Small Woodworking Firms and Hobbyists: Building Your Own Lumber Dry Kiln with Local Building Materials*. 2007. Bowe, S., P. Molzahn, B. Bond, R. Bergman, T. Mace, and S. Hubbard. University of Wisconsin Extension PUB-FR-396. www.dnr.wi.gov/files/pdf/pubs/fr/FR0396.pdf. 16 p.

Quality Specifications

Ash lumber has sapwood that is light-colored to nearly white, and the heartwood varies from greyish brown to light brown to pale yellow streaked with brown. The wood is generally straight grained with a coarse uniform texture. The degree and availability of light-colored sapwood will vary according to the growing regions and species. For example, Southern ash lumber may be faster grown and contains more sapwood, and, therefore, a higher percentage of white color, but compared to Northern ash, it has a more open texture and grain (AHEC 2009).

Visual grading rules exist for ash lumber that provide buyers and sellers with consistent language for use in lumber transactions. The National Hardwood Lumber Association (NHLA) has developed grading rules that allow for a common understanding of grades for both domestic and export use. The grade of lumber purchased will determine the cost and amount of waste that can be expected. Hardwood lumber grades are based on the size and number of clear wood pieces that can be obtained from a board when it is cut into pieces and used in the manufacture of products (AHEC 2009). The NHLA standard grades for hardwood lumber are FAS, FAS One Face and Selects, Number 1 Common (No. 1C), Number 2A Common (No. 2AC), and Number 3 Common (No. 3AC) (NHLA 2012). The higher grades are typically defect-free and include FAS and FAS One Face and Selects. They are often used for long clear moldings, joinery products such as door frames, architectural interiors, furniture, and flooring products. The common grades are typically resawn into shorter pieces when clear lumber is required or left with natural characteristics for rustic or character application. No. 1C, No. 2AC, and No. 3AC are regularly used in the cabinet, flooring, and furniture industries (AHEC 2009). Detailed information on lumber grades and grading procedures can be obtained from NHLA at: www.nhla.com.

Smaller manufacturers may not utilize the formal NHLA grades but instead purchase lumber that is referred to as either clear/rustic or character grade. The natural wood conditions in rustic or character grades include heartwood and sapwood color variation, knots (clusters, open, pin, and sound), burl, mineral stain or streaks, glassworm, bark pockets, and insect damage such as worm or larvae holes and tracks. It is typical that buyers and sellers of non-NHLA grades develop custom definitions and specifications to determine acceptable sizes, quantities, and condition of characteristics found in rustic or character grades. **Figure 3.2** shows examples of clear and character samples of black, green, and white ash.

Market Opportunities

Ash and other hardwood logs are typically purchased by the hardwood sawmill manufacturing sector. Small quantities are also often purchased by operators of small portable sawmills. Once sawn, the lumber can be sold in either green or dry conditions to lumber wholesalers or brokers, concentration yards, and retail outlets (Cassens 2012). Larger secondary manufacturing companies, such as large pallet producers, may operate their own sawmills, kilns, and other equipment to produce end products. Other secondary manufacturers that purchase green or dry lumber, such as cabinet or flooring manufacturers, may operate their own dry kilns and rough mills that have ripsaws, chopsaws, planers, molders, and gluing equipment.

From 1999 to 2011, there were significant shifts in the use of hardwood lumber. **Table 3.1** shows the major market sectors that used hardwood lumber in 1999 and 2011. There was a significant decrease in the amount of hardwood lumber used for furniture as production shifted from the United States to China and other Asian companies. There has been an increase in the amount of hardwood used for pallet lumber and railroad ties.

Product Summary

Materials: Green or dry lumber

Thicknesses: 4/4 (four quarters refers to a 1-inch-thick (25 mm) board) to 8/4 (2-inch-thick (51 mm) board)

Widths: 2 to 10+ inches

Grade: FAS, FAS One Face and Selects, No. 1, 2A, and 3A Common

Visual Characteristics: Clear to character knotty

Black ash, character

Black ash, clear

Green ash, character

Green ash, clear

White ash, character

White ash, clear

Figure 3.2. ~ *Ash samples. Photos courtesy of True North Woods.*

Key Trade Associations

American Hardwood Export Association: www.ahec.org

Appalachian Hardwood Association: www.appalachianwood.org

Table 3.1. ~ *Hardwood lumber consumption changes from 1999 to 2011.*

Primary market sector	Hardwood lumber consumption (%)	
	1999	2011
Cabinets	9.3	5.6
Exports	9.3	16.9
Flooring	10.9	7.2
Furniture	20.2	4.7
Millwork	10.1	5.6
Railroad ties	5.4	13.7
Pallets	34.9	45.3
Road/mat timbers	--	0.9

Source: Johnson 2011.

Hardwood Distributors Association: www.hardwooddistributors.net

Hardwood Manufacturers Association: www.hmamembers.org

National Hardwood Lumber Association: www.nhla.com

Wood Component Manufacturers Association: www.woodcomponents.org

Wood Products Manufacturers Association: www.wpma.org

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Denig, Joseph, E.M. Wengert, and W.T. Simpson. 2000. Drying Hardwood Lumber. General Technical Report FPL–GTR–118. USDA Forest Service, Forest Products Laboratory, Madison, WI. 138 p.

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National Hardwood Lumber Association (NHLA). 2012. NHLA Grading Rules for North American Hardwoods. www.nhla.com/assets/1603/rules_card9.pdf. Accessed August 15, 2012.

USDA Forest Service. 2004. Northeast Forest Inventory and Analysis: Common Definitions Used by the FIA. www.fs.fed.us/ne/fia/methodology/def_qz.htm. Accessed August 15, 2012.

Wengert, G. 1996. The Wood Doctor's Rx. Robert C. Byrd Hardwood Technology Center, Princeton, WV. 378 p.

Veneer

Large diameter, clear logs have potential for use as veneer. Typically, veneer logs are defined logs from which visually appealing, thin veneer can be produced for use in decorative applications. These logs generally have 1.5 to 6 times more value than a traditional sawlog that is used for lumber. Urban trees can be used in veneer applications due to their large diameter and typically branch-free lower bole (**Fig. 3.3**).

Production Considerations

Special care needs to be used when harvesting trees that have potential as veneer logs. For example, felling a tree in an urban setting could cause impact damage to the log. It is also important to determine whether there is metal contamination. Many logs from urban settings have nails, spikes, or other metal contaminants that may not be visually identifiable merely from looking at the tree.

In traditional forest harvesting operations, all of the sawlogs are brought to a wood yard for sorting into visual grades. The woodyard staff may then select high-grade logs that have potential as veneer logs. The logs are placed in an area where veneer log buyers make individual log purchase decisions.

Figure 3.3. ~ *Ash veneer logs.*

Thin veneer (typically between 1/50 and 1/4 in.) is produced using two primary technologies: slicing and rotary peeling. Both methods select high-grade logs that are cooked or steamed prior to the veneering process. To produce sliced veneer, either a half or quarter log flitch is mounted so that the center of the log is facing away from a sharp slicing blade. All slicing is done parallel to the length of the log flitch. In rotary peeling, a log is mounted to a lathe and turned against a knife, as if unrolling paper toweling. Following production, the veneer is carefully dried, clipped to width, and graded prior to further processing into panel size widths (**Fig. 3.4**).

Figure 3.4. ~ *Ash veneer.*

Quality Specifications

There are a number of attributes that define hardwood veneer logs. Wiedenbeck et al. (2004) provide a detailed summary of information on veneer tree, log, and product quality characteristics for appearance grade veneer markets. The veneer log quality attributes most common among all species and uses are:

- round, sound, and straight,
- straight-grained,
- free of knots, bark distortions, decay, seams, worm holes, and bird peck on each of the four log faces,
- centered heart,

- uniform color,
- uniformly spaced growth rings, and
- free of metal contamination.

White ash is the primary ash species used for veneer. Typically, minimum log diameter requirements range from 12 to 14 inches with usable lengths of 8 to 12 feet (plus 6 to 8 in. trim), depending on the company. Uniform color in the sapwood and heartwood is very important. An undesirable characteristic is an irregular heartwood in which the darker heartwood flares into the sapwood. This color irregularity prevents long strips of clear sapwood veneer from being produced. Depending on markets and product trends, logs may be selected to either maximize the light-colored sapwood or the brown-colored heartwood. It is important to notice stress cracks as ash displays some brittle characteristics. The grain must be straight and logs free of insect damage known as glassworm tracks caused by a cambium miner. Defect indicators are relatively easy to see on ash bark, but glassworm does not create bark distortions, making it difficult to evaluate (Wiedenbeck et al. 2004).

Market Opportunities

Hardwood veneer is produced in the United States and many other regions around the world with a concentration in Europe and the greater China region of southeast Asia. Both logs and veneer are exported from North America to these regions as well. There are over 21 North American veneer producers/suppliers listed as members of the Hardwood Plywood & Veneer Association (HPVA) (2012). These manufacturers will often use both flat slicing and rotary peeling technologies to produce veneer. There are also smaller veneer operations in the northeastern United States that are not members of HPVA. Potential veneer log and veneer customers can be identified through state-level primary and secondary wood products directories, industry trade journals, internet searches, manufacturers directories, and association member lists.

The most important species for veneer in the United States are alder (*Alder* ssp.), birch (*Betula* spp.), black walnut (*Juglans nigra*), cherry (*Prunus serotina*), maple (*Acer* spp.), and red and white oak (*Quercus* spp.). Ash (*Fraxinus* spp.) veneer is more commonly found in a variety of products in Europe, often as an alternative to red oak.

Hardwood veneer is typically laminated to a variety of substrates to create the appearance of solid lumber or produce full-size panels. These substrates include lumber, plywood, particleboard, and medium density fiberboard (MDF). End products for hardwood veneer include cabinetry, interior and exterior doors, flooring, furniture, windows components, and decorative panels.

Key Trade Associations

Architectural Woodwork Institute: www.awinet.org

Composite Panel Association: www.compositepanel.org

Hardwood Plywood & Veneer Association: www.hpva.org

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Hardwood Plywood & Veneer Association (HPVA). 2012. HPVA Veneer and Veneers Sales Members. www.hpva.org/node/1056/. Accessed May 10, 2012.

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Furniture

Black, green, and white ash lumber and veneer have excellent potential for use in the production of furniture for both residential and commercial settings (**Fig. 3.5**). For family homes, it is suitable for bedrooms, closets, dining rooms, studies, family or living rooms, hallways, and outdoor living spaces. In commercial buildings, ash can be used in office or retail settings. Ash is easy to machine and can be used to produce many types of designs and styles, such as contemporary, speciality arts and crafts, rustic, and vintage.

Figure 3.5. ~ *Examples of furniture with wood veneer. Eames® lounge chair and ottoman (top) and table (bottom), designed by Charles and Ray Eames, part of the Herman Miller® Collection. Photos courtesy of Room & Board.*

Production Considerations

Residential and commercial furniture producers typically purchase lumber or lumber components and laminated panel products directly from producers or through wood products distributors.

The lumber, lumber components, and panel products are then processed using a variety of woodworking technologies to produce furniture components or products. Processing usually includes combinations of the following portable or automated technologies: sawing (rip saws, chop saws, and panel saws), gluing (clamp systems, fingerjointing, edgebanding, and laminating), machining (routers, jointers, planers, lathes, molders, and shapers), sanding, and finishing. This may range from simple woodworking equipment in smaller plants to full-scale automated production lines for high volume manufacturers. Access to lists of equipment companies can be found through trade associations including the Wood Machinery Manufacturers of America and the Woodworking Machinery Industry Association, or through leading trade shows such as the International Woodworking Fair held in Atlanta, Georgia and LIGNA held in Hannover, Germany.

Quality Specifications

Ash is a ring porous hardwood with an open grain pattern that is often broken by mineral streaks or small knots. It has a visual appearance very similar to red oak. Most furniture applications use clear cuttings of lumber that may be used as individuals boards or edge glued into wider panels (**Fig. 3.6**). Ash furniture often utilizes quarter-sawn lumber, especially in arts and crafts style furniture. The variation in color among the species in the United States ranges from light cream (sapwood) to dark brown (heartwood) and can be found in both clear and character grades. The durability and surface

Figure 3.6. ~ *Ash furniture lumber.*

hardness of ash make it a good choice for furniture applications. It is also relatively easy to finish with a variety of stains and finishes.

Decorative ash plywood is often used in furniture, casegoods, and cabinetry applications. The ash veneer may have been produced from either rotary or slicing equipment, providing unique decorative options such as traditional bookmarked or cathedral designs or unique quartersawn or riftsawn designs. In cathedral designs, the veneer growth rings form V- or U-shaped patterns that result from annual rings that barely intersect the cutting plane (Wiedenbeck et al. 2004).

Market Opportunities

Ash can be used in all types of furniture and furniture products for use in both residential and commercial settings. In living room areas, ash could be used for tables, chairs, benches, bookcases, sofas, storage or media cabinets, and recliners. Dining room furniture uses include tables, chairs, hutches, and china cabinets. In bedrooms, ash could be used for beds, chests and armoires, dressers, and mirror frames. Office furniture options include desks, chairs, armoires, bookcases, and cabinets. Outdoor furniture could be produced from thermal modified ash and includes outdoor kitchen cabinets, bar tops, benches, sofas, chairs, or stools. In commercial settings, ash veneer and lumber could be used for office furniture including casegoods such as desks, cabinets, and bookcases. In retail applications, uses include store fixtures such as display cases and racks, tables, and slatwall fixtures. In other commercial settings such as banks or medical offices, ash could be used in custom fabricated displays, work stations, counters, and desktops.

Market entry for ash furniture could occur in a number of ways, from interest generated by small custom furniture manufacturers at craft and goods shows to formal specification by an architect as part of a large commercial project. Partnerships with designers, furniture companies, and customers are important for creating new market opportunities for this species.

Recently the use of EAB ash has been highlighted in art shows and woodworking courses. To promote the advantages and attributes of urban wood, the Illinois Wood Utilization Team co-sponsored *Rising From Ashes: Furniture From Lost Trees*, a juried furniture show featuring fine furniture made of ash lumber salvaged from EAB-killed trees (**Fig. 3.7**). It also supported two semesters of an Architecture and Furniture Design class, *Environmental Wood Reclamation via Creative Arts & Crafts Products*, at the Illinois Institute of Technology. Class participants made furniture and gift items which are now on display at various locations. The Illinois Team also exhibited at the National Cabinet Conference & Woodworking Expo and the Illinois Valley Woodcarvers Show in an effort to encourage companies and individuals to consider using ash wood in future projects and products (Illinois Emerald Ash Borer Wood Utilization Team 2012).

Figure 3.7. ~ *Ash furniture produced for a Chicago area furniture show, "Rising from Ashes: Furniture from Lost Trees." Photo courtesy of Kurt Vannucci.*

Key Trade Associations

American Home Furnishings Alliance: www.ahfa.us

American Woodwork Institute: www.awinet.org

Appalachian Hardwood Manufacturers, Inc.: www.appalachianwood.org

Business and Institutional Furniture Manufacturer's Association: www.bifma.org

Hardwood Manufacturers Association: www.hmamembers.org

Hardwood Plywood & Veneer Association: www.hpva.org

National Home Furnishings Association: www.nhfa.org

Wood Component Manufacturers Association: www.woodcomponents.org

Wood Products Manufacturers Association: www.wpma.org

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Illinois Emerald Ash Borer Wood Utilization Team: Woodworkers. 2012. Woodworkers – Build Wood Products From Lumber. www.illinoisurbanwood.org/woodworkers.html. Accessed August 15, 2012.

Wiedenbeck, J., M. Wiemann, D. Alderman, J. Baumgras, and W. Luppold. 2004. Defining Hardwood Veneer Log Quality Attributes. General Technical Report NE-313. USDA Forest Service, Northeastern Research Station, Newtown Square, PA. 36 p.

Cabinetry

Black, green, and white ash lumber and veneered panels have excellent potential for use in the production of a variety of cabinets for primary rooms such as kitchens and bathrooms. As with furniture, cabinets are produced from both solid lumber and veneered panel products. Ash products can be used to produce many types of traditional styles including arched, raised panel, flat panel, and slab, along with newer contemporary styles containing mullions and non-wood materials such as glass, metal, or exotic species (**Fig. 3.8**).

Figure 3.8. ~ *Ash kitchen cabinets. Photo courtesy of Douglas Remodeling.*

Production Considerations

Cabinet and cabinet component manufacturers typically purchase lumber, lumber components, veneer, and laminated panel products directly from producers or through wood products distributors. Dry lumber would be purchased with recommended target moisture contents of 6% to 8%. The lumber, lumber components, and panel products are then processed using a variety of woodworking technologies to produce furniture components or products. Processing usually includes combinations of the following portable or automated technologies: sawing (rip saws, chop saws, and panel saws), gluing (clamp systems, fingerjointing, edgebanding, and laminating), machining (routers, jointers, planers, lathes, molders, and shapers), sanding, and finishing. This may range from simple woodworking equipment in smaller plants to full-scale automated production lines for high volume manufacturers. Cabinets are assembled from these components into framed or frameless product lines.

Some manufacturers produce their own laminated cabinet doors using wood veneer. In this process, dry veneer flitches ranging in moisture content from 7% to 12% (Cassens 2004) are usually purchased directly from veneer suppliers. This veneer is then stored in higher humidity conditions to minimize cracking or defects. Then the veneer is cut to size using veneer cutting equipment such as veneer guillotine shears or saws. Particleboard or MDF are cut and profiled using either panel saws or nesting CNC routers. Adhesive is applied to the core, and laminating takes place using flat platen, membrane forming, or nip presses. Following pressing, veneer panels may be carefully sanded and finished. Solid wood cabinet stile and rail components are added to veneer raised panels and then finished to produce cabinet doors. Many manufacturers are just component suppliers and ship unfinished cabinet doors to cabinet manufacturers. There are many books, publications, websites, and trade journals associated with cabinet manufacturing. An excellent link to this information is available from the Cabinet Manufacturers Association: www.cabinetmakers.org/links_industry.html.

Access to lists of equipment companies can be found through trade associations including the Wood Machinery Manufacturers of America and the Woodworking Machinery Industry Association, or through leading trade shows such as the International Woodworking Fair held in Atlanta, Georgia and LIGNA held in Hannover, Germany.

Quality Specifications

Quality specifications for ash cabinetry are very similar to those for furniture. Ash is a ring porous hardwood with an open grain pattern that is often broken by mineral streaks or small knots. It has a visual appearance very similar to red oak. While the majority of traditional or contemporary styles use clear veneer, country or rustic designs incorporate natural characteristics such as knots. The variation in color among the species in the United States ranges from light cream (sapwood) to dark brown (heartwood) and can be found in both clear and character grades. The durability and surface hardness of ash make it a good choice for cabinetry applications. It is also relatively easy to finish with a variety of stains and finishes.

Decorative ash plywood is often used in cabinetry applications. The ash veneer may have been produced from either rotary or slicing equipment, providing unique decorative options such as traditional bookmarked or cathedral designs or unique quartersawn or riftsawn designs. Many cabinet manufacturers purchase veneer plywood that is cut into blanks for use in cabinet doors or end panels. The quality of veneer used depends on the preference of the end user. Additional applications for lower grade hardwood lumber and veneer panels include cabinet frames, end-panels, and drawer boxes.

Market Opportunities

All of the ash species have potential for use in nearly all types of cabinetry products in both residential and commercial settings. While the majority of cabinets are destined for kitchens and bathrooms, other cabinet markets would include closets, home offices, guest rooms, entertainment centers, home theaters, bars, firearms storage, garages, humidors, libraries, and curio cabinets. Ash lumber could be used to produce cabinet doors, frames, drawer boxes, and shelves, while ash veneered particleboard, medium density fiberboard, or plywood could be used as insert panels in doors, drawer boxes, shelves, and side or back panels.

A product review of hardwood cabinet manufacturers shows that several companies produce cabinetry from ash lumber or veneer. Producers include small custom cabinet builders and large cabinet and cabinet component manufacturers. Partnerships with designers, cabinet companies, and customers are important in creating new market opportunities for this species. A comprehensive list of large cabinet manufacturers is available from the Kitchen Cabinet Manufacturers Association (KCMA 2012). Information on small custom producers is often available through state-level wood products manufacturing directories from state agencies. One such example is the searchable database within the Minnesota Secondary Wood Products Producer Directory (MN DNR 2012).

An excellent publication, *Hardwood by Design*, prepared by the American Hardwood Information Center focuses on using hardwoods for cabinetry, flooring, and furniture. This booklet offers a wealth of photos, ideas, and advice from eight leading design professionals. In addition, the booklet provides tips for using paint and hardwood moldings to transform your home and other important information about the green benefits of American hardwoods (AHIC 2006). The booklet is available at: www.hardwoodinfo.com/pdfs/newsroom/Hardwoodsbydesign.pdf.

Key Trade Associations

Cabinet Manufacturers Association: www.cabinetmakers.org

Kitchen Cabinet Manufacturers Association: www.kcma.org

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Minnesota Department of Natural Resources (MN DNR). 2012. Minnesota Secondary Forest Products Producer Directory. webapps1.dnr.state.mn.us/timberproducer-rails/companies/filter?company_filter[producer_type]=Secondary. Accessed September 5, 2012.

Millwork

All species of ash have potential for use in millwork applications. Typically, larger companies have focused on utilizing white ash, with smaller, regional companies manufacturing millwork products from black or green ash. Millwork is usually defined as woodwork, such as doors, window components, moldings, paneling, and mantles that are produced using wood machining equipment (**Fig. 3.9**).

Figure 3.9. ~ *Hardwood moldings. Photo courtesy of Weaber, Inc. and the American Hardwood Information Center.*

Production Considerations

Appropriate grades of lumber are purchased or produced by hardwood manufacturing plants for conversion into milled products. Popular materials for millwork applications include oak, walnut, and maple which are typically stained or clear finished and poplar, birch, or maple for painted finishes. The lumber is dried to a target moisture content of 6% to 8%. Usually the lumber is processed through a hardwood rough mill where it is cut into the appropriate dimensions based on the end product requirements. Most millwork operations focus on producing long, clear lengths of wood strips that can be machined into final products. This results in most rough mills having the following processing steps: grading, planing, ripping to width, cutting to length, and stacking. Following processing into strips or pieces of lumber, the material is processed through planers, shapers, and molders. New molding technology uses high-speed production tooling that is capable of rapid changeovers to meet the smaller production runs common today.

An increasing number of millwork product options are being produced from veneer and engineered wood composites such as particleboard and MDF. The veneer is laminated to the substrate through membrane pressing, profile wrapping, or flat pressing equipment. With profile wrapping, the substrate is machined in advance to the desired shape and then the veneer is wrapped onto the substrate producing long clear products. Millwork produced in this manner is frequently and commonly used in products such as residential door jambs. In contrast, the window industry typically laminates a softwood or hardwood veneer over a fingerjoint lumber core in order to meet the property requirements for these products.

Following production, millwork may be shipped in an unfinished or finished condition. Finishes include sealers, stain, and topcoats for the natural products and paint for other products. There has been a relatively significant increase in the number of prefinished millwork products such as moldings, doors, and paneling over the past decade (**Fig. 3.10**).

Figure 3.10. ~ *Ash ceiling and wall paneling. Photo courtesty of Aitkin Hardwoods.*

Quality Specifications

Most architectural millwork applications involving molding products focus on long lengths with uniform color that are clear wood without knots or other visual defects (**Fig. 3.11**). This results in the need for molding companies to purchase select and better lumber grades. Recent trends have resulted in more interest in products using character or rustic grades in which knots, color variation, and other natural defects are permitted. Clear and defined specifications are used between manufacturers and wholesale dealers for millwork to ensure consistency in product quality and appearance. As a means of standardizing product quality, the Architectural Woodwork Institute (AWI) has developed a comprehensive publication, *Architectural Woodwork Quality Standards*, available through the online AWI store. This publication addresses every aspect of millwork production including technical specifications for materials, joinery, finishing, and installation of a wide range of millwork products such as cabinets, doors, windows, and trim. AWI has established three quality grades: economy, custom, and premium. Economy grade is rarely specified in commercial millwork, while the majority of projects are based on either custom or premium grades (AWI 2009).

Figure 3.11. ~ *Black ash engineered plywood panels and solid wood were used in this office. Photos courtesy of Scott Wothe.*

Market Opportunities

Ash millwork producers can vary from small, local woodworking companies that focus on customer directed projects to large industrial manufacturers working from architect or designer specifications. To encourage the use of ash, demonstration projects and case studies can be used to educate customers, designers, and architects who are specifying the wood species. It will be important for these professionals to fully understand the wood characteristics and properties of white, green, and black ash and to have confidence that an adequate and consistent supply can be obtained. This educational effort can also take place with local government and school districts that are considering remodeling or new construction projects of public buildings. The use of local species can help support and score points in the U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED) program. LEED certification provides independent, third-party verification that a building, home, or community was designed and built using strategies aimed at achieving high performance in key areas of human and environmental health: sustainable site development, water savings, energy efficiency, materials selection, and indoor environmental quality (U.S. Green Building Council 2012). Specifically, the Materials & Resources category encourages the selection of sustainably grown, harvested, produced, and transported products and materials.

Key Trade Associations and Organizations

Architectural Woodwork Institute: www.awinet.org

Association of Millwork Distributors: www.amdweb.com

U.S. Green Building Council: www.usgbc.org

References

American Woodwork Institute (AWI). 2009. Architectural Woodwork Standards 1st Edition. Potomac Falls, VA. 640 p.

U.S. Green Building Council. 2012. What LEED is. www.usgbc.org/DisplayPage.aspx?CMSPageID=1988/. Accessed September 17, 2012.

Flooring

Ash species commonly used for flooring include black, white, and green. Ash hardwood flooring is available as traditional, solid pieces or as engineered materials where an ash wear layer is laminated to a substrate. The typical grain pattern used to produce flooring is either flatsawn or quartersawn, depending on the desired look of the finished product (**Fig. 3.12**).

Figure 3.12. ~ *Ash floor in a natural variety of coloration. Photo courtesy of Columbia Flooring and the American Hardwood Information Center.*

Production Considerations

Hardwood flooring manufacturers purchase kiln-dried lumber or thick veneer (also known as sawn lamellas) at a preferred moisture content of 6% to 8%. Depending on the size of the company or location in the United States, the lumber can be acquired from a company's own sawmill, purchased directly from other sawmills, or through wholesale distributors.

Historically, 4/4 hardwood lumber of various widths has been purchased for solid hardwood flooring. Industrial equipment required for the production of ash hardwood flooring may include a ripsaw to saw the lumber into narrow widths, a chopsaw to remove defects, a molder to produce the desired face and edge profiles, and an end-tenoner to produce end joints. This may range from simple woodworking equipment in smaller plants to full scale optimizing production lines for high volume manufacturers. Solid hardwood flooring ranges from strip flooring that is typically 2-1/4 inches wide to plank flooring which is available in wider widths, typically 3 to 7 inches. Solid hardwood flooring reacts to seasonal relative humidity changes, which cause wood width to shrink as the humidity decreases or expand as the humidity increases.

For engineered hardwood flooring, ash wear layers ranging from 0.125 to 0.250 inch may be purchased from suppliers or produced internally by resawing lumber using bandsaws, high-speed splitter saws, or reciprocating resaws known as thin cutting frame saws. This material is then laminated onto a variety of core or base layers such as hardwood or softwood plywood, solid lumber, or engineered wood composites including particleboard, MDF, or oriented strandboard lumber using a wide range of pressing technologies. There are many adhesives that can be used to laminate the wear layer to the substrate including polyvinyl acetate (PVA), emulsion isocyanates, polyurethanes, and dry film adhesives. This laminated structure provides excellent dimensional stability for engineered wood flooring, which reduces concerns associated with shrinking and expanding due to relative humidity or temperature changes.

Figure 3.13. ~ *Solid ash flooring with a traditional cherry stain. Photo courtesy of Armstrong Hardwood Flooring and the American Hardwood Information Center.*

Many different kinds of surface finishes can be used on ash hardwood flooring including water base, ultraviolet cured, and solvent cured. Historically, wood finishes have been applied to solid wood flooring on site after installation, but increasing numbers of manufacturers are also offering prefinished solid wood flooring products (**Figs. 3.13 and 3.14**). Most of the engineered flooring products are prefinished.

A recent trend has been chemical or thermal modification of hardwood products. This extra treatment improves performance characteristics such as increased dimensional stability, decreased moisture sensitivity, and decay resistance. Thermal modification commonly changes the color of the wood allowing for the creation of new, exotic looking products for flooring applications.

Figure 3.14. ~ *Natural and stained ash flooring complement this eclectic office. Photo courtesy of Armstrong Hardwood Flooring and the American Hardwood Information Center.*

Quality Specifications

Ash is a ring porous hardwood with an open grain pattern that is often broken by mineral streaks or small knots. It has a visual appearance very similar to red oak. Ash flooring is commonly characterized using two visual grades, clear and character. The variation in color among the species in the United States ranges from light cream (sapwood) to dark brown (heartwood) and can be found in both clear and character grades. Clear grades are generally free of knots and mineral streaks. Character grades may often contain streak stains and knots, provided the knots are all tight. Ash can be flat sawn or edge (quarter) sawn to achieve a variety of grain patterns. The durability and surface hardness of ash make it a good choice for high traffic areas or areas prone to falling items. Ash nails well and installs as easily as other common types of wood flooring. It can be used in many construction locations including over concrete slab, radiant heat foundations, and areas where moisture is a concern. It is also relatively easy to finish with a variety of stains and finishes.

Market Opportunities

The strength, hardness, and visual characteristics of ash make it an excellent choice for interior flooring in both residential and commercial markets. Large producers typically purchase green or dry ash lumber directly from sawmills or from hardwood lumber distributors. Small integrated producers may purchase and saw ash logs into lumber or purchase ash lumber directly from sawmills for machining into final products. Wholesale lumber pricing information is available from a number of publications including the *Hardwood Market Report* and the *Hardwood Review*. Typically, residential customers can purchase ash flooring directly from flooring retailers or mill direct distributors. Commercial applications are often specified through architects and designers.

Product Summary

Construction:	Solid strip, plank, and engineered
Width:	2 1/4 to 8+ inches
Thickness:	9/16 to 3/4 inch
Grade:	Clear or character
Finish:	Unfinished or prefinished

Key Trade Associations

Hardwood Manufacturers Association: www.hmamembers.org

National Wood Flooring Association: www.woodfloors.org

Wood Floor Covering Association: www.wfca.org

Biomass (Firewood, Chips, Residues)

All of the ash species can be used as biomass for products including firewood, fuel pellets, fuel chips, paper chips, and mulch applications. These products are relatively low value when compared to value-added applications such as flooring, cabinetry, or furniture. While biomass options are not high-value applications, they offer an important market for extremely large quantities of low-grade or underutilized ash wood. Even though firewood is considered a viable option for hardwoods affected by invasive species, extreme care must be taken to minimize the transport of untreated firewood.

Production Considerations

Firewood is produced from log forms of ash and other hardwoods. Depending on the firewood company, ash logs may be obtained from urban wood disposal or processing yards, loggers, private landowners, or other sources (**Fig. 3.15**). It is very important that all firewood producers are aware of and compliant with all wood transport quarantines that are in place for wood affected by invasive species. Firewood companies should be in direct contact with the appropriate state agency to be aware of all state and Federal restrictions and quarantines and to obtain compliance permits as required. It is strongly suggested that all firewood be used locally or be heat treated according to state and Federal requirements. Part 4 of this book provides detailed information on heat treating and sterilization procedures.

Figure 3.15. ~ *Log processing yard. Photo courtesy of Multitek North America LLC.*

Firewood production equipment ranges from small scale, chainsaws and wood splitters, to production logging and turn-key firewood production cutting and splitting systems. **Figures 3.16 and 3.17** show low production and high production firewood processing equipment, respectively. Following splitting, firewood producers will typically air dry or heat treat materials to reduce moisture content or to sterilize it (**Fig. 3.18**). Some producers use kilns to produce a premium kiln-dried firewood. Split firewood is then loaded onto trucks or bundled for retail sales locations including campgrounds and convenience stores.

Figure 3.16. ~ *Low production firewood processing equipment.*

Harvested ash trees may be converted into wood chips for a variety of applications including paper, pellets, or engineered composites such as particleboard, MDF, or hardboard. For these applications, logs typically need to be debarked to produce clean, bark-free chips. Some producers may be able to accept chips that contain bark, often referred to as whole tree chips. Large-scale production and processing equipment are required for these applications.

Figure 3.17. ~ *High production firewood processing equipment. Photo courtesy of Multitek North America LLC.*

Several paper companies purchase clean ash chips for use as a small percentage of their raw materials supply. The percentage of ash used in paper varies but is relatively low compared to other hardwoods such as aspen, birch, or maple. Particleboard, MDF, and hardboard manufacturers also use ash in their production, but usually only a low percentage received from a logging company. These companies would typically process the chips using hammermills, defibrillators, or refiners.

Ash is currently used by some wood pellet manufacturers as a component in either hardwood or hardwood softwood blends. In the pellet production process, wood chips or residues are processed into fine particles using hammermill or grinding equipment. If the material is green,

Figure 3.18. ~ *Firewood for retail markets, after heat treatment and bundling.*

Figure 3.19. ~ *Hardwood mulch.*

Figure 3.20. ~ *Hardwood softwood blend of wood pellets containing black ash.*

it is usually dried to a moisture content of approximately 15%, and then inserted into the pellet mill where it forced through dies, creating 1/4 to 3/4 inch pellets. The most common size of pellets produced is 1/4 inch diameter. The pellets are then cooled and placed into 50-pound bags, supersacks weighing 500 to 1,000 pounds, or large silos or trucks for bulk delivery.

Ash chips or residues are also used as fuel stock for industrial boiler systems or as a feedstock for mulch products. Generally, these are produced using chipping or grinding equipment from whole trees, tops and limbs, or urban tree waste from dead or dying trees. Large mulch producers may also rely on traditional logging suppliers to obtain the large quantities of material needed for the mulch market (**Fig. 3.19**). Mulch is often dyed to achieve various colors for urban mulch markets. The material is chipped or ground to specification and either bagged for retail application or transported in bulk to commercial garden or landscape centers.

Quality Specifications

Depending on the product application, the quality specifications for ash vary considerably. Highly demanding applications such as paper, composites, or pellets usually require a clean chip that contains minimal or no bark. For paper and composites, the incorporation of bark results in a lower quality product that is not preferred by secondary customers. In wood pellets, the presence of bark often results in a pellet that has an inorganic ash content of greater than 1%, the limit for premium wood pellets (**Fig. 3.20**). A large percentage of bark can cause the formation of clinkers in some residential and commercial stoves, boilers, or furnaces, creating a negative perception by the customer.

White ash and black ash have a rated heating value of approximately 8,000 Btu/lb., or 24.0 to 26.0 million Btu per cord of dry wood (California Energy Commission 2012, USDA 1974). Ash is often rated as a very good species for firewood due to its good heating value, ease in splitting, light smoke, and minimal sparking (Marcouiller and Anderson 2007). Another advantage is the relatively low moisture content of white ash (44% to 46%) and green ash (58%) (USDA 2010). These ash moisture contents are lower than most other commercial hardwoods, resulting in shortened drying times for firewood and an improvement in the potential to burn green chips.

A wide range of wood quality from logs, tops, and limbs can be used in mulch products. Residential and commercial customers for mulch desire uniform size and shape, so some screening is required to produce these products. Other applications for urban wood mulch, such as city trails, are able to accept higher levels of nonuniform material that may be produced from large tub grinding systems.

Market Opportunities

Market opportunities for wood fuels increase as the price of fossil fuels such as heating oil, natural gas, propane, or electricity increase. From 2008 to 2012, significant increases in wood pellet and firewood consumption occurred in the northeastern United States, due to the extremely high cost of heating oil and electricity. Recent efforts in the Midwest to increase these markets have been challenged by the extremely low costs of natural gas and the 2012 decreases in the cost of propane. But, grass roots organizations such as the Northeast Biomass Thermal Working Group and Heating the Midwest with Renewable Biomass have focused on encouraging the use of biomass fuels as a means to create new regional jobs, provide markets for wood and agricultural biomass, and lower energy costs. There are large biomass energy companies located in several regions of the Midwest and Northeast that have the potential to utilize ash or other urban species. For example, District Energy, St. Paul, Minnesota, operates a combined heat and power plant that heats and cools buildings in downtown St. Paul and produces more than 25 megawatts of electricity. It utilizes more than 300,000 tons of woody biomass per year, using wood residuals from manufacturing processes, construction waste/clean dimensional lumber, urban and park tree trimmings, storm and disease damaged trees, and trees removed as part of a timber management plan/restoration (Smith 2012).

Additionally, there is interest in using wood chips, residues, or torrefied wood products for cofiring in coal electrical power plants as a means to reduce air emissions. Torrefied wood pellets or briquettes are often referred to as biocoal, since they are dark brown in color, have similar grinding or pulverizing characteristics, and have increased energy values of more than 10,000 Btu/lb.

Firewood is typically a local product, and firewood producers may be identified through a review of local telephone books, state directories, or internet searches. Many producers operate on a part-time basis. The cost will vary based on wood species and whether the wood is split, delivered, or dried.

Small quantities of wood are often bagged and sold locally at convenience stores, campgrounds, or other retail outlets. Recently, some Midwest manufacturers have identified markets for heat-treated firewood or specialty cooking woods that may include traditional species such as oak or ash, or specialty products which can be shipped to other states or counties. These products, if produced in areas with EAB, must have compliance certificates from the USDA Animal and Plant Health Inspection Service (APHIS).

One key component to developing market potential for firewood and other wood fuels is to be able to accurately compare typical unit costs of various fuels. A fuel value calculator and spreadsheet have been developed by the USDA Forest Service. It is available at: www.fpl.fs.fed.us/documnts/techline/fuel-value-calculator.pdf. Additionally, a calculator for comparing fuel costs for small commercial-scale boiler systems is available from the Michigan Wood Energy website at: www.michiganwoodenergy.org.

State agencies and local government should work with large regional manufacturers, such as paper, engineered wood composites, or biofuel companies, to investigate market potential for ash that is harvested in response to current or potential infestations by EAB.

The Mulch and Soil Council website lists more than 45 companies offering more than 250 mulch products. Typically these companies are larger producers offering both bagged and bulk products through various market outlets. Smaller regional producers can be identified through local and state listings or internet searches.

Key Trade Associations and Advocacy Groups

Biomass Thermal Energy Council: www.biomassthermal.org

Composite Panel Association: www.compositepanel.org

Heating the Midwest with Renewable Biomass: www.heatingthemidwest.org

Mulch and Soil Council: www.mulchandsoilcouncil.org

National Firewood Association: www.nationalfirewoodassociation.org

Northeast Biomass Thermal Working Group: www.nebioheat.org

Pellet Fuel Institute: www.pelletheat.org

Tappi: www.tappi.org

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Pallets, Shipping Containers, and Railroad Ties

Produced from both hardwood and softwood lumber, pallets, shipping containers, and railroad ties provide ongoing and new opportunities for wood species affected by EAB and other invasive insects. Approximately 60% of eastern hardwoods are currently used in industrial applications, an increase from 37% in 2002 (Brindley 2010). Pallets and shipping containers are important components of domestic and international trade, and wood is the primary material used in their production.

Production Considerations

Components for pallets, containers, and railroad ties are sawn by sawmills and pallet manufacturers from lower grade logs into pallet lumber for deck boards, stringers, blocks, and other components. Logs are also sawn into cants that are resawn into pallet lumber or used as ties. Integrated hardwood sawmills typically sell the higher grades of exterior lumber as NHLA grades for value-added applications such as flooring, cabinets, and millwork and use the center sections of the log for pallet cants or railroad ties. Pallet cants are typically 4 by 4 inches or 4 by 6 inches. Crosstie dimensions are most commonly 7 by 9 inches, with some 6 by 8 inch and 7 by 8 inch ties being used. Pallet lumber or cants are used to produce top and bottom deckboards, stringers, and blocks.

For pallet construction, sawn lumber is used to produce the two types of pallets: block and stringer. Both green and kiln-dried lumber are used in the construction of these pallets, and there may be combinations of hardwood and softwood in the same pallet. Stringer pallets are usually constructed from hardwood and are the main pallet type used in the United States (**Fig. 3.21**). Block pallets are often used in Europe and typically contain softwood lumber (**Fig. 3.22**). Wood pallets and containers may be produced by hand equipment by small manufacturers, but are usually produced with automated manufacturing equipment by larger manufacturers. These larger pallet manufacturers would typically have an automated lumber remanufacturing and pallet assembly line. This would include a resaw and cross-cut system, lumber stacker, and automated nailing systems. These systems range in production capacity from 300 to more than 2,000 pallets in an 8-hour production shift.

Figure 3.21. ~ *Stringer pallet design.*

Figure 3.22. ~ *Block pallet design.*

A significant pallet recycling industry exists, as large volumes of wood pallets are repaired and reused. Specific lumber components are manufactured or purchased and used in manual, automated, or combination repair equipment. Recycled pallets are assessed to identify components that need to be removed and replaced with new pieces.

Wood packaging material made with unprocessed raw wood is recognized as a pathway for the introduction and spread of pests. To limit the entry and spread of quarantine pests through international trade, the International Plant Protection Convention (IPPC) adopted the International Standards for Phytosanitary Measures Pub. No. 15, *Guidelines for Regulating Wood Packaging Material in International Trade* (ISPM 15). The IPPC is an international treaty to secure action to prevent the spread and introduction of pests in plants and plant products and to promote appropriate measures for their control. Under the ISPM 15 standard, wood packaging materials are required to be either heat treated to 56°C (132.8°F) to the core for 30 minutes or fumigated with methyl bromide to the schedule in the ISPM 15 document (USDA APHIS 2012). The heat treatment can be accomplished by either purchasing certified heat-treated lumber or by heat-treated assembled pallets or packaging material.

Railroad ties are sold green to end users, but they are air dried before treatment with a wood preservative. They are often end plated with metal gang nail plates to minimize splitting. Oak species are allowed to have a maximum moisture content of 50%, and mixed hardwoods are allowed a maximum moisture content of 40% under the American Wood Protection Association Standard T1-07. Ties are usually treated with creosote or copper napthenate using a pressure treating process.

Quality Specifications

Typically, pallets are manufactured from lumber that has been obtained from interior portions of higher grade sawlogs, low-valued species, or low-quality roundwood. The hardwood material used in pallet production must be sound, but usually contains knots and/or other visual defects which would lower the grade value under the NHLA rules for lumber appearance grades. The most common form of pallet lumber is 4 by 4 inch or 4 by 6 inch pallet cants that are resawn into 4-inch-wide material of varying thicknesses based on pallet type and design (Luppold 2012). There is no common grading system currently in place for pallet lumber or components, but a comprehensive Uniform Standards for Wood Pallets and Wood Containers has been developed by the National Wooden Pallet and Container Association (NWPCA) and is available at: www.palletcentral.com/index.php?option=com_content&view=article&id=365&Itemid=205/.

Railroad tie lengths in North America are 8 feet, 8 feet 6 inches, and 9 feet long. The most common length is 8 feet 6 inches (**Fig. 3.23**). Crosstie dimensions are most commonly 7 by 9 inches, with some 6 by 8 inch and 7 by 8 inch ties used. The heartwood should be centered on the tie face (Conners 2008).

Figure 3.23. ~ *Railroad crossties.*

The Railway Tie Association (RTA) has developed a comprehensive handbook, *Tie Guide for Commercial Timbers Used by the Crosstie Industry*, that provides a description of the identification, treatment, and ultimate use of wood in the engineering crosstie system. It is available at: www.rta.org/tieguide/. It has also developed specifications and visual defect guides for timber crossties and bridge timbers which is available at: www.rta.org/specifications/.

Market Opportunities

Wood packaging products, especially pallets, are used to transport materials within manufacturing plants, as a one-way transport for products to customers, between company facilities, in exports, and as a closed-loop between producers and customers (Modern Materials Handling 2010). The majority of pallets are 48 by 40 inches and are focused on grocery and retail products, followed by 42 by 42 inches for chemicals. Other sizes include 40 by 48 inches, 36 by 36 inches, and 40 by 40 inches. Packaging containers are usually custom sized and constructed based on the product being shipped. Pallet manufacturers typically purchase raw materials regionally, so focused searches through wood products trade associations and state agencies will identify potential lumber customers. National lists of pallet producers are available through NWPCA and the Canadian Pallet Council. While other non-wood materials, such as plastic, composites, and metal, are being used increasing in pallets, it is expected that wood will continue to be the primary material.

For crossties, many treating plants purchase green ties from small sawmills or from larger sawmills that consolidate ties from additional smaller sawmills. Some sawmills will sell directly to railroads that will organize and manage the treating process (Conners 2008). Long-term relationships have been established between sawmills, treating plants, and railroads. The RTA produces a detailed list of its more than 3,400 members in several categories: producer (sawmill, purchaser of white tie, treating plant), supplier (preservative and non-preservative), contractor, recycling management, railroad corporate, timberland owner, and associate.

Urban and forest logs from invasive-affected ash, elm, birch, and maple have potential use in the production of wood packaging materials and railroad ties. The markets for both products have been relatively consistent over the past decade, with strong consumption of ties predicted over the next several years. A recent crosstie forecast projects continued increases in the number of new tie purchases, rising from 22,169,000 in 2012 to 23,834,000 in 2015 (Norrell 2012).

Key Trade Associations

American Wood Protection Association: www.awpa.com

Canadian Pallet Council: www.cpcpallet.com

National Wooden Pallet and Container Association: www.palletcentral.com

Railway Tie Association: www.rta.org

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Sporting Goods

Ash has been a predominant species used in sporting goods such as baseball bats and wooden snowshoes. The unique hardness, toughness, durability, and strength-to-weight ratio made northern white ash the primary wood species used for baseball bats until about 2000, when an increasing number of players switched to sugar maple. Ash is still a popular choice among baseball players because of its ability to flex more than other hardwoods (**Fig. 3.24**). About half of all of the wood baseball bats made today are made from northern white ash, which is primarily harvested from Pennsylvania, New York, or other upper Midwestern states.

Figure 3.24. ~ *Ash baseball bats.*

The primary species used to produce wooden snowshoes in North America is white ash, although green and black ash have also been used. Ash offers unique characteristics for snowshoes, specifically its ability to be steamed and bent into the common shapes required for various snowshoe designs, such as the Bearpaw, Ojibwa, Huron, Alaskan, and Green Mountain styles (**Fig. 3.25**).

Figure 3.25. ~ *Ash can be steamed or bent into shapes required for snowshoes.*

Lacrosse is a team game of Native American origin played using a small rubber ball and a long-handled stick called a crosse or lacrosse stick. The game is mostly played in the United States and Canada. While the majority of the long-handled sticks are made from aluminum or composites, increasing numbers are being produced from hardwood species, including ash (**Fig. 3.26**).

Figure 3.26. ~ *Lacrosse sticks in game play. Photo courtesy of Al Holappa.*

Production Considerations

High-quality white ash logs are selected and purchased by wood baseball bat manufacturers. These logs are then processed into blanks using traditional sawmill equipment or a traditional splitting method. These blanks are then processed into round billets (2.75 to 3 in. diameter) using wood lathes (**Fig. 3.27**). Following careful drying using traditional wood steam kilns or newer vacuum kilns, the blanks are graded to detailed specifications for youth, high school, amateur, or professional baseball. The blanks are then loaded into a duplicating lathe that uses physical templates for each style or a computer controlled lathe that uses digital files created for each bat design. The bats are then sanded, cut to length, inspected, and finished through a spraying or dipping system.

Figure 3.27. ~ *Baseball bat blanks.*

Most lacrosse shafts are made of aluminum, titanium, scandium, or alloys (Dick's Sporting Goods 2012), but some shafts are still made from other materials, including wood, plastic, or fiberglass. The most common stick length for offensive players is 30 inches, defensive players 60 inches, and goalies 40 inches. For women, the sticks can be 35.5 to 43.25 inches long and have a smaller diameter than men's lacrosse shafts. Wood shafts are produced by selecting straight, tight-grained lumber that is cut into strips, shaped to create the octagon shape, sanded, and finished using typical wood finishes such as varnishes, polyurethanes, or water-based finishes. Some companies also laminate ash and other species to create a unique 3- to 7-ply laminated stick.

Wooden snowshoe manufacturing is a relatively labor intensive process. It begins with white ash logs that are either split into sections or sawn into lumber. These blanks are then processed into individual strips of the required sizes using traditional handtools or machined using modern saws and molders. These ash pieces are then usually placed in a steamer to give the wood more flexibility before bending it into shape. Once removed from the steam tank, the pliable lumber is formed into the style desired using a mold. These snowshoe frames are then dried in a kiln or hot room for up to a week. Air drying at room temperatures will extend this drying process. Once the frames are dry, sanding will create the final shape and smoothness of the product. The wood frames are typically finished with an exterior grade varnish or polyurethane wood finish. The snowshoe is laced using traditional materials such as rawhide or modern materials such as neoprene or tubular nylon lacing. Rawhide laces are also finished with varnish or polyurethane finishes.

Quality Specifications

For all of these sporting goods products, the wood quality specifications are similar. Each requires clear, straight-grained ash that is without defects such as knots or grain distortions. White ash logs are carefully selected and purchased by baseball bat manufacturers to achieve high yields of end products. Following processing into round bat billets, each billet is weighed and visually inspected to determine grain orientation, number of growth rings, and potential defects. Each billet is then sorted into end use categories for production into youth, high school, college, or professional bats. The highest grades with specific length-to-weight ratios are used in professional baseball. It is common that only about 1% of ash billets become Major League Baseball bats.

There has been considerable interest in the quality aspects of wood baseball bats of various species over the past 4 years. In 2008, Major League Baseball partnered with the USDA Forest Products Laboratory to understand the increased number of broken bats that were occurring, especially bats made from sugar maple. A comprehensive assessment of broken bats was completed that included video review of all broken bats, inspections at production facilities, laboratory testing, and visual inspection of large numbers of broken bats. Most of the initial recommendations addressed slope of grain issues (Kretschmann 2011). Slope of grain refers to the straightness of the wood grain along the length of a bat. Straighter grain lengthwise is associated with less likelihood for breakage. There were also recommended adjustments to bat geometry dimensions, wood density restrictions, and wood drying recommendations as the result of this ongoing partnership. This research has led to a better understanding of wood species and characteristics that affect the durability and failure rates of wood bats, offering potential for increased use of wood species for baseball bats.

Market Opportunities

Until 2000, white ash was almost exclusively used to produce baseball bats. New product introductions have resulted in bats now being produced from other hardwoods such as sugar maple or yellow birch and imported species such as bamboo. Ash bats, however, still command about 50% of the bat market in the United States. Markets for ash logs exist, but relationships need to be developed with loggers, log buyers, and producers to be able to access this market. Most wood bat manufacturers have an internet advertising presence and are relatively easy to locate in each state.

New high school baseball bat safety requirements were implemented by the National Federation of State High School Associations in 2012. This rule required the use a BBCOR (Ball-Bat Coefficient of Restitution) rating system for non-wood bat products, as a means to standardize the speed that a batted ball leaves a bat. The rule was passed as a safety measure to create a similar batted ball velocity for wood and non-wood bats. Implementation should result in increased numbers of wood bats used in the U.S. sports market.

Lacrosse is a growing sport, with increasing participation at youth levels. Currently most wood sticks are considered specialty products, with a marketing emphasis on more advanced players who are looking for product differentiation or a unique product for their use.

Often, wood snowshoe manufacturers are relatively small with lower wood volume requirements. Individual craftsmen and smaller producers are often located through special forest products directories within each state. There are only a few larger wood snowshoe production companies present in North America.

Key Trade Associations

National Sporting Goods Association: www.nsga.org

Sporting Goods Manufacturers Association: www.sgma.com

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National Federation of State High School Associations. 2009. 2010 Baseball Rules Changes Include Bat Standards Adjustment. www.nfhs.org/content.aspx?id=2772&terms=BBCOR/. Accessed August 21, 2012.

Specialty Products

There are a wide variety of additional products that can be manufactured from ash trees or lumber. These include tool handles, bowls, picture frames, wooden boxes, gunstocks, game boards, and custom furniture. While tool handles may have consistent industrial markets, the other products are considered relatively low volume specialty products, lending themselves to small entrepreneurs, small businesses, or craft shop owners.

Production Considerations

Tool handles are produced from clear blanks of white ash, which is selected for its relatively high strength, straight grain, excellent durability, ease in fabrication, and toughness. Blanks may be processed using a round rod molding machine. They are then turned using a duplicating lathe, produced on a lathe from square blanks, or produced on a high production CNC lathe. The highest grades are made from clear sapwood and lower grades from brown heartwood.

Specialty products are produced from various types of material that could be obtained from urban or forest sources. This could include wide planks, log sections, branches, and burls. Most of these manufacturers are small producers using a wide variety of woodworking equipment including planers, table saws, chop saws, lathes, sanders, and hand tools. Products may be finished using oil and wax, stains, varnish, shellac, or urethane topcoats.

Quality Specifications

Tool handles require straight grain wood that is usually defect free (**Fig. 3.28**). This is typically obtained by purchasing FAS or Select grades or by cutting clear sections from lower grades. Many handle manufacturers desire white wood, obtained from ash sapwood, but others may be willing to accept darker-colored, brown heartwood.

The other specialty products typically do not have any grade specifications, as many producers include the natural defects into their product. These may include color and grain variations, knots, glassworm defect, and other imperfections desired in character type products.

Figure 3.28. ~ *Ash is often used for tool handles.*

Market Opportunities

Traditional markets exist for wood handle producers. This market is typically defined as producers purchasing hardwood lumber from sawmills, but the potential exists for new producers to provide clear blanks to the market. There is a wide range of handle products produced for the following tools: shovels, post hole diggers, pitchforks, rakes, tampers, brooms, mops, ice scrapers, axes, logging tools, garden shears, and wheelbarrow handles. Producers can be identified through state agency wood products directories or through national trade associations.

Specialty products may include decorative products such as bowls, vases, baskets, custom furniture, picture frames, treasure boxes, clocks, unique carving blanks, jewelry, pens, kitchen utensils, coasters, or cutting boards. Recreation products produced include games, puzzles, and toys (**Fig. 3.29**). Limited only by creativity, there is an incredible amount of product diversity among the specialty products produced in North America.

Small custom crafts companies and individuals use a variety of market outlets for their specialty products. Specialty products are sold through individual company websites or unique web portals designed for small companies. An example of a portal is Etsy, an internet marketplace for artists, creators, collectors, thinkers, and doers (Etsy 2012). A simple search for ash products on the Etsy portal (www.etsy.com) revealed more than 1,600 specialty products produced from ash species. Furthermore, a large number of specialty wood products are sold at local farmers markets or regional craft shows. For example, Goods from the Woods 'Up North' Fine Arts and Crafts Show is held during September in Grand Rapids, Minnesota. It is the largest showcase of handcrafted forest-based and related arts and crafts in the Midwest. The show features Minnesota and regional artists, artisans, and millworks that produce the art, carvings, jewelry, turnings, furniture, pottery, fabrics, architectural millwork, and other unique products that support a vibrant arts and artisan economy. Goods from the Woods was organized in 2003. The show has been held each year and earned its reputation as a high-quality show of juried artists and artisans with an enthusiastic following of visitors from the Midwest region (True North Woods 2012). Recently there has been increasing interest from artists who are using urban wood affected by invasive species. **Figure 3.30** shows one of the vendors booths during a recent Goods from the Woods event.

Photo courtesy of Mullins Woodworks.

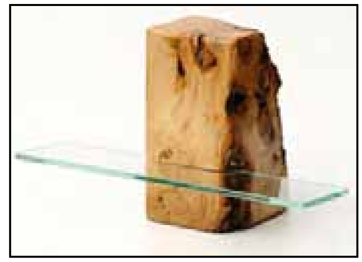

Photo courtesy of Calla Wood Creations.

Photo courtesy of Rick Siewert.

Photo courtesy of Woodsong Hill.

Photo courtesy of Howells Wood Products.

Photo courtesy of Jerry's Woodworks.

Figure 3.29. ~ *Specialty products made from ash.*

Figure 3.30. ~ *Vendor booth at Goods from the Woods fine arts and craft show. Photo courtesy of True North Woods.*

Urbanwood Project

by Jessica Simons
Southeast Michigan Resource Conservation and Development Council

Another unique marketing approach for urban forest products is the Urbanwood project, developed in partnership between the Southeast Michigan Resource Conservation and Development Council (SEMIRCD), Recycle Ann Arbor (RAA), the Michigan Department of Natural Resources (MI DNR), and the USDA Forest Service Wood Education & Resource Center (WERC).

The Urbanwood Project began as an effort to find valuable uses for some of the millions of trees killed by the EAB in southeastern Michigan. This insect left homeowners, businesses, and cities burdened with dead trees and mountains of wood waste for disposal. But in reality, communities lose trees all the time, due to a wide range of causes. In fact, a 2007 study by Michigan State University estimated that the dead and dying trees in southeastern Michigan's urban areas could produce over 73 million board feet of lumber each year. Fortunately, several local sawmills were already working to recover the value in these removed urban trees. These mills, however, had often faced serious difficulties in securing markets, particularly for their highest quality materials. Often, mills were forced to sell grade lumber for pallet stock, railroad ties, or other lower value markets.

In September 2005, SEMIRCD, RAA, MI DNR, and local leaders came together to promote the creation of value-added products from the local wood residues available due to the EAB outbreak. The result of this partnership was the creation of the Urbanwood Project, a network of small sawmills and arborists who recover quality logs from urban tree removals, process them into lumber, and collectively market products with a shared brand. The group began with a very informal structure and commitment: to work together to promote products from trees not harvested for their timber value. Through the Urbanwood Project, these mills and other partners have joined together to share marketing responsibilities, collectively promote their cause, create new retail markets, and offer exceptional quality and service to their customers.

In 2008, the Urbanwood Project developed an online presence and began consignment retail sales at RAA's ReUse Center. Although the retail effort was quite small, with only a few small racks of lumber, gross sales improved more than 60% in the second year and continued to grow steadily over time. In fact, sales in 2011 were 80% higher than in 2010. Given the customer interest in Urbanwood, RAA continued to increase the size of the lumber sales area each year (**Fig. 3.31**). By early 2012, this resulted in 1,600 sq. ft. of retail space at the front of the ReUse Center designated as the Urbanwood Marketplace. The space features products from seven different local producers. While overall profits are not huge by any measure, the continued growth in sales shows that the operation has potential. The group is working to promote its products within local green building efforts and has gained the support of several prominent architects and builders. For example, wood from Urbanwood sawmills was used in the well-regarded A3C Architects Collaborative LEED-CI Gold Certified office

Figure 3.31. ~ *RAA's ReUse Center. Photo courtesy of Jessica Simons.*

remodel in Ann Arbor. The Urbanwood Project has generated positive local press and was featured on both Greenovation.TV (a green renovation website) and greencabinetworks.com.

In 2012, the Urbanwood Project took a huge leap forward by opening a second retail location. This opportunity was created through Michigan's Genesee Conservation District's (GCD) Flint Forestry Program, which brought together federal, state, and local funding to conduct tree inventories, street tree management planning, hazardous tree removal, replanting, and wood utilization in the City of Flint. While trying to find the best use for the wood from the hundreds of hazard trees that were being removed in this program, partners from the GCD, SEMIRCD, and the Genesee County Habitat for Humanity saw the potential to establish another Urbanwood Marketplace and opened the retail operation within Flint's Habitat for Humanity ReStore in April 2012. The new retail space offers products from four local businesses, along with GCD-branded Urbanwood products that are made specifically from trees removed in Flint.

The Urbanwood Project has created many important benefits. First, despite the slow economy, there is steady customer interest and good brand awareness among local builders, architects, and woodworkers. Second, the Urbanwood Project has strong advocates and partners in RAA and the Genesee County Habitat for Humanity, since the products give their retail operations a unique differentiation from other competitors. Third, as interest in urban wood use grows throughout the country, Michigan's Urbanwood Project is increasingly looked at as a model for other regions. Finally, and perhaps most importantly, there is a clear sense of cooperation and trust among the mills, arborists, and organizations that are involved in the project. The group has a strong, although informal, partnership that has become more efficient and effective over time. The members refer customers, trade services, and have a helpful camaraderie, all a significant change from early meetings when businesses were wary of cooperation. In a tough business climate, having a network of dependable colleagues can be a tremendous asset. Overall, the Urbanwood Project has been successful in laying a solid foundation in its early years. Many opportunities exist to transition this project into a sustainable, long-term operation that can be a model for the formation of urban forest cooperatives in other regions. More information about the Urbanwood Project may be found at: www.urbanwood.org.

Key Trade Associations

American Association of Woodturners: www.woodturner.org

Wood Component Manufacturers Association: www.woodcomponents.org

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Engineered Materials and Components

The hardwood lumber industry is a key component of the forest products industry in many parts of the United States. As presented earlier in this chapter, hardwood lumber is the raw material for a wide range of high-value products, including millwork, furniture, and flooring. An excellent research base exists on the use of a number of hardwoods in these applications, including ash species.

Engineered wood components, including mechanically graded lumber, trusses, I-joists, glued-laminated timbers, and laminated veneer lumber, represent one of the fastest growing segments of the forest products industry in North America. Most engineered wood components are manufactured from softwood species such as Douglas-fir, the southern pines, or groupings of similar species such as the spruce-pine-fir lumber mix. During the past decade, significant research and development efforts have been devoted toward investigating the use of lower grade hardwood resources in engineered materials and components. Studies aimed at developing appropriate drying technologies, grading procedures, and various engineered materials and components have been conducted (**Fig. 3.32**).

Figure 3.32. ~ *Floor truss on a testing rack.*

The USDA Forest Service Forest Products Laboratory (FPL), in cooperation with the Forest Products Society, University of Minnesota Duluth, Michigan Technological University, and several industrial partners, published a comprehensive book on the use of lower value hardwood materials, *Undervalued Hardwoods for Engineered Materials and Components* (Ross and Erickson 2005). This book is a compilation of results obtained from research and development studies focused on using the low-grade hardwood resource in engineered materials. Part One of the book focuses on basic information about this resource: availability, mechanical properties, log grading techniques, and appropriate drying methods. Part Two summarizes studies that examined the use of this resource in trusses, laminated veneer lumber, I-joists, and other applications such as timber bridges and residential construction (**Fig. 3.33**). While not aimed specifically at the use of wood from trees killed by invasive insects, this book serves as an excellent, primary reference on the use of low-value hardwood in engineered materials and components.

Figure 3.33. ~ *Roof trusses containing hardwood lumber web stock.*

Reference

Ross, R.J. and J.R. Erickson. 2005. Undervalued Hardwoods for Engineered Materials and Components. Forest Products Society, Madison, WI. 132 p.

Part Four – Heat Treatment of Wood for Invasive Forest Pests

by Xiping Wang

Introduction

Invasive forest pests pose enormous threats to our nation's forests and ecosystem and affect a diverse array of consumable products and services. State and federal agencies have been fighting the spread of a number of foreign pests including emerald ash borer (*Agrilus planipennis Fairmaire*), Asian longhorned beetle (*Anoplophora glabripennis*), hemlock woolly adelgid (*Adelges tsugae*), Sirex wood wasp (*Sirex noctilio Fabricius*), and gypsy moth (*Lymantria dispar* L.). Wood packaging materials (through international trade) and firewood moved within infested states and into adjoining states have been recognized as two major contributors to the introduction and spread of these species. Heat sterilization is currently the most practical and environmentally friendly treatment used to kill pests in solid wood materials and prevent their transfer between continents and regions. Consequently, regulations requiring heat sterilization are becoming increasingly common in the United States.

The keys to the success of the heat sterilization process are to:

1. increase the kiln/chamber temperature high enough to meet the heat-treatment standard in which the core temperature of a piece of wood reaches the lethal temperature for a certain period of time; and

2. monitor the core temperatures of the largest wood pieces to ensure that the temperature–time requirement is met before the heat-treating cycle is completed.

This chapter addresses some practical issues in heat treating solid wood packaging materials and hardwood firewood. It focuses on various factors that should be considered when planning and implementing a heat-treatment process and then presents technical information on the heat-treatment operation, temperature monitoring, and thermal verification.

The preferred units of measure used in this chapter are in the English system because of the current high demand for this information in the United States. Metric units or conversion factors are also provided.

Factors Affecting Heat Treatment

The time required for the center of solid wood material to reach the lethal temperature for these invasive pests depends on many factors, including the type of energy source used to generate the heat, the medium used to transfer the heat (e.g., wet or dry heat), and the effectiveness of the air circulation in the heating facility. These factors will determine if the heat-treatment standards can be met and how quickly the treatment process can be completed.

Heat Energy

Energy is the amount of heat supplied during the heat-treatment process. Heat-treating chambers typically employ systems that utilize steam, hot air (direct fire), electricity, and hot water or hot oil as mechanisms to generate the heat necessary to sterilize the wood. The choice of heat energy primarily depends on the heat-treating method, energy resources available, and the cost of the energy.

Heating Medium

The temperature and humidity of the heating medium significantly affects heating times. Higher heating temperatures yield shorter heating times, and heating wood in saturated steam (wet heat) results in the shortest heating times. The temperature of air is measured using a normal temperature sensor, called a dry-bulb. The humidity of the air is usually discussed in terms of relative humidity, which can be measured using a combination of dry-bulb and wet-bulb (a temperature sensor covered by a wet wick) temperatures. The difference between the dry-bulb temperature reading and the wet-bulb temperature reading is known as the wet-bulb depression. The greater the wet-bulb depression, the lower the relative humidity. When the heating medium is air that is not saturated with steam, the relative humidity is less than 100% (wet-bulb depression >0°F), and drying occurs as water evaporates from the wood surface. As the heating medium changes from wet to dry heat, the time needed to reach the required temperature increases. This is illustrated in **Figure 4.1**, which shows experimentally derived heating times as a function of wet-bulb depression for a series of lumber and timber products.

When the wet-bulb temperature in the heating medium approaches or falls below the target center temperature, the heating time becomes much longer than with wet heat (Simpson 2002,

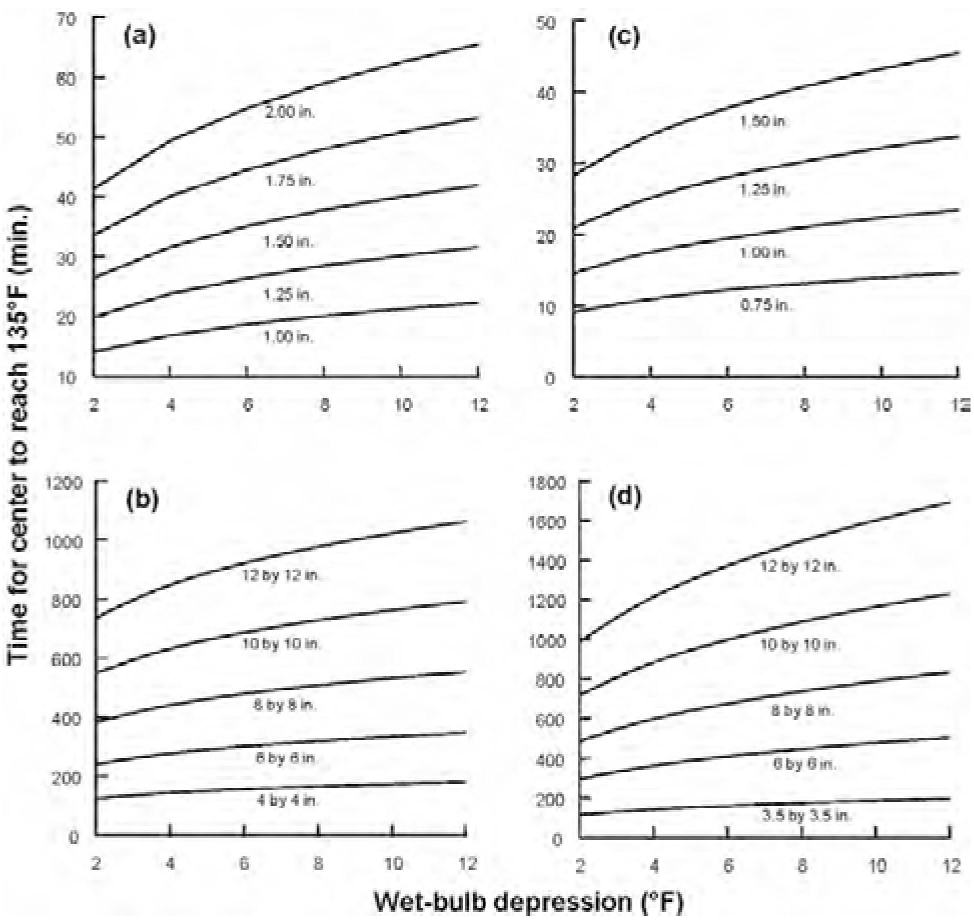

Figure 4.1. ~ *Dependence of heating time on wet-bulb depression for (a) 1- to 2-inch-thick ponderosa pine boards, (b) 4- to 12-inch ponderosa pine timbers, (c) 3/4- to 1-1/2-inch-thick Douglas-fir boards, and (d) 3-1/2- to 12-inch Douglas-fir timbers. Initial temperature for all experiments was 60°F. (°C = (°F – 32)/1.8; 1 in. = 25.4 mm).*

Simpson et al. 2003). This is because evaporation of water from the wood surface with dry heat cools the surface and lowers its temperature, thereby reducing the surface-to-center temperature gradient that is the driving force for transferring heat. With wet heat, there is little or no evaporation of moisture and thus little surface cooling to slow heat transfer.

Air Circulation

Maintaining adequate air circulation is also important in heat-treatment processes. The circulating air performs two functions, as it does in kiln drying: it carries heat to the wood to increase wood temperature and effect evaporation, and it removes the evaporated water vapor. Good air circulation ensures uniform heat distribution in the chamber and keeps the wood surface temperature high so that the surface-to-center temperature gradient is as high as possible. This is usually accomplished with fans and baffles in a treatment chamber. Poor air circulation is one reason why a facility can fail to pass heat-treatment certification.

Heat Treatment of Wood Packaging Materials

Heat-Treatment Standards

The current international standard for heat sterilization of solid wood packaging materials is the International Standards for Phytosanitary Measures Pub. No. 15 (ISPM 15), *Guidelines for Regulating Wood Packaging Material in International Trade*, which requires heating wood to a minimum core temperature of 133°F for a minimum of 30 minutes (IPPC 2002, APHIS 2004). These guidelines are for all forms of wood packaging material that may serve as a pathway for plant pests posing a threat to living trees. This temperature–time regime is chosen in consideration of the wide range of pests for which this treatment combination is documented to be both lethal and commercially feasible. **Table 4.1** lists the pest groups associated with wood packaging material that can be practically eliminated by heat treatment under the ISPM 15 standard. Although it is recognized that some pests are known to have a higher thermal tolerance, quarantine pests in this category are managed by the National Plant Protection Organizations (NPPOs) on a case-by-case basis (IPPC 2002). Future development may identify other temperature–time regimes required to kill specific insects or fungi.

Table 4.1. ~ *Pest groups that are practically eliminated by heat treatment under the ISPM 15 standard.*

Insects
Anobiidae
Bostrichidae
Buprestidae
Cerambycidae
Curculionidae
Isoptera
Lyctidae (with some exceptions for HT)
Oedemeridae
Scolytidae
Siricidae
Nematodes
Bursaphelenchus xylophilus

Effects of Size, Species, and Stacking Methods

As would be expected, heat-treatment processes are affected by wood configuration and size. Heating time increases with size and at a rate that is more than proportional to the configuration. For example, heating time can range from only a few minutes for thin boards to many hours for large timbers. The effect of wood configuration on heating time can be seen in **Figure 4.1** for a series of wet-bulb depressions.

Studies of five northern hardwood species (red maple (*Acer rubrum*), sugar maple (*Acer saccharum*), northern red oak (*Quercus rubra*), American basswood (*Tilia americana* L.), and aspen (*Populus tremuloides*)) at the USDA Forest Products Laboratory have indicated that the actual effect of species was not large (Simpson et al. 2005). In fact, the differences in heating times of different species are of a similar magnitude to the expected natural variability between individual boards and square timbers. In a heat-treatment operation, there is no practical reason to heat treat different hardwood species separately.

No data is currently available to directly assess the effect of species in heat treating softwood products. There are practical reasons, however, for separating species when drying softwood lumber, and heat treatment of softwood products is often accomplished during the wood drying process.

Proper stacking of lumber or timbers is an essential aspect of heat-treating processes, as it directly affects heat transfer and, consequently, heating times. If a heat-treating facility received solid-piled bundles of lumber or timbers, it may be desirable to heat treat in the solid-piled configuration. It should be noted, however, that a solid bundle of lumber or timbers results in much longer heating times, when compared to a similar quantity of lumber or timbers that are stickered before treating. **Figure 4.2** shows the ratio of heating times for equal quantities of lumber or timbers, one being heat treated as a solid bundle (4 by 3.2 ft.) and the other treated after stickering. Note that the ratio ranges from about 2 for 12- by 12-inch timbers to more than 14 minutes for 1- by 6-inch boards, indicating that heat treating stickered materials can result in substantial decreases in heating times. In addition, a higher degree of variation in heating times for solid-piled materials than for stickered materials results from how closely the individual pieces fit together in a stacking bundle (Simpson et al. 2003). Gaps between individual pieces allow hot air to penetrate and thus warm the surface more than when adjacent pieces fit tightly together. In commercial practice, this high variability could cause complications in estimating heating times.

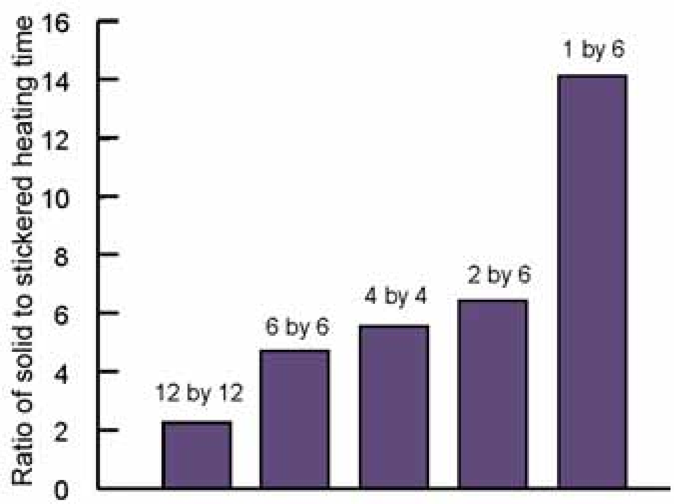

Figure 4.2. ~ *Ratio of heating times of solid-piled boards and timbers (4 by 3.2 ft.) to stickered boards and timbers for Douglas-fir (1.5°F/2.2°F wet-bulb depression). (°C = (°F – 32)/1.8; 1 in. = 25.4 mm).*

Heating Times for Wood in Various Forms

A series of heating experiments have been conducted at the USDA Forest Products Laboratory (Simpson 2001, 2002; Simpson et al. 2003, 2005). **Tables 4.2 and 4.3** are summaries of experimental heating times to heat ponderosa pine (*Pinus ponderosa* Laws) and Douglas-fir (*Pseudotsuga menziesii*) boards and square timbers to a center temperature of 133°F in a heating environment of 160°F dry-bulb temperature and various wet-bulb depressions. **Table 4.4** summarizes the average heating times required to reach 133°F for six sizes of five northern hardwood species (red maple, sugar maple, northern red oak, American basswood, and aspen) at two wet-bulb depressions (0° and 10°F). It should be noted that the heating times in these tables are for wood in the green condition. When referencing the data, it is also important to consider that these heating time tables were obtained through laboratory experiments in a small-scale dry kiln (approximately 1,500 board foot capacity) under well-controlled heating conditions. Although the experimental results have not been calibrated to commercial operation, they have served as the bases for developing heat-treatment schedules for industrial applications (ALSC, Inc. 2009).

Table 4.2. ~ *Summary of experimental heating times to heat ponderosa pine boards and square timbers to a center temperature of 133°F in a heating environment of nominal 160°F dry-bulb temperature and various wet-bulb depressions.*[a]

Wet-bulb depr. (°F)	Experimental heating times (min.)				
	1 by 6[b]	2 by 6	4 by 4	6 by 6	12 by 12
Stickered					
2.5	17 (8.1)[c]	43 (13.1)	153 (8.9)	299 (17.7)	1,006 (15.5)
6.2	16 (5.9)	53 (2.4)	180 (6.0)	271 (6.2)	980 (12.1)
12.0	23 (3.1)	67 (15.0)	207 (17.3)	420 (28.3)	1,428 (8.2)
26.8	188 (45.2)	137 (12.5)	256 (19.0)	568 (7.2)	1,680 (13.9)
47.5	427 (18.1)	361 (30.7)	817 (53.9)	953 (38.1)	2,551 (22.2)
Solid-piled[d]					
2.8	166 (70.3)	361 (64.9)	831 (14.0)	1,201 (30.1)	1,736 (26.4)
13.4	201 (22.7)	391 (23.4)	710 (48.1)	1,617 (26.7)	2,889 (22.4)

[a] °C = (°F – 32)/1.8; 1 in. = 25.4 mm.
[b] Actual sizes are the same as nominal sizes.
[c] Coefficient of variation in parentheses (%).
[d] Solid pile of 4 ft. wide and 3.2 ft. high.

Table 4.3. ~ *Summary of experimental heating times to heat Douglas-fir boards and square timbers to a center temperature of 133°F in a heating environment of nominal 160°F dry-bulb temperature and various wet-bulb depressions.*[a]

Wet-bulb depr. (°F)	Experimental heating times (min.)				
	1 by 6[b]	2 by 6	4 by 4	6 by 6	12 by 12
Stickered					
2.2	7 (22.2)[c]	21 (21.3)	78 (12.5)	209 (8.9)	840 (8.8)
6.3	8 (10.3)	25 (21.9)	91 (10.5)	202 (11.6)	914 (13.9)
12.5	10 (6.7)	34 (22.3)	138 (17.8)	262 (7.7)	1,153 (7.0)
27.1	216 (39.9)	157 (23.1)	255 (25.1)	715 (22.8)	1,679 (3.1)
44.2	233 (62.8)	223 (20.3)	362 (28.0)	849 (6.1)	2,005 (23.3)
Solid-piled[d]					
1.5	103 (45.2)	137 (46.9)	432 (27.2)	977 (9.3)	1,931 (13.5)
13.8	143 (69.1)	195 (77.4)	521 (54.7)	1,847 (25.7)	1,847 (25.7)

[a] °C = (°F – 32)/1.8; 1 in. = 25.4 mm.
[b] Actual sizes are the same as nominal sizes.
[c] Coefficient of variation in parentheses (%).
[d] Solid pile of 4 ft. wide and 3.2 ft. high.

American Lumber Standards Committee Enforcement Regulations

Depending on the treating schedules used, the heat-treating processes can be classified as one of the following two types:

Heat-treated (HT) – lumber or used, previously assembled, or repaired wood packaging which has been placed in a closed chamber and artificial heat added until the lumber or packing achieves a minimum core temperature of 133°F for a minimum of 30 minutes.

Kiln-dried heat-treated (KD HT) – lumber or used, previously assembled, or repaired wood packaging which has been placed in a closed chamber and artificial heat added

Table 4.4. ~ *Summary of experimental heating times to 133°F for six sizes of five hardwood species heated at a nominal dry-bulb temperature of 160°F and two wet-bulb depressions.*[a]

Wet-bulb depr. (°F)	Piece size (in.)	Heating times (min.)				
		Red maple	Sugar maple	Northern red oak	American basswood	Aspen
0	1 by 6[b]	14 (15)[c]	13 (14)	14 (15)	12 (14)	13 (14)
	1-1/2 by 6	29 (31)	28 (30)	26 (28)	26 (28)	29 (32)
	2 by 6	50 (52)	48 (49)	49 (53)	46 (48)	50 (54)
	3 by 3	59 (64)	58 (61)	57 (60)	51 (58)	61 (64)
	4 by 4	115 (119)	107 (113)	109 (112)	100 (108)	113 (117)
	6 by 6	265 (283)	255 (277)	252 (259)	226 (243)	262 (278)
10	1 by 6	17 (18)	14 (15)	15 (16)	15 (17)	15 (16)
	1-1/2 by 6	36 (38)	31 (34)	32 (33)	29 (31)	32 (33)
	2 by 6	59 (62)	53 (56)	56 (59)	54 (58)	57 (62)
	3 by 3	85 (96)	63 (67)	66 (69)	63 (69)	69 (74)
	4 by 4	137 (143)	121 (127)	124 (129)	114 (120)	129 (133)
	6 by 6	294 (304)	284 (299)	284 (298)	262 (284)	285 (195)

[a] °C = (°F – 32)/1.8; Heating times were adjusted to a common initial temperature of 60°F and the overall actual average heating temperature of 157°F.

[b] Actual sizes.

[c] 99% upper confidence bounds of heating times.

until the lumber or packing achieves a minimum core temperature of 133°F for a minimum of 30 minutes and has dried to a maximum moisture content of 19% or less.

American Lumber Standards Committee (ALSC) enforcement regulations require that a heat-treating facility should be inspected and verified by an accredited third-party agency for initial qualification. Agencies will verify the accuracy of temperature measuring and recording devices in the heating chamber, require that thermocouples be located to accurately measure the temperature achieved in the heat chamber, and require an appropriate number of thermocouples are utilized given the chamber configuration. A thermocouple verification study is needed for any kiln schedule operating in a heat chamber using:

1. both dry and wet heat (steam) with a wet-bulb temperature of less than 140°F; or
2. only dry heat of less than 160°F; or
3. no set schedule, but instead using thermocouples inserted directly into the wood which does not maintain a core temperature of 140°F or greater.

In such a verification study, an appropriate number of thermocouples are used to accurately measure the temperature conditions of the chamber and the wood to ensure that time and temperature requirements for heat treating are met. Any equipment variance of more than ± 5°F requires recalibration or replacement.

Heat-treatment facilities are also required to monitor temperatures throughout the heat-treatment cycle by any of the following options:

1. Wet- and dry-bulb temperatures

2. Dry-bulb only – unless the specific schedule has been verified, required heating times shall be equal to or greater than the time specified for the applicable schedule assuming the maximum wet-bulb depression as provided in either of the following:

   a. FPL-RP-607, *Heat sterilization time of ponderosa pine and Douglas-fir boards and square timber* (Simpson et al. 2003); or

   b. FPL-RP-604, *Effect of wet bulb depression on heat sterilization time of slash pine lumber* (Simpson 2002); or

   c. CFIA PI-07, T*he technical heat treatment guidelines and operating conditions manual*, Option C (CFIA 2006).

3. Direct measurement of the wood core temperature of the thickest piece(s) by use of thermocouple(s) properly sealed with non-conductive material. The number of thermocouples in use should be determined by the agency's initial qualification of the facility or any subsequent verification study. Any charges determined not to meet heat-treatment requirements shall not be quality marked unless properly re-heat treated.

Heat-treatment facilities are currently required to calibrate the temperature monitoring and recording equipment annually for each facility's heat-treating chamber and requalify a heat-treating chamber when there is a major change in equipment or remodeling of the chamber. Except in the case of the wood core temperature of the thickest piece(s) being directly measured by using thermocouples, when the wood moisture content is not determined at the beginning of the heat-treatment cycle, facilities are required to select and use appropriate time–temperature schedules assuming the lowest initial wood moisture content from one of the following publications:

a. FPL-GTR-130, *Heating times for round and rectangular cross sections of wood in steam* (Simpson 2001);

b. FPL-RP-607, *Heat sterilization time of ponderosa pine and Douglas-fir boards and square timber* (Simpson et al. 2003);

c. FPL-RP-604, *Effect of wet-bulb depression on heat sterilization time of slash pine lumber* (Simpson 2002); or

d. CFIA PI-07, *The technical heat treatment guidelines and operating conditions manual*, Option C (CFIA 2006).

Quality Mark

The International Standards for Phytosanitary Measures Pub. No. 15 requires that treated packaging must be marked with an official stamp that includes an International Plant Protection Convention (IPPC) symbol, an International Standards Organization (ISO) two-letter country code, an abbreviation of the type of treatment used (heat treatment is indicated by the mark HT), and a unique number assigned by the country's national plant protection organization to the producer of the wood packaging material who is responsible for ensuring that appropriate wood is used and properly marked (**Fig. 4.3**). If wood packaging materials arrive in a member country without this quality mark, officials at the port of arrival have the right to

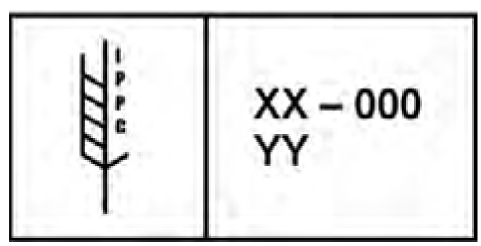

Figure 4.3. ~ *ISPM 15 requires the use of a quality mark on wood packaging materials to certify that proper treatment has occurred.*

refuse entry or require treatment (such as fumigation) at the port – a costly situation. Recycled, remanufactured, or repaired wood packing material should be recertified and remarked. All components of such material are required to be properly treated.

Other Considerations

Heating Capacity

It is critical in heat sterilization that the heating and humidification system be designed to meet the production schedule. Typically, the heating capacity of a hardwood kiln ranges from 0.5 to 1.5 boiler horsepower per thousand board feet of lumber (7,100 to 21,300 Btu/h per cubic meter of lumber). To achieve the rapid heating needed, the boiler horsepower needs to be sized from 6.0 to 12.5 boiler horsepower per thousand board feet (85,100 to 177,300 Btu/h per cubic meter), depending on the lumber used and the starting temperature (Denig and Bond 2003).

Structure Damage

The environment used for heat sterilization of wood can be extremely corrosive and damaging to some structures. In addition to using the proper materials, a floor drain system should be used, especially when using high humidity schedules.

Mold Prevention

Heat sterilization only kills mold, fungus, and insects that are present when the material is sterilized. In certain cases, mold and fungus have rapidly infested heat-sterilized lumber that was not dry (Denig and Bond 2003). It is critical for the pallet operator and user to keep their production facility free of waste wood, minimize pallet inventory of heat-treated pallets, and ensure some air movement around green pallets that have been heat treated.

Heat Treatment of Firewood

Heat-Treatment Standards

Federal and state quarantine regulations prohibit the transport of all hardwood firewood from known emerald ash borer (EAB)- or gypsy moth-infested areas across state lines or to adjacent non-infested areas within a state unless a mitigating treatment has been made. Heat treatment is an approved method used to kill these two common wood pests in firewood and allows infested firewood to be moved and used freely.

The current heat-treatment schedule for EAB in firewood requires the core temperature to reach a minimum of 140°F for 60 minutes (Treatment T314-a, USDA APHIS PPQ 2011[a]). Prior to January 2011, a more stringent schedule (160°F for 75 min.) was used. The heat-treatment standard for EAB exceeds the ISPM 15 standards because of the higher thermal tolerance of EAB.

The current heat-treatment schedule used for gypsy moths in firewood requires the core temperature to reach a minimum of 133°F for 30 minutes (Treatment T314-b, USDA APHIS PPQ 2011), which is same as the ISPM 15 standards. If the firewood comes from areas quarantined for both EAB and gypsy moth, the higher standard must be used.

USDA APHIS PPQ Enforcement Regulations

The heat treatment of firewood must be performed at an approved facility that maintains a current compliance agreement. USDA Animal and Plant Health Inspection Service (APHIS) Plant

[a] Emerald ash borer regulated materials include: firewood of all hardwood species, nursery stock, green lumber, and other material living, dead, cut, or fallen, including logs, stumps, roots, branches, and composted and uncomposted chips of the genus *Fraxinus* (68 FR 59088, October 8, 2003, as amended at 72 FR 30460, June 1, 2007 (7CFR301 2011)).

Protection and Quarantine (PPQ) enforcement regulations stipulate that a heat-treating facility be inspected and certified by a PPQ official for initial qualification. The official certification test has three main components:

1. calibrating the temperature sensors,
2. thermal mapping (cold spot mapping), and
3. conducting an actual test treatment.

Certified heat-treatment facilities are required to monitor the core temperatures of several firewood pieces during the heating process and keep a temperature history record of each treatment run. The PPQ official will review facility treatment records to ensure that treatment temperature and duration requirements have been met.

Heat-Treating Options

There are three possible options for heat treating firewood in field operations. Selection of the heat-treating method depends on the type of heating facility, energy sources, and market needs. A study funded by the USDA Forest Service Wood Education and Resources Center examined the efficacy of different heat-treatment options through a series of heating experiments (Wang et al. 2009). The laboratory heating experiments were conducted under three heating schemes:

1. Dry-heat schedule for heat treating green ash firewood with moisture reduction;
2. Wet-heat schedule for heat treating green ash firewood without moisture reduction; and
3. Dry-heat schedule for heat treating seasoned (<20% moisture content) ash firewood.

1. Heat Treating Green Firewood with Moisture Reduction (Dry-heat schedule)

This strategy integrates the heat-treatment procedures with a kiln-drying process and is considered a primary option by many firewood producers with dry-kiln facilities. The heating medium used is typically dry heat (no additional moisture added). The green firewood pieces are first heated to the target core temperature for an extended period of time (heat treatment stage). After the heating standard is met, the firewood loads are continuously heated and kiln-dried until the moisture content of the firewood reaches 20% or below (kiln-drying stage). The heating capacity of dry-kiln facilities for firewood businesses varies widely. Maximum kiln temperature can range from below 160°F to over 280°F, depending on the type of kiln and energy source used.

Table 4.5 summarizes the heating times to achieve a core temperature of 160°F for green ash (*Fraxinus americana*) firewood at various heating conditions (Wang et al. 2009). The heating time ranges from a few hours at kiln temperatures of 240°F and 280°F to over 10 hours at a kiln temperature of 170°F. (Note: This was based on the heat-treating standard prior to January 2011). The effect of kiln temperature on heating time can also be seen in **Figure 4.4**.

The laboratory study showed that the initial temperatures of firewood have a practical effect on heating times when kiln temperatures were 200°F and below, as shown in **Figure 4.4**. The lower the initial wood temperature, the longer the heating time. This implies that heat-treating operations in the winter season should take into consideration initial firewood temperature and plan for longer heating times than in warmer seasons.

2. Heat Treating Green Firewood Without Moisture Reduction (Wet-heat schedule)

This heating strategy applies to situations in which firewood only needs to be heat treated to meet the U.S. Federal regulations and no drying is required. Heating with wet heat (no or low

Table 4.5. ~ *Heating times to a core temperature of 160°F for green ash firewood using dry-heat schedules.*[a]

Kiln temp. setting (°F)	Actual kiln temp. (°F)		Initial temp. of firewood (°F)	Heating times (min.)		
	Dry-bulb	Wet-bulb		Avg.	Min.	Max.
170	167	116	13	471	370	672
			36	411	290	635
			69	396	333	484
180	176	120	27	251	199	325
			43	232	199	271
			69	198	176	257
200	195	128	14	198	164	231
			34	161	143	208
			63	144	94	173
240	234	155	11	133	92	185
			34	126	109	157
			70	118	89	138
280	272	160	16	142	103	185
			36	139	104	159
			64	129	83	146

[a] °C = (F – 32)/1.8.

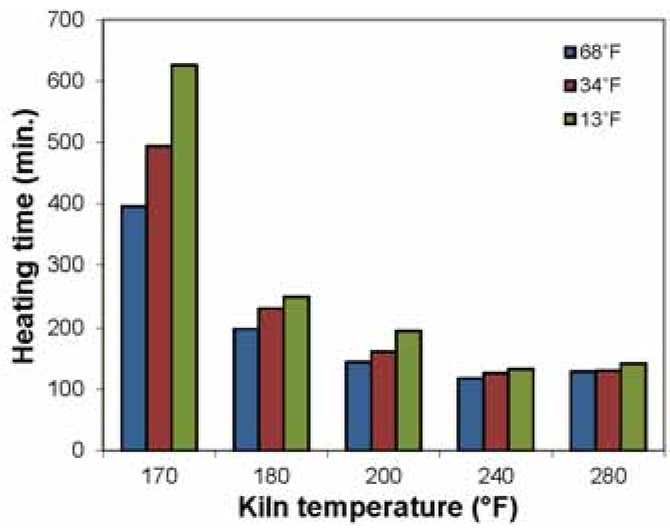

Figure 4.4. ~ *Average heating times for green ash firewood with dry heat at varying kiln and initial wood temperatures. (°C = (°F – 32)/1.8).*

wet-bulb depression) is the most efficient way to accomplish the heat-treatment goal in this scenario, and it yields much shorter heating times than heating with dry heat.

Table 4.6 shows heating times for green ash firewood under several different wet-heat conditions, which were a combination of three kiln temperatures at 160°, 170°, and 180°F and two wet-bulb depressions (0° and 10°F). The heating times to a core temperature of 160°F were generally in the range of 2 to 4 hours in a fully saturated heating medium with a kiln temperature of 160° to 180°F. Heating time increased significantly as wet-bulb depression increased from 0° to 10°F. **Figure 4.5** shows the effect of heating medium on average heating times to a core tempera-

Table 4.6. ~ *Heating times to a core temperature of 160°F for green ash firewood using wet-heat schedules.*[a]

Kiln temp. (°F)		Initial wood temp. (°F)	Heating times (min.)		
Dry-bulb	Wet-bulb depr.		Avg.	Min.	Max.
160	0	76	200	149	239
	10	74	229	165	273
170	0	64	152	114	196
	10	53	205	160	241
180	0	56	151	119	189
	10	60	159	124	197

[a] °C = (F – 32)/1.8.

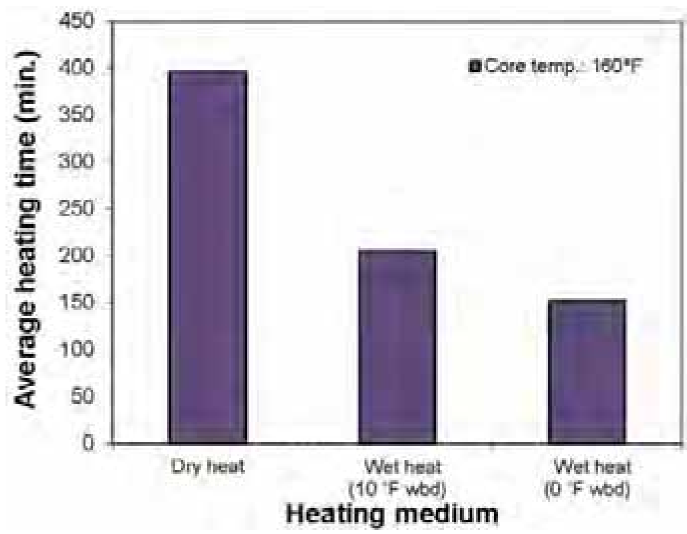

Figure 4.5. ~ *Average heating times for green ash firewood with dry heat and wet heat schedules (dry-bulb temperature of heating medium: 170°F; wbd is wet-bulb depression). (°C = (°F – 32)/1.8).*

ture of 160°F for green ash firewood in a 170°F kiln temperature. Note that under similar initial wood temperature conditions, the heating times for wet-heat schedules at 0° to 10°F wet-bulb depression were significantly lower than the heating times for a dry-heat schedule and the heating medium with 0°F wet-bulb depression resulted in the shortest heating time.

3. Heat Treating Seasoned Firewood (Dry-heat schedule)

Another scenario used by commercial firewood producers is heat treatment of firewood after it has been air-dried (<20% moisture content). This procedure would only be used to meet the U.S. Federal regulations in order to freely move firewood from EAB quarantine areas. Although both dry-heat and wet-heat schedules can be used to heat treat seasoned firewood, dry-heat schedules are more likely to be used, as firewood producers who air-dry firewood typically do not have a traditional steam kiln.

The experimental heating times for seasoned firewood with dry-heat schedules are shown in **Table 4.7**. The comparison of heating times between green and seasoned firewood is illustrated in **Figure 4.6**. The results indicated that the heating time for seasoned firewood is significantly less than that for green firewood. In the case of 170°F kiln runs, it took 2 to 4.8 hours to heat the seasoned ash firewood to a core temperature of 160°F, compared to 5.6 to 8 hours for green ash firewood.

Table 4.7. ~ *Heating times to a core temperature of 160°F for green ash firewood using dry-heat schedules.*[a]

Kiln temp. setting (°F)	Initial temp. of firewood (°F)	Heating times (min.)		
		Avg.	Min.	Max.
160	22	n/a	n/a	n/a
	42			
	66			
170	68	223	128	290
180	64	169	100	218

[a] °C = (F – 32)/1.8.

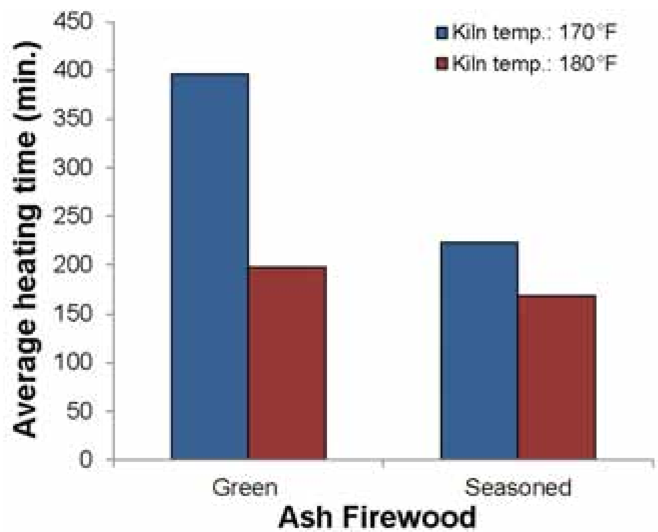

Figure 4.6. ~ *Average heating times to a core temperature of 160°F for green and seasoned ash firewood. (°C = (°F – 32)/1.8).*

Temperature Monitoring

Monitoring Air Temperature Inside a Kiln/Chamber

Typically, commercial dry kilns and heating chambers designed for heat treatment are equipped with one or two temperature sensors or temperature gauges that display the dry-bulb temperature of the heating medium. Most kilns/chambers used to heat treat or dry firewood do not have a wet-bulb temperature sensor installed. (Note: monitoring both the dry-bulb and wet-bulb temperatures allows for greater control of the kiln conditions necessary for drying lumber). The dry-bulb temperature of the heating medium is usually called kiln temperature or chamber temperature and is used for real-time checks of the kiln conditions and as guidance for kiln control. In facilities without a computer monitoring or control program, kiln temperature information is often not recorded. To meet the heat-treatment monitoring requirement, a firewood producer may need to install a temperature recording device to obtain a record of the temperature history of the kiln/chamber.

Monitoring Core Temperatures of Firewood

Monitoring the core temperatures of firewood requires having temperature sensors properly inserted into the largest firewood pieces during a treatment run. The sensor should reach the center of the cross section if inserted from a side face or reach more than 4 inches deep if inserted from the end of the piece.

Types of Temperature Senors

There are two types of temperature sensors that can be used for monitoring core temperatures of firewood: resistance temperature detector (RTD) and thermocouple.

Resistance Temperature Detector

Resistance temperature detectors are based on measuring changes in the electrical resistance of pure metals. A linear positive change is correlated with a temperature change. Most RTD elements consist of a length of fine coiled wire wrapped around a ceramic or glass core. The element is usually quite fragile, so it is often placed inside a sheathed probe for protection. A RTD is one of the most accurate temperature sensors used in industrial applications, but is generally more expensive than alternatives because of its careful construction and use of platinum.

Figure 4.7 shows two examples of RTD probes in different lengths. To measure the core temperature of firewood, the probe should be inserted into the center of the firewood piece through a pre-dilled hole. The challenges of using RTD probes to measure internal wood temperatures are:

1. The sheath that houses the RTD element requires drilling a relatively large hole (1/4 in.) either from the end or at the midsection of the firewood. Any gap between the probe and the hole is difficult to seal, thus causing hot air to enter into the hole and affect the RTD's readings.
2. The APHIS PPQ Heat Treatment Manual requires that the pre-drilled hole be a minimum of 4 inches deep if the sensor is inserted into the end of the firewood (USDA APHIS PPQ 2011). Therefore, a RTD probe should be at least 4 inches long.
3. The typical RTD probes used in commercial kilns are somewhat fragile and can be damaged during firewood handling processes.

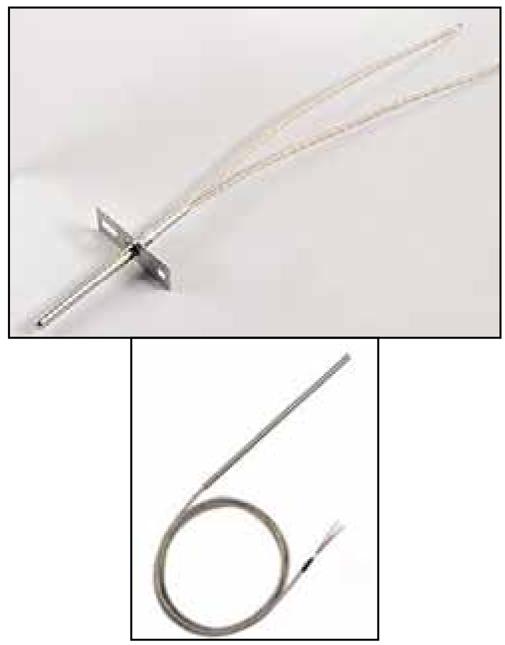

Figure 4.7. ~ *Two typical RTD probes in different lengths: (top) a 2-inch-long RTD probe and (bottom) a 6-inch-long RTD probe (Omega Engineering, Inc. 2011a).*

Thermocouple

A thermocouple is based on measuring the voltage at a junction between two different metals. Heating or cooling the junction produces a voltage which is correlated with temperature (**Fig. 4.8**). Thermocouples are widely used temperature sensors suitable for measuring across a large temperature range. They are inexpensive, interchangeable, and come fitted with standard connectors. Thermocouples are available in different combinations of metals or calibrations. The four most common calibrations are J, K, T, and E. Type T (copper-constantan) thermocouples operate in the −328° to 662°F (−200° to 350°C) temperature range (Omega Engineering, Inc. 2011b) and are best suited for firewood heat-treatment applications.

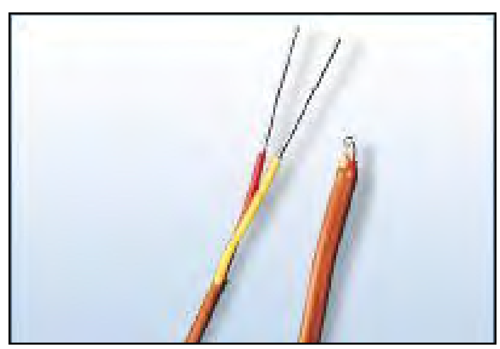

Figure 4.8. ~ *A typical insulated thermocouple (Omega Engineering, Inc. 2011b).*

Temperature Data Loggers

Temperature data loggers are stand-alone data collecting devices that can read and store temperature data in internal memory for later download to a computer. Some data loggers provide an option for real-time monitoring. The advantage of data loggers is that they can operate independently of a computer, unlike many other types of data acquisition devices. Data loggers are also less expensive than chart recorders and are available in various shapes and sizes. Options include simple economical single channel fixed function loggers to more powerful programmable devices capable of handling hundreds of inputs. When choosing a temperature data logger, the following parameters should be considered:

- number of inputs,
- size,
- speed/memory, and
- real-time operation (option).

Heat-Treatment Monitoring System

The temperature monitoring system for a heat-treatment operation can vary depending on the configuration and capacity of the heating chamber or kiln and the availability of the monitoring equipment. In general, a monitoring system for a heat-treating operation should include multiple temperature sensors (thermocouples or RTD probes), a data acquisition and recording device, and a personal computer. **Figure 4.9** shows a typical temperature monitoring system in a firewood operation. The cost for a basic monitoring system that includes thermocouple sensors and a data logger ranges from $1,000 to $3,000 depending on the number of data inputs. A desktop computer or a laptop computer is essential for initiating the data logger, downloading temperature data, and monitoring in real-time.

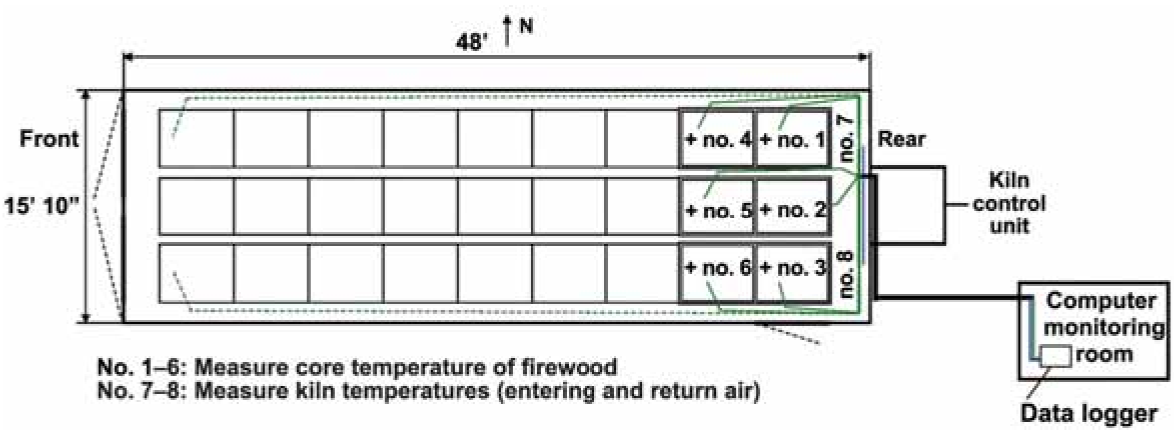

Figure 4.9. ~ *A typical temperature monitoring system in a firewood heat-treatment facility.*

Thermal Verification

The firewood samples monitored should be the largest pieces in a kiln charge, and they are required to be placed in the coldest areas of the kiln/chamber. Internal wood temperatures should be collected at least once every 5 minutes and stored in a data file. The sensors used to monitor firewood temperatures need to be calibrated annually and read within ±0.9°F of the treatment temperature.

Table 4.8 is an example of the temperature data recorded by a data logger during a heat-treatment operation. It includes the date of the heat treatment, a time stamp, and the temperature of each channel. Channels 1 to 3 correspond to the core temperatures of the firewood

Table 4.8. ~ *Portion of the temperature data recorded during a firewood heat treament.*

Date mm/dd/yy	Time	T-1 Sample 1 (°F)	T-2 Sample 2 (°F)	T-3 Sample 3 (°F)	T-4 Kiln temp (°F)	T-0 Ambient (°F)
2/13/2009	4:00:00 AM	159.30	158.50	159.70	166.80	30.70
2/13/2009	4:05:00 AM	159.30	158.50	159.70	166.80	30.70
2/13/2009	4:10:00 AM	159.30	159.20	159.80	167.50	30.79
2/13/2009	4:15:00 AM	159.30	159.20	159.80	167.50	30.79
2/13/2009	4:20:00 AM	159.40	159.30	160.50	167.60	30.88
2/13/2009	4:25:00 AM	160.10	159.30	160.50	168.30	30.88
2/13/2009	4:30:00 AM	160.10	160.00	160.50	168.30	30.88
2/13/2009	4:35:00 AM	160.10	160.00	161.20	167.60	30.88
2/13/2009	4:40:00 AM	160.70	160.00	161.20	168.30	30.88
2/13/2009	4:45:00 AM	160.70	160.00	161.20	168.30	30.88
2/13/2009	4:50:00 AM	160.70	160.60	161.90	168.30	30.88
2/13/2009	4:55:00 AM	161.30	160.60	161.90	168.30	30.88
2/13/2009	5:00:00 AM	161.30	161.20	161.90	168.90	30.88
2/13/2009	5:05:00 AM	161.30	161.20	161.90	168.90	30.88
2/13/2009	5:10:00 AM	161.30	161.20	161.90	168.90	30.88
2/13/2009	5:15:00 AM	162.10	161.30	162.60	169.60	30.99
2/13/2009	5:20:00 AM	162.10	161.30	162.60	169.60	30.99
2/13/2009	5:25:00 AM	162.10	162.00	162.60	169.60	30.99
2/13/2009	5:30:00 AM	162.70	162.00	163.20	169.60	30.99
2/13/2009	5:35:00 AM	162.70	162.00	163.20	169.60	30.99
2/13/2009	5:40:00 AM	163.20	162.50	163.10	170.20	30.88
2/13/2009	5:45:00 AM	163.20	162.50	163.80	170.20	30.88
2/13/2009	5:50:00 AM	163.10	162.40	163.70	170.10	30.74
2/13/2009	5:55:00 AM	163.10	163.00	163.70	170.10	30.74
2/13/2009	6:00:00 AM	163.80	163.00	164.30	170.10	30.74
2/13/2009	6:05:00 AM	163.80	163.00	164.30	170.70	30.74
2/13/2009	6:10:00 AM	163.80	163.70	164.30	170.70	30.74
2/13/2009	6:15:00 AM	163.80	163.70	164.30	170.70	30.74
2/13/2009	6:20:00 AM	163.80	163.70	164.30	170.10	30.74
2/13/2009	6:25:00 AM	164.40	163.70	164.30	170.70	30.74
2/13/2009	6:30:00 AM	164.50	163.80	165.00	170.80	30.85

Note: Data within the shaded area indicates that the treatment has met the temperature–time requirement for the emerald ash borer.

samples. Channel 4 corresponds to the temperature of the return air (kiln temperature), and channel 5 records ambient temperature. A complete temperature history record should be provided to APHIS PPQ staff as a thermal verification of the heat-treatment process.

Heat-Treatment Operating Procedures

The following is a step-by-step procedure for conducting heat-treatment runs and monitoring the temperatures of both the kiln and the firewood samples during the heating process. This operating procedure has been demonstrated and improved through field demonstration projects (Wang et al. 2011).

Step 1. Initiate the temperature monitoring system

The temperature monitoring system should be initiated before starting a heat-treatment process. This is usually done by initiating the data logger immediately before or after loading the kiln; however, it is recommended that the data logger be initiated to collect data before loading the firewood into the kiln to ensure that all of the temperature sensors function properly and that the temperature data is being recorded (**Fig. 4.10**).

Figure 4.10. ~ *Initiate a data logger prior to starting the heat-treating cycle.*

Step 2. Select the monitoring samples

Carefully select the largest pieces of firewood for placement of temperature sensors. The size and forms of firewood vary and are difficult to quantify. APHIS regulations require that the largest pieces of firewood be selected and used as temperature monitoring samples in each heat-treatment run. If a firewood load includes both wet and dry pieces, wet pieces should be selected as samples (**Fig. 4.11**).

Figure 4.11. ~ *Select the largest firewood pieces as monitoring samples.*

Step 3. Determine the center of the firewood

Mark the center of the cross-section from the ends of the firewood and measure the depth of the center from a side surface (**Fig. 4.12**).

Figure 4.12. ~ *Locate the center of the firewood from the end.*

Step 4. Drill a hole for the temperature sensor

Drill a small-diameter hole into the center of the firewood to accommodate the temperature sensor. If a thermocouple wire is used to measure the core temperature of a firewood piece, drill a small hole into the center at the midsection of the firewood. If a long temperature probe (RTD or thermocouple probe) is used to measure the core temperature, drill a small hole of at least 4 inches deep from one end (**Fig. 4.13**).

Figure 4.13. ~ *Drill a hole in the firewood to accommodate a temperature sensor. Drill a hole from the side at midsection for a thermocouple (left). Drill a hole from the end for a probe (right).*

Step 5. Insert a sensor

Insert a temperature sensor into the hole, ensuring that the tip of the sensor reaches the center of the firewood sample (**Fig. 4.14**).

Figure 4.14. ~ *Insert a temperature sensor/probe into the firewood pieces being monitored.*

Step 6. Seal the sensor hole

Use a round toothpick and silicon sealant to fill and seal the hole, ensuring that the sensor is secured in position (**Fig. 4.15**).

Figure 4.15. ~ *A thermocouple wire secured in the firewood.*

Step 7. Arrange the samples in bins

Place the firewood samples into the firewood baskets or bundles, ensuring that all of the firewood monitoring samples are buried deep within each bin. The bins containing monitoring samples should be placed in the cold areas in the kiln as determined by PPQ staff during the kiln certification process (**Fig. 4.16**).

Figure 4.16. ~ *Monitored firewood placed into the firewood basket.*

Step 8. Complete kiln loading

Once the test samples have been arranged, complete the loading and close the kiln door (**Fig. 4.17**).

Figure 4.17. ~ *Close the kiln door.*

Step 9. Check the temperature monitoring system and start heating

It is recommended that kiln operators record the initial kiln temperature, the initial firewood core temperature, and the cycle starting time in a kiln operation journal (**Fig. 4.18**).

Figure 4.18. ~ *Check the temperature monitoring system.*

Step 10. Monitor temperatures throughout

Periodically monitor the kiln temperatures and the core temperatures of the firewood samples (**Fig. 4.19**).

Figure 4.19. ~ *Monitor the core temperature of the firewood.*

Step 11. Complete the heat-treatment cycle

Determine the end of the heat-treatment cycle after verifying that the samples have met the APHIS heat-treatment standard (**Fig. 4.20**).

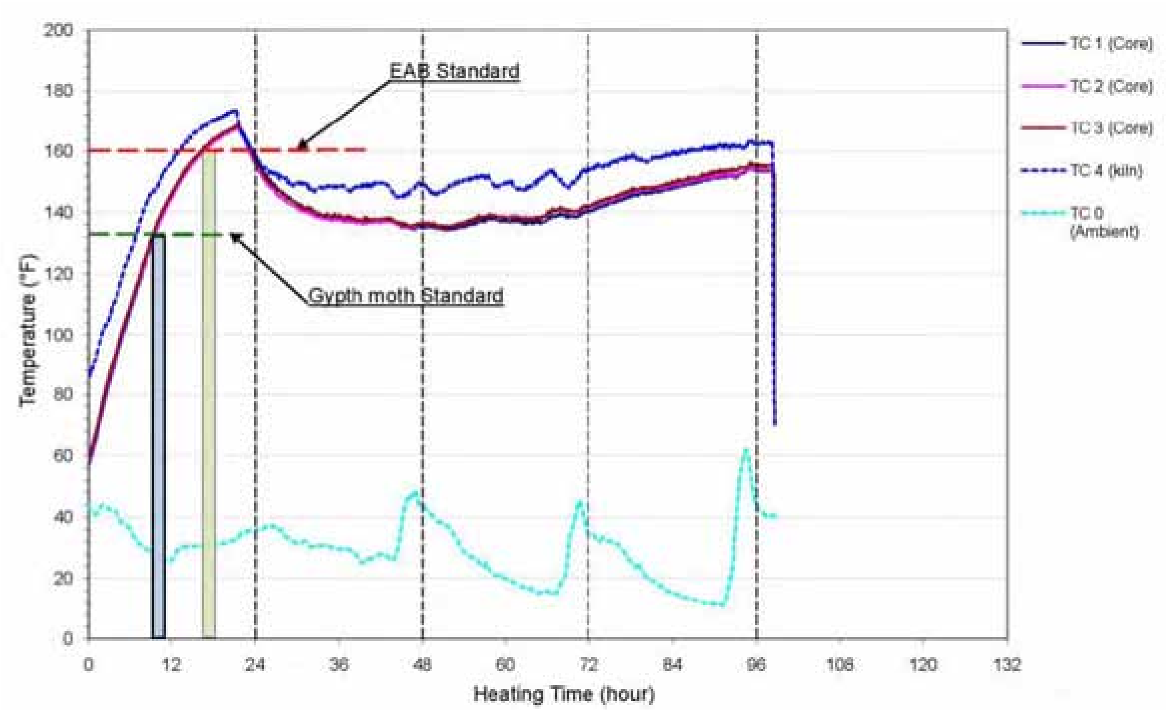

Figure 4.20. ~ *Thermal verification based on firewood core temperatures.*

Firewood Heat-Treatment Workshop

Through a heat-treatment demonstration project funded by the U.S. Forest Service Wood Education and Resources Center (WERC), the Natural Resources Research Institute (NRRI) of the University of Minnesota Duluth and the USDA Forest Products Laboratory jointly developed two technical workshops to educate and train field operators and regulatory staff in states affected by EAB infestation or where commerce of hardwood firewood is under federal quarantine. These workshops outlined the fundamentals of heat treatment of firewood, the use of temperature monitoring systems, and the certification and verification of heat-treatment operations. The webinar sessions of the training workshop have been recorded and archived for reviewing at the following web location: https://umconnect.umn.edu/p89465540/.

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