Forest Products Industry Technology Roadmap

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Transforming the Forest Products Industry through Innovation

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The 2010 roadmap was developed under the guidance of Ron Brown, Executive Director of the Agenda 2020 Technology Alliance, and with the financial support of Agenda 2020 and the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Industrial Technologies Program. The principal writers were Fred Hansen, Mallory James, Amanda Greene, and Matt Munderville of Energetics Incorporated and Ron Brown of Agenda 2020. The document was designed by Julie Chappell of Energetics Incorporated. Many knowledgeable people in the forest products industry provided useful suggestions for the content of the roadmap report.

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Executive Summary

The *2010 Forest Products Industry Technology Roadmap* provides both the industry and the research community with guidance on the research and development (R&D) priorities necessary to transform the industry's products and manufacturing processes and position the industry for sustainable, long-term growth. Breakthrough technologies are needed to facilitate the industry's continuing progress as a producer of goods made from a renewable, carbon-neutral resource, while increasing its leadership position in bioenergy and recycling of waste products.

The research community—including both those who actively conduct research and those who fund it—plays a vital role in ensuring the industry's continued success. In collaboration with industrial partners, the research community produces the scientific breakthroughs that support the development of new technology solutions, which in turn enable industry to become more efficient and to develop new products and serve new markets. The partnership with the research community is particularly important for the forest products industry because the manufacture of new types of paper, pulp, and wood-based products requires a broad range of technology solutions.

The primary purpose of this *2010 Forest Products Industry Technology Roadmap* is to provide the research community with information about technology needs in the forest products industry. By synthesizing and prioritizing the issues that industry representatives have designated as most crucial and timely, this document invites the research community to engage in collaborative, pre-competitive research, development, and demonstration programs that will provide the foundation for deployment of new technology-driven solutions.

Industry Importance

The global forest-based industry is an important component of society in many nations. Its total economic value was US$468 billion in 2006, employing 13.7 million people, according to the United Nations. The world's pulp and paper industry covers six continents, with North America, Europe, and Asia having the largest portions.

The United States forest products industry accounts for approximately 6 percent of the total U.S. manufacturing gross domestic product (GDP), placing it on par with the automotive and plastics industries. The industry generates more than $200 billion a year in sales and employs approximately 900,000 people earning $50 billion in annual payroll. The industry is among the top 10 manufacturing employers in 42 states. This geographic diversity results in a widespread employment base that is concentrated in the nation's rural communities.

Trees, the raw material basis for the forest products industry, are an abundant, sustainable, renewable, and valuable national resource. Trees sequester carbon, help to mitigate climate change, and represent a vast storehouse of renewable feedstock for production of pulp, paper, wood products, biomass-derived fuels, power, and chemicals. Forests also provide important environmental benefits, including watershed management, wildlife habitat, and recreation. As a result of the industry's responsible stewardship of our forests and commitment to sustainable practices, the U.S. has more forests today than it did just 25 years ago.

Innovation

The forest, wood, and paper industry can significantly improve by encouraging innovation as an essential element of long-term sustainability; recognizing that investment in technology can dramatically reduce manufacturing costs and enable individual companies to pursue progress in new and advanced products. A robust industry-driven R&D program is an important building block in changing the image of the industry to investors and the public. Breakthrough R&D is the best path for achieving the product innovations and reductions in manufacturing costs that are necessary for a sustainable economic future long-term.

In recent years, many companies in the industry and related supplier companies have embraced the concepts of "open innovation." In this approach, companies look externally for technologies that can advance their objectives and collaborate meaningfully with partners in industry and the research community, bringing the best available talent to bear on priority R&D targets. Open innovation is a basis for the collaborative programs that will be undertaken to advance technology objectives in this roadmap.

Trends and Drivers

A comprehensive technology roadmap for the forest products industry was published in 2006, and much of its content is still relevant. In the last four years, however, the need to address significant issues such as climate change, water availability, energy security, and sustainability has become more urgent and more complex. The 2010 roadmap effort was undertaken to rethink priorities and goals particularly in response to several key trends and drivers:

- ***Societal Concerns:*** While covered in the 2006 roadmap, concerns over climate change, water availability, energy security, and sustainability have grown exponentially, especially in light of recent efforts to regulate the emission of greenhouse gases. Further concerns, such as global population growth, have also influenced the forest products industry's priorities.
- ***Manufacturing Considerations:*** Input costs have risen dramatically in recent years, often punctuated by significant short-term fluctuations, driving a desire for next-generation approaches. In addition, improving the industry's currently high energy intensity will require advanced technologies and processes.
- ***Economic Pressure:*** The recent economic recession directly impacted the forest products industry globally, with large declines in demand for many of its products. Sharp drops in housing starts and construction reduced sales of wood-based building products. Steep drops in advertising led to large declines in demand for printing papers. Lower overall economic activity resulted in reduced need for packaging. While the industry is now recovering from the impacts of the severe recession, it is positioned to build on its strengths and embrace new technologies and market opportunities.
- ***Market Forces:*** Customers increasingly want products from renewable materials. The desire is growing also for fuels and chemicals from renewable sources. A significant advantage for wood-based products, as well as fuels and chemicals derived from wood, is the "green" and sustainable aspect of the primary raw material. In addition, competition from alternative products and materials, particularly electronic media and plastic substitutes, continues to complicate market needs and erode industry margins.
- ***Impact of Government Policies on Wood Supply:*** Governments at all levels are imposing mandates or providing incentives for renewable energy. In the United States, government agencies project that biomass use will grow more rapidly than other renewable energy sources to meet these mandates or in response to governmental incentives. This projection has heightened concerns over competition for wood between traditional uses for the production of forest products and newer uses for bioenergy.

The 2010 roadmap effort was necessary to realign research and technology development with industry needs that respond to the trends and drivers facing the industry. Taking full consideration of these recent developments and their impacts upon forest products, the updated roadmap reframes and clarifies the industry's technology strategy and messages to its key audiences: federal agencies, universities, and researchers. It provides an updated framework for understanding the technological innovation that industry needs to improve manufacturing performance, develop new value streams from forest resources, and enable greater profitability.

Roadmap Content and Structure

The *2010 Forest Products Industry Technology Roadmap* was developed with the help of more than one hundred knowledgeable representatives from industry, universities, and government agencies. A multi-step process was used to first identify the important strategic issues facing the industry, and then translate those issues into specific R&D needs and pathways that provide researchers with clear points of entry for designing relevant research initiatives. Figure ES.1 provides a graphical representation of the roadmap's content and structure.

Strategic Issues

The roadmap identifies six strategic issues that establish critical imperatives for the forest products industry. The six issues represent a broad consensus of leaders from the forest products industry, government, and universities, and comprise an integrated set of priorities for meeting the new challenges posed by the trends and drivers.

- **Reduce substantially carbon emissions and energy consumption in mills and plants.** Pressure from customers and stakeholders to improve the industry's carbon footprint, uncertainty surrounding the impacts of pending legislation on climate change, and recent years' large fluctuations in energy costs justify a strategic focus on reducing carbon emissions and energy consumption.
- **Reduce fresh water intake in manufacturing at least 50%.** Water is essential to the manufacture of paper and wood products, yet its future availability is in question in many areas of the world due to societal concerns about water quality and quantity, and the need to provide fresh water for a growing population.
- **Increase the supply of high-quality fiber and low-cost biomass.** Continuous and ample supply of trees with sufficient wood quality for the intended use—whether in wood products, pulp and paper, steam and power generation, biobased chemicals, or biorefinery feedstock—is essential to the forest products industry.
- **Increase the value from high-quality fiber and low-cost biomass.** Deriving additional value streams from woody biomass that go beyond traditional wood, pulp, and paper products is a strategic issue driven in part by recent years' low returns from traditional products.
- **Enable new products and product features.** Developing technologies that enable companies to develop new products and product attributes valued by customers is a strategic priority for the industry in order to improve economic returns and demonstrate commitment to fulfilling customer wants and needs.
- **Improve recovery and recycling of waste wood and fiber products.** Continuing an historical emphasis on recycling and reusing waste forest products is strategically important to provide new value streams and improve the industry's reputation and leadership in managing shared social issues.

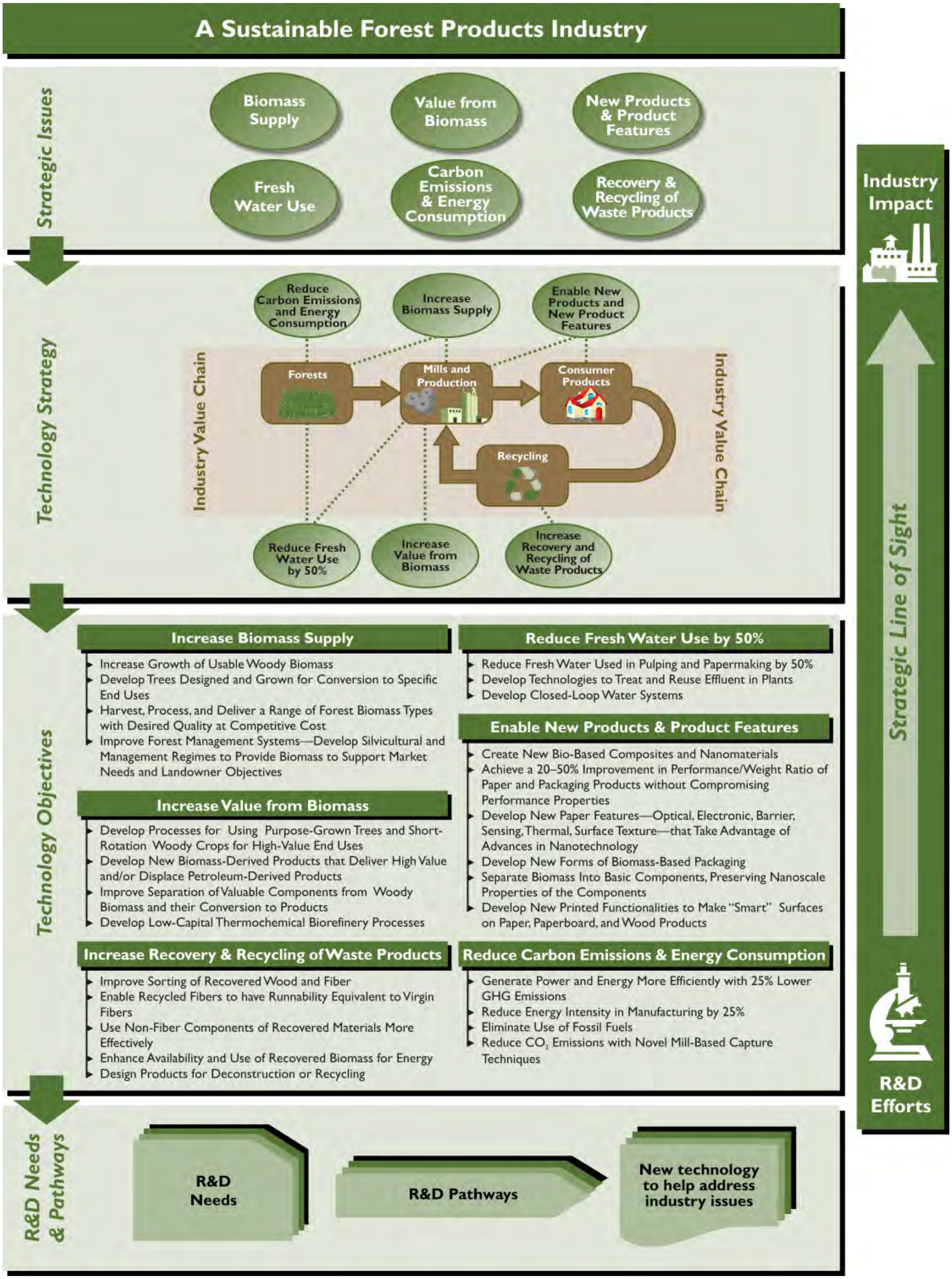
Technology Strategy

The technology strategy is (1) to define priorities in research and development that would provide breakthrough solutions for the forest products industry to use in transforming its processes and products, and (2) to advance collaborative programs that address the industry technology priorities. The roadmap presents an updated technology strategy that maps the strategic issues onto the industry value chain. As the graphic in Figure ES.1 illustrates, the strategic issues cover the entire forest products value chain, from forestry and manufacturing operations to consumer products and recycling. This technology strategy provides the basis for a planned approach to strengthening the industry's competitiveness and ensuring its continuing contributions to the overall economy and to societal goals of resource independence and environmental sustainability. The strategy also builds on the industry's strengths: an abundant, renewable, and sustainable raw material base and a manufacturing infrastructure that can process wood resources into a wide variety of products, from traditional wood, pulp, and paper products to new bio-based "green" products.

Technology Objectives

The strategic issues encompass the overall technological challenge, but do not identify specific technology needs or targets. To identify needs and provide direction to researchers, the roadmapping process engaged leaders from industry, government, and academia to establish technology objectives for each strategic issue. Each set of technology objectives identifies the ways that new technology can help the industry address the strategic issue.

Figure ES.1: Overview of the 2010 Forest Products Industry Technology Roadmap



R&D Needs and Pathways

To complete the translation from industry perspective to R&D perspective, the roadmap identifies specific R&D needs within the identified technology objectives. They comprise a research oriented translation of the strategic issues that provide directly actionable items to the R&D community. For selected top priority needs, the roadmap presents pathway maps. Each pathway map is a detailed characterization of the stream of research activity required for a particular R&D need and includes information about outcomes, barriers, and desired impacts.

Strategic Line of Sight

By linking broad strategic issues to specific R&D pathways, this roadmap establishes a *strategic line of sight* between R&D efforts and industry impact. This is an essential function of a technology roadmap and critical to its effective implementation. The line of sight enables research partnerships to maintain the efficacy and relevance of ongoing knowledge creation activity. It helps funding agencies to make efficient allocation decisions and maximize the impact of R&D investments. For individual researchers, the line of sight helps them to see how their work makes a difference and provides them with the basis for constructing a compelling argument to funding sources as to why their work should be supported.

Implementation Strategy

The technology strategy focuses on innovative, breakthrough solutions that no single company can accomplish on its own. As such, collaborative, cost-shared R&D is the cornerstone of the implementation strategy. Collaborative efforts are essential because the technical challenges and solutions are multidisciplinary and because diverse teams with breadth of knowledge and experience are necessary to move technologies from concept to commercialization. Meaningful industry-government partnerships will help to ensure that adequate resources—including funding, scientific know-how, demonstration facilities, etc.—are applied to achieving shared industry and national goals.

Implementing the roadmap will require efforts in all parts of the R&D continuum, from concept generation to technology demonstration and deployment. Basic research and the exploration of new concepts are needed to address many of the R&D needs in this roadmap.

The benefits offered by the roadmap's research areas can only be realized if the new technologies are accepted and implemented broadly by the industry. Strategic alliances involving forest products industry producers and supplier companies, federal, state and local government agencies, the research community, and other stakeholders will be utilized to accelerate the demonstration and commercialization of promising new technologies.

Path Forward

The development, demonstration and deployment of multiple new transformational technologies that will make the industry more competitive, sustainable, and efficient is beyond the resources and capabilities of forest products companies acting alone or even in concert. This task will require sustained involvement and collaboration among industrial organizations, government agencies, and research institutions. This roadmap is offered both as an invitation to and as guidance for these ongoing efforts.

Agenda 2020 will pursue an active role in the implementation of the roadmap. It will work with industry to monitor priority needs and with government and academia to reinforce the strategic line of sight. It will track progress and keep the roadmap up-to-date. It will maintain lines of communication and facilitate research partnerships. The Agenda 2020 Technology Alliance intends to lead the path forward on key programs outlined in the 2010 roadmap.

1. Introduction

The forest products industry provides society with essential products made from renewable, carbon-neutral resources and leads other industries in the use of bioenergy and recovery of waste products. With its geographically diverse operations, it employs nearly 14 million people globally in mostly rural areas, with about 1 million jobs in the United States. As an industry, it demands the sustainability of forests, which ensures that woodlands will continue to remove carbon dioxide (CO_2) from the atmosphere, give homes to wildlife, and provide clean water from the forest watersheds, as well as supplying wood for building products, pulp and paper, and energy. In its manufacturing operations, the industry leads others in use of renewable energy sources and has made good progress in reducing energy intensity and fossil fuel use. Recovery and recycling of waste products continue to improve each year.

The industry envisions a future with sustainable, long-term growth, with continual improvements in its environmental footprint and demands for energy and water. It also envisions that many of its products and manufacturing processes will be transformed and new revenues realized from products and markets not currently served by wood-based materials. Many new technologies, including both incremental and breakthrough, are needed to enable this vision and facilitate the industry's continuing progress as an efficient producer of goods made from a renewable resource, while increasing its leadership position in bioenergy and recycling of waste products.

At the same time the forest-based industry is working on sustainability, recycling, and energy efficiency, it faces a challenging and complex business environment. Increased competition from alternative technologies, rising materials costs, growing concerns about availability of water and land, and impending regulations all threaten the industry's viability and profitability. To meet today's challenges and position itself for future growth, the forest products industry needs innovative technology solutions that can transform the way traditional wood-derived products are made, facilitate the development of innovative "green" products based on renewable materials, and enable significant improvements in environmental footprint, manufacturing efficiency, and productivity.

These challenges to the industry are happening at a time when many technology areas such as nanotechnology, biotechnology, information technology, computational modeling, and separation science are advancing more rapidly than at any point in history. Technology is becoming increasingly important to a healthy future for the industry although the industry's economic pressures in recent years have constrained it's capacity for and interest in internal development of transformational technologies.

The pipeline of new and innovative technology solutions depends on ongoing, industry-focused research and development (R&D) that is beyond the means of the industry itself. The Agenda 2020 Technology Alliance is an industry-led partnership with government and academia that leverages collaborative programs to accelerate research, demonstration, and deployment of breakthrough technologies. Since Agenda 2020 led the development of a technology roadmap in 2006, there have been significant changes in the social, political, and economic forces that shape the industry's technology needs. Accordingly, the Agenda 2020 Technology Alliance, in partnership with Georgia Tech's Institute of Paper Science & Technology, initiated a project to update the 2006 Roadmap.

The new *2010 Forest Products Industry Technology Roadmap* identifies critical R&D needs and maps out specific research pathways for the development of new technology solutions in six top-priority areas over the next 10 years. The roadmap is the culmination of a unique strategic planning process that brought together industry, government, and university stakeholders to create an actionable technology strategy that will encourage R&D collaborations with federal agencies, universities, and researchers to help address the industry's top needs.

Roadmap Purpose and Scope

This roadmap focuses on the strategic issues facing the forest products industry and technology's role in addressing those issues. It identifies technology objectives and research agendas that span the entire forest products value chain—from resource procurement to product manufacturing to product consumption and post-consumer waste recycling. This roadmap has two primary purposes.

- Promote ongoing collaboration and alignment of industry companies in order to address industry-wide concerns and increase the industry-level competitiveness of forest products in the global marketplace. The roadmap provides an organizing framework to stimulate and focus strategic action at an industry level. It is designed to foster greater cooperation and common understanding across the value chain and help the industry compete more effectively as an integrated whole.
- Influence the research agendas of federal agencies, universities, laboratories, and researchers to more effectively serve the technology needs of the forest products industry. The roadmap provides the research community and funding sources with information on specific technical challenges and research needs that are considered priorities by the U.S. forest products industry. It also identifies and maps specific research pathways that offer multiple points of entry for specific research projects. The intention is not only to guide, but to engage the interest of researchers from a wide range of institutions by demonstrating how their work can make a difference. In addition, the roadmap establishes deployment criteria for effective technology solutions to encourage more demonstration initiatives.

Organization of this Roadmap

The remainder of this roadmap is organized as follows:

- Chapter 2 describes the value of the forest products industry and identifies the top strategic industry challenges that require new technology solutions.
- Chapter 3 outlines a technology strategy that will help deliver the needed technology solutions, strengthening the industry and creating a more effective industry value chain.
- Chapter 4 describes how the roadmap translates the top industry-identified strategic challenges into actionable R&D needs and pathways.
- Chapters 5 through 10 identify technology objectives, R&D needs, and R&D pathways for the six top-priority strategic challenges.
- Chapter 11 presents research needs realted specifically to wood products and based on input from both the Society of Wood Sciences and Technology and the Wood Utilization Research program.
- Chapter 12 describes how the 2010 roadmap aligns with and builds on the 2006 roadmap in accordance with changes in the business, social, and regulatory landscapes.
- Chapter 13 presents an overview of roadmaps and technology programs outside the United States that present technology research and development needs of the forest products industry.
- Chapter 14 outlines the plans for roadmap implementation and discusses key factors that may influence successful outcomes, including elements of industry-level collaboration and the need for new capabilities and partnerships.

2. The Forest Products Industry

This roadmap defines the forest products industry as a major manufacturing sector which includes the operations of growing, harvesting, and processing wood and wood-derived materials into a wide variety of tissue, paper, paperboard, solid wood, and engineered wood products and chemicals. The global forest-based industry in 2006 represented 1.0% of the total gross domestic products (GDPs) worldwide, with total economic value of US$468 billion, employing 13.7 million people, according to the Food and Agriculture Organization of the United Nations (FAO). Table 2a shows the value and employees by forestry sector.[1]

Included within this industry are thousands of logging operations; sawmills; veneer, plywood, and engineered wood product mills; pulp, paper, and paperboard mills; and other solid and composite wood products facilities.

The world's pulp and paper industry covers all continents, with North America, Europe, and Asia the largest, as shown in Table 2b. North America makes a larger share of pulp (39%) than paper (25.6%), while Asia has the reverse situation (21.9% pulp, 38.5% paper).[2] Notably, China has increased it share of global paper production from 7% in 1990 to 16% in 2006.[3]

Table 2a. Overview of the World's Forest Products Industry in 2006[1]

	Gross Value Added	Employment
Wood Production and Harvesting	US$117.5 billion	3.88 million
Wood Processing	US$149.8 billion	5.46 million
Pulp and Paper Manufacture	US$200.6 billion	4.37 million
TOTAL WORLD	**US$467.9 billion**	**13.71 million**

Table 2b. Pulp and Paper Production in the World in 2007[2]

	Pulp	Paper
Asia	21.9%	38.5%
Europe	26.5%	29%
Latin America	9.6%	4.8%
North America	39%	25.6%
Rest of World	3%	2.1%
WORLD TOTAL	**194.2 million metric tons**	**394.3 million metric tons**

The forest products industry markets its products globally. For example, in 2008, the U.S. industry exported $30 billion worth of sustainable forest products—about 15% of its total sales—while importing about $35 billion in forest products for U.S. markets.

Industry Value Chain

The technologies used in forestry and logging operations, lumber and wood products mills, and pulp and paper mills differ significantly from one another. Forestry operations rely on tree hybridization and genetic engineering; plant propagation and planting; forest and soil management; and wood harvesting, storage, and transport. Principal processes in lumber and wood products include log grading and debarking; log processing; and product fabrication, treatment, and drying. Major pulp and paper processes include pulping, bleaching, chemical recovery, stock preparation, papermaking, coating, power generation, recycling recovered fiber, and water and waste treatment. The *2010 Forest Products Industry Technology Roadmap* covers R&D needs in all of these areas.

Industry Impact

In the course of producing hundreds of wood, paper, and paperboard products that are important to our day-to-day lives, the forest products industry contributes greatly to environmental sustainability and the health of vital forest resources, while employing hundreds of thousands of workers in the United States and millions worldwide.

Snapshot of the U.S. Forest Products Industry
(2008 data unless otherwise indicated)

Paper and Paperboard Products	
Employment[1] (thousands)	445,000
Value of shipments[1] ($ billion)	$140
Paper/paperboard capacity[2] (million tons)	96.3
Paper/paperboard production[3] (million tons)	88.8
Paper/paperboard exports[4] (million tons)	42.9
Paper/paperboard imports[4] (million tons)	24
Pulp capacity[2] (million tons)	66.0
Pulp consumption by U.S. mills[6] (million tons)	56.6
Energy consumption[8] (trillion Btu)—2006	2,346
Recovered paper consumption[3] (million tons)	51.8
Recovered paper recovery rate[3]	57.4%

Wood Products	
Employment[1] (thousands)	460,000
Value of shipments[1] ($ billion)	70
Production of softwood lumber[7] (million board feet)	27,351
Production of hardwood lumber[7] (million board feet)	9,501
Value of exports[5] ($ billion)	$5.3
Value of imports[5] ($ billion)	$15.2
Energy consumption[8] (trillion Btu)—2006	450

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Products

Paper and packaging are essential components of modern life. Their everyday uses—from tissue paper and newspapers, to milk cartons and corrugated boxes, to copier and writing paper—are numerous and pervasive. Communication, food service, and product delivery are just a few of the aspects of daily life that paper and packaging improve and make more accessible.

Wood is the building material of choice for strength, aesthetic appeal, and environmental responsibility. Wood is renewable, recyclable, reusable, and continues to store carbon dioxide even as a finished product. Moreover, wood products are less energy- and carbon-intensive to produce than competing materials such as concrete and steel.

Sustainability

- **Forest Conservation:** Sustainable forest management practices are the foundation of the industry globally. Almost all makers of wood-derived products in the world use wood that is certified to be from sustainably-managed forests. As an example of the industry's responsible stewardship of forests and its commitment to sustainable practices, the United States has more forests today than it did just 25 years ago. One third of the United States is forested—751 million acres—and 60 percent of that forestland is privately owned. Privately-owned forests supply 91 percent of the wood harvested in the United States; state, tribal, and federal forests supply only 8 percent of the wood used by the forest products industry. Private landowners in the United States plant about 4 million trees each day—five trees each year for every man, woman, and child in the United States. Each single tree can absorb more than 10 pounds of CO_2 per year, and U.S. forests and forest products store enough carbon per year to offset approximately 10 percent of the nation's CO_2 emissions.
- **Renewable Resource:** Forests provide habitat for plants and wildlife, filter water and air, and mitigate climate change through carbon sequestration. Properly managed forests provide important environmental benefits, including watershed management, wildlife habitat, and recreation. They also represent a valuable, renewable, and sustainable economic resource that produces raw materials for paper, packaging, and wood products. Trees are a vast storehouse of renewable feedstock for the production of biomass-derived fuels, power, and chemicals.
- **Sustainable Energy:** The forest products industry far exceeds all other industries in the use of renewable biomass energy, and is a leader in cogenerating electricity. Renewable energy provided approximately two thirds of pulp mill, paper mill, and wood product facility energy needs in 2006 in the United States and more than half in Europe.[2] Virtually all forest products industry facilities that generate electricity in the United States do so using cogeneration technology. In 2005, the forest products industry produced more than four-fifths of the total biomass energy generated by all industrial sectors.
- **Recycling:** The forest products industry practices recovery and recycling throughout its operations. Paper is among the most intensively recycled materials in the United States. In 2008 in the United States, the paper recovery rate (i.e., the ratio of recovered paper collected to new supply) rose to an all-time high of 57.4%. This rate has climbed up from 22% in 1970, and now represents 340 pounds per year for every man, woman, and child. Such recovered paper and paperboard is an important part of the paper industry, which has set a 60 percent recovery goal for 2012. In Europe, the recycling rate was 66.6% in 2008, indicating that further progress is possible in the United States.[2] Three quarters of U.S. paper and paperboard mills used some recovered paper in 2008, and 132 of them used only recovered paper. Overall, more than a third of the fiber used in new paper and paperboard products derives from recovered paper. Clearly the industry prioritizes and supports the environmentally responsible practice of recycling.
- **Sustainable Industry:** Strengthening the long-term economic viability of the forest products industry is necessary for a sustainable industry and is a purpose of the 2010 roadmap. Transforming today's industry into a successful producer of a range of biomaterials is a desired outcome from the technology solutions outlined in this report.

Economic Value

- **Jobs:** In the United States in 2008, makers of pulp, paper, and packaging employed 445,000 people earning an estimated $36 billion. Beyond this direct employment by manufacturers, more than 9,000,000 jobs— one of every twelve in America—depend on paper or packaging as an important part of their daily operations.

  Wood products manufacturing employed some 460,000 people in 2008, earning an estimated $22 billion annually in the United States. With approximately 1,000 wood products manufacturing facilities and $70 billion in product shipments, wood products manufacturing is essential to the success of many communities nationwide.

  The industry is among the top 10 manufacturing employers in 42 states. This geographic diversity results in a widespread employment base that is concentrated in the nation's rural communities.

- **Economic Activity:** The forest products industry accounts for approximately 6 percent of the total U.S. manufacturing gross domestic product (GDP), placing it on par with the automotive and plastics industries. The industry generates more than $200 billion a year in sales and employs nearly a million people earning more than $50 billion in annual payroll, representing a significant portion of the U.S. economy.
- **Support for Other Industries:** A number of related industries and other economic sectors depend heavily on primary forest products. These include consumer goods marketing and distribution, shipping and warehousing, printing and print advertising, housing and construction, and furniture manufacture. Overall, $850 billion in U.S. economic activity depends on paper or packaging as an important part of daily operations.

Industry Challenges

The forest products industry is increasingly challenged by alternative materials and technologies in a truly global marketplace. Pressures on the industry include the growing use of electronic media in place of printed materials, aging mills, limited capital available for new investments, and few technology breakthroughs in the last decade.

As a result of recent economic pressures, the forest products industry in the United States has lost 360,000 jobs, more than a quarter of its workforce, since 2006. U.S. paper and paperboard production capacity edged down 0.8% to 96.3 million tons in 2008 (AF&PA 2009). Last year's decline was just slightly below the 1.0% long-term trend rate of contraction recorded from 2001 through 2007. Cumulatively, paper and paperboard capacity has declined 7.3% since its 2000 peak level, and is projected to continue to decline throughout 2010.

Need for a New Roadmap

A comprehensive technology roadmap for the forest products industry was published in 2006, and much of its content is still relevant. In order to provide the research community and their funding organizations with information on the industry's high priority technical challenges and research needs, the Agenda 2020 Technology Alliance developed the *2006 Forest Products Industry Technology Roadmap* in collaboration with industry volunteers and the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Industrial Technologies Program. The 2006 roadmap's successes included the following:

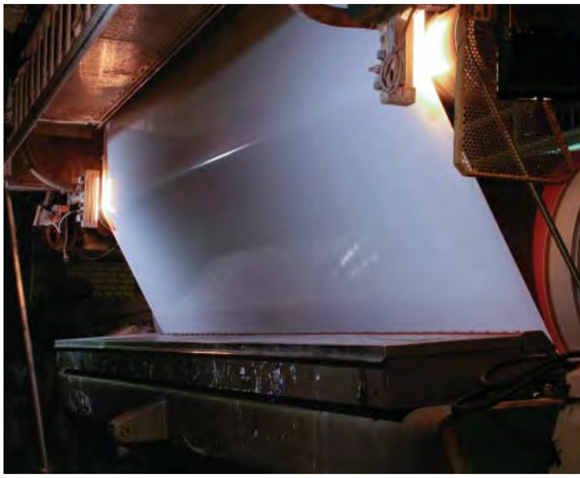
- 17 organizations, including companies, universities, and federal labs, partnered to establish the Value Prior to Pulping (VPP) consortium, with $2.7 million in total funds to develop integrated biorefinery processes for conversion of hemicelluloses to ethanol. The VPP program has made good progress on its objectives and is scheduled to end in 2010.
- A VPP partner, American Process Inc., opened a pilot plant in 2010 to fractionate wood in conjunction with pulping and convert cellulosic components to ethanol.
- An Agenda 2020 member company, Thermo-Chem Recovery International, opened a demonstration plant in 2009 for evaluation of thermochemical conversion of woody biomass to fuels.
- Multiple commercial-scale demonstration plants and fully operational sites for converting biomass to biofuels will soon be operational. Biorefinery processes integrated with pulp and paper mills are being built for commercial use at Flambeau River and NewPage in Wisconsin using thermochemical processes and at Old Town in Maine using hemicellulose extraction prior to pulping similar to VPP and subsequent conversion to alcohol.
- Forest productivity continued to improve, with new techniques developed in alignment with the 2006 roadmap. The Pine Genome Initiative achieved good progress since 2006.
- The industry established a formal partnership with the U.S. National Nanotechnology Initiative to promote funding for projects to increase product strength and provide water resistance, vapor barrier, opacity, fire retardancy, and new electronic features, and to develop new high-value nanomaterials from wood.
- Partnerships with federal agencies and labs were built and strengthened, including with the U.S. Forest Service and its Forest Products Laboratory, the U.S. Department of Energy's Biomass Program and Industrial Technology Program, the National Science Foundation, the U.S. Department of Agriculture, and the National Institute of Science and Technology. These partnerships helped the industry to keep these agencies abreast of its current priorities.

These successes highlight the technology roadmapping's transformative potential, and emphasize the importance of keeping the roadmap up to date.

Four years later, a new roadmap is necessary because of numerous opportunities to move the industry forward in ways that increase its benefits to society, while addressing increasingly urgent pressures the industry is facing, including the following trends:

- Societal concerns, such as climate change, water and energy availability, and sustainability are areas in which the industry has made excellent progress in recent years. However, additional progress will be needed in the next 5–10 years and is likely to require transformative approaches based on new technologies.
    - National policies on climate change are likely to force many industries to reduce emissions of greenhouse gases, causing manufacturing to decrease its fossil fuel consumption.
    - The world's population will continue to grow, from 6.5 billion people in 2009 to more than 9 billion in 2050, with most of the increase in developing countries. The population growth will increase demand for resources, including water, energy, and food. Many parts of the United States and the world will find fresh water in short supply, and the increasing demand for food from agricultural land will place pressure on forest lands.
    - The desire for energy independence in the United States and many other nations will increase interest in biofuels facilities integrated with pulp and paper mills.
    - Recovery and recycling of post-consumer waste papers will continue to increase in North America.
- Manufacturing issues, such as the considerably rising input costs of recent years, often with significant short-term fluctuations, will drive a demand for next-generation approaches.
    - Input costs for materials and energy used in paper manufacture increased significantly in 2008 versus 2007, with wood costs up 13% and starch costs up 19%, as examples.
    - The U.S. forest products industry consumed 11% of the energy used by all industries in 2002, whereas it represented about 6% of manufacturing's economic output.
- Financial pressures from the recent economic recession directly impacted the forest products industry globally, with large declines in demand for many of its products. While the industry is now recovering from the impacts of the severe recession, it is positioned to build on its strengths and embrace new technologies.
    - Sharp drops in housing starts and construction reduced sales of wood-based building products. "Green" building programs favor wood products as construction rebounds.
    - Steep drops in advertising during the recession and as a result of more electronic communication led to large cuts in demand for printing papers.
    - Lower overall economic activity resulted in reduced need for packaging. Customer demands for more sustainable packaging make products based on wood fiber more attractive.
- Market pressures from customer demands and alternative products (e.g., electronic media and plastics substitution) present additional challenges.
    - Corporate social responsibility and demand from customers of forest and paper products will call for products that are more sustainable than today's offerings. The industry continues to work hard to reduce use of fossil fuels and raw materials derived from fossil fuels, and to improve its overall carbon footprint.
    - Wood-based products have the "green" advantage over oil-based products such as plastics used for packaging because of the use of renewable wood as the primary material. Developing substitutes for oil-based chemicals and plastics is a promising opportunity for the forest products industry.

The *2010 Forest Products Industry Technology Roadmap*, was considered necessary to identify the most important and current priorities for technology development in light of the above societal, manufacturing and market trends. It takes into account the recent developments impacting forest products, and reframes and clarifies the industry's technology strategy to its key audiences: federal agencies, universities, and researchers. This new roadmap provides a framework for the technological innovation the industry needs to help it realize its potential as a provider of new "green" products made from sustainable forests and manufacturing, improve manufacturing performance efficiency, and develop new value streams from forest resources.



3. Technology Strategy for the Industry

The technology strategy is (1) to define priorities in research and development that would provide breakthrough solutions for the forest products industry to use in transforming its processes and products, and (2) to advance collaborative programs that address the industry technology priorities. Given the opportunities and pressures that ongoing social changes are placing upon it, the forest products industry must develop a strategic response for technology development. This strategy should outline a plan of action to achieve the ultimate goal at hand: to ensure the future competitiveness and prosperity of the entire industry so that it may continue to provide good jobs in diverse geographic areas and contribute to environmental health and economic strength while generating its valuable products sustainably from renewable resources.

In essence, the trends described in the previous chapter have raised the challenge of developing new breakthrough technologies from the company to the industry level. Meeting this challenge is beyond the means of companies acting individually. Rather, it is an undertaking that the entire industry should pursue. If the industry is to prosper in the current economic and technological landscape, owners and operators across the value chain must find the common ground and shared understanding that allows them to work together for the good of all.

Therefore, collaborative programs that involve multiple companies and research institutions and are supported financially by public funds are the foundation of the industry's technology strategy. In addition to the benefits to society that will be realized as a result of successful development and deployment of the breakthrough technologies envisioned in this roadmap, publicly-funded R&D generates a significant return on investment ranging from 20 percent to 67 percent according to the U.S. Department of Energy.[5]

The Strategic Issues

In December of 2008, leaders from the forest products industry, government, and universities participated in a Strategic Issues Workshop hosted by the Agenda 2020 Technology Alliance. They reached consensus on a short list of issues for which new breakthrough technologies are needed. In service of one of the major purposes of the roadmap—to promote ongoing collaboration with industry companies to address industry-wide concerns—this workshop was the first step of an industry-level response to developing a new technology roadmap.

The following six imperatives emerged from the December 2008 workshop as the priority issues:

1. Reduce substantially carbon emissions and energy consumption in mills and plants
2. Reduce fresh water intake in manufacturing at least 50 percent
3. Increase the supply of high-quality fiber and low-cost biomass
4. Increase the value from high-quality fiber and low-cost biomass
5. Enable the development of new products and product features
6. Improve recovery and recycling of waste wood and fiber products

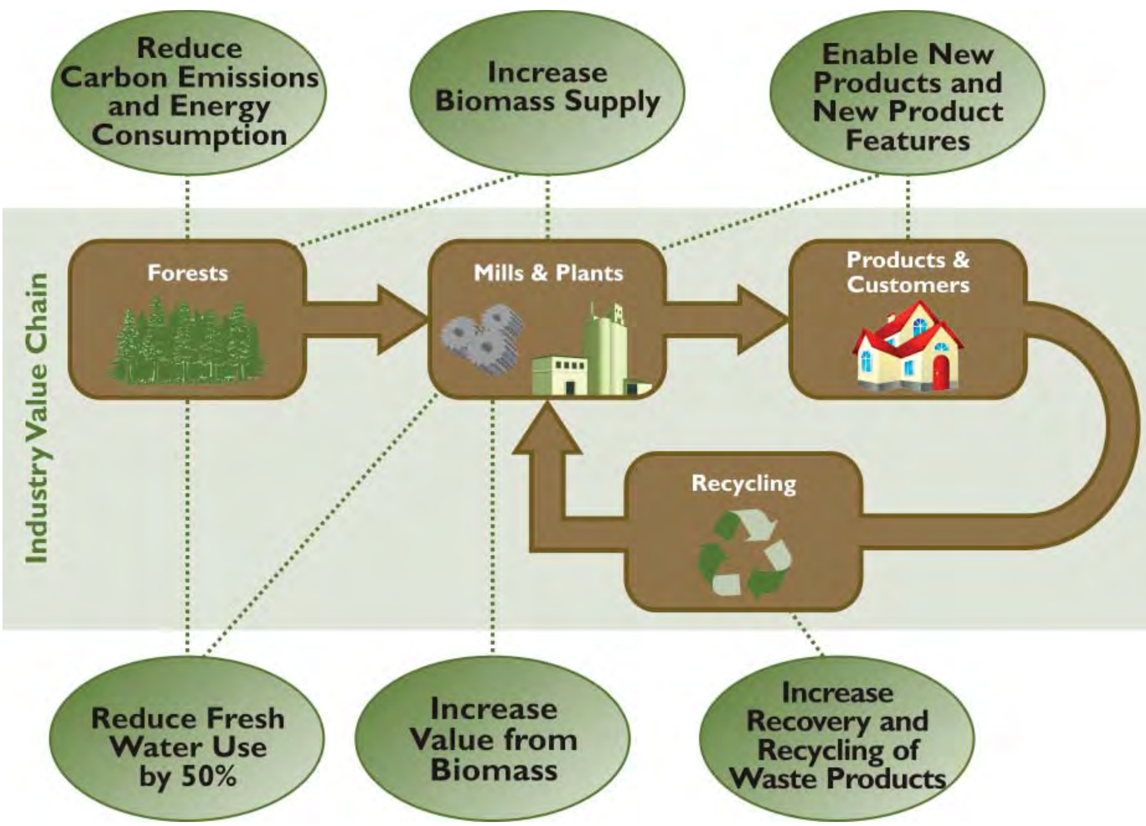
These issues are deemed "strategic" as opposed to merely "important" because they comprise an integrated set of priorities for the industry's future in response to the demands and constraints of its business environment. They serve as a structure for a planned approach to achieving the ultimate goal of a vital, prosperous future for this manufacturing sector. Addressing these issues will strengthen the industry's continuing contributions to society, national goals, the economy, and the environment.

Technology Strategy Framework

Figure 3.1 is a graphical characterization of the industry's revised 2010 technology strategy which provides the organizing framework for this roadmap. The graphic depicts a high-level view of both (1) the biomass-to-products conversion value chain process, and (2) the priority issues that must be addressed in order to enable that process to be more valuable to society and the industry. According to this visualization of strategy, the six issues fall at different stages along the forest products value chain—from procurement of resources and raw materials, to product manufacturing, to product consumption and waste recycle.

The figure provides a picture of how the strategic issues structure an integrated response to industry opportunities. The framework is designed to promote common understanding within the industry and at the same time provide a concise summary to industry outsiders, such as academic researchers, of the key areas of need for research support. It aims to both articulate the industry's collective priority concerns, and solicit research and development efforts toward addressing them.

Figure 3.1: Technology Strategy Framework (Six Strategic Issues overlaid on the Forest Products Value Chain)



4. A Call for Research and Development

The strategic issues facing the forest products industry require an array of technology innovations to be made and implemented by industry companies. However, private individual companies do not have adequate resources and in-house R&D capabilities to support the needed innovation on their own. This roadmap calls for the involvement of government, academia and researchers to work collaboratively with the industry in providing the needed technology solutions.

A strong, innovative, and collaborative R&D program focused on breakthrough technologies is needed. This is important for the industry to strengthen its competitiveness, reduce its energy and water intensity, improve its capital effectiveness, become an increasingly attractive place for the best and brightest people to work, and continue to provide the world with essential, innovative, and environmentally compatible products from renewable and reusable raw materials.

The R&D called for in this roadmap needs the participation of researchers from many disciplines and institutions. While the academic R&D community that has served the industry well in recent years is a critical part of the desired technology developments, researchers in other institutions and disciplines who have the knowledge to find solutions to the technology needs of the industry also are needed.

Bridging the Gap between Industry and Academia

The disconnect between the advancement of technical knowledge and the operational deployment of a new technology solution is often referred to as the technology transfer (TT) gap.[5] It stems from the difference in perspectives and focus between the R&D community and industry. Researchers focus on knowledge creation in accordance with the requirements and standards of scientific rigor and academic scholarship, and often have to stay within the confines of the scopes of the grants funding their research. Industrial managers, on the other hand, focus on value creation in accordance with the requirements and standards of demanding customers and a competitive marketplace

This roadmap calls for R&D to help the forest products industry address the strategic issues identified in the previous section. In order for this call to be effective it must bridge the TT gap and bring the two perspectives together. It must convey the issues and needs of the industry in terms that help the R&D community make a connection to their own research interests and efforts.

In April 2009, the Agenda 2020 Technology Alliance sponsored a workshop for this new roadmap. The specific purpose was to translate the six strategic issues, which represent an industry oriented focus, into R&D needs that are more closely aligned with a research perspective. This translation was done in two steps as illustrated in Figure 4.1.

Figure 4.1: Workshop Translation Steps

Figure 4.2: Line of Sight from Research to Impact

First, participants were asked to identify *technology objectives* for each of the six strategic issues. The technology objectives identify how new technology can help the industry address the strategic issue. The objectives set the criteria for the effective deployment of new R&D advancements or breakthroughs by specifying what a new technology solution arising from advancements in knowledge needs to do or accomplish for the industry.

As a second step, participants identified R&D needs for the top technology objectives. The R&D needs break the technology objectives down into more specific technical problems that could be directly addressed by research. The R&D needs comprise a research oriented translation of the strategic issues that researchers and funding agencies can use to identify specific research projects that contribute to the needs of the forest products industry.

Figure 4.2 reverses Figure 4.1 to show how this structure helps researchers maintain a *strategic line of sight* between their knowledge creation efforts and the strategic issues facing the forest product industry. By linking the outcomes of their research to specific R&D needs and tracking them through technology objectives to a strategic industry issue, researchers can determine how their work may make a difference for forest products companies and society. Equally important, this line of sight also provides researchers with the basis for constructing a compelling argument to funding sources as to why their work should be funded.

Pathway Maps for Priority R&D Needs

The R&D needs identified at the April workshop provide a basis for identifying R&D projects that may contribute to the success and prosperity of the forest products industry. To provide a further level of guidance to the R&D community, workshop participants developed *pathway maps* for some of the top priority R&D needs. Each pathway map is a detailed characterization of the stream of research activity required for a particular R&D need. This characterization includes a description of the current state of the technology and knowledge and the desired end-state in terms of the criteria for an effective technology solution. The characterization also identifies the key knowledge and technology advancements required to move from the current state to the desired end-state and barriers to achieving those advancements. Finally, the pathway map provides an indication of the potential impacts of an effective technology solution that meets the end-state specifications.

Figure 4.3 shows the template that is used to present these pathway maps. The pathway maps are designed to provide more specific information about the R&D needs that enables individual researchers to find ways to connect their research interests and efforts to the strategic issues of the forest products industry. The italicized text in Figure 4.3 describes how the information in each space may be useful to researchers.

Figure 4.3: Template for the Pathway Maps

PRIORITY R&D NEED

[Look here to find a more detailed description of the R&D need.]

Current State of Technology & Knowledge

[Look here to further understand the foundation on which new research efforts in this area must build. This is the starting place that sets the baseline for advancements and breakthroughs in this area.]

End-State Specs for Technology Solution

[Look here to further understand the kind of technology solutions effective research should ultimately lead to. This sets the target toward which research efforts should be directed and the criteria against which they may be evaluated.]

Key Knowledge and/or Technology Advancements Required

[Look here to further understand the milestones or breakthroughs that are required to move from the current state to the end-state. This should help researchers find specific points of entry for connecting their own research with issues and challenges facing the industry. Each item in this box may also identify an avenue or stream of research activity that provides the basis for a new research project.]

Potential Impacts

[Look here to identify impacts upon society and/or the industry that could be used to justify funding for research projects in this area.]

Barriers

[Look here to learn about anticipated barriers to achieving an effective technology solution that meets the end-state specifications. These barriers should be considered throughout the planning and design of research projects, and may also suggest research avenues.]

Other Guidance

[Look here for additional information that may be helpful.]

Structure for Chapters 5–10

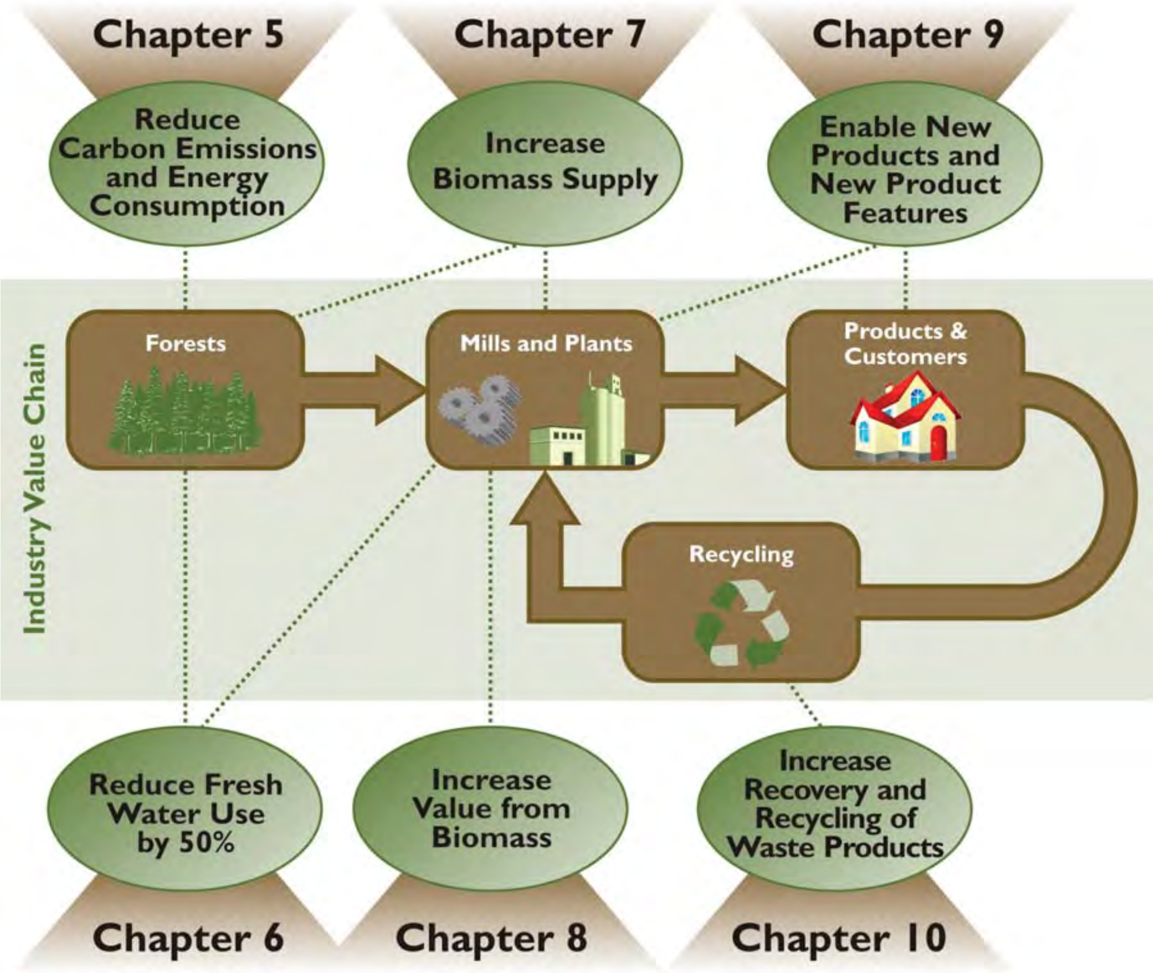
The following six chapters present the technology objectives, R&D needs, and pathway maps for each of the six strategic issues respectively. Each chapter begins with an overall description of the strategic issue and why it is important at this point in time. Next is a brief summary of the technology objectives, including an overview of how the achievement of the objectives would serve the industry and a description of each objective presented in table form. The third section presents a table of the specific R&D needs that were identified for each technology objective, with the top priority needs for which a pathway map was developed indicated in bold type. The final pages of each chapter contain the pathway maps for selected R&D needs.

Issue Chapter Outline

1. Description of the Strategic Issue
2. Summary of Technology Objectives for the Strategic Issue
3. Table of R&D Needs for Each Technology Objective
4. Pathway Maps for High Priority R&D Needs

Figure 4.4 shows the correspondence between the six chapters and the six strategic issues, along with a reduced picture of the strategic framework from Chapter 3. This figure allows researchers and funding agencies to identify areas of interest along the wood-to-products conversion process, providing another way for the R&D community to find points of entry for their research projects and interests.

Figure 4.4: Correspondence between Chapters 5–10 and the Strategic Issues



5. Reduce Carbon Emissions and Energy Consumption

Reducing greenhouse gas (GHG) emissions and energy consumption in manufacturing are key priorities for the forest products industry. Pressure from customers and stakeholders to further reduce the industry's carbon footprint, uncertainty surrounding the impacts of pending federal legislation on climate change, and recent years' large fluctuations in energy costs justify a strategic focus on reducing carbon emissions and energy consumption.

Carbon Emissions

The industry has worked diligently to reduce carbon emissions using available technologies. From 2000 to 2006, member companies of the American Forest & Paper Association (AF&PA) decreased direct and indirect greenhouse gas emissions intensity from 0.738 to 0.637 tons of CO_2 equivalents per ton of production—a decrease of 13.6 percent.[6] While this is a noteworthy accomplishment for the U.S. industry, especially in a period of low spending on new capital equipment, much more progress will be needed in coming years.

Energy Consumption

Energy sources typically constitute the third largest cost component for the forest products industry. Transforming whole trees into lumber and wood products or into pulp and paper products is highly energy-intensive. In 2006, the U.S. forest products industry consumed 2.8 quadrillion Btu (quad), accounting for 13 percent of total manufacturing energy demand. 2.3 quads were used in pulp and paper manufacture, and 0.5 quads were used for producing wood products.[7] Overall, the industry is the third most energy intensive industry after petroleum and chemicals.[8] Globally, the pulp and paper industry is the fourth largest industrial sector in terms of energy use, according to the International Energy Agency (IEA), consuming six percent of total global industrial energy demand.[3]

Fossil fuels currently provide much of this energy, and the industry is successfully decreasing its fossil fuel consumption. In 2002, fossil fuel use represented 36 percent of the U.S. industry's energy input, while carbon-neutral woody biomass produced 54 percent[9] and purchased electricity provided the balance. Since 2002, energy input from renewable sources has grown to 64 percent, and fossil fuel usage has declined.[10] To continue this trend, almost all fossil fuel consumption in integrated pulp and paper mills can be eliminated through the development of new process technologies and the adoption of best available technologies and by using renewable fuels from biorefineries integrated with pulp mills. Reducing fossil fuel consumption is a timely and high-priority issue that supports the national goals of decreasing carbon dioxide emissions and lowering dependence on foreign energy sources.

Additional significant reductions in the industry's overall energy consumption from all fuel sources are possible. A 2006 report sponsored by the U.S. Department of Energy (DOE) concluded that the U.S. pulp and paper industry could reduce energy consumption from 2.36 quads to 1.75 quads, a 25 percent reduction from 2002 levels, by broadly implementing the best available technologies. Further reduction to 1.45 quads was cited as achievable through the development of new energy-reducing technologies, providing an overall reduction possibility of nearly 40 percent. Currently, widespread implementation of the best available technologies cited in the DOE study is not likely due to the low economic returns anticipated from the capital investments that would be required. Despite this obstacle, reducing energy consumption (as the DOE has concluded to be possible) and efforts towards this end will be essential for ensuring the industry's long-term economic viability and for achieving the industry's potential to contribute to societal goals of reducing greenhouse gas emissions and dependence on foreign oil.

Improving fuel conversion efficiencies in operations and producing more by-product electric power through cogeneration are priorities for the industry. The energy intensity (energy input per ton of product) has been improving in recent years, and is expected to continue to improve as new energy-saving technologies are implemented commercially. Many manufacturing sites in the industry use combined heat and power (CHP) cogeneration systems to yield electric power concurrently with steam generation for process use. Many locations produce more electricity than is needed on site, and sell the excess to local electric utilities. As energy intensity is improved and new technologies are employed, the generation of more "green" by-product power will increase significantly.

Reducing Both

Carbon dioxide emissions and energy consumption are closely related—reductions in one generally lead to reductions in the other. Eliminating fossil fuel consumption and making improvements that reduce the energy intensity in manufacturing are good ways to further reduce greenhouse gas emissions.

Summary

Reductions in energy intensity and in the emission of CO_2 are environmentally responsible, benefit the industry's public image, and will serve to ease compliance with potential regulatory requirements. Further benefits from significantly reducing carbon emissions and energy consumption will include lowered input costs for energy and fuels, improved operational efficiency, and increased customer satisfaction that the industry is committed to sustainability. Public demands for sustainable manufacturing and the industry's energy intensity drive this issue's timeliness and significance.

Technology Objectives

Table 5.1 below lists the technology objectives for reducing energy consumption and CO_2 emissions. These objectives specify the impacts that the development and deployment of new technology solutions must achieve to address this strategic issue. The technology objectives call for the development of new equipment, materials, and techniques to help manufacturing operations increase efficiency in the on-site generation and use of energy. Desired improvements include both enhancements that incrementally decrease the energy consumption of existing operational processes and breakthrough technology solutions to enable new operational processes or techniques for significant increases in energy efficiency. As energy use is one of the chief contributors to carbon emissions, greater efficiency will lead to fewer carbon emissions. Innovative technologies that allow renewable energy sources to replace fossil fuels in plant operations and to increase generation of "green" electric power, will

Table 5.1: Technology Objectives for Energy Use and Carbon Emissions

Generate Power and Energy More Efficiently with 25% Lower GHG Emissions	Develop and deploy new equipment, materials, techniques, and energy sources to improve the efficiency of on-site power generation and to reduce emissions of greenhouse gases by at least 25%
Reduce Energy Intensity in Manufacturing by 25%	Develop and deploy new technologies and techniques that will significantly reduce energy requirements and improve operational efficiency in manufacturing such that energy intensity is improved 25% or more
Eliminate Use of Fossil Fuels	Identify, develop, and deploy sustainable technologies that will replace fossil fuels as an energy source to significantly reduce CO_2 emissions and dependence on foreign energy
Reduce CO_2 Emissions with Novel Mill-Based Capture Techniques	Develop and deploy technologies to capture existing CO_2 emissions synergistically in mill processes

remain necessary and desirable. Achieving these technology goals will lead to reductions in energy use and carbon emissions and ultimately result in environmental benefits, better financial sustainability, and an improved public image for the forest products industry.

R&D Needs

Table 5.2 shows the R&D needs for each technology objective. These R&D priorities represent the areas that have the greatest potential for producing breakthroughs and innovations that, when effectively demonstrated and

Table 5.2: Summary of Top Priority R&D Needs

Generate Power and Energy More Efficiently with 25% Lower GHG Emissions	Develop new materials to enable high temperature operation of steam generating boilers (especially recovery boilers) Improve energy efficiency of recovery boilers Significantly improve fluidized-bed boilers to achieve high steam values and power values	Develop and deploy practical, cost-effective black liquor gasification Develop advanced gasification combined-cycle technologies for black liquor and solid forest-based biomass Generate more by-product electric power
Reduce Energy Intensity in Manufacturing by 25%	**Deliver a drier sheet (55–65% moisture) to the paper machine dryer section** **Reduce energy for black liquor concentration by 50%—including reducing pulp washing water usage** Increase pulping consistency to 30% from current levels of 15%–16%) Better recover and utilize waste heat Develop a next generation refiner to achieve more efficient mechanical pulping Reduce energy intensity of refining and fiber preparation for papermaking Use steam more efficiently in manufacturing processes Use steam more efficiently in combined heat & power (CHP) systems yielding more cogeneration of electric power	Improve lime kiln efficiency Develop alternative way to change sulfate to sulfide Reduce energy use in chemical pulping—including pumping pulp and chemicals Dry wood more efficiently Reduce process water needs to that which enters with wood (Overlaps Water) Reduce fiber in products to enable the product's intended function and require lower energy input (Overlaps Product Features) Recover and reuse waste heat (Overlaps Water) Optimize the integration of new processes such as biorefineries into pulp and paper mills
Eliminate Use of Fossil Fuels	**Use biomass to replace fossil energy—Renewable source for non-steam thermal demand** Eliminate fossil fuel use in lime kiln Better utilize lignin as an energy source Find waste streams that can be sources of energy	Use internally generated solid waste streams as fuel Develop waste water treatment as an energy source—recover VOCs
Reduce CO_2 Emissions with Novel Mill-Based Capture Techniques	Recover CO_2 from lime kiln stack and use it synergistically in mill	Grow algae or other biomass as fuel with CO_2 feed

deployed, will meet the technology objective. These priorities, therefore, are the areas where the R&D community can make the biggest contribution to the industry. The needs selected for the pathway maps because of their importance are in bold type.

Pathway Maps

The following pages present the pathway maps for the R&D needs indicated with bold type in Table 5.2. Chapter 4 contains a detailed description of the content of these pathways maps. Researchers may wish to refer to Figure 4.4 for specific guidance on how to use the information presented in each section of the pathway map.

PRIORITY R&D NEED: DELIVER A DRIER SHEET TO THE DRYER SECTION

Papermaking process that reduces energy consumed in sheet drying by increasing solids to the dryer by 10–15 points

Current State of Technology & Knowledge

- Current theoretical limit is around 80% solids
- Fiber impacts are well understood in terms of drainage effects (WRV) given current state and understanding of fiber treatment
- 65% solids can be achieved in the lab. Current press configuration and felt design limit achievement of this level on machine because of re-wet
- Increased pressing decreases bulk
- Dwell time and nip impulse govern water removal
- Extended nip pressing represents the best available technology
- Given current energy consumption, there is a large potential for significant energy savings

End-State Specs for Technology Solution

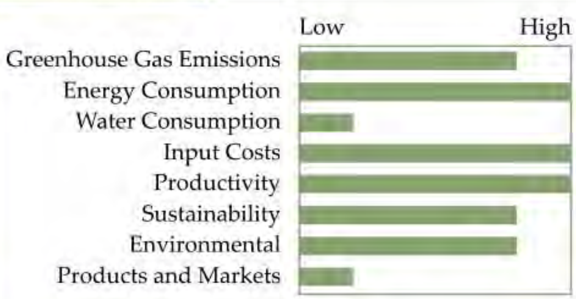
- 65% solids entering dryer section
- No increase in sheet density (lower would be desirable)
- No loss in sheet strength, smoothness, or other sheet properties
- No impact on uptime or machine runnability

Key Knowledge and/or Technology Advancements Required

Average 15 point increase in solids (~30%)

- Fabric that removes more water under the same load (mid-term)
- Stronger web that is not more difficult to press or dry (breaks the strength, freeness, water retention paradigm); fiber releases water more easily in pressing and drying (long-term)
- Paper web that presses to a drier level without loss of caliper or paper resilience (long-term)
- Fabric that does not rewet after pressing (mid-term)
- Functional sheet with higher filler content (mid-term)
- Optimization of press impulse, fabric, and roll combination—press redesign (long-term)
- Non-destructive hot pressing (unknown)
- Nanomaterials that increase wet web strength, aid dewatering, and avoid press felt re-wet (unknown)
- Forming the web with no or low water content (unknown)
- Simulation/modeling of pressing process (unknown)

Potential Impacts



Barriers

- Requires new fabric materials
- Fibers that bond well don't dewater well
- Cost effective better bonding fillers
- Need a consortium
- Requires active involvement by major equipment supplier and long-term commitment to success
- Needs substantial R&D funding from government sources for early-stage concept development

Other Guidance

This is high-cost, high-risk, high-reward R&D that needs collaboration by industry companies, equipment and machine clothing suppliers, and research institutions, along with substantial funding from government sources, particularly for early-stage research to define and prove conceptual approaches.

PRIORITY R&D NEED — REDUCE ENERGY FOR BLACK LIQUOR CONCENTRATION BY 50%

Reduce energy required to wash pulp and prepare black liquor for firing into the recovery boiler by 50%

Current State of Technology & Knowledge

- Digester solids 21%
- Typical black liquor off washer 14–16%
- Use water to wash organics and inorganics out of fiber
- 7-stage evaporators to get to 50% black liquor solids (BLS)
- 2-stage evaporators (where concentrators follow the evaporators) to get to 75–80% BLS for recovery boiler
- ~1/3 inorganics
- ~2/3 organics
- Good data base for black liquor properties/ components

Need

- Osmotic pressure of black liquor

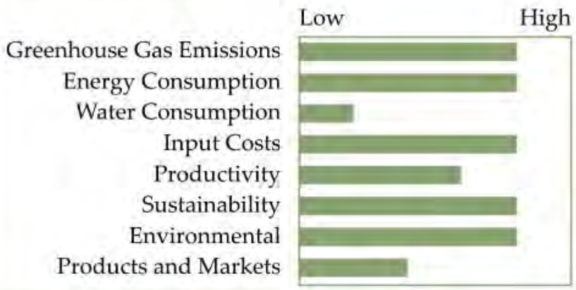
End-State Specs for Technology Solution

- 80% solids for recovery boiler
- Need clean pulp off washer with current physical properties of fiber
- Reduce energy use by 50% in brown stock washing, evaporation, and concentration
- Lower capital costs than today's equipment for washing and evaporation

Key Knowledge and/or Technology Advancements Required

- Water removal by membrane technology to replace early stages of multiple-effect evaporator (≈25–30% solids) (5–10 years)
  - Development of membrane with acceptable performance characteristics (separation efficiency, cost, reliability, maintenance, etc.)
  - Understand impact on evaporator steam economy and overall plant energy costs
- Washing process enhancement—get closer to theoretical (5–10 years)
  - How to use less water
  - Different wash medium/fluid
- New concepts for separating water from black liquor solids
- Materials that withstand the process conditions in new technologies

Potential Impacts



Barriers

- Durability of membranes
- Fouling, economics
- Diffusion as well as displacement mechanisms in pulp washing
- Mechanical
- Chemistry
- New concepts defined and demonstrated
- Funding for developing new approaches
- Test sites for pilot trials

Other Guidance

Overall needs—overall impact on mill energy and mass balance of approaches that reduce demand for medium-pressure steam

Priority R&D Need: Use Biomass to Replace Fossil Energy

The forest products industry is a significant user of energy. While a large portion of the energy comes from bio-renewable sources, approximately 25% of total energy is still fossil fuel based. Targeting those specific unit processes that use large amounts of fossil fuel provide a high impact opportunity for fossil fuel reduction by replacing with renewable sources of energy. Target unit operations are lime kilns, gas-fired dryers, power boilers, and purchased power.

Current State of Technology & Knowledge

Potential Fuel Source	Technology Issues
1. Combustion of powered wood sander dust	Material handling & non-process elements (NPE)
2. Torrefied biomass	Material sizing & NPE
3. Pyrolysis oil	Viscosity corrosion
4. Syngas from gasification	Heating value of fuel
5. Precipitated lignin	Cost, material handling, explosive, sulfur
6. Glycerin from biodiesel	High octane, heating value

End-State Specs for Technology Solution

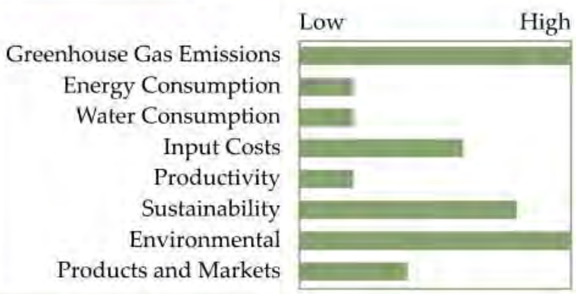
Note, these end-state specs apply specifically to the lime kiln.

- Must still generate product lime
  - @>90% availability
  - <2–5% residual carbonate
  - <5% non-process elements
- Fuel characteristics (gas liquid or solid)
  - Heating value > ISO 20/50°F if gaseous
  - Flame temperature range 2500–3000°F
  - Low water content
  - Low contaminants
    - Non-process elements
    - Ash
    - Heavy metals
    - Sulfur
  - Maintain kiln temp of 500–1600°F
- Cost must be less than fossil fuel alternative and carbon penalty

Key Knowledge and/or Technology Advancements Required

- Develop non-proprietary model for lime kiln performance including economics, lime conversion, productivity and non-process element cycling (near-term)
- Compare and prioritize alternative fuel choices based on performance, availability, and operating and conversion costs (near-term)
- Engage lime kiln technology experts to better understand performance criteria (near-term)
- Develop solutions to materials handling and other issues (mid-term)
- Develop source of priority alternative fuels (e.g.,precipitated lignin) (mid-term)

Potential Impacts



Barriers

- Lack of long-term commitment to alternative fuels
- Funding for pilot trials
- Test sites for pilot trials
- Information sharing with cement industry
- Funding for longer term development needs
- Capital funds for installing new burner technology

Other Guidance

Considerable work is currently underway on this topic. The current state of knowledge will change rapidly over the next 2–5 years. Consider what is known before initiating new R&D.

6. Reduce Fresh Water Use by 50%

Water is essential to the manufacture of paper and wood products, yet its future availability is in question due to societal concerns about water shortages in many areas, the need to provide fresh water for a growing population, and customer desires for sustainability. Despite significant industry progress in improving the quality of the water it discharges and reducing the amount of water it uses, water quality in some areas is a genuine concern, as is its availability in the quantities needed by industry. Consequently, reducing fresh water use in manufacturing by 50 percent or more is a strategic priority for the forest products industry.

Water-Intensive Production

Currently, the U.S. forest products industry takes in over 1.541 trillion gallons of water per year, and returns 88 percent to waterways. Approximately 1.464 trillion gallons enter manufacturing processes from surface water and groundwater sources, and 77 billion gallons enter as water already contained in wood, recovered paper, and purchased non-fiber raw materials. The pulp and paper products industry segment takes in most of this water; since wood products facilities use less than 1 percent of the total. Approximately 88 percent of this water is treated and returned directly to surface waters, and the rest is either converted to water vapor and emitted (11 percent), or is imparted to products or solid residuals (1 percent). Overall, the intake of sufficient fresh water is essential to the industry's value chain and its ability to produce pulp, paper, and paperboard goods.

Water availability and quality issues and social concerns surrounding water use will only increase in priority for the industry over the coming years. A recent report[11] by the National Council for Air and Stream Improvement (NCASI) notes, "[t]he forest products industry's manufacturing operations are among the largest industrial water users and thus figure prominently in local and regional discussions concerning water resource decisions." As the growing population places further demands on these resources, the industry's water-intensive manufacturing may encounter increasingly critical scrutiny.

> *A handful of companies have started tracking…"water footprints" as a growing threat of fresh water shortages looms. … The drive, modeled partly on carbon footprinting, a widely used measurement of carbon-dioxide emissions, comes as groundwater reserves are being depleted and polluted at unsustainable rates in many regions. Climate change has caused glaciers to shrink, eroding vital sources of fresh water. And growing global demand for food and energy is placing even more pressure on diminishing supplies. Two-thirds of the world's population is projected to face water scarcity by 2025, according to the United Nations. In the U.S., water managers in 36 states anticipate shortages by 2013, a General Accounting Office report shows.*
>
> —Alter, Alexandra. "Yet Another 'Footprint' to Worry About: Water." Wall Street Journal, February 17, 2009.

Reductions in water usage also will yield meaningful benefits in energy savings, since requirements for pumping and filtering will be lowered. Additional energy savings will be seen in lower thermal losses in the treated water returned to the waterway.

Reduction Goal

Considerable progress already has been achieved in reducing the water required for manufacturing forest products. Since the mid-1970s, pulp and paper mills have greatly improved their water reuse and conservation efforts, leading to a 50 percent reduction in the amount of water used for raw material processing. However, additional reductions are needed to address concerns about water availability and consumer desires for sustainably developed products. Industry technology leaders have set a goal of reducing current intake by 50 percent. Meeting this goal will necessitate new technologies for separation processes, contaminant removal, low-grade heat recovery, and waste water treatment. Attaining it will free water resources for other urgent needs, and strengthen the industry's position as a leader in responsible, sustainable use of natural resources.

Summary

Societal concerns over water availability and environmental sustainability—which will only grow with time—drive the industry to focus strategically on further reducing the billions of gallons of water it currently takes as an essential input for paper, pulp, and paperboard manufacturing processes. Reducing water use by 50 percent or more is a strategic priority driven by limited resource availability and the need to address public concern over responsible consumption in the face of those limitations. If the issue of reducing water intake is not addressed, the industry will likely encounter increasing societal and financial pressure as fresh water becomes increasingly scarce.

Technology Objectives

Table 6.1 below lists the technology objectives for reducing fresh water use by 50 percent or more. The technology objectives for this issue call for R&D advancements that lead to new technologies and processes for contaminant removal, separation, heat recovery, and waste water treatment. The industry needs practical technology and process innovations that can reduce the amount of water required in pulping and papermaking by 50 percent or more. New technology solutions must allow for water that is used to be treated and reused, removing contaminants and recovering large amounts of heat energy. Ultimately, technology innovations will need to enable the development of closed-loop water systems, allowing for all water to be recovered, treated, and reused thus eliminating the need for the entry of new water into the system. Attaining these objectives will provide for less water-intensive manufacturing processes and reduced or eliminated effluent waste.

Table 6.1: Technology Objectives for Reducing Fresh Water Use

Reduce Fresh Water Used in Pulping and Papermaking by 50%	Develop and deploy new technologies, processes, and models to significantly reduce water consumption in pulping and papermaking
Develop Technologies to Treat and Reuse Effluent in Plants	Develop processes to remove contaminants and recover heat from waste water to enable reuse within the plant
Develop Closed-Loop Water Systems	Develop and evaluate technologies and processes which enable the 100 percent recovery, treatment, and reuse of water

R&D Needs

Table 6.2 shows the R&D needs for each technology objective. These priorities represent the areas that have the greatest potential for producing breakthroughs and innovations that, when effectively demonstrated and deployed, will meet the technology objective. These priorities, therefore, are the areas where the R&D community can make the biggest contribution to the industry. The needs selected for the pathway maps because of their importance are in bold type.

Pathway Maps

The following pages present the pathway maps for the R&D needs indicated with bold type in Table 6.2. Chapter 4 contains a detailed description of the content of these pathway maps. Researchers may wish to refer to Figure 4.4 for specific guidance on how to use the information presented in each section of the pathway map.

Table 6.2: Summary of Top Priority R&D Needs

Reduce Fresh Water Used in Pulping and Papermaking by 50%	**Remove non-process elements (NPEs) from chips prior to pulping** (e.g., hemicellulose extraction, segregation in bleach plant, water treatment) **Reduce fresh water used in pulp washing, including alternative washing processes and pressurized washing** (Overlap with need in Carbon and Energy) Develop trees engineered to avoid calcium and barium	Build on existing work on chip leaching and hemicellulose extraction to remove metal ions Develop a better understanding of how metals become fixed in wood Improve process modeling tools for engineering studies, including chemical equilibrium for ion tracking and lifecycle analysis on chemical inputs
Develop Technologies to Treat and Reuse Process Water in Plants	**Separate dilute contaminants (both organic and inorganic) from reusable water streams** Remove ions from filtrate to enable reuse as fresh water	Avoid scaling issues associated with process water Develop heat recovery systems to better recover waste heat from water
Develop Closed-Loop Water Systems	Develop testing protocol for in-plant evaluation of process water streams and to evaluate new technologies Separate contaminants and useful components from water-based process streams Survey mills on waste-water management to determine feasibility of totally closing mill water systems	Apply biological treatments in waste water streams earlier than at central waste-treatment plant at end of mill Understand and learn from past efforts at achieving 100% closed water systems in paper mills

Priority R&D Need: Removal of Non-Process Elements (NPEs) from the Wood Chips Prior to Pulping

Removal of NPEs will enable the bleach plant filtrate to be recirculated in the pulp mill thus reducing overall water consumption.

Current State of Technology & Knowledge

- Limitation:
  - Additional process unit is needed to extract NPEs
  - Capital required
  - Chip moisture goes up
- Gap:
  - Understanding extent of metal removal
  - Effect on pulping and bleaching efficiency
  - Separation of metal ions from the leachate
  - Feeding the extracted chips to the chip column movement in continuous digester
  - Effect on pulp quality—strength, etc.
  - Value Prior to Pulping program currently in progress will provide some answers about NPE extraction from wood and pulp quality impacts

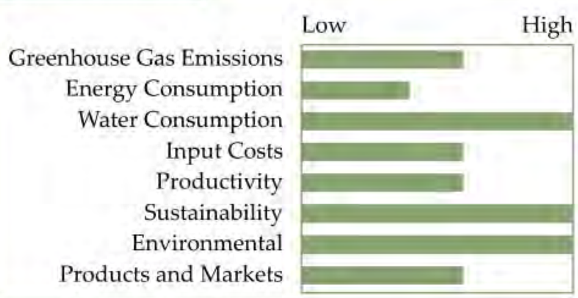
End-State Specs for Technology Solution

- Removal of 95% of NPEs from wood chips
- Removal of NPEs from the leachate so the water can be recycled
- A thorough understanding of extracted chips behavior in the continuous digester through the involvement of a digester manufacturer
- Pulp quality is not adversely affected
- Same pulp yield

Key Knowledge and/or Technology Advancements Required

- Optimize the leaching to remove maximum amount of NPEs (near-term, 1–2 years)
- Simulation of heat and water balance for the leaching stage (near-term, 1–2 years)
- Lab and pilot evaluation of separation of NPEs from the leachate (near- to mid-term, 1–2 years)
- Study the chip column/packing density in the digester (near, 1–3 years)
- Investigate the pulping and bleaching characteristics of extracted chips
- Simulation of recirculation of bleach plant filtrate
- A full-scale mill trial (mid-term, 2–4 years)
- Implementation of extraction vessel (near- to mid-term, 3–5 years)
- How to combine NPE extraction with other process steps to achieve simpler overall operation

Potential Impacts



Barriers

- R&D funding
- Low pulp quality
- NPE removal may be secondary if combined with other operation such as hemicellulose extraction
- Equipment and process design
- Sites for commercial-scale demonstration of new approaches

Other Guidance

Could be a synergy with Value Prior to Pulping program involving hemicellulose extraction.

Priority R&D Need: Reduce Fresh Water Used in Pulp Washing

Fresh water is currently used in selected bleach plant washers and often as makeup in recycled water evaporator condensers and in some brown stock washing systems. Improved washing technologies would allow reduced requirements for fresh water in recovering soluble material from pulp suspensions.

Current State of Technology & Knowledge

- Technology Development in order of increasing efficiency of fresh water
  - Blow tank washing
  - Screen press washing
  - Rotary vacuum filters—atmospheric
  - Atmospheric diffusion washing
  - Slightly pressurized rotary filters
  - Slightly pressurized rotary diffusion washers
  - Slightly pressurized table (Fourdrinier-type washer)
  - Pressurized diffusion washers—low temperature
  - Roll type press washers
  - High temperature, high pressure in digester diffusion/displacement washing
- Limitations & Gaps
  - Actual understanding of transfer process at work
  - How to remove spent pulp cooking and bleaching chemicals, cost effectively without using water
  - Development of technology to facilitate rollover/solubilization of contaminants from the pulp fibers

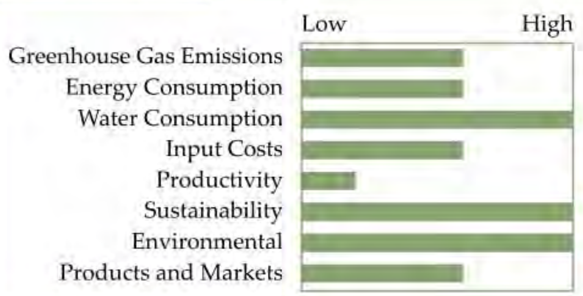
End-State Specs for Technology Solution

- Improve the efficiency of current technology to remove contaminants
  - Pressure/temperature/alternative technology [new equipment design]
- Reduce the need for fresh water in bleach plant washers
  - Remove metal contaminants up-stream (hemicellulose extraction /pulp leaching) [separation technology]
- Change the requirement for washing
  - Recycle more effectively > improved filtration/ screening > better water management [global mill process review—close up water circuits]
- New washing process approaches
  - Nano-technology—biomimetic—ionic liquid separation
- Revisit bleaching processes that do not use any form of chlorine
- Performance criteria
  - Brown stock washing—maintain lower sodium/ COD in washed pulp
  - Bleach plant washing—maintain pulp quantities with 50% reduction in use of fresh water

Key Knowledge and/or Technology Advancements Required

- Better understanding of transfer processes at work in pulp washers (near- to mid-term)
- Development of technologies to facilitate removal/ solubilization of contaminants from fibers (mid- to long-term)
- How to remove spent pulp cooking and bleaching chemicals cost effectively without using water (long-term)

Potential Impacts



Barriers

- R&D funds; "current" knowledge
- R&D funds; poor understanding of potential benefits, both economic and operational
- R&D funds; high development costs; perceived low economic benefits
- Test sites for pilot trials
- Collaboration of equipment suppliers, industry companies, and researchers in open innovation market

Other Guidance

New pulp washing concepts are desired, with focus on bleach line washers rather than brown stock washers. Pulp quality must not be affected.

Priority R&D Need: Separate Reusable Water from Dilute Contaminants, Both Organic and Inorganic, and from Undesired Ions

Remove ionic solutes and contaminants present in low concentrations from process water streams sufficiently to enable reuse of the water in process operations

Current State of Technology & Knowledge

- Currently we do not have high volume membrane or absorptive technologies that can help the separation processes
- Transition metals separation is a challenge
- The filtrate has colloidal components that may need pre-treatment separation process before we use membrane/absorptive technologies
- Fast acting systems in biological, electrical coagulation, chemical coagulation and enzymatic processes are a gap (footprint issue)
- Knowledge—are there existing water treatment technologies in other industries that we can use for our systems?
- Disposition of concentrated streams after separation is an issue (contaminant disposal and/or reuse)

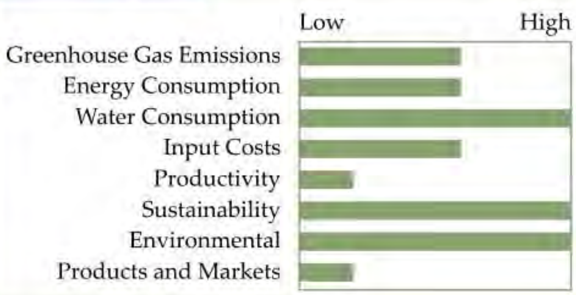
End-State Specs for Technology Solution

- Definition of reusable water
  - For substitution of fresh water
  - For substitution as shower water for brown stock washer
  - For substitution as shower water for bleach plant
- Definition for membrane size
  - Volumes of 5–30 million gallons per day capability
- Definition on concentrations of contaminant categories (alkaline earth, transition metals, anions)—incoming and percentage removal, and allowable concentrations for intended use
- Estimate of total installed cost for processing per million gallons per day and evaluation on operating cost
- Cost and effectiveness benchmarking in relation to desalination and other approaches

Key Knowledge and/or Technology Advancements Required

- Membrane technologies (3–10 years)
- Process modeling, including trace materials (2–3 years)
- Transition metal separation processes (3–10 years)
- Fast acting systems for separation technologies (pre-treatment) (3–10 years)
- Full range of possibilities on separation technologies (less than one year)
- Access to information and technologies in other industries
- Funding for developing and demonstrating new separation concepts

Potential Impacts



Barriers

- Market this need to membrane technology community
- Potential need to pilot operation at mill sites
- Capabilities and capacities
- Need industry consortium

Other Guidance

Fresh water intake is high in pulp and paper manufacture, and societal pressures to reduce intake will build and will encourage the industry to implement technologies to further reduce water intake. Reusing more water within mill systems helps this objective. Technologies such as those used in desalination and chemical processes should be investigated for applicability.

7. Increase Biomass Supply

Continuous and ample supply of trees with sufficient wood quality for the intended use—whether in wood products, pulp and paper, fuel intake, or biorefinery feedstock—is essential to the forest products industry. Trees are a renewable, broadly beneficial resource demanding responsible stewardship. The industry has strongly embraced sustainable forest management practices. Alternative uses for wood beyond the traditional value streams, and recent policies and regulations that affect demand for wood, are expected to increase competition for this vital raw material. Especially given the multi-year time delay between planting and harvesting, a strategic focus on increasing the supply of woody biomass is both timely and well-justified.

Renewable Energy Rules Impact Wood Availability

Thirty-five states already have renewable electricity standards or goals, and pending legislation in the U.S. Congress would impose a national Renewable Electricity Standard (RES). The impact of anticipated compliance with a potential federal RES, as well as the existing Renewable Fuel Standard (RFS), will likely be greatest on southern and northeastern states. In a study focused on southern states, Abt and coworkers note the concerns about availability and cost as they conclude that "even under optimistic wood supply scenarios, timber harvesting residuals alone will be unable to meet bioenergy demands from policy-based renewable portfolio standards. The unmet demand could be supplied by harvesting standing timber (roundwood), which will increase timber prices, standing timber removals, and forest landowner incomes, as well as alter the structure of the forest resource. In addition, expected lack of price responsiveness by the new policy-driven wood-users would reduce supply of roundwood for the current more responsive pulpwood users."

—Abt, Robert C., Karen L. Abt, Frederick W. Cubbage, and Jesse D. Henderson. 2009. Effect of policy-based bioenergy demand on southern timber markets: a case study in North Carolina. Manuscript prepared for submission to Biomass and Bioenergy. In review.

With the anticipated future pressures on land use globally and increasing demands for wood from multiple end uses, high growth rates will be needed in some locations and regions to satisfy wood demands. Growing more wood on less land is a likely scenario in some areas. The regional focus is important because most wood travels less than 100 miles to its destination due to the energy and labor costs of transporting woody biomass. With high rates of biomass growth, concerns about water and nutrients need to be addressed to avoid undesired coincidental impacts.

Value of Forests

Trees, the base feedstock for forest products manufacture, are an abundant, sustainable, renewable, and valuable national resource, which the industry works to responsibly maintain. Trees sequester carbon, help mitigate climate change, and provide renewable raw material for wood and paper products and biomass-derived fuels, power, and chemicals. Forests also provide wildlife habitat and filter air and water.[12] The vast majority (91%) of wood harvested in the U.S. derives from privately-owned forests, which demonstrates the forest products industry's role and stake in maintaining large swaths of forest on private land.

Accordingly, increasing the supply of wood—for high-quality, value-added products as well as low-cost biomass for energy—must be done sustainably. Genetically improved trees, purpose-grown biomass, distributed harvesting operations, and advanced forest management practices will help to ensure an ample and sustainable forest resource base for the world's growing human population, while providing biomass for a range of traditional and non-traditional uses. The forest products industry has shown leadership in implementing sustainable forest management practices, and will require the continued development of innovative technologies enabling higher biomass growth and allowing efficient biomass processing while minimally disturbing forest ecosystems.

Competition for Wood

New governmental policies and regulations have heightened concerns over competition for wood between traditional uses such as pulp and paper and emerging demands for wood in energy applications. Such policies in the United States include the Renewable Fuel Standard (RFS), which mandates large volumes of cellulosic biofuels under the Energy Independence and Security Act of 2007, and the proposed legislation pending in Congress considered during 2009 for a National Renewable Electricity Standard (RES). The RES would increase demand for woody biomass for generating electric power. In response, many utilities have initiated capital projects to burn wood in place of coal. Within the industry itself, demand for biomass energy in mills and plants is also likely to grow, as forest products manufacturers reduce fossil fuel consumption and implement biofuels processes integrated with mills.

Growth Cycle Delays

Because of the time delay involved in tree growth, efforts to increase the supply of woody biomass will not manifest for several years. Most of the wood to be used in the next 10–15 years is already planted and growing. Even short-rotation woody crops, purpose-grown for energy production, require five or more years prior to being ready for harvest. This time lag further raises the importance of developing new technologies to increase biomass supply.

Land Use

Increasing the area of land covered by forests is desired from a societal perspective and from recognition of the multiple benefits that forests provide. However, other demands for land use, such as agriculture for food or development to satisfy the needs of a growing population, will limit the conversion of land to forests in many cases. Therefore, the forest products industry on a local or regional basis needs to be prepared to grow wood at high growth rates to get more wood from less land. In some extreme cases, it is conceivable that as much as 80 percent of the wood needed would be grown on 20 percent of the land required today for the same wood supply. Concurrent with high growth rates is the necessary focus on water and nutrients required and potential impacts on forest ecosystems and watersheds.

Summary

Pressures on wood supply required to satisfy multiple end uses and concerns about future availability and cost necessitate that the forest products industry prioritize ensuring an adequate supply of acceptable woody biomass. Given regulatory and legislative influence over the demand for wood for energy in utilities and mills, the time delay between planting and harvesting woody biomass, the uncertain future availability of land for additional forest acreage, and the need to continue sustainable and responsible forest stewardship, the issue of biomass supply is a strategic choice. Providing for the industry's future biomass needs is essential to sustaining the production of wood, paper, pulp, and paperboard goods and simultaneously satisfying the societal needs for robust and sustainable forests.

Technology Objectives

Table 7.1 below lists the technology objectives for increasing biomass supply. These technology objectives require R&D advancements in technologies, techniques, and processes to improve tree properties, increase harvest efficiency, produce more wood on less land area, and develop more efficient forestry practices. Industry calls for advancements and breakthroughs in the genetic modification of trees to help forestry operations improve the quality, value, and supply of trees grown. Industry also needs innovations that improve how forest biomass is harvested, such as specific methods and technology to maximize the efficiency and yield of harvesting operations. The objective of increasing the production of usable woody biomass requires new tools and studies that characterize alternative growing regimes and help optimize aspects such as nitrogen use efficiency. Technology innovations are also needed to improve forest management models and systems, including those which help the industry maximize wood and other biomass production across the entire forest lifecycle. Attaining these objectives will help ensure the continued availability of essential biomass feedstocks.

Table 7.1: Technology Objectives for Biomass Supply	
Increase Growth of Usable Woody Biomass	Identify and develop methods to increase growth rates of forest biomass
Develop Trees Designed and Grown for Conversion to Specific End Uses	Identify and implement methods to improve the quality and supply of trees for specific purposes
Harvest, Process, and Deliver a Range of Forest Biomass Types with Desired Quality at Competitive Cost	Develop and demonstrate systems capable of more efficient management, harvesting, pre-processing, and delivery of various types of forest biomass
Improve Forest Management Systems—Develop Silvicultural and Management Regimes to Provide Biomass to Support Market Needs and Landowner Objectives	Develop and deploy modeling and information systems to better manage forest systems throughout the life cycle

R&D Needs

Table 7.2 shows the R&D needs for each technology objective. These priorities represent the areas that have the greatest potential for producing breakthroughs and innovations that, when effectively demonstrated and deployed, will meet the technology objective. These priorities, therefore, are the areas where the R&D community can make the biggest contribution to the industry. The needs selected for the pathway maps that follow because of their importance are in bold type.

Pathway Maps

The following pages present the pathway maps for the R&D needs indicated with bold type in Table 7.2. Chapter 4 contains a detailed description of the content of these pathway maps. Researchers may wish to refer to Figure 4.4 for specific guidance on how to use the information presented in each section of the pathway map.

Table 7.2: Summary of Top Priority R&D Needs

Increase Growth of Usable Woody Biomass	**Develop improved methods to increase production of woody biomass through high growth rates** Develop genetically engineered trees that have high growth rates Explore nitrogen use efficiency and benefits of fertilization and nutrients Produce more wood from fewer inputs	Synthesize information from whole-tree harvesting studies to determine sustainability options Understand the impact of high-growth rates on water requirements and watershed
Develop Trees Designed and Grown for Conversion to Specific End Uses (Purpose-grown Trees and Superior Properties)	**Understand the genomics of major species and develop superior trees** **Improve methods to reproduce high-value trees such as conifers (e.g., somatic embryogenesis technology)** Develop purpose-grown, short-rotation woody crops for emerging bioenergy/ biomaterials markets	Improve methods to insert genes into high-value conifers Develop trees engineered to give superior properties for specific products and purposes, e.g., high fiber strength, ease of pulping, etc. Develop energy-efficient methods to supply nutrients to growing purpose-grown trees
Harvest, Process, and Deliver a Range of Forest Biomass Types with Desired Quality at Competitive Cost (Harvest Efficiently throughout the Supply Chain)	**Develop and deploy systems for efficient harvest, processing and delivery of quality feedstocks for various conversion processes at competitive costs** Develop, demonstrate, and deploy efficient systems for growing and harvesting small-diameter, short-rotation woody crops and purpose-grown trees Develop organizational/logistics systems improving overall performance Understand water and nutrient requirements for short-rotation woody crops	Develop techniques and protocols for rapid and accurate assessment of processed feedstock characteristics (e.g., moisture content, ash, nutrients, lignin, BTU, etc.) Develop effective short-rotation woody crop (SRWC) management systems—integrate genetic material, silviculture, and harvesting technology Develop cost-effective approaches for field or distributed pre-processing of woody biomass prior to conversion (e.g., torrefaction)
Improve Forest Management Systems—Develop Silvicultural and Management Regimes to Provide Biomass to Support Market Needs and Landowner Objectives	**Develop innovative forest management systems to supply wood for multiple purposes simultaneously** Prepare life cycle inventory for management systems as part of overall product LCA Model growth and yield for mixed management systems Evaluate planting densities, inter-cropping, high vs. low technology trees Understand the impacts of climate change on forests—various species, pests, disease, growth rate, etc.	Develop a dedicated global satellite monitoring system for information on forests worldwide (requires international cooperation) Develop valuation models for non-fiber forest outputs Understand and plan for the objectives of the next generation of landowners with regard to the production of woody biomass Understand land-use implications for supply investments to satisfy market demands Determine planting densities, species selection, thinning regimes to produce maximum volumes for array of products (bio-feedstock/fiber/solid wood)

Priority R&D Need: Increase Production of Wood Biomass Through High Growth Rates

Producing more wood on less land economically is the objective. Precision forestry that results from work in this area will be highly applicable to producing more wood from a specific area of planted forests.

Input costs related to nitrogen, phosphorus, and herbicide have front-end costs with future benefits in growth rates, and these issues need investigation. The impact of higher growth rates on water needed to support the tree growth needs to be understood to ensure that watersheds are not adversely affected. At harvest, the organic matter retention and residues affect forest economics and also our social "license to operate."

Current State of Technology & Knowledge

- Limited knowledge of where the markets for woody biomass are going in coming years and how much increase in wood growth rate will be needed
- Uncertainty about whether non-industrial private land owners will supply additional biomass for all markets
- Confusion about how much wood waste and forest residuals are available for bioenergy purposes, and the concern that traditional wood supply patterns will be adversely affected by new policies and markets
- Lack of fundamental understanding of the factors that would allow very high growth rates, e.g., 80% of wood needed to come from 20% of the land area
- Insufficient availability of trees genetically engineered for high growth rates

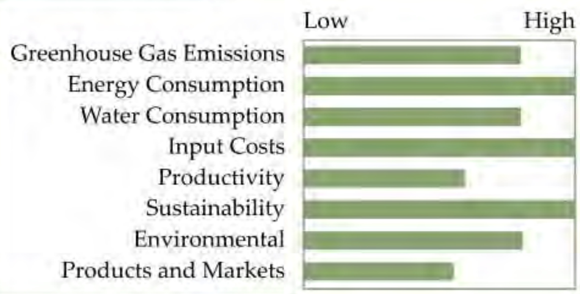
End-State Specs for Technology Solution

- Sufficient wood supply to satisfy all market demands at any time in the future
- Greater understanding of site-specific limitations and opportunities to increase growth and forest productivity
- Plantations of genetically-preferred trees with high growth rates
- Diagnostic tools available to land owners to monitor multiple tradeoffs
- Suite of science-based guidelines that satisfy multiple objectives, such as biodiversity, wildlife, aesthetics, water quality, and economics

Key Knowledge and/or Technology Advancements Required

- Develop multiple species of genetically-engineered trees that have high growth rates
- Translate estimates of future biomass demand into the necessary forest productivity improvements needed to satisfy the different demand levels (near-term)
- Match projections of demand with existing regional and sub-regional capacity and productivity improvement potentials (near-term)
- Accelerate testing and deployment of clonal forestry systems for plantations
- Understand the impact of high growth rates on watershed and water requirements
- Develop and deploy cold-hardy eucalyptus for plantations in the southern United States
- Identify the productivity enhancement tools for sub-regional forest land needed to achieve the biomass production increase at costs satisfactory to the land owner and at selling price acceptable to wood user (near-term)
- Develop energy-efficient routes to supplying purpose-grown trees with nutrients when needed—for example, biological nitrogen, recycling of wood ash, forest litter (near to long-term)

Potential Impacts



Barriers

- Uncertainties of future wood demands for various purposes, particularly, energy end uses
- Wood supply and demand are specific for a local area; generalizing to larger regions can be difficult
- Lack of high-efficiency propagation systems
- Potential societal and policy restraints on use of genetically-modified trees

Other Guidance

Producing more biomass on less land is the likely direction that will be pursued in coming years in view of global population growth and competition for land use.

Priority R&D Need — Understand the Genomics of Major Species and Develop Superior Trees

Genetic improvement of tree species is critical to enhancing the productivity and health of forests. While traditional selection and breeding methods have made good advances in the last 50 years, progress can be greatly accelerated by integrating biotechnology approaches with traditional methods.

- The species of most interest are pine and Eucalyptus. Pine is the most important species in the southern United States, and also grows in other regions of the world such as Brazil. Eucalyptus is important globally, and with genetic improvements could be modified to be cold-hardy so that it could be grown in the southern United States.
- The work falls in three areas: (1) find genes that control traits of interest; (2) enhance genetic improvement efficiency with markers, etc; (3) move target genes through molecular methods.

Current State of Technology & Knowledge

- Sequence technology is available but funding is limited to apply to pine and Eucalyptus
- Transformation is possible but limited success rates are holding back the technology
- Traditional breeding and selection of pine and Eucalyptus needs to continue

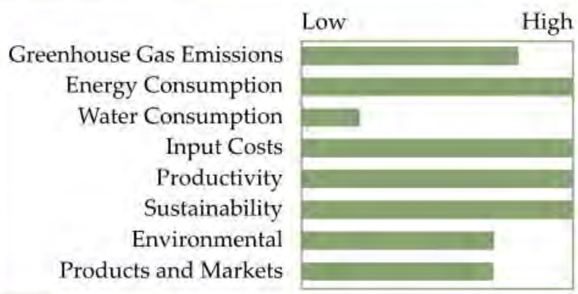
End-State Specs for Technology Solution

- Understanding of the functions of the genes that have been sequenced
- Identification of the genes that control important characteristics
- Technologies to easily screen trees for genes of interest
- Improved technology to insert foreign genes and to target desired gene expression

Key Knowledge and/or Technology Advancements Required

- Sequence the genomes of pine and Eucalyptus (mid-term)
- Identify the gene functions to understand the effect on the plant (near to long-term)
- Accelerate deployment of clonal forestry systems in softwoods and plantation species
- Develop transformation technology—biotechnology and genetic engineering methods for transforming trees using genetic tree improvement methods (near to long-term)
- Use molecular biology techniques to produce high-value planting stock
- Develop and deploy cold-hardy Eucalyptus
- Develop and deploy superior trees tailored for specific purposes, possibly high growth rates, high lignin content, low lignin content, high extractives, etc.
- Develop and deploy trees that are resistant to pests and disease

Potential Impacts



Barriers

- Transformation technologies
- Lack of critical genomic information
- Regulatory and policy requirements for genetically modified organisms
- Societal concerns about genetically modified organisms

Other Guidance

Traditional tree breeding activities need to continue to fully realize the value of this R&D objective. A team of experienced researchers qualified in the field of genomics will be needed to really complete this work. Progress on mass propagation methods will speed up implementation of findings.

Success in this work will be most helpful to technology objectives in "Getting More Value from Biomass."

Priority R&D Need: Improve Methods to Reproduce High-Value Tree Seedlings

To fully capitalize on advances in genetics, a reliable and efficient propagation system for superior planting stock is needed.

- The major interest is in softwoods such as pine and in genetically-engineered trees such as cold-hardy Eucalyptus
- Consider systems involving rooted cuttings and somatic embryogenesis

Current State of Technology & Knowledge

- Lack of ability to start cultures on selected materials, since some are recalcitrant
- Large proportion of cultures decline rapidly
- Embryos do not fully mature
- Increasing difficulty to produce robust somatic seedlings, which increases costs
- Not all varieties root well
- As trees age, they lose ability to be propagated by rooted cutting or somatic embryogenesis

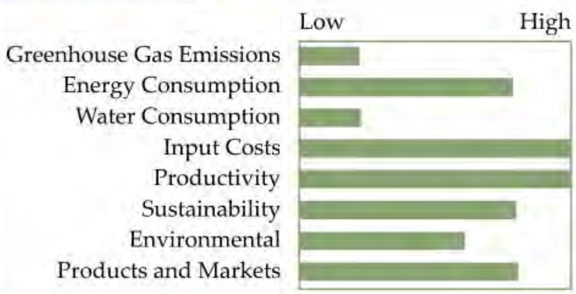
End-State Specs for Technology Solution

- Ability to multiply high-value trees at low cost
- Applicable to any species
- Seedlings available in millions
- Not dependent on manual labor

Key Knowledge and/or Technology Advancements Required

- Better understanding of seed physiology (e.g., analysis of metals, sugars, organic acids), during seed maturation and germination
- Role of hormones in seed physiology and embryo development (near to mid-term)
- Scale-up technology to go from hundreds of seedlings to millions—artificial seed, embryo sorting, embryo selection (near to mid-term)
- Ability to reprogram mature tissue to increase rooted cutting success and somatic embryogenesis (mid-term)

Potential Impacts



Barriers

- Seed development biology
- Gene function in development of embryo
- Linking with knowledge and methods in propagating agricultural species
- High cost of tree multiplication from somatic embryogenesis due to high manual labor required
- Lack of automation technology for mass multiplication of high-value trees from somatic embryogenesis

Other Guidance

Additional input should be sought into physiology. Genes discovered in genomics project could speed progress on high-speed propagation.

Priority R&D Need: Develop Systems for Efficient Harvesting, Processing, and Delivery of Wood

More efficient systems for getting wood from forests to mill site are desired, especially when multiple conversion processes are used.

- Harvesting and logistics are major cost components in total delivered cost of wood
- Need to access additional wood supply sources, such as small trees, crowns, small tracts, wood residues
- Short-rotation woody crops are of interest
- Feedstock requirements may vary from one conversion process to another

Current State of Technology & Knowledge

- Systems for high wood production rates currently available only for stem diameters larger than 4 inches.
- Conventional harvesting systems for short-rotation woody crops (SRWC) limited in efficiency
- Some prototype systems for SRWC developed
- Limited technology for cleaning and separating biomass fractions
- Low density from the forest is a limitation
- Fuel use per delivered ton is a significant cost and emission source
- Limited ability to rapidly measure biomass properties
- Concerns about environmental impacts influence harvesting, processing, and delivery
- Supply chain not adapted to changing market needs
- Changing land ownership affects harvesting requirements and systems

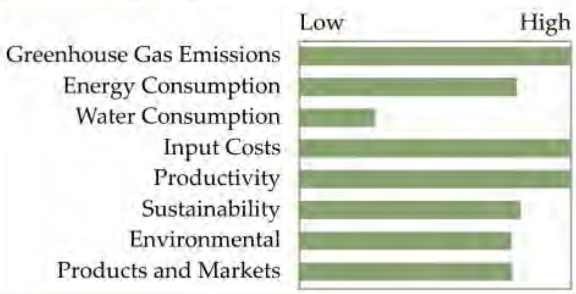
End-State Specs for Technology Solution

- Efficient and cost-effective systems to harvest, process, and deliver all available above-ground biomass forms
- Systems work in sustainable manner on a wide range of forest sites
- Significantly lower fossil fuel use per delivered ton
- Much improved transportation efficiency with low carbon footprint
- Real-time measurement of critical biomass properties through the supply chain
- Systems that meet requirements of a variety of resource ownership patterns
- SWRC systems that provide uniform feedstock
- Systems that separate bark and wood, particularly with SRWC

Key Knowledge and/or Technology Advancements Required

- Develop new technology and equipment for harvesting
- Develop standards for biomass properties that are applicable across the supply chain
- Develop systems and equipment specifically designed for harvesting and processing short-rotation woody crops
- Develop technologies for separating raw material fractions—sizes, wood from bark, etc.
- Evaluate techniques for processing wood between forest and mill to improve feedstock properties and reduce transportation costs, e.g., torrefaction
- Develop sensors for key biomass properties
- Complete understanding of environmental impacts associated with harvesting and processing
- Conduct energy audit of supply chain to identify opportunities for improvement

Potential Impacts



Barriers

- Limited R&D activity for new machine development for wood harvesting and processing
- Lack of established uniform standards for biomass quality
- Feedstock variability
- Lack of production-scale planting of short-rotation woody crops
- Support for energy audits and sensor development

Other Guidance

Cost of transporting wood from forest to site of conversion processing is dependent on distance and weight, and therefore limits the accessible region around a mill from which wood can be obtained cost-effectively.

Demand for short-rotation woody crops will depend on growth of biofuels industry and government policies.

Priority R&D Need: Develop Innovative Forest Management Systems to Supply Wood for Multiple Purposes Simultaneously

Innovative forest management systems are needed that provide flexibility and the ability to supply wood for multiple conversion processes concurrently, while achieving land use and land ownership objectives and maintaining forest health, watershed management, wildlife protection, etc.

Current State of Technology & Knowledge

- Current management systems not optimized for multiple objectives and products, including energy
- Limited datasets for integrated uses that include biomass for energy
- Limited data and knowledge on growth and outcomes of varietal forestry
- No selection of existing open pollinated (OP) and mass controlled pollinated (MCP) lines for energy value and production
- Lack of evaluation information for multiple markets and services
- Benefits and outcomes of integrated management systems unclear at the landscape level

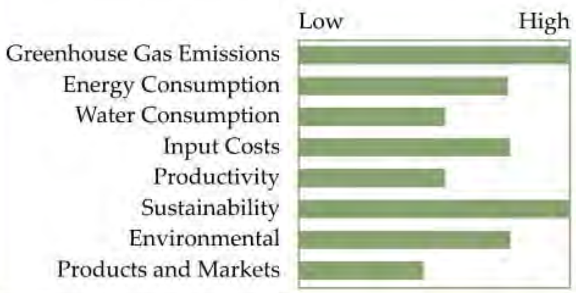
End-State Specs for Technology Solution

- Sustainable management options, systems, and practices for a range of species, densities, compositions, and ownership objectives for integrated and specialized forest systems
- Lower wood production costs
- Growth and yield models of stand components and models of management systems
- Comprehensive datasets on growth, outcomes, and environmental impacts
- Silvicultural systems that integrate biomass production for energy with wood supply for traditional forest products, with focus on health, environmental impact, productivity, and value enhancement
- Good understanding of biomass demands of various types for all uses, including wood products, pulp and paper, and energy

Key Knowledge and/or Technology Advancements Required

- Provide forest managers better tools to evaluate and monitor investments in new forest management systems
- Test innovative practices and management systems, and synthesize the available information (3–5 years)
- Study new variables (3–5 years)
- Develop effective mathematical description of stand and landscape dynamics, outcomes, and products (3–5 years)
- Update growth and yield models to account for changes in stand conditions, forest management practices, and environmental variables
- Evaluate varietal plantings for energy value and production along with wood for other products (3–5 years)
- Select and test existing OP and MCP lines for energy value and production for certain species (3–5 years)
- Develop goods and services valuation data and analysis (3–5 years)
- Install and test integrated management systems over different landscapes (5–10 years)
- Develop new techniques for forest fertilization, including formulations, application methods, and diagnostics

Potential Impacts



Barriers

- Availability of planting stock; accessibility of clone banks if they exist
- Availability of OP planting stock
- Methodology for measuring and monitoring forest resources and their contributions to social and economic objectives
- Securing landscape level sites for testing integrated management systems

Other Guidance

Demand for wood for various conversion processes, such as pulp and paper, lumber, and biofuels, is influenced by government policies and factors that are not related to technologies. The involvement and support of landowners is essential.

Progress in this area will benefit the objectives in "Getting More Value from Biomass" by providing sustainable wood supplies at lower costs.

8. Increase Value from Biomass

Delivering new value streams—beyond the traditional wood, pulp, and paper products—from woody biomass is a strategic issue that promises new, sustainable approaches to chemicals and energy needs from a renewable resource, as well as significant new revenues for the industry. While cellulose, hemicelluloses, lignin, and extractives in wood offer many avenues for yielding chemicals and biofuels, this potential must be further developed and commercialized. The desire is that wood like that currently harvested for lumber or pulpwood be used for the highest value end use possible, and that only low-value wastes and forest residuals be used for low-value energy applications. As the industry explores new ways to extract more value from trees, demonstrating the benefits of new processes relative to the value offered by current methods (e.g., the value that black liquor from pulping presently offers as fuel in pulp mill recovery boilers) will remain a central challenge.

Biomass for Fuels and Chemicals

The use of woody biomass to generate fuels and chemicals in biorefineries can provide important potential value streams for the industry to complement the traditional value streams using woody biomass. This is currently an active field for many companies and research institutions[13,14] in the forest products industry. Several biorefinery projects are underway in the United States, including:

- The DOE-supported Value Prior to Pulping program, sponsored by eight pulp and paper producing companies and led by Agenda 2020, which is investigating optimal ways to convert hemicelluloses removed from wood chips before pulping into ethanol and acetic acid
- A plant for converting hemicelluloses to butanol in Maine
- Facilities for producing bioenergy and biofuels from waste wood in Wisconsin
- Partnerships between industry and universities to develop wood-based biorefinery technologies

These value streams offer the industry the opportunity to leverage its competitive advantage, a renewable resource that can reduce the country's dependence on fossil fuels. They also offer an efficient alternative to biomass fuel generated by food crops. The current political and social climate provides increased incentives and support for development of next-generation biofuels from wood wastes and forest residuals; to take advantage of this opportunity, the forest products industry needs new enabling technology.

Biomass for Energy

The forest products industry far exceeds all other industries in using renewable biomass for energy. Renewable energy provided the United States 64 percent of pulp and paper mill and 74 percent of wood product facility energy needs in 2006. The forest products industry is working diligently to increase the use of renewable biofuels to reduce the need for fossil fuels and to improve thermal efficiencies in its operations. The industry also is increasing by-product electric power generation, and at many sites produces more electricity than is needed and sells the excess to utilities as "green" power.

Integrating biorefinery operations with pulp and paper mills offers many benefits, notably an increase in synergies between the mill steam and power systems. Procuring wood and preparing it for use in subsequent chemical unit operations is a core competency of the pulp and paper industry. The location of existing pulp and paper mills near available wood supplies is advantageous for the industry in general, and also supports its use of biomass for energy.

Other Value Streams from Biomass

Other industries, notably the oil, gas, power, and chemical industries, have become active in investigating the commercial opportunities offered by woody biomass. The chemical industry in particular sees wood as a potential substitute for fossil fuels in the role of a high-volume chemical feedstock.[15] As outside players become more involved, the forest products industry and forest land owners will need to maintain a leadership position in growing, harvesting, and using wood.

Summary

The high potential that woody biomass holds for sustainably producing chemicals, biofuels, electricity, and new product forms and functionalities in addition to the traditional pulp, paper, and wood products, supports the case for a strategic focus on deriving greater value from biomass. Contemporary demand for environmentally friendly biofuels and chemical feedstocks, combined with the need to reduce fossil fuel dependence and to match industrial processes to feedstock availability and market needs, highlights the strategic importance of technology innovations to maximize the total value derived from renewable forest biomass. Focusing on this strategic issue will strengthen the industry's value chain by advancing the evolution from existing mills into next-generation biorefineries, meeting market needs, reducing fossil fuel consumption, and increasing the economic returns from available feedstocks.

Technology Objectives

Table 8.1 below lists the technology objectives for increasing biomass value. Industry calls for practical technology solutions that can be applied to improving both the raw materials as well as the operations for converting materials into intermediate and final products such as bio-based chemicals. Advancement and innovations in purpose-grown crops could be leveraged to reduce costs and increase profitability of plant and mill operations.

Table 8.1: Technology Objectives for Biomass Value

Develop Processes for Using Purpose-Grown Trees and Short-Rotation Woody Crops for High-Value End Uses	Develop and fully leverage advantages of purpose-grown trees and short-rotation crops for high-value end uses
Develop New Biomass-Derived Products that Deliver High Value and/or Displace Petroleum-Derived Products	Develop and demonstrate new wood-derived products that add greater value than existing products and/or that displace products derived from petroleum
Improve Separation of Valuable Components from Woody Biomass and their Conversion to Products	Investigate techniques to deconstruct wood into components and extract valuable materials from biomass that can be converted to products
Develop Low-Capital Thermochemical Biorefinery Processes that Scale to Feedstock Availability and Host Site	Develop integrated biorefinery technologies and processes with reduced capital investment and increased flexibility that satisfy needs of host site and feedstock available
Increase the Flexibility and Efficiency of Integrated Biorefinery Processes	Increase the flexibility of biomass conversion processes to enable industry to respond effectively in a volatile business environment

Process innovations are needed to enable new functionalities to make wood-derived products more desirable and profitable. Industry needs advancements in materials and processes that will enable the deployment of less capital-intensive technologies and improve production flexibility and scalability. Additionally, new technologies should enable more effective chemical and physical separation of woody biomass into usable components. Attaining these technology objectives will help to increase the value derived from biomass and the benefits to society from use of a renewable, sustainable raw material that displaces petroleum-based products.

R&D Needs

Table 8.2 shows the R&D needs for each technology objective. These priorities represent the areas that have the greatest potential for producing breakthroughs and innovations that, when effectively demonstrated and deployed, will meet the technology objective. These priorities, therefore, are the areas where the R&D community can make the biggest contribution to the industry. The needs selected for the pathway maps because of their importance are in bold type.

Table 8.2: Summary of Top Priority R&D Needs

Develop Processes for Using Purpose-Grown Trees and Short-Rotation Woody Crops for High-Value End Uses	**Transform pulp mills into flexible biorefineries by employing low-lignin feedstock, replacing current recovery cycle, simplifying pulping/bleaching, and using advanced fractionation and energy management techniques** Use high-lignin trees for biorefinery applications that exploit the higher energy density of lignin versus cellulosic materials	Develop methods to manipulate lignocellulose/wood chemical components while the tree is growing Maximize carbon in biomass for thermochemical biorefinery technology platform Genetically engineer plants to achieve biomass with low recalcitrance
Develop New Biomass-Derived Products that Deliver High Value and/or Displace Petroleum-Derived Products	**Produce chemicals, advanced fuels, and polymers from sugars and lignin, including processes to produce lignin-based materials with higher value than fuel value** Develop efficient processes for the production of platform molecules as chemical feedstocks Develop products for medicinal and medical applications derived from extractives and other wood components	Develop new uses/markets for lignin-based carbon fibers, nanocellulose-based materials, and other high-value products derived from wood Develop biopolymers for use in place of plastics derived from fossil fuels

Table 8.2: Summary of Top Priority R&D Needs (cont.)		
Improve Separation of Valuable Components from Woody Biomass and their Conversion to Products	**Improve separation of woody biomass into valuable components with set specifications** Demonstrate the benefits of hemicellulose extraction prior to pulping at commercial-scale Improve the efficiency of separating hemicelluloses from wood chips and converting them to sugars Investigate universal, low-cost, high-volume separation technologies	Develop methods to achieve solvent and/or enzymatic deconstruction of wood into components Develop pulping or other processes allowing the separation of lignin into useful forms (i.e., for carbon fibers) Improve the capture of extractives from wood chips and their conversion to high-value chemicals Create affordable size reduction techniques Research supercritical water (SCW) de-polymerization for biomass separation
Develop Low-Capital Thermochemical Biorefinery Processes that Scale to Feedstock Availability and Host Site	**Develop more cost-effective processes for thermochemical conversion of biomass, including lignin and black liquor, to syngas or pyrolysis products for fuels, power, and chemicals—syngas conditioning, catalyst development, etc.** Develop catalysts for product flexibility and scalability with syngas Identify and reduce the cost of required syngas conditioning and cleaning Develop capital-intensive technologies for thermochemical conversion	Develop a scaled down Fischer-Tropsch process that fits the needs of a typical pulp mill Develop a viable black liquor gasification process and bring to market Increase flexibility in material handling and processing; feedstock-independent pulping process/papermaking Develop catalysts for syngas and pyrolysis reformation that offer flexibility of products
Increase the Flexibility and Efficiency of Integrated Biorefinery Processes	Develop flexible biomass fractionation technologies Develop cost-effective custom microbes for specific fermentation applications (e.g., ethanol, butanol) Create multiple products from the same sugars Demonstrate at commercial-scale the value of hemicellulose extraction and conversion to biofuels integrated with pulp and paper production	Apply effective heat and water process integration of biorefinery processes with existing pulp mills, and seek other synergies Optimize the integration of biorefineries into pulp and paper mill systems Develop economic processes to concentrate dilute solutions of ethanol, butanol, etc.

Pathway Maps

The following pages present the pathway maps for the R&D needs indicated with bold type in Table 8.2. Chapter 4 contains a detailed description of the content of these pathway maps. Researchers may wish to refer to Figure 4.4 for specific guidance on how to use the information presented in each section of the pathway map.

Priority R&D Need

Transform Pulp Mills into Flexible Biorefineries by Employing Low-Lignin Feedstock, Replacing Current Recovery Cycle, Simplifying Pulping/Bleaching, and Using Advanced Fractionation and Energy Management Techniques

- To evolve existing pulp mills into integrated forest biorefineries that produce new biomaterials and/or export substantial amounts of renewable energy while continuing to meet growing demands for traditional pulp and paper products.
- By the end of 2012, have in place one or more commercial-scale facilities that demonstrate the commercial production of power, chemicals, and transportation fuels.

Current State of Technology & Knowledge

- Kraft pulping and recovery process is dominant
- Existing mills are highly integrated for kraft process
- Many mills have capcity to handle biomass for bioenergy purposes in addition to pulp demands
- Low-lignin pines are under development
- Current pulping and recovery process is highly capital-intensive and consumes large amounts of energy
- Woody biomass is used as energy source via combustion and represents about two-thirds of energy used by industry
- Technologies for wood-to-biofuels are under active development, including hemicellulose extraction prior to pulping
- Some technologies for wood-to-biofuels, such as gasification, are ready for commercial demonstration

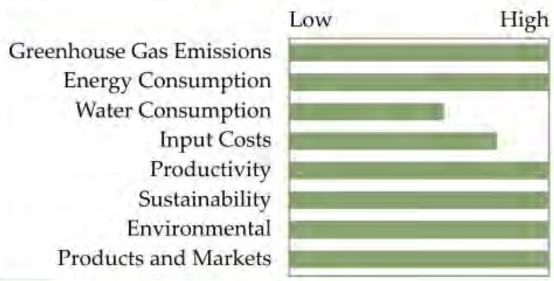
End-State Specs for Technology Solution

- Critical performance
  - Higher pulp yield (+20%)
  - Less bleaching chemical (-70%)
  - Lower overall energy intensity/capital intensity
  - Minimum effluent (~0)
  - New product stream choices
- Enabled by
  - Lower lignin feedstock ($\leqslant$15%)
- Requiring:
  - New energy balance and integration
  - Radical improvement in thermal efficiency of thermochemical technology
  - Advanced reliable separation technologies
  - Simplified bleaching sequence (O_2, H_2O_2, enzyme)
  - Non-sulfur pulping and non-chlorine bleaching with superior pulp quality
  - Fractionation of pulping liquors and bleaching extracts (hemicelluloses, lignin)
  - New effective conversion technologies

Key Knowledge and/or Technology Advancements Required

- Adaptability and optimization of non-sulfur pulping technologies to low-lignin feedstocks—fiber-driven (near-term)
- Adaptability and optimization of non-sulfur pulping technologies to high-lignin feedstocks—driven by interest in thermochemical conversion (near-term)
- Optimization of non-chlorine bleach sequences with emphasis on use of enzymes (mid-term)
- Energy management associated with mill rebalancing and integration of biorefinery (mid-term)
- Separation technologies (efficient and reliable) to enable closed waste loops (near-term)
- Confirmation of acceptable or enhanced pulp properties with integrated biorefinery (mid-term plus)
- Radical new recovery technologies based on fractionation of pulping liquors and bleach extracts (mid-to long-term)
- New effective conversion technologies for fuels and chemicals (mid-term plus)

Potential Impacts



Barriers

- Lack of capacity for rapid deployment of competing new technologies
- Funding to develop new recovery and separation technologies
- Sites for pilot trials
- Demonstration sites
- Long-term commitment to changes of this magnitude

Other Guidance

This need encompasses many sub-needs, including new technologies for low-lignin trees, chemical recovery systems, simplified pulping and bleaching processes, and greater energy efficiency, as well as development of appropriate technologies for converting woody biomass to bioenergy synergistic with pulp mills.

Priority R&D Need: Chemicals, Advanced Fuels, and Polymers from Sugars and Lignin

- Sugars from lignocellulose are different from sugars from food crops—more 5-carbon sugars in woody biomass
- A diverse portfolio of products is important to the economic viability of an enterprise in this market
- Platform chemicals are more resistant to market cycles

Current State of Technology & Knowledge

- Limitations of existing chemical synthesis pathways
- Unfavorable energy balance
- Societal impacts (food for fuel)
- Environmental impacts
- Ability to produce to market standards
- Lack of compatibility with existing assets
- Capital expenditure for cost-effective processes
- Catalyst selectivity
- Robustness of microorganisms/enzymes when exposed to heat, pH, osmotic pressure, and oxidation

End-State Specs for Technology Solution

Potential Products:

Specialty Chemicals
- PHA (polyhydroxyalkanoates)
- Xylitol
- Furfural
- Carboxylic acids
- Polymers

Advanced Fuels
- Ethanol
- Methanol
- Butanol
- Dimethyl ether
- Alkanes

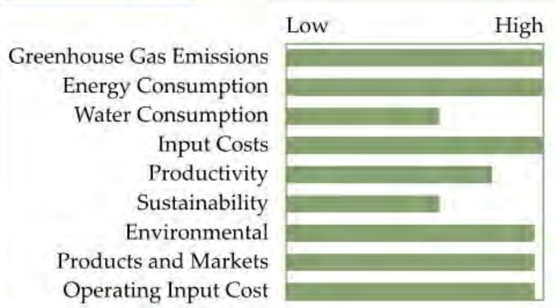
Lignin-based materials
- Syngas
- Aromatics
- Macromolecules

Criteria
- Purity to market standards
- Environmental stewardship
- Economically viable
- Preferably compatible with existing assets

Key Knowledge and/or Technology Advancements Required

- Wild strain microorganism collection, identification, and cataloging (near- to mid-term)
- Improve microorganism screening techniques for selectivity toward particular substrates and process extremes (near- to mid-term)
- Improve genetic modification techniques for microorganisms (near-term)
- Enzyme identification; isolation and cost-effective replication (near- to mid-term)
- Development of more selective catalysts for oxidation, hydrogenation, and dehydration (near- to mid-term)
- Selective cracking catalyst for lignin (mid- to long-term)
- Develop tools for ensuring safety and sustainability of new chemicals
- Develop process technology for converting solids with solid catalysts or enzymes/microorganisms (long-term)
- Improve kinetics of enzymatic or microbial reactions to reduce total installed cost of facilities (mid- to long-term)
- Improve economics of biomass pretreatment (i.e., size reduction, hydrolysis, etc.) (mid- to long-term)
- Improve robustness of catalyst (inorganic) relative to hydrothermal conditions and poisons (mid-term)
- Evaluate market potential for new materials (ongoing)
- Novel deconstruction of biomass (long-term)
- Novel reaction media (mid-term)

Potential Impacts



Barriers

- Funding
- Communication and focus
- Materials to serve as starting block
- Availability of solid/solid catalysts
- Experience at commercial scale
- Consultation with material scientists

Other Guidance

More forums to allow cross-pollination between industrial research institutions and among industries will be useful.

Priority R&D Need: Separate Wood into Valuable Components

Lignocellulosic feedstocks, by their nature, are heterogeneous and non-uniform, both physically and chemically. If these feedstocks could be made more uniform, biorefinery processes would be more efficient and produce higher yields. The challenge is to find methods of physical and chemical deconstruction and feedstock blending that are cost-effective compared to the value of the increased yield they would provide.

Current State of Technology & Knowledge

- Processes are currently designed for uniform homogeneous feedstocks, but they can seldom be provided inexpensively
- Individual equipment components exist (hog grinders, dryers, etc.), but designed, engineered, optimized systems for feedstock preparation do not.
- Feedstocks currently are grown for lumber, paper, food, etc., and not for biorefinery processes

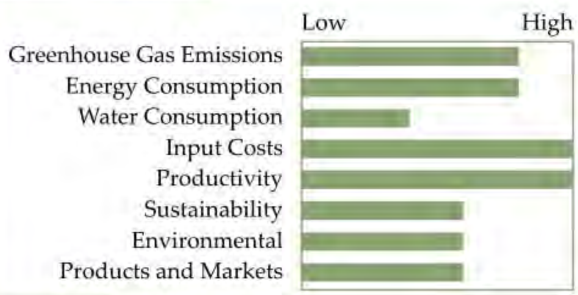
End-State Specs for Technology Solution

- Technologies that will provide feedstock having these properties:
  - Specified size and size distribution
  - High density
  - Low moisture percent
  - High Btu value
  - Consistent elemental analysis: both valuable components (carbon, hydrogen, oxygen, etc.) and inhibitory components (silica, sulfur, etc.)
  - Consistent chemical composition (e.g., sugar content, lignin content, inhibitors)
- Given a spec, processes that can deliver available biomass to that spec cost-effectively, in terms of capital and operating costs.

Key Knowledge and/or Technology Advancements Required

- Biomass market structure (mid-term)
- Biomass processing plants (long-term)
- Cost-effective size reduction: mechanical, enzymatic, thermal, chemical, and combinations thereof. Need processes that reduce mechanical energy intensity of size reduction (mid-term)
- Chemical separation techniques to fractionate species: sugars, metals, phenolics, organic acids, alcohols, etc. (long-term, unknown)
- Enzymes for size reduction and homogenization (mid-term)
- High-throughput, highly efficient biomass drying systems for thermochemical platform (long-term, unknown)
- Rapid, low-cost methods and sensors to characterize feedstocks: size, density, moisture, Btu value, component composition, and elemental composition (near- to long-term)
- Process to remove silica from agricultural residue biomass (near- to mid-term)

Potential Impacts



Barriers

- Supply chain structure and organization
- Low value of biomass, no market structure
- High cost of electrical power
- Large number of chemicals to be separated. Low selectivity of conventional separation techniques
- Real-time on-line sensors need improvement

Other Guidance

Designing and growing trees with improved ability to separate components and with more uniformity will be helpful.

Priority R&D Need — Thermochemical Conversion of Woody Biomass

Conversion of biomass, including lignin to syngas or pyrolysis products for fuels, power, and chemicals

Current State of Technology & Knowledge

- Black liquor gasification—chemical reaction—O_2—high temperature—moving to demonstrate biorefinery at commercial scale
- For solid biomass—a few, low-temperature, indirect-heated technologies are being demonstrated (e.g., by Thermo-chem Recovery International and Range Fuels, also silvagas)
- Gas clean-up—currently the existing cold-gas-clean-up technologies are being adapted to biomass—too many processing steps
- Expensive, high capital—desired biomass application much smaller than coal
- Catalysts—based on Group VIII transition metals

End-State Specs for Technology Solution

- High carbon conversion to fuels and/or chemicals
- Need conditioned syngas suitable for subsequent process
- Good thermal efficiency and heat recovery
- Catalysts tolerant of higher impurities
- Low catalyst cost
- Broader catalyst map to enable greater product diversity
- Have effective process simulation and economic models
- Need scenarios (plans) for both greenfield sites and retrofit in existing mills

Key Knowledge and/or Technology Advancements Required

Carbon Conversion

- Further understanding of best ways to prepare and introduce feedstock to gasifier (near-term)
- Catalysts, nano-coatings, etc., to accelerate carbon conversion in gasifier (mid-term)
- Exploiting the chemical composition in improving carbon conversion (near-term)

Syngas Conditioning

- Gas clean up technologies that are suitable for smaller scale (near- to mid-term)
- Screen existing catalysts for new processes/products. Based on these results look at pathways to develop new ones that perform better, and at lower cost (full span as new products emerge)

Thermal Efficiency and Heat Recovery

- Optimize the integration between the endothermic and exothermic processes (e.g., biorefinery and pulp mill) (near- to mid-term)

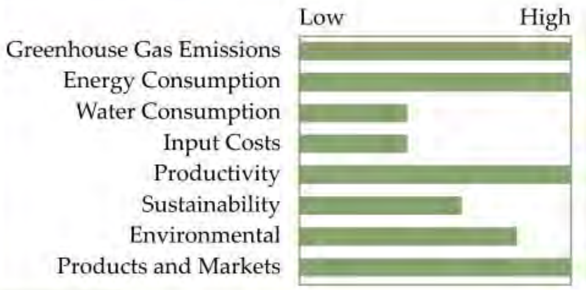
Broaden Catalyst Map/Flexibility

- Develop specific catalysts that will enable broader product choices driven by future economics (full span)

Effective process simulation and economic model

- Determine process steps, feedstocks, products, markets—then determine best platform or new platform if needed. Task the right people to complete (near-term)
- Next generation (mid-term)

Potential Impacts



Barriers

- Scalability
- Timely and sufficient funding particularly for fundamental research
- Lack of appropriate test, lab, and pilot facilities
- Private sector incentives to take the risk
- Public education and awareness

Other Guidance

Capital costs for thermochemical conversion processes need to be reduced to encourage more widespread use of the technologies as they become available.

9. Enable New Products and Product Features

New technology-based solutions that enable companies to develop new products and features valued by customers is a strategic priority for the forest products industry in order to demonstrate its commitment to fulfilling customer desires and needs. To address the numerous opportunities for product features promised by findings in new fundamental sciences, such as nanotechnology, photonics, and separation science, forest products manufacturers need innovations that will enable them to apply these results from fundamental research to the development of new products and product features. By doing so, the industry will manufacture sustainable products made from renewable raw material and displace products such as plastics that are derived from petroleum.

Desirable Product Characteristics and Performance

The forest products industry must continue to provide valued products to its customers. A key to future growth in revenues is development of superior products that customers will buy instead of alternative products. Various product attributes are valued by customers, and the specific characteristics that are desired depend on the specific performance requirements expected of the product. For example, many consumers currently desire products with lower greenhouse gas emissions life cycles. "Lightweighting" products—i.e., reducing the weight of products while maintaining performance level—is one way to significantly reduce fiber consumption and its associated energy use and greenhouse gas emissions.

Enabling Technologies

While developing new product features for commercial implementation is a strategic activity best managed by producer companies, developing the enabling technologies that build on fundamental science and demonstrate emerging concepts in lab- and pilot-scale settings is a pre-competitive endeavor appropriate for academia, government, and multi-company collaborative programs. For example, developing the fundamental science and techniques needed to take commercial advantage of nanotechnology is viewed as pre-competitive. Given corporate R&D's limited capacity for moving high-risk concepts from lab to commercialization, collaborative approaches are required that leverage the benefits of open innovation by combining the strengths and competencies of multiple organizations.

Summary

The industry's evolving market demands for new products and improved properties and performance drive the importance of a strategic focus on the knowledge, processes, and materials that enable improved products and features. Enabling technologies to bring product improvements to fruition will strengthen the industry value chain's link between manufacturing capabilities and consumer markets and facilitate the use of wood-derived products in place of products based on fossil fuels such as plastics.

Technology Objectives

Table 9.1 below lists the technology objectives for enabling the development of new products and expanding product features. Many of the needed technology solutions will require early-stage, high-risk, pre-competitive R&D to demonstrate underlying scientific concepts for the technology providing the desired product innovations. Within three years, advancements enable the development of biomass-based packaging that is competitive with other materials, particularly non-renewables such as plastic polymers. Near-term innovations are also needed to increase the performance-to-weight ratio of forest products by 20 to 50 percent. In particular, lighter substrates that replace current products in corrugated containers, folding cartons, and printing papers would significantly improve the competitiveness of paper products. Promising outcomes are being seen in nanotechnology studies around the world that illustrate the potential for advances in these directions.

Within five years, advancements are desired to add functionalities to paper, including smart paper and packaging that can indicate the condition of the contents, the integrity of the package, and the conditions experienced during transportation and distribution. Advancements are also wanted in technologies that will enable the industry to enter totally new markets and develop radically different products. Long-term technology objectives include the development of new processes for deconstructing biomass into basic components which do not compromise the component at the nano-scale, and the application of the unique properties of biomass in the development of new composite materials and processes. Attaining these objectives for new products and product features will help strengthen the industry's ability to meet customer needs and provide products made from renewable raw materials that reduce the demand for products from non-renewable sources.

R&D Needs

Table 9.2 shows the R&D needs for each technology objective. These priorities represent the areas that have the greatest potential for producing breakthroughs and innovations that, when effectively demonstrated and deployed, will meet the technology objective. These priorities, therefore, are the areas where the R&D community can make the biggest contribution to the industry. The needs selected for the pathway maps because of their importance are in bold type.

Table 9.1: Technology Objectives for Product Features

Create New Bio-Based Composites and Nanomaterials	Develop bio-based composites and nanomaterials that leverage the unique properties of biomass and provide features desired by customers
Achieve a 20–50% Improvement in Performance/Weight Ratio of Paper and Packaging Products without Compromising Performance Properties	Increase the performance-to-weight ratio of paper and packaging products by 20–50% through the development of new technologies and techniques
Develop New Paper Features—Optical, Electronic, Barrier, Sensing, Thermal, Surface Texture—that Take Advantage of Advances in Nanotechnology	Modify existing and/or create new paper characteristics to increase product capabilities and value, and develop commercial applications of promising advances in nanotechnology
Develop New Forms of Biomass-Based Packaging	Develop sustainable biomass-based packaging competitive with existing packaging technologies
Separate Biomass Into Basic Components, Preserving Nanoscale Properties of the Components	Investigate and develop technologies and methods to deconstruct biomass into fundamental components for commercial use, without disrupting nanoscale properties
Develop New Printed Functionalities to Make "Smart" Surfaces on Paper, Paperboard, and Wood Products	Develop technologies to add "smart" functions via printing to surfaces of paper and paperboard and wood products

Table 9.2: Summary of Top Priority R&D Needs

Create New Bio-Based Composites and Nanomaterials	**Create functional interfaces between inorganic materials and value-added cellulosic materials to enable new forms of composites** **Understand and exploit the self-assembly process and non-covalent interactions in wood, woody components, and wood-based materials** Develop cost-effective processes for extracting cellulosic nanomaterials from wood and preparing them for commercial applications	Develop technologies to disperse/intermix components to capture the desirable properties of each component in the matrix Investigate interaction of cellulose/lignin materials with other components within plastic and cement materials Develop metrology tools to measure and characterize dispersion of components in a matrix Improve methods to characterize the shape and size of micro-/nano-materials
Achieve a 20–50% Improvement in Performance/Weight Ratio of Paper and Packaging Products without Compromising Performance Properties	**Achieve a 20–50% improvement in performance/weight ratio of paper and packaging products with new technologies and product forming methods** Improve interfiber bonding by understanding interfacial interactions of fiber and other furnish components at the micro- and nano-scale Develop alternative to mechanical fiber refining to get bond development without sheet densification	Develop stronger and/or more efficient flute geometries for corrugated boxes Develop controlled-porosity base sheets to enhance bulk Understand the structural strength limits of structured/layered materials using nanocrystalline cellulose and lignin derivatives Develop cost-effective additives and surface treatments for strength enhancement
Develop New Paper Features—Optical, Electronic, Barrier, Sensing, Thermal, Surface Texture—that take advantage of advances in nanotechnology	Develop new materials to control photon dispersion and achieve improved optical features such as opacity Control paper surface properties between the micro and nano levels with either innovative coating or forming Create economically viable method for surface application of conductive ink to make smart paper	Exploit interactions between paper/cellulosics and functional polymers like organic semi-conductors, enzymes, thermal-sensitive, etc Perform basic research in protein penetration abilities to suspend sensors in coatings Characterize the substrate properties needed for printed electronics on paper
Develop New Forms of Biomass-Based Packaging	**Develop bio-based coatings and fiber treatments that can replace non-renewable polymer films in current and future packaging designs** Identify surface treatments to reduce water permeability of cellulosic material Create a measure of oil and grease barrier that is independent of the paper substrate	Characterize biomass compounds for physical and chemical properties—link to properties of non-renewable materials to highlight the advantages of wood-derived materials Develop test that quickly measures oxygen and moisture barrier in evaluating packaging materials

Table 9.2: Summary of Top Priority R&D Needs (cont.)		
Separate Biomass Into Basic Components, Preserving Nanoscale Properties of the Components	Develop methods and systems to manufacture crystalline nanocellulose and microfibrillar cellulose cost effectively Develop means for generating large volumes of nanocellulose for commercial use Separate lignin and hemicelluloses from cellulose while preserving properties of each stream Develop new characterization tools for biological nanomaterials	Develop modeling tools that work below the fiber level using chemical and physical properties Inject wood before harvesting to begin disaggregation in the forest—reduce chemical and energy use in processing Remove lignin cost effectively, without chemically modifying or altering unique properties
Develop New Printed Functionalities to Make "Smart" Paper and Paperboard Surfaces	Develop cost-effective printable sensor technologies on paper surfaces for applications such as RFID, electric circuits, energy storage, biomedical tests, etc.	Develop surface treatment methods to prepare paper surfaces for printable functionalities Modify inkjet and other digital print methods to enable printing of surface functionalities

Pathway Maps

The following pages present the pathway maps for the R&D needs indicated with bold type in Table 9.2. Chapter 4 contains a detailed description of the content of these pathway maps. Researchers may wish to refer to Figure 4.4 for specific guidance on how to use the information presented in each section of the pathway map.

PRIORITY R&D NEED: CREATE NEW FORMS OF COMPOSITES BY CREATING FUNCTIONAL INTERFACES BETWEEN INORGANIC MATERIALS AND VALUE-ADDED CELLULOSIC MATERIALS

There is a great opportunity to transform cellulosic materials into one of the most suitable renewable replacements for current petroleum-based materials for advanced composite applications. This would involve both the creation of new cellulose-inorganic interfaces as well as value addition to cellulose itself by functionalization.

Current State of Technology & Knowledge

- Existing methods for creating inorganic/polymer composites are not directly applicable to cellulose composites
- There is not enough knowledge on transforming the intrinsic properties of cellulose by chemical functionalization
- There is a lack of basic knowledge (both experimental and modeling) of characterizing such complex materials
- All approaches should be cost-effective and scaleable for large-scale manufacture; also environmentally friendly

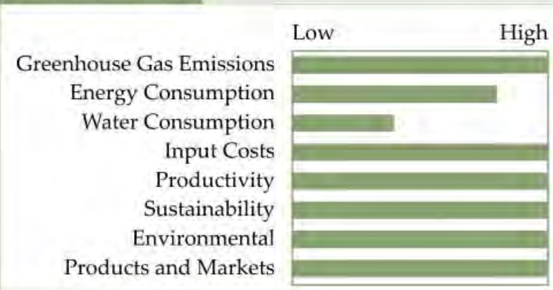
End-State Specs for Technology Solution

- Create a material platform that would be competitive with synthetic polymers for composite materials applications
  - Mechanical properties
  - Chemical properties
  - Optical properties
  - Thermal and transport properties
- Create both nanostructured materials as well as nanoscale devices (which operate at molecular/nanometer scales
- Create composites whose properties are "greater than the sum of the constituents"
- Examples: 1) creating "perfect" barrier coatings (electronics, food packaging); 2) high-strength, lightweight composites (automotive, aerospace); 3) photonic materials from cellulose (electronic sensor)

Key Knowledge and/or Technology Advancements Required

- Development of methods for characterization of cellulose and inorganic interfaces at the nanoscale. This characterization would require both structural and functional (property) characterization at the nanoscale. (near-term)
- Development of predictive multi-scale models that utilize only limited experimental inputs, to predict the processing structure-function relationships (near-term)
- Development of new chemistries for combining 1) and 2) information to create advanced composites (near- to mid-term)
- Development of new technologies for producing cellulose with a controlled micro/nanostructure, on a large (commercial) scale (e.g., new extraction/reaction technologies) (mid- [lab scale] to long- [mfg] term)
- Sufficient "scale-up" capabilities needed in order to obtain reproducible evaluation/characterization of cellulosic composites/nanomaterials (near-term [lab-scale])
- Development of new technologies for producing cellulose with a controlled micro/nanostructure, on a large (commercial) scale (e.g., new extraction/reaction technologies) (mid- [lab scale] to long- [mfg] term)
- Sufficient "scale-up" capabilities needed in order to obtain reproducible evaluation/characterization of cellulosic composites/nanomaterials (near-term [lab-scale])

Potential Impacts



Barriers

- Building intra/inter-university teams to work cohesively on characterization of interfaces and model development
- Building fundamental science with engineering approaches in models
- Interfacing manufacturing technologies with researchers

Other Guidance

The roadmap needs to be aggressively disseminated to universities, national labs, funding agencies, congressional committees (science and technology), and industrial companies.

Priority R&D Need: Understand and Exploit Self Assembly and Non-Covalent Interactions of Wood-Based Materials and Wood

- Enabling technology for adapting nanotechnologies to forest products
- Important aspects are biometrics and biomimicry—understanding nature's optimal architectures
- Another major aspect is utilizing non-covalent interactions to self-assemble useful materials
- Self-assembly is use of minimum energy structures to build from bottom up

Current State of Technology & Knowledge

- Large knowledge in self-assembly of inorganic materials
- Existing expertise in non-covalent interactions of petroleum-based materials
- Existing knowledge of non-covalent interactions in biomolecules like DNA, RNA, proteins
- Experimental methods and models exist for non-covalent characterization

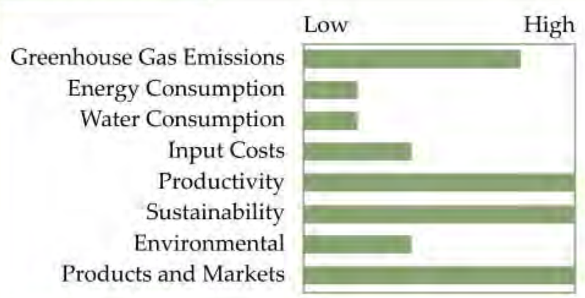
End-State Specs for Technology Solution

- Understand chemistry of cellulosics and its manipulation of solubility in liquids and subsequent processing
- Understand cell-well formation in trees and plants
- Understand inorganic cellulose-linking chemistry
- Determine how to self-assemble crystalline nanocellulose into other materials (inorganic/organic) for strengthening (includes modification of other materials to enable hydrogen bonding)
- Construct models to predict macroscopic properties of nanostructure

Key Knowledge and/or Technology Advancements Required

- Gene sequencing and functional genomics of tree formation; how to modify them based upon product functional needs, e.g., high strength and stiffness. (long-term)
- Characterize all the nano-structural components of wood (mid- to long-term)
- Develop the metrology for surface characterization, strength (near-term)
- Functionalize surfaces through chemical modification (mid- to long-term)
- Molecular and multi-scale modeling, e.g., chemical modification at the molecular level and how it affects macro-properties (mid- to long-term)
- Self-assembly of nanocellulosics and other inorganic or polymeric components (long-term)

Potential Impacts



Barriers

- Non-uniformity of cellulosics and cell wall structures; variation from sample to sample
- Attracting scientists to this new field (Nano Science) various disciplines to work together
- Viability and representation (artifacts) of the measurements at the nano (10^{-9}) scale
- None other than money and time

Other Guidance

Good opportunity to involve researchers in nanotechnologies who traditionally work in other fields.

Priority R&D Need — 20–50% Improvement in Performance/Weight Ratio

Produce products with lower basis weight, saving energy and fiber without any compromise in performance criteria

Current State of Technology & Knowledge

- Insufficient knowledge about interactions among fiber, fillers, polymers, and other materials in paper furnish and final product
- Insufficient understanding of fiber bonding mechanism at nanoscale and microscale—too much dependence on fiber refining and strength additives
- Understanding of adhesive bonding mechanisms in papermaking or converting
- Wet or dry-end interaction of fillers and fibers
- Limits of strength/weight—what are the limits?
- Controlled orientation of fibers during forming including orientation for best use in the end use

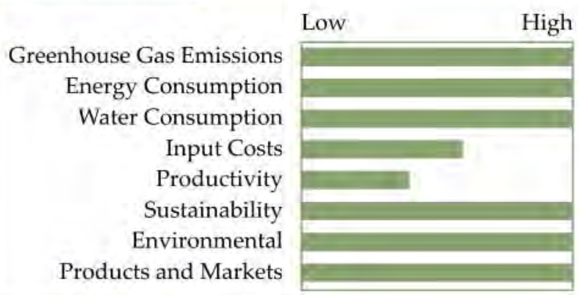
End-State Specs for Technology Solution

- Increase in strength must retain ductility and strength required for convertibility, as an example
- Differing paper structures, e.g., non-felted layers, oriented fibers, cloth like structures
- Mathematical modeling and computer simulations to establish limits of strength/weight
- Solution must be shown to be potentially scalable
- Improvement or controlled interactions with non-fibrous materials that allows reduced weight of fiber

Key Knowledge and/or Technology Advancements Required

- Relationship between fiber-fiber hydrogen bonding and mechanical entanglement of fibers and impact of refining (3 years)
- Understand governing principles of bonding of materials to fiber, e.g., starch to fiber, filler to fiber, polymers to fibers (3 years)
- Understand difference in bonding of materials to fibers in wet and dry states (3 years)
- New method for aligning fibers in production, for advantageous gains in strength "dial-in" orientation capability (5–7 years)
- New methods of converting paper to optimize directional properties of paper (3 years)
- Numerical model to predict paper properties based on known raw material properties, fiber orientation (3 years)
- Computational model for paper at the microscopic level to predict paper properties (3 years)
- Application of nanomaterials for strength increase

Potential Impacts



Barriers

- Non-uniformity of fibers and cell wall structures; variation from sample to sample
- Measurements to understand fiber bonding and interactions with other materials at the nanoscale
- Time, money, and will
- Capital investment, interest and buy-in from manufacturer
- Development of new concepts for web forming, fiber bonding, and strength enhancement

Other Guidance

Many customers would like lower weight paper and paperboard products that do not sacrifice performance characteristics.

Priority R&D Need

Develop bio-based coatings and fiber treatments that can replace non-renewable polymer films used in current and future packaging designs (flexible and rigid)

For environmental and sustainability concerns with current LDPE-based packaging designs, there is a high market potential for paper-based packaging that uses renewable, bio-based coatings and treatments at equal usage costs.

Current State of Technology & Knowledge

Synthetic Polymers

- Functional properties are better than biopolymers
  - Barrier—oil and grease, moisture, gas
  - Heat-sealable
  - Moldable
  - Product protection—fungal/spoilage/bacteria
- Current composite paper packaging designs often contain synthetic polymers
- Lightweight
- Installed base of high capital converting equipment
- Other issues—pinholes/defects in paper that disrupt film formation and barrier

End-State Specs for Technology Solution

- Match non-renewable polymer barrier properties with bio-based structures/films—replace LDPE
  - Cost-effective—equal use/manufacturing cost
  - Step change in "paper" base functionality to minimize defects
  - Improved coating technology
  - Highly effective on-time converting
- Material science
  - Bio-based aqueous coating structures with required barrier properties
  - Advances in wood chemistry based bio-polymers—lignin, etc.

Key Knowledge and/or Technology Advancements Required

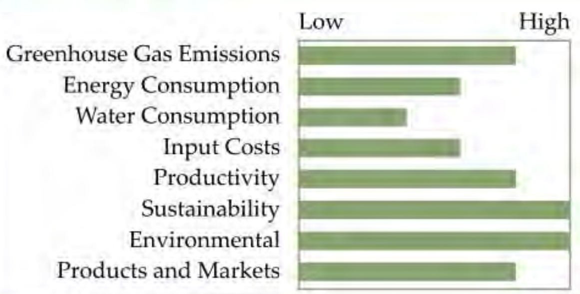
Industry Development

- Benchmark existing bio-based coatings and treatments against current LPDE packaging designs
- Address the technical issues with current paper-based designs caused by basic paper defects and coating film issues (aqueous-based)
  - Improved coating techniques
  - Novel base paper treatment

Room For Research

- Identification and characterization of new bio-based polymers (mid- to long-term)
  - Starch (polylactic acid polymers are expensive)
  - Chitosan
  - Corn proteins—zein
  - Other proteins/materials
- LCA review of new materials—application and testing techniques—includes scale-up and technology needs (mid- to long-term)
- Develop new wood-based polymers that have packaging potential for multiple barrier properties (mid- to long-term)
- Compatibility of materials—reduce coating defects from foaming and air entrainment

Potential Impacts



Barriers

- Limitation of current aqueous based
  - Installed coating base
  - Fundamental research
  - Scale-up
  - Economics
- Dis-aggregation, isolation and application of lignin-based polymers to packaging barrier designs

Other Guidance

Wax substitution is another opportunity

10. Increase Recovery and Recycling of Waste Products

Continuing the forest products industry's historical emphasis on recycling and further improving the processes and products for reusing waste forest products is strategically important to provide new value streams and improve the industry's reputation and leadership in managing shared social issues. Although recovered paper now accounts for more than 36 percent of fiber used to make new paper and paperboard products in the United States[16], new and advanced technologies for waste wood and paper product collection, sorting and recovery, and methods for more efficient use of recovered materials are needed to further improve in this regard. A strategic focus on this issue will further enhance the industry's environmental stewardship while improving the quality and quantity of recovered fiber and wood materials, their effective use, and the value they provide.

Environmental Responsibility

The forest products industry has encouraged recovery and recycling of its products for decades. Every ton of paper that is recovered saves 3.3 cubic yards of landfill space, and diverts this potential waste back into producing essential materials for communication, food service, product delivery, and other everyday applications. Appropriately, paper is among the most intensively recycled materials. The United States has dramatically increased the recovery and reuse of paper in recent years. In 1970, the recovery rate for paper was 22 percent. By 2008, that percentage had climbed to 57.4 percent, and the U.S. industry is on track to raise that to 60 percent by 2012. Europe reports a higher recovery rate than the United States in recycling waste papers, although the European and U.S. reporting methods are not identical. In 2008, the recycling rate in Europe was 66.6 percent.[2]

Value Streams from Waste

Recovered products can be valuable for more than just the fiber content, and new value streams from waste materials would be welcome as an additional revenue source for the industry. New technologies to separate and reuse non-fiber materials, such as fillers, coating pigments, binders, and ink, could be developed to best utilize every component of recovered materials. Another development pathway may identify new value-added uses for recovered products—which will be particularly helpful, as the United States is reaching a plateau in some markets for the amount of recovered fiber that can be used effectively.

Summary

Strengthening recovery and recycling efforts is a strategic priority for the forest products industry, which will help the industry remain a leader in environmental stewardship while identifying and developing new sources of value in waste. Saving costs and increasing efficiency in the gathering, sorting, processing, and production of recycled goods are strategically important for future economic viability, and protecting the environment is both socially responsible and valuable for ensuring public goodwill. For both social and financial benefit, bringing waste, used products, and byproducts back into the value chain and employing them as usable material inputs as effectively as possible is a strong strategic move.

Technology Objectives

Table 10.1 below lists the technology objectives for improving recovery and recycling for forest product mills. The industry wants technologies that enable the identification, recovery, and use of new energy sources among recovered wood materials and paper recycling byproducts. Other innovations should greatly enhance recycled and recovered materials processing by improving the systems used to sort recovered product by grade and contaminant; enabling greater recovery and reuse of the non-fiber components of materials; and enhancing paper machine water use, product quality, and product runnability. Lastly, advancements are needed that can be applied within the manufacturing process to create products designed for eventual destruction and recovery. All of these innovations would increase the effective use of recovered and recycled content, enable the recycling of a wider range of materials, and improve the quality of recycled products.

R&D Needs

Table 10.2 shows the R&D needs for each technology objective. These priorities represent the areas that have the greatest potential for producing breakthroughs and innovations that where the R&D community can make the biggest contribution to the industry. The needs selected for the pathway maps because of their importance are in bold type.

Table 10.1: Technology Objectives for Recovery and Recycling

Improve Sorting of Recovered Wood and Fiber	Develop new sorting systems to better separate waste items by grade, contaminant, and heavy metal content
Enable Recycled Fibers to have Runnability Equivalent to Virgin Fibers	Develop methods and techniques to increase the quality of recovered fibers to a level equivalent to virgin pulp fibers when used on a paper machine
Use Non-Fiber Components of Recovered Materials More Effectively	Develop methods and processes to leverage existing non-fiber components of recovered products
Enhance Availability and Use of Recovered Biomass for Energy	Determine ways to identify and recover currently unused potential sources of energy
Design Products for Deconstruction or Recycling	Design products for eventual end-of-use destruction to maximize potential recovery

Table 10.2: Summary of Top Priority R&D Needs		
Improve Sorting of Recovered Wood and Fiber	Develop certified document destruction processes which maintain fiber integrity and reduce contaminants Improve sorting in recycle paper mills to better separate grades and contaminants	Detect, sort, and remove wood that contains heavy metals
Enable Recycled Fibers to have Runnability Equivalent to Virgin Fibers	**Develop new techniques that enable recycled fibers to have first grade production rate (runnability) equivalent to virgin fibers—machine design, water, fiber modification, nanotechnology**	Develop improved process control technologies for contaminants Increase fiber yield during paper recycling Optimize paper machine water use and quality
Use Non-Fiber Components of Recovered Materials More Effectively	**Develop separation techniques to remove filler from recycling mill wastes and ways to reuse the recovered filler**	Identify approaches for beneficial reuse of paper recycle mill residue such as sludge Develop process to transform recovered filler into useful or saleable product
Enhance Availability and Use of Recovered Biomass for Energy	**Recover urban wood wastes (e.g., from construction and clearing) for energy** Recover paper recycle mill ash and separated sludge for energy or chemicals	Recover energy from pulp/paper mill heavy rejects
Design Products for Deconstruction or Recycling	Identify methods and materials for systems approach to wood product design	Incorporate product end-of-use recovery into design of wood products and paper, paperboard, and packaging

Pathway Maps

The following pages present the pathway maps for the R&D needs indicated with bold type in Table 10.2. Chapter 4 contains a detailed description of the content of these pathway maps. Researchers may wish to refer to Figure 4.4 for specific guidance on how to use the information presented in each section of the pathway map.

Priority R&D Need

Enable Recycled Fibers to Have Runnability Equivalent to Virgin Fibers: Machine Design; Water Systems; Fiber Modification (Nanoscale and Microscale)

- Objective: Improve paper machine operating efficiency while utilizing recycled fibers in papermaking furnish
- Degradation of runnability on a paper machine when using large quantities of recycled fiber limits the amount of recycled fiber that can be used cost effectively

Current State of Technology & Knowledge

- Measurement, identification, and control of contaminants is adequate but needs improvements
- Quantitative impact of contaminants on productivity is somewhat understood
- Inability to maximize water reuse and maintain water system quality
- Lack of understanding of means by which to increase fiber bonding ability to make recycled fibers bond like virgin fibers
- Lack of ability exists to minimize generation of fines in processing recycled fibers

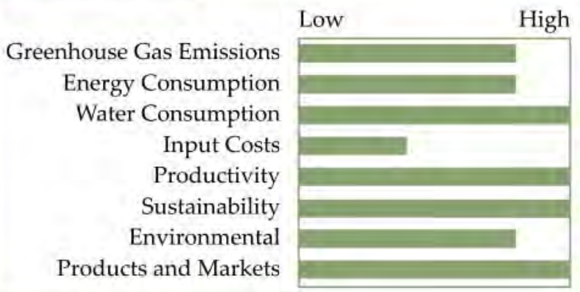
End-State Specs for Technology Solution

- Paper machine uptime with high recycled fiber content equivalent to all-virgin furnish with equal or better sheet properties
- High drainage and dewatering rates on paper machine with high levels of recycled fiber
- Water usage below current levels
- Reduction in contaminant carry-over by improving water barriers (thickening) and contaminant removal and control

Key Knowledge and/or Technology Advancements Required

- Improved methods for on-line or off-line quantification of contaminants in recycled fiber (e.g., stickies) (mid-term)
- Techniques to reduce contaminant generation during repulping and processing for reuse (mid- to long-term)
- New approaches for higher efficiency contaminant removal from fiber streams (mid- to long-term)
- New approaches to removal and management of contaminants (chemical, mechanical) from recycled plant and paper mill water (near- to mid-term)
- Enhancement of properties of recycled fibers using new technologies, e.g., fiber charge, nano-based fiber repair, individual fiber coating (mid- to long-term)
- Method for minimal fines generation in process equipment or through fiber modification (mid- to long-term)

Potential Impacts



Barriers

- Standardization, acceptance, implementation, feasibility
- Cost
- Size of contaminants too similar to fibers
- Non-optimal variables in properties of incoming contaminants
- Knowledge , lack of effective measurement

Other Guidance

Approaches to make recycled fiber more useful must not be too expensive.

Priority R&D Need: Develop Techniques to Separate Filler (Minerals, Particulates) from Recycled Fiber Streams and Recycling Mill Wastes

Filler separation from recycling mill wastes: Filler is a large fraction of recycle mill residuals. Meeting this need will reduce the landfill fill costs to mills and open up the potential for both fiber and energy recovery from the remaining materials. Opportunities to develop higher value-products from these inorganic materials would be a useful revenue stream for recycled mills.

Current State of Technology & Knowledge

- No cost-effective methods currently exist for separating mixed inorganic materials from a stream of recycled fibers.

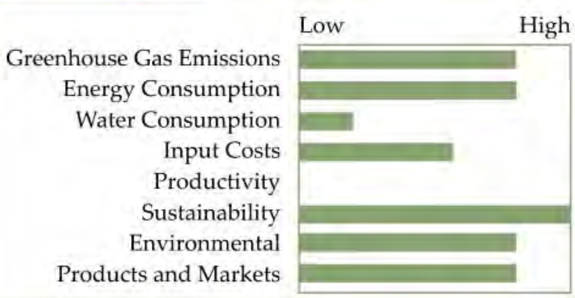
End-State Specs for Technology Solution

- For reuse as filler in paper, the separation has to lead to a product that has acceptable particle size brightness and physical properties similar to the virgin filler.

Key Knowledge and/or Technology Advancements Required

- Filler from fiber: The separation is very complex. Any technology needs to consider the various types and functions that inorganic materials serve in sheets. If flotation is the technology choice, the surface chemistry of typical materials will require study. Pretreatment may be required to facilitate separation. (7–10 years)
- Filler from filler: Best properties will be obtained if it is possible to separate the various filler materials from each other (e.g. calcium carbonate from clay from titanium dioxide) (7–10 years)
- Controlling contamination by other elements may be a problem. For example, iron oxides in inks may result in low brightness products. (7–10 years)
- Processing filler to products will require careful control of particle morphology. (7–10 years)
- Product design to facilitate recovery of filler materials may be possible. (7–10 years)
- Work on characterizing the streams available in a mill for this type of project has not been done. (7–10 years)

Potential Impacts



Barriers

- Knowledge, technology development
- Economic incentive

Other Guidance

Pigment recovery and reuse from mill effluents and from deinked sludge are good targets. Look into landfill costs.

Calcination and reprecipitation of deinked sludge and critical point extraction could be viable technologies with some additional research.

Priority R&D Need: Recover Urban Wood Waste for Energy

Recover urban wood waste for energy: A report from the U.S. Forest Products Laboratory suggests that 35.5 million metric tons of urban wood waste is available, and that a significant fraction of municipal landfill space is being used for urban wood waste. For the purpose of this discussion, urban wood waste includes construction debris, demolition, trees, stumps, limbs and any other woody biomass. The benefit meeting this need includes (1) extending the lifetime of landfills, (2) reducing pressure on cost and supply of wood, and (3) providing a potentially low cost energy source.

Current State of Technology & Knowledge

- The limitation on using this material is the lack of effective sorting techniques. Contaminating materials include stained, painted, and pressure-treated materials.
- There are policy problems associated with the definitions of fuel versus waste, and tight restrictions on burning contaminated woods (e.g. pressure-treated wood)

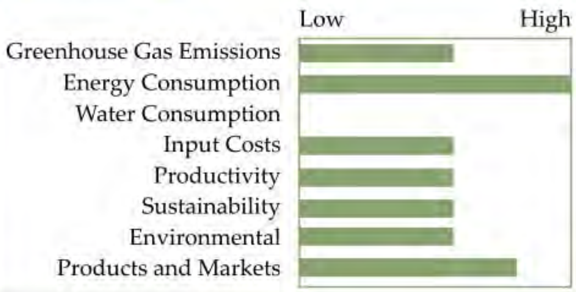
End-State Specs for Technology Solution

- Fast and accurate methods for identifying and removing contaminant materials
- Processing methods that can handle a wide range of sizes and provide a consistent and dense product.

Key Knowledge and/or Technology Advancements Required

- Urban wood for energy: real-time sorting line or handheld device for identifying significant levels of lead, arsenic, chromium, and mercury, (5 years)
- The method needs to be applicable to materials with a wide range of sizes and shapes, (5 years)
- Validation and wide-spread acceptance of methods, (7 years)

Potential Impacts



Barriers

- Technology development: many facilities (e.g., cities, towns, counties, etc.) that could use this technology have limited capital available.
- Industry and government awareness and acceptance.

Other Guidance

11. Wood Products Research Needs

Introduction

The wood products segment of the forest products industry was not well represented at the roadmapping workshop documented in this report. While many of the identified R&D needs apply to wood products, the technology objectives and R&D needs covered in Chapters 5—10 are not sufficient to be fully representative of the wood products segment. Both the Society of Wood Science and Technology and the Wood Utilization Research program have developed research needs related to wood products.

Wood Utilization Research Program

The Wood Utilization Research (WUR) program supports research at 13 universities in the United States and is funded largely by the U.S. Department of Agriculture. The WUR website, www.woodutilization.org, includes a discussion of its research agenda and plans.


WOOD SCIENCE AND TECHNOLOGY:
A NATIONAL RESEARCH NEEDS ASSESSMENT WORKSHOP
Published: November 30, 2009

Society of Wood Science and Technology

The Society of Wood Science and Technology (SWST) completed a research needs assessment in 2009. The summary report can be downloaded from the SWST website, www.swst.org. Excerpts from the report are included below without changes, in accordance with the SWST copyright policy. Please go to the original document for more detail than is included below.

SWST National Research Needs Assessment

Executive Summary

The mission of the Society of Wood Science and Technology (SWST) is to provide service to members; *develop, maintain, and promulgate the educational, scientific, and ethical standards that define the profession; and advocate the socially responsible production and use of wood and lignocellulosic products*. SWST believes that it is necessary to regularly review research needs in light of drivers and changes occurring within and external to the wood products community. Because of evolving social, economic and environmental priorities and perspectives, it has again become clear that a periodic review of research needs and priorities in wood science and technology was needed in light of today's drivers for change and emerging issues. Accordingly, SWST sponsored a National Research Needs Assessment (NRNA) Workshop (June 25, 2008) in St Louis, Missouri. The NRNA workshop was to provide a forum from which a unified and prioritized vision of research needs in wood science and technology (WS&T) would be created for SWST members. At the same time the American Society of Civil Engineers (ASCE) committed to having a parallel workshop on wood engineering needs and priorities. It was decided that both ASCE and SWST would conduct their respective workshops, then share the outcomes and seek to appropriately merge the two outcomes.

The purpose of this SWST NRNA workshop was to develop a unified and prioritized consensus and then develop an agenda for wood products research needs and opportunities among industry, universities and government. The attendees at the SWST NRNA Workshop acknowledged that the following drivers variously affected societal, economic and environmental needs for research and development:

- Accelerating pace of science and technology
- Growing population and affluence and changing demographics
- Achieving national energy security
- Integration of the world economy with subsequent escalation of industrial quality and cost competitiveness
- Mitigating the impacts of climate change through reduced use of fossil fuels
- Reducing the environmental footprint of human activities
- Reducing the carbon footprint of products and manufacturing processes
- Increasing efficiency of energy- and materials-use
- Emergence of the concepts of Sustainability, Green Buildings, Green Chemistry, and Green Engineering
- Need for making rational comparisons among competing products and materials via use of life cycle assessment

To address these societal, economic and environmental needs, the participants focused discussions on eight broad research areas in wood and lignocellulosic science and its technologies. Many of the social, economic and environmental drivers and critical research issues related to and affected more than one research area. Thus, while it may appear several times, the integrity of the individual research areas has been maintained.

- Those eight research areas were:
- Manufacturing and Processing
- Building Systems
- Fundamentals/Material Science
- Environmental Issues
- Education
- Sustainability
- Marketing
- Modification Technology

From these eight (8) Research Area reviews, the consensus of the participants, as documented in this report, recommends the following actions be undertaken by SWST:

- Influence policy makers about the need for research in the diverse areas in wood science and technology
- Influence public perception about the environmental benefits of using wood and similar bio-based lignocellulosic materials
- Communicate to Congress and funding agencies about the need to support fundamental research in wood science and technology, advanced bio-based composites, and the use of wood as a means to achieve energy efficiency and improved carbon sequestration
- Engage and educate stakeholders and partners in other professions
- Obtain funding from government funding agencies and through partnerships with businesses and organizations
- Develop active research programs to provide fundamental knowledge on wood and lignocellulosic material properties to support development of advanced materials having improved energy footprints and environmental quality
- Transfer research findings to industry, codes and government agencies and incorporate them into user and industrial practices

Recommendations

Manufacturing and Processing

Adopt and adapt technology from allied industries: There is a need to develop and support a contact network that allows for importing ideas and technology from outside the SWST group. New methods are continually being developed and refined for commercial viability for the conversion of roundwood to smaller elements for direct use or reconstitution, and the production of hybrid products combining wood with nanofibers, glass, resins, aluminum and other metals, inorganics, recycled products, etc. to produce items that address societal needs. New ideas and new products are almost always associated with new machinery and equipment, often through cross pollination of ideas with other related disciplines.

Product enhancement: Market consensus suggests that solid lumber and minimally refined engineered composites are favorable with respect to maximizing customer value in the housing sector, that is, the largest market for wood products. A variety of research opportunities remain with respect to retaining maximum lumber value through the conversion chain, improving physical and mechanical properties of existing products, and enhancing durability such as to protect people's homes a major investment.

Optimization: Starting with production forestry, through conversion, final product architecture, and structural design, there is room for further merchandising and optimization. It is appropriate that machine-driven or machine-enhanced decision making be developed and implemented as early on in the conversion process as possible. Furthermore, optimization should be integrated throughout as a means of assuring the maximum possible return on each woody fiber.

Energy policy: Methods to extract energy from wood include direct combustion, gasification, charcoaling, cellulosic ethanol, bio oil, and others. The carbon-based nature of wood makes it attractive as a means of producing green heat, electricity, or other energy. More research is needed with respect to the economic, energetic, and environmental life cycle analysis of bio fuels and bio energy. Such information would contribute to the development of prudent national energy policy, as well as internationally.

Environmental impacts: As an alternative to waste generation from manufacture of wood products, there are potential opportunities to market co-products into the stream of commerce. Waste generation is generally a detractor from green product value, while benefits are often associated with converting waste products into co-products, including cost reduction from the elimination of disposal fees. Examples include selling bark for mulch rather than storing it, selling sawdust for fuel or animal bedding rather than stockpiling it, and condensing vapor to bio-oil as part of the charcoaling process. Promoting waste reduction during manufacture and the development of new markets for co-products are effective means of addressing the issue of environmental impacts.

Building Systems

Develop products through creative use of wood resources; produce wood-based materials from short rotation woody crops, and small diameter timbers for use in building systems.

Improve the design of building systems by maximizing structural performance of wall systems built with wood and wood-based products.

Perform whole house evaluations on the comparative performance of building systems including energy to manufacture, cost to maintain, costs of utilities, air quality.

Develop materials that are more reliable, and sustainable, with components that could be easily recycled or modified.

Design building systems that are durable, that are designed to offer protection from moisture, minimize or prevent condensation, prolonging service life with improved means of protection.

Develop high performance engineered wood products that are lightweight yet strong, with have good insulating properties, and dimensional stability.

Develop methods for reuse/recycling of materials during construction, and for deconstruction.

Evaluate the cost effectiveness of new building systems and materials; their manufacture and maintenance.

Develop user-friendly building systems; adaptive technologies to monitor and control temperature, relative humidity, light, air quality.

Improve the building standards, codes, and rating systems by determining and defining the critical performance measures, evaluating building performance with these measures, and modifying codes, rating systems and standards based on these results.

Fundamentals/Materials Science

These discussions were focused in three areas: Properties, Processing and Products.

Properties

Wood Quality/Material Characterization: Fundamental research is needed for assessing wood quality in traditional and novel products by applying newer rapid technologies such as near infrared spectroscopy, microtomography, NMR, etc. along with the application of statistical analysis tools can help us better understand wood quality.

Nanotechnology: The cellulosic nanocrystallite may provide bio-based nanomaterials for a fraction of the cost of synthetic materials such as carbon nanotubes. Thus, the development of bio-based nanomaterials from forest products, and their properties must continue to be a significant focus area for research.

Genetic Traits and Enhancement: Although significant work has been done in the area of tree genetic engineering, and there is focus on changing wood chemical properties for easier pulping and composite processing, basic wood material characterization work is needed to assess genetically modified wood for physical, mechanical and chemical characterization.

Assessment & Modeling: There is a need to develop conceptual and mathematical models that link the various hierarchical scales of wood structure, utilizing the molecular features of the natural polymers that comprise the wood cell wall to determine how they impact material properties at the macro level.

Processing

Adhesion/Adhesives: Fundamental work is needed on understanding the mechanisms of durable wood adhesive bonds, including studies on electrostatic mechanism of adhesion in wood, the search for whether covalent bonding occurs between wood and any polymer adhesive, the impact of solubility parameters on wood/adhesive bonding, understanding adhesion in wood/cellulose nanocomposites, and multi-scale modeling and simulation of wood adhesion, and bio-based adhesives.

Composite Optimization: Research on the processing parameters required to optimize wood composite products for particular end-product attributes as related to base materials physical, mechanical and chemical properties is necessary.

Nanocomposites and Nanoprocessing: A probable first commercial application of nanotechnology may involve reinforcement of a variety of composite products with nanocrystalline cellulose and other nanomaterials. Process control of adhesion at nanoscale surfaces and quality control/assurance will need to be quantified, understood, and controlled to exploit these technologies.

Composite Modeling: Computational modeling of micro- and nano-scale materials and their processes is necessary to provide both the understanding of the materials and control of the manufacturing processes. Such modeling efforts are critical if new product and process development is desired.

Scaling up: Research funding must be made available for researchers to scale up successful bench scale processes to pilot- and commercial-scale applications, and to facilitate partnerships between researchers and potential industrial partners. Often this area is high risk, but the potential benefits can be huge. We need to create a bridge over the "valley of death" between basic research and commercialization of technologies.

Products

Technology Transfer/Standardization: As new materials are developed, technology transfer and standards development are necessary to move the new products into the industrial arena.

Hybrid Products/Integrated Processing: Research on hybrid wood-synthetic materials and integrated processing systems should receive continued research focus. There are great opportunities for commercial development of such technologies.

Environmental Issues

Develop forest operations that do not impact the environment.

Life cycle analyses of forest-based products including but not limited to carbon accounting, GHG emission, embodied energy, water use.

Promote sustainability throughout forest-to-product value chain.

Promote wood as a green building material by development of green building certification programs, organic/metal free wood preservatives, and durable green wood products.

Promote forest and ecosystem management to ensure the supply of wood for societal use is part of the sustainability of a forest.

Develop policies and practices that minimize particulates and organics emissions from wild fire.

Educate policy makers and the general public on the environmental benefit of using wood products.

Minimize environmental impacts (positive/negative) of plantation forestry relative to water, soil, biodiversity and wood properties.

Education

Develop new curricula at all levels that will educate the public about LCI/LCA, carbon caps and trade, biomaterials, bioenergy, green building, and other topics related to wood and cellulosic materials science.

Develop vehicles for carrying wood science and technology education into other curricula at all educational levels. Teacher education is of particular importance to the effort to improve public perceptions and attitudes.

Develop educational and outreach materials that incorporate interactive technologies including web-based technology and interactive games and simulations.

Better integrate biomaterials science educational programs.

Improve the effectiveness of technology transfer in wood and biomaterials science. This includes improving the translation of science into popular materials for dissemination to the public and expanding audiences for technology transfer activities beyond the traditional industrial client base.

Expand collaborative linkages with other disciplines, in particular teacher education, public relations, and social sciences.

Develop means to successfully assess and evaluate the effectiveness of wood science education.

Sustainability

Life cycle assessment: LCA is the standard method for evaluating the environmental impact of products and processes. There is a need to expand the inventory of life cycle data for wood-based energy and products and document comparisons with substitutes.

Carbon dynamics: One response to climate change is the attempt to sequester carbon in stable 'sinks.' The role of wood products in carbon sequestration is poorly understood and undervalued. There is a need to promote the use of wood products as a means of carbon sequestration.

Industry sustainability: The wood industry is experiencing significant challenges. Access to raw materials, globalized competition and product substitution are important issues. A healthy and sustainable industry is critical to our continued ability to access our most sustainable building material and a significant renewable energy source. Ways to compensate the industry for its ecosystem services, to increase processing efficiency and to reward the production of 'green' products should be investigated.

Product durability and recycling: Wood is a material with low environmental impact. However, increasing product service life and recovery and recycling options will further reduce environmental impacts. The important role of wood energy as part of product use and disposal must also be considered.

The forest resource: Forests are the 'factories' that produce wood products and energy. Thus forest health and sustainability is the foundation for the sustainable use of wood. While forestry is the science that considers the maintenance of forests, wood science can play an important role, by developing and improving the forest products that provide financial and other incentives for maintaining forests as forests. The profitable use of small and low-value trees and the impact of forest biotechnology and forest certification are all areas of research interest.

Modification Technology

Develop advanced wood products that have mechanical properties that span the gap between traditional wood products and steel and concrete.

Develop practical technologies that prevent dimensional change of wood when exposed to changing humidity environments.

Investigate new treatment chemistries to eliminate degradation by fungi or insect attack. Treatment must have low human toxicity, long-term effectiveness, and not leach into the environment. Understand the mechanisms that drive the effectiveness of these treatments.

Characterize the chemical and physical changes, from a holistic standpoint, that occur to the cell wall as a result of chemical, thermal, mechanical, and radiation treatments.

Develop engineering design tools, such as simulation models, to assist with the development of new modified wood products.

Model micromechanical behavior, supported by experimental measurements, to address questions about the mechanics of complex cellular materials like wood, particularly in the presence of changing temperature and humidity.

Explore new liquid phase, gas phase, and supercritical fluid technologies to improve chemical treatment of wood currently hindered by wood's heterogeneity and closed cellular structure.

Research new adhesives and adhesive products targeted toward the manufacture of wood and wood-hybrid composite materials.

Stimulate the development of new forest-based biochemical technologies to produce bio-based wood modifications useful for next generation products.

Focus modification technology on underutilized wood species and wood from intensively managed forest plantations.

Scale research processes up to viable commercial operations.

Conduct life cycle assessment to include the impact of various wood modification processes, and include the impact on duration of useful life as a result of the modification.

Marketing

Based on the drivers identified in the above section, the following research needs were identified that would be helpful to improve the business competitiveness of the forest products industry, as a whole:

- Identify new market opportunities and efficiency in marketing through an educated workforce
- Develop sustainable wood products from the forest to support local economies (reinvigorating the local economy of many states that have been dependent on wood products manufacturing)
- Create market-based mechanisms to match the forest resource to the changing needs of the global economy through more efficient supply chain management
- Examine new promotional strategies to help improve the perception of the consumers about the forest products industry
- Develop strategies to improve the awareness of the importance of forest products to the global consumer as well as to the GREEN consumer (may include the use of Life Cycle Analysis, Environmental and Carbon Footprint and other means)

12. Building on the 2006 Roadmap

The *2010 Forest Products Industry Technology Roadmap* was developed to build on the 2006 roadmap rather than to replace it. In the four years between roadmaps, many changes occurred or are anticipated in the business, social, and regulatory landscapes in which the industry works. In this period, some technologies advanced significantly while others did not.

The 2006 roadmap, which can be downloaded from www.agenda2020.org, presents excellent summaries of R&D needs in several areas. Even though some of the 2006 needs have been developed nicely in the past four years, most of the 2006 needs are still valid for the industry. Many needs overlap directly the needs contained in the 2010 roadmap.

Figure 12.1: Overview of the 2006 Forest Products Industry Technology Roadmap

The 2006 roadmap was based on seven technology platforms, as seen in the ovals of Figure 12.1. Each of these is discussed below along with its areas of focus. Overlap with the 2010 roadmap is outlined for each platform.

Advancing the Forest Biorefinery

- Extract value prior to pulping
- New value from residuals and spent pulping liquors

The Forest Biorefinery platform sought to transform existing manufacturing infrastructure in the industry into centers for production of green energy and bioproducts. Extracting value before pulping and producing new products and power from wood residuals and spend pulping liquors were the primary focus areas. These focus areas are still important to the industry. This 2006 platform directly overlaps "Increasing Value from Biomass," Chapter 8, in the 2010 roadmap. It also has some overlap with "Reduce Carbon Emissions and Energy Consumption," Chapter 5, and "Enable New Products and Product Features," Chapter 9.

Sustainable Forest Productivity

- Biotechnology and tree improvement
- Improving wood quality delivered to mills
- Forest management
- Optimizing ecological functions of managed forests

In this 2006 platform, the objective was to develop and deploy wood production systems that are ecologically sustainable, socially acceptable, energy efficient, and economically viable. Enhancing forest conservation and the global competitiveness of forest products manufacturing and biorefinery operations was the desired outcome. In the 2010 roadmap, these focus areas are still critically important to the industry, and these areas and technology needs are captured in Chapter 7, "Increase Biomass Supply."

Breakthrough Manufacturing Technologies

- Reduced energy in paper dewatering and drying
- Next-generation technologies for pulping and bleaching
- Sheet property development using less energy and materials
- Increased filler/Sustainable cost-effective pigments
- Reduced energy for causticizing
- Reduced energy for black liquor concentration

In the 2006 roadmap, developing breakthrough approaches in manufacturing of wood and paper products was a key theme, in order to significantly lower energy and materials costs. Most of the focus areas in the list above are included in the 2010 roadmap's Chapters 5 and 6, "Reduce Carbon Emissions and Energy Consumption," and "Reduce Fresh Water Use by 50%." The third area, sheet property development using less energy and materials, also is covered in Chapter 9, "Enable New Products and Product Features."

Advancing the Wood Products Revolution

- Manufacturing costs of wood and wood-based products
- Wood-based building materials and systems
- Integrated wood-based building systems
- Understanding and awareness of life cycle impacts

Creating superior, low-cost, high-value, sustainable wood products and wood-based building systems was the objective of this 2006 platform. The current assessment of research needs in these areas is covered in Chapter 11, "Wood Products Research Needs," while a few of these concepts are included in Chapter 9, "Enable New Products and Product Features."

Next Generation Fiber Recovery and Utilization

- Sort systems for recovered paper
- Innovative mill systems for recycled paper and board

The 2006 roadmap targeted making recycled fiber interchangeable with virgin fiber with respect to product quality, functionality, and availability. The focus areas were directed at improving the quality and quantity of recovered fiber and improving process technologies at recycling mills. In the 2010 roadmap, this platform aligns directly with Chapter 10, "Increase Recovery and Recycling of Waste Products."

Positively Impacting the Environment

- Create beneficial uses for solid wastes
- Eliminate detectable odors
- Reduce effluent discharges
- Reduce energy consumption for air pollution control
- Reduce energy and costs for biological effluent treatment

Developing an optimal mix of in-process and add-on technologies that would facilitate continued improvement of the industry's environmental performance was targeted in 2006. For the 2010 roadmap, environmental aspects are included in several of the 2010 issue areas, including Chapter 5, "Reduce Carbon Emissions and Energy Consumption," Chapter 6, "Reduce Fresh Water Use by 50%," and Chapter 10, "Increase Recovery and Recycling of Waste Products."

Technologically Advanced Workforce

In 2006, the roadmap developers recognized the need for training and education of employees, both current ones and potential new hires, to ensure that new and existing technologies used in the future forest products industry would be operated by a technically superior workforce. Since 2006, good progress has been made in this task. Tappi, a professional society for the paper industry, developed a recruitment kit which is accessible at www.careersinpaper.org, highlighting the strengths of the industry as an employer. The National Network for Pulp and Paper Technology Training (npt)[2] has grown with financial support from the National Science Foundation and has developed a strong curriculum for pulp and paper training, with emphasis on training classes at community colleges near pulp and paper mills. Learn more about (npt)² at www.npt2.org. The oversight of the Technologically Advanced Workforce platform transferred from the Agenda 2020 Technology Alliance to Tappi because this area did not involve developing new technologies and it fits well with Tappi's mission, although Agenda 2020 continues to receive status updates through Tappi's participation in Agenda 2020.

Summary

The two-stage process for developing the 2010 roadmap did not use the 2006 roadmap as a starting point. Instead, the process first engaged business and policy leaders in identifying critical issues facing the industry from business, social, and regulatory perspectives. In the second stage, technical experts discussed technology solutions needed in the critical issue areas identified in the first stage. As a result, the structure of the 2010 roadmap looks very different from that of the 2006 version. However, the set of research and development needs in the two roadmaps overlap to a high degree and the two versions align well with each other. An overall analysis of how the 2006 roadmap aligns with the 2010 version is presented in Figure 12.2.

Figure 12.2: Alignment of 2006 Roadmap with 2010 Roadmap

2006 ROADMAP	*2010 ROADMAP*
Advancing the Forest Biorefinery • Extract value prior to pulping • New value from residuals and spent pulping liquors	**Increase Value from Biomass** *Secondary:* • Reduce Carbon Emissions and Energy Consumption • Enable New Products and Product Features
Sustainable Forest Productivity • Biotechnology and tree improvement • Improving wood quality delivered to mills • Forest management • Optimizing ecological functions of managed forests	**Increase Biomass Supply**
Breakthrough Manufacturing • Reduced energy in paper dewatering and drying • Next-generation technologies for pulping and bleaching • Sheet property development using less energy and materials • Increased filler/Sustainable cost-effective pigments • Reduced energy for causticizing • Reduced energy for black liquor concentration	**Reduce Carbon Emissions and Energy Consumption** **Reduce Fresh Water Use by 50%** *Secondary:* • Enable New Products and Product Features
Advancing Wood Products • Manufacturing costs of wood and wood-based products • Wood-based building materials and systems • Integrated wood-based building systems • Understanding and awareness of life cycle impacts	**Wood Products Research Needs**
Next Generation Fiber Recovery • Sort systems for recovered paper • Innovative mill systems for recycled paper and board	**Increase Recovery and Recycling of Waste Products**

Figure 12.2: Alignment of 2006 Roadmap with 2010 Roadmap (cont.)

2006 ROADMAP	*2010 ROADMAP*
Impacting the Environment • Create beneficial uses for solid wastes • Eliminate detectable odors • Reduce effluent discharges • Reduce energy consumption for air pollution control • Reduce energy and costs for biological effluent treatment	**No Direct Match** *Some aspects are covered in:* • Reduce Carbon Emissions and Energy Consumption • Reduce Fresh Water Use by 50% • Increase Recovery and Recycling of Waste Products
Technologically Advanced Workforce	**No Direct Match** The 2010 roadmap addresses technology needs rather than workforce development. Oversight of this platform transferred to Tappi

13. Roadmaps and Technology Programs Outside the United States

Developing new breakthrough technologies for the forest products industry is a global effort and not one confined to the United States. Several programs from other parts of the world are noteworthy, both for their commitment to producing new technologies and for their overlaps with the U.S. roadmaps. U.S. efforts towards developing new technologies must stay abreast of the advancements taking place in Europe, Canada, China, Brazil and other locales, and seek opportunities for collaboration and cooperation. Some of these international programs are highlighted below.

Europe

The European Union (EU) has encouraged development of emerging and breakthrough technologies for a range of industries through a series of framework programme. The **Seventh Framework Programme for Research and Technological Development** (FP7) is the EU's main instrument for funding research in Europe. FP7 was designed to respond to Europe's needs for employment, competitiveness, and quality of life, and will run from 2007 to 2013. It has a budget of more than €50 billion over its seven year span.[17]

Forest-Based Sector Technology Platform

One key component of the Seventh Framework Programme is the **Forest-Based Sector Technology Platform** (FTP), a European partnership for research and development. The FTP is an industry-driven platform for collaboration in a sector that makes crucial contributions to Europe's sustainable development and competitiveness.[18] It was formed by an initiative of the European Confederation of Woodworking Industries, the Confederation of European Forest Owners, and the Confederation of European Paper Industries, and later joined by the European State Forest Association. These associations, and a wide range of supporting stakeholders, saw the necessity of establishing a technology platform for forest-based manufacturing.

FTP Vision for 2030

The European forest-based sector plays a key role in a sustainable society. It comprises a competitive, knowledge-based industry that fosters the extended use of renewable resources. It strives to ensure its societal contribution in the context of a bio-based, customer-driven and globally competitive European economy.

The FTP has defined and is currently implementing a research and development roadmap for the European forest-based sector.

Strategic Research Agenda

During February 2006, after nearly one year of thinking, writing, and debate involving an estimated €3.4 million investment, over 700 proposals from across Europe were condensed into a **Strategic Research Agenda** (SRA) for the FTP. Through innovative joint R&D activities, the SRA will strengthen the sector's competitiveness and contribute to improving European quality of life.

The SRA is based on proposals spanning the sector's full range of complexity and variety—from paper to packaging, construction to bio-energy, new trees to new trends. Stakeholders from all areas, including industry, forest owners, researchers, and public bodies, participated in formulating the Agenda, while European Commission representatives observed. Sustainability, development and manufacturing of innovative products, resource availability, multiple forest uses, biodiversity, bio-energy production, and energy efficiency—in tackling these areas and more through its five strategic objectives, the Strategic Research Agenda is clearly an ambitious undertaking.[19]

The FTP Strategic Research Agenda includes five strategic objectives[20], as shown below with intended research areas under each objective. They agree well with the U.S. objectives outlined in this report. The many areas of common interest suggest the possibility of collaboration with European scientists towards common goals, and highlight the importance of remaining aware of research progress in other national communities.

FTP Strategic Research Agenda: Five Strategic Objectives

1. Development of innovative products for changing markets and customer needs
   - A new generation of functional packaging
   - Paper as a partner in communication, education and learning
   - Advancing hygiene and healthcare
   - Living with wood
   - Building with wood
   - Commercializing soft forest values
   - Moving Europe with the help of biofuels
   - Pulp, energy and chemicals from wood biorefinery
   - "Green" specialty chemicals
   - New generation of composites
2. Development of intelligent and efficient manufacturing processes, including reduced energy consumption
   - Reengineering the fibre-based value chain
   - More performance from less inputs in paper products
   - Reducing energy consumption in pulp and paper mills
   - Advanced technologies for primary wood processing
   - New manufacturing technologies for wood products
   - Technologies to boost heat and power output
3. Enhancing availability and use of forest biomass for products and energy
   - Trees for the future
   - "Tailor-made" wood supply
   - Streamlined paper recycling
   - Recycled wood products—a new material resource
4. Meeting the multifunctional demands on forest resources and their sustainable management
   - Forests for multiple needs
   - Advancing knowledge on forest ecosystems
   - Adapting forestry to climate change
5. The sector in a societal perspective
   - Assessing the overall performance of the sector
   - Instruments for good forest sector governance
   - Citizens' perceptions

Other Sector Technology Platforms

In addition to the Forest-Based Sector Technology Platform, the European Union supports other industrial sectors. Technology platforms of interest to the forest products industry are as follows:

- European Construction Technology Platform: www.ectp.org
- MANUFUTURE—Platform on Future Manufacturing Technologies: www.manufuture.org
- Plants for the Future: www.epsoweb.org/Catalog/TP/index.htm
- SUSCHEM—Technology Platform on Sustainable Chemistry: www.suschem.org
- Water Supply and Sanitation Technology Platform: www.wsstp.eu/site/online/home
- Biofuels Technology Platform: www.biofuelstp.eu

Canada

In 2008, the Government of Canada identified forestry research as a priority area to sustain the Canadian economy over the next decade.

Forest Sector R&D Initiative

The Canadian government supports research and development programs for the forest products industry through its **Natural Sciences and Engineering Research**

Council of Canada (NSERC). NSERC has partnered with FP Innovations and Natural Resources Canada (NRCan) to create the **NSERC Forest Sector R&D Initiative**, a Can$34 million, five-year initiative to support commercially relevant research programs that will create new market opportunities for the Canadian forest sector.

All three organizations have agreed that the **FP Innovations Flagship Innovation Program** is the best mechanism to ensure increased research collaboration within the forest sector innovation system. This program contains five research themes[21]:

- Next Generation Building Solutions
- Next Generation Pulps and Papers
- Energy and Chemicals from Forest Biomass
- Novel Bioproducts from Forest Biomass
- Integrated Value Maximization

To complement the FP Innovations Flagship Innovation Program, and as part of the NSERC Forest Sector R&D Initiative, NSERC established four new NSERC forest sector strategic networks in 2009:

- Biomaterials and Chemicals
- Innovative Wood Products and Building Systems
- Innovative Green Papers
- Value Chain Modeling

Each of these initiatives will be funded at up to Can$1 million per year for a five-year period.

ArboraNano

In addition to the FP Innovations program, the Government of Canada established **ArboraNano**—the Canadian Forest NanoProducts Network—as one of four new business-led networks. ArboraNano is receiving Can $8.9 million over four years. Announced in Budget 2007, the goal of the business-led networks of Centres of Excellence program is to fund large-scale, collaborative networks led by the private sector and focused on specific business research needs.

ArboraNano, a research and development network bringing together nanotechnology and forest sector expertise, will strive to create a new Canadian bio-economy based on innovative, highly-engineered, carbon-neutral products containing nanomaterials. Wood and wood fiber from Canada's vast forests can converted into high-value nanomaterials and intermediates, and these can be used to produce a variety of unique advanced products, with a focus on these opportunities[22]:

- Reinforced polymers
- High-strength spun fibers and textiles
- Advanced composite materials
- Films for barrier and other functions
- Coatings, paints, lacquers, and adhesives
- Switchable optical devices
- Pharmaceuticals and drug delivery
- Bone replacement and teeth repair
- Improved paper and packaging products
- Improved building products
- Additive for foods and cosmetics
- Aerospace and transportation

Biopathways

The Canadian forest products industry determined that integrating the production of bioproducts and bioenergy into existing forestry operations is an opportunity for growth, and calls on the Canadian government for additional investments in R&D to develop technologies needed to make this happen[23].

The Future Biopathways Project examined a wide range of options for renewal of the Canadian forest products industry. The project involved more than 65 top Canadian experts in fields as diverse as bio-technology, investment banking and carbon pricing. The study places traditional products, especially lumber and pulp, at the heart of a new, green business model for the Canadian industry, with emphasis on integrating bioenergy and bioproducts manufacture with existing mills that make wood products, pulp, and paper. Go to www.fpac.ca for more information.

Other Nations

Many other countries have notable programs in forest products technologies, and most of the research priorities have elements in common with the U.S. technology roadmaps. Australia, Brazil, New Zealand, Japan, South Korea, and China have effective R&D capabilities in forest products.

14. Implementation

This roadmap has provided an overview of six strategic issues facing the forest products industry today and shown how they are relevant to both societal and national goals and the entire industry value chain. It has translated each strategic issue into technology objectives. For each technology objective the roadmap identifies research and development (R&D) advancements that would lead to new technology solutions that the industry could use to achieve the objective. For the industry companies, this content responds to their common concerns and promotes collaboration to strengthen the forest products value chain and enhance global competitiveness. For the R&D community, this content identifies points of entry for specific research endeavors and creates a line of sight from R&D activity to deployable technology solutions that serve both the industry and society.

Establishing the line of sight for R&D helps to bridge the technology transfer gap and enable a smooth transition between advancements in scientific knowledge and the commercialization of products and processes that directly address industry needs. The roadmap's implementation—including the degree of ongoing communication between industry and the research community, the continual monitoring of changing industry trends, and the periodic updating of the roadmap—will greatly influence the degree to which R&D efforts remain aligned with the technology needs of the industry.

Figure 14.1 outlines an implementation process that will help the roadmap achieve its designed impact. The process consists of four interconnected phases: Roadmap Communication and Oversight, R&D Assessment, R&D Activity, and Technology Transfer.

Roadmap Communication and Oversight

The first phase of roadmap implementation is the communication and socialization process, which involves the publication, dissemination, and promotion of the roadmap among stakeholders. Socialization enables stakeholders to recognize both the value of the roadmap and the importance of a vital and prosperous forest products industry. For industry companies along the value chain, it is a call to arms to unite around common industry needs and objectives and form partnerships that enable industry-level efforts in these shared areas. For the R&D community it is a request for help and the promise of significance and impact for their research efforts. It is an opportunity for both funding sources and researchers to find points of connection and common interest between their research agendas and the needs of the industry.

Communication is an important first step because it showcases the essential features of the roadmap that can inspire and motivate industry collaboration and R&D efforts. The six strategic issues identified as priority concerns for the forest products industry also represent larger social matters that have critical and immediate importance, such as addressing climate change, stewardship of natural resources, and independence from foreign oil. The roadmap demonstrates the importance of the forest products industry in addressing these concerns.

In addition, communication and socialization leverage the value of the roadmap as a model for creating research partnerships that bring together industry, academia, research institutions, and government stakeholders. In particular, the roadmap demonstrates an approach for establishing and maintaining an R&D line-of-sight that helps to bridge the technology transfer gap and enables a smooth transition between technology innovation and commercialization.

The Agenda 2020 Technology Alliance will carry out the publication, dissemination, and promotion of the roadmap. Early on, the Alliance will also call on representatives from both the research community and industry to serve as oversight committees tasked with keeping the roadmap current and seeking programs to advance the technology priorities using Agenda 2020's staged development process. These groups within Agenda 2020 will provide a direct connection to the key stakeholders who have a working role in implementing the roadmap. Agenda 2020, in performing its oversight function, will spearhead the ongoing implementation effort and perform core activities to sustain momentum, facilitate partnerships, and align contributions.

R&D Assessment—Mapping and Prioritizing

Effective implementation of the roadmap will require Agenda 2020 to carry out two ongoing initiatives. In collaboration with the R&D community, it will conduct a periodic assessment of current R&D activities in government and academia and then map these activities against the framework of issues, objectives, and needs identified in the roadmap. This mapping initiative will provide the basis for tracking progress, verifying the development stage, identifying gaps and opportunities, and updating the roadmap itself. It will also help the industry to keep stakeholders abreast of new developments and changing priorities.

Second, Agenda 2020 will work with industry to maintain a current list of the highest priority issues, objectives, and needs. The roadmap intentionally casts a wide net to engage the broadest possible audience in the R&D community. At the same time, however, it is important for the industry to maintain a sense of urgency with respect to a narrow set of critical priorities.

R&D Activity—Collaboration and Alignment

At this stage the R&D community will begin researching and responding to applicable requests for proposals (RFPs) related to the high priority research areas and collaborating with industry to obtain various government sources of funding. Agenda 2020 will work to facilitate this collaboration by tracking RFPs and helping to create partnerships. Agenda 2020 will continue to monitor R&D activity and keep the research community informed of significant industry developments, which could influence or change the industry's major technology objectives and needs. This ongoing monitoring and communication helps keep R&D initiatives aligned with industry needs.

Technology Transfer—Demonstration and Deployment

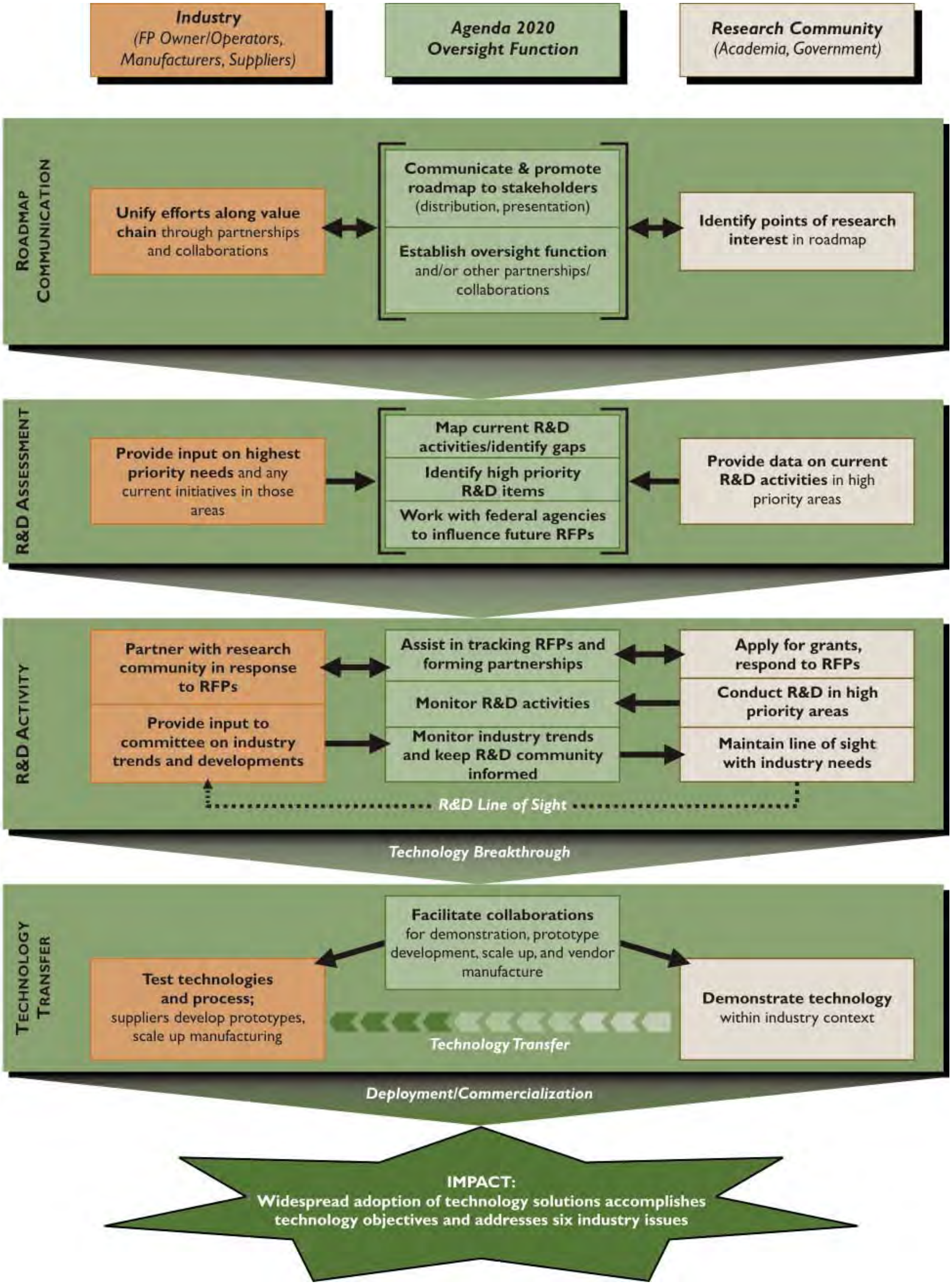
R&D initiatives that remain aligned with industry goals are likely to result in breakthrough technologies that industry will want demonstrated in commercial settings. Collaborations among the research community, suppliers and industry will be critical for testing new technologies and processes. At this stage, manufacturing facilities will begin integrating new processes into their operations, and suppliers will begin to manufacture the new proven technologies demanded by manufacturers. As before, Agenda 2020 will work to facilitate these collaborations.

Figure 14.1 indicates that the ultimate impacts of the roadmap will be the commercialization and widespread adoption of technologies that meet the roadmap technology objectives and help address the six strategic issues.

Sustaining Efforts

Initially, implementation of the roadmap is a linear process whereby these phases occur consecutively. Over time, however, the implementation must transition to an ongoing process which includes revisions to roadmap goals and priorities. At this point, the stages become concurrent and intertwined. Roadmap promotion leads to collaboration and partnerships that in turn promote the roadmap. R&D efforts produce technologies that are commercialized, impacting the industry and potentially altering industry needs. As industry issues are reassessed, technology priorities change and require adjustment in the focus and alignment of R&D efforts. Agenda 2020 provides the organization and leadership to encourage ongoing R&D activity and keep this activity aligned to industry needs.

Figure 14.1: Roadmap Implementation Framework



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Appendix B: Workshop Raw Results

Note: *The orange dots indicate voting results by the work group for the highest priority R&D needs.*

Carbon & Energy—R&D Needs for Technology Objectives

Generate Energy More Efficiently	Use Energy More Efficiently In Existing Technology (Current Unit Operations)	Breakthrough Technology To Reduce Energy Demand (Major Change In Unit Operations)	Eliminate CO_2 Generation From Fossil Fuels	Capture Co_2 & Use It
• Black liquor gasification • • • • • • Improve energy efficiency of recovery boilers • New materials to enable higher temperature operation like utilities, up from 900°, especially in recovery boilers • • • • Advanced gasification combined-cycle technologies for both black liquor and solid forest-based biomass • Development of advanced black-liquor-fired recovery boilers with electricity-generating efficiencies significantly higher than those of present-day standards • Significant improvement of fluidized-bed boilers to achieve high steam values (power outputs) with difficult-to-handle forest-based biomass fuels	• Greater recovery and utilization of waste heat • • • • • More efficient mechanical pulping—next generation refiner • • • • Dry wood more efficiently • • Alternate way to change sulfate to sulfide • • More efficient use of steam • Reduce energy in chemical pulping—including pumping pulp and chemicals • Reduce energy in paper forming and pressing	• Deliver a drier sheet to dryer section 55%–65% • • • • • • • • • • • Reduce energy intensity of fiber preparation • • • • • • • • Reduce product basis weight required to enable a given product's intended function ("lightweighting") • • • • • • Improve lime kiln efficiency • • • • • Major redesign of papermaking process to significantly reduce water, energy, chemicals • • • • • Alternate chemical recovery or alternate pulping chemistry—target energy in black liquor evaporation and lime kilns • • • Develop paper drying process that uses 50% less energy • • • Improve energy use—drying technology—high consistency forming • • Alternative forms of energy delivered (not steam) to process • • Use ethanol or supercritical CO_2 to replace water in pulping • Specific to Reducing Pulp & Paper Process Water: • Reduce energy for black liquor concentration by 50%—including reducing pulp washing water usage • • • • • • • • • Increase pulping consistency to 30% from current levels of 15–16% (water removal) • • • • • Reduce process water needs to that which enters with wood (don't add water) • •	• Renewable source for non-steam thermal demand—use biomass to replace fossil energy • • • • • • • • • • Waste water treatment as energy source - recover VOC's • • • • • • • • Eliminate fossil fuel use in or need for lime kiln • • • • • Incineration of internally generated solid waste stream (e.g., clothing, pallets, sludge) • • • More lignin utilization for energy resource • • • Develop hydrogen utilization technology, thermal, solar • • • Advanced process to competitively produce synthetic natural gas from forest-based biomass	• Co-generation of fuels—algae (CO_2 feed) (Target trees optimized for co-gen) • • • • • • Recovery of CO_2 from lime kiln stack • • • • Algae production, alternative product (ethanol, biodiesel, biomass), create solid product

Fresh Water Group—R&D Needs by Technology Objective

Drastically Reduce The Amount Of Fresh Water Used In Pulping And Papermaking	Develop Technologies For Reuse Of Effluent In Plants After Treatment	Develop Closed-Loop Water Systems
• Chip leaching/VPP hemicellulose extraction to remove metal ions (Build on European work) ●●●●●●●●●● • Improve process modeling tools (for engineering studies) ●●●●●●●●● • Chemical equilibrium for ion tracking • Lifecycle analysis on chemical inputs • Combine Aspen and Wingems for best combination of modeling options • Trace components—colloids • Survey mills on high ion streams • Pulp washing with less fresh water ●●●●●●●●● • Alternative washing processes (improved) • Pressurized washing (high temperature and pressure) • Alternative processes for avoiding washing—biomimetic, supercritical CO_2, nanotechnology, liquid-ion separation, membranes • Understand how metals are fixed in the wood ●●●● • Develop engineered trees to avoid calcium and barium ●●● • Transgenics and biotechnology • Wood component to capture minerals • Alternative pulping processes, i.e., solvent, that will use less water ●● • Improved filtration systems for use with secondary fiber processing • Paper machine with less fresh water—high consistency web forming • Improve digester process and reduce water input • Recover fresh water from vapor losses (<25% of process water) • VPP hemicellulose extraction, segregation in bleach plant, water treatment—remove non-process elements (NPEs) to enable more water reuse in mill	• Separation of low-concentration contaminants ●●●●●●●●●●●●●● • Physical, chemical, biological • Calcium and barium removal and other ions • Combinatorial treatment • Remove ions to be able to reuse filtrate as fresh water ●●● • Avoid scaling issues for process water ● • Heat recovery system to discharge water at intake temperature and to recover waste heat for process	• Testing protocol for in-plant evaluation—process water streams, to evaluate new technologies ●●●●●●● • Performance validation • Over-the-fence • Survey mills on waste water to determine ability to close system ●●● • Apply biological treatments earlier in process (in-pipe) rather than at central waste treatment plant ● • Distributed effluent treatment—electrochemical, other • Heat recovery system to avoid excessive water temperatures

Biomass Supply Group—R&D Needs by Technology Objective

Tree Property Improvement	Efficient Harvest Supply Chain	Produce More Wood	Management Systems
• Develop trees designed for conversion to specific products • Design trees with high α-cellulose and low lignin content that: a) require no pretreatment prior to hydrolysis and fermentation and b) lead to 10% higher yield of pulp from wood in kraft pulping • How to value woody biomass materials for biofuels and bioenergy—quick moisture content, quick energy content • Improve methods to create high-value trees through genetic engineering technology • Improve methods to multiply high-value trees (from breeding/selection or genetic engineering programs) (e.g., somatic embryogenesis technology)	• Harvest, process and deliver range of forest biomass with desired quality at competitive cost in a sustainable manner • Process biomass with minimum supply chain costs and minimum ecosystem disturbance • Increase productive capacity of wood supply logistics • Event-related issue: Facing increasing fire and invasive species or bugs out of range. Maximize capacity to utilize supply, transport/storage of damaged wood • Restore productivity to degraded/threatened landscapes	• Increase production of usable woody biomass that includes efficiency and return to landowner • Increase growth rates by genetic improvement • Through genetics/biotechnology, develop trees capable of growing biomass at rates that offer landowners incentive to plant plus returns comparable to saw timber • Apply appropriate silvicultural techniques (nutrient, water, vegetation management) • Optimize nutrient supply to planted forests	• Develop silvicultural and management regimes to provide biomass as a product to support industry needs and landowner objectives • Develop trees and forest management systems to increase the outputs from a unique forest stand: wood products and biomass productivity plus carbon sequestration • Management systems that integrate energy feedstock production with other product objectives • Development of cropping systems that support existing as well as new biomass markets • Incorporate CO_2 management and environmental factors into multiple objective/management systems • Monetize multiple objectives • Minimum ecosystem disturbance. Increase confidence, gain license to manage—guarantee actions don't reduce other functions—recognize adaptation • Managing forests for multiple objectives

Biomass Supply Group—R&D Needs by Technology Objective

Develop Trees Designed For Conversion To Specific Products (Tree Property Improvement)	Harvest, Process And Deliver A Range Of Forest Biomass With Desired Quality At Competitive Cost In A Sustainable Manner (Efficient Harvest Supply Chain)
• Genomics of major species ● ● ● ● ● ● ● ● ● • Pine Genome Initiative (P.G.I.) • Improve methods to multiply high-value trees (conifers) (e.g., somatic embryogenesis technology) ● ● ● ● ● ● ● • Improve methods to insert foreign genes into high-value conifers (genetic engineering) ● ● ● ● • Expand varietal selection and testing for mass controlled pollinated (MCP) orchard initiation—pines/Douglas fir ● ● ● • Increase the integration between classic tree improvement and biotechnology ● • Develop trees with higher bulk density to aid transportation cost, lower moisture content to aid drying cost ● • Increase growth rates at reduced cost (seedlings) • Biotech trees adaptive to climate change and other stressors. • Screen current populations for ability, affinity to adapt. • Common garden seed banks • Identify traits under genetic control with variation • Insert genetic material that is designed to trigger enzyme hydrolysis in cellulosic materials under specified process conditions to overcome current recalcitrance of softwoods in biochemical processes • Identify genetic markers for lignin and cellulose growth in commonly available woody crops and develop ability to promote or reduce growth (depending on end use)	• Demonstrate harvesting systems capable of efficient multi-product separation and delivery ● ● ● ● ● ● ● ● ● ● ● ● • Fuel-efficient and productive systems for collecting small stems and crown biomass • Develop harvesting machines adapted to different kinds of forest—bigger and smaller trees, cloned and seedling forests, etc. • Develop equipment and processes to cost effectively resize, dry and transport woody biomass to meet predetermined gate prices • Fuel efficient, high capacity, environmentally sensitive, small-scale equipment • Effective short-rotation woody crop (SRWC) management systems—integrating genetic material, silviculture, harvesting technology ● ● ● ● ● • Develop more robust and reliable low cost equipment that simultaneously harvests and chips short rotation woody crops (less than 4" diameter) on a whole tree basis • Whole tree harvest systems for small diameter and coppice crops • Techniques and protocols for rapid and accurate assessment of processed feedstock characteristics—moisture content, ash, nutrients, lignin, Btu, etc. ● ● ● ● • Develop organizational and logistics systems to improve performance ● ● ● • Develop long-term supply strategies including biomass storage to equalize supply, level supply distance (long-range) ● • Increase Btu value of harvested biomass ● • Define financial viability of forest operations contractors • "Sustainable Wood Procurement" • Wood and bark separation (clean chipping) technology for value-added product production

Biomass Supply Group—R&D Needs by Technology Objective (cont'd)

Increase Production Of Usable Woody Biomass, Including Efficiency And Return To Landowner (Produce More Wood)	Develop Silvicultural And Management Regimes To Provide Biomass As A Product To Support Industry Needs And Landowner Objectives (Management Systems)
• Nitrogen use efficiency ●●●●●●●●●● • Synthesize information from existing whole tree harvesting studies to help determine sustainable options • Produce more wood with fewer inputs • Quantitative tools to assess biomass and nutrients available in understory, crowns, and downed materials—live or dead • Study beneficial tree endophytes to improve growth • Better understanding of soil characteristics (nutrients, organic matter)—what will happen in long term • Quantify C, N, etc. that can be removed while maintaining site productivity • Understand motivation of next generation of landowners with production of biomass—craft/develop strategies. ●● • Evaluate forest landowner attitudes/motivation to increase supply • Develop understanding of maximum production for biomass by region of U.S. ● • Develop approaches to tailor understory plantings to increase wood supply • Determine optimum planting density, fertilization and growth cycle for a wide variety of bio-energy crop candidates that maximizes bone-dry tons of biomass per year in order to maximize landowner return	• Model growth and yield for mixed management systems ●●●●●●●●●● • Determine planting densities, species selection and thinning regimes to produce maximum volumes for an array of products—bio-feedstock /fiber/solid wood • Evaluate planting densities, inter-cropping, high technology vs. low technology trees • New systems using open-pollinated (OP) pine • Aspen management systems that increase productivity of aspen • LCI (life cycle inventory) for management systems as part of overall product LCA (life cycle analysis) ●●●●● • LCA of forest operations with full range of impacts • Develop valuation models for non-fiber forest outputs ●●● • Develop ecosystems supporting market technologies/economics to diversify landowner investments • Understanding land use implications for supply investments ●●● • Technology to include marginal areas not considered today

Value from Biomass Group—R&D Needs by Technology Objective

Processes That Scale To The Feedstock Availability	Maximize Return On Existing Assets Through Products With Added Value Higher Than Current Mix Of Products (Pulp/Wood Products, Energy, Fuels, Electricity, Chemicals)
• Catalyst development for product flexibility/scalability ●●●●●● • Syngas conditioning and clean up is a major cost before catalytic processes. How much cleaning is really needed? ●●●●●● • Develop technologies which are not capital intensive - pyrolysis and upgrading ●●●●● • Scaled down economic Fischer-Tropsch process (microchannel approach) ●●● • Economic processes for concentrating dilute solutions of ethanol, butanol, etc. ●●● • Flexibility in material handling and processing. Feedstock independent pulping process/papermaking ●● • Prioritize R&D investment on use of newest generation enzymes for biomass-to-ethanol conversion ●● (This need relates to Biomass Supply need "Insert genetic material that is designed to trigger enzyme hydrolysis in cellulosic materials under specified process conditions to overcome current recalcitrance of softwoods in biochemical processes") • Step change in biomass transportation cost by increasing energy density ● • Economical approach to non-acid hydrolysis • Identify high value bio-products and viable processes to produce them • Develop processes that are efficient at widely varying processing rates to account for feedstock seasonality • Test use of existing commercial equipment at 100–300 dry tons per day • Energy conservation—power and heat integration	• Find processes to produce lignin-based materials with higher value than fuel value ●●●●●●●●●● • Chemicals, polymers, and advanced fuels from sugars (Develop region-selective catalyst for conversion of sugars ●●●●●● • Develop new uses/markets for carbon fibers and nanocellulose-based materials ●●●●● • Develop a viable black liquor gasification process and bring to market ●● • Effective heat and water process integration of pulp mill with bio-refinery processes ●● • CO_2 capture and conversion ●● • Relook/develop new policies that are enabled by transition to biorefineries ● • Improve chemical pulping yield by 50+% • Quick-turnaround paper machines (process) to enable smaller production runs • Biochemical conversion to value-added products

Value from Biomass Group—R&D Needs by Technology Objective (cont'd)

Maximize Profit From Purpose Grown Crops	Processes That Are Flexible To Produce Different Products, Depending On Market Conditions	Separation Of Woody Biomass Into Usable Components
• Genetically engineered plants with low recalcitrants •••••••• (This need relates to Biomass Supply need "Insert genetic material that is designed to trigger enzyme hydrolysis in cellulosic materials under specified process conditions to overcome current recalcitrance of softwoods in biochemical processes") • Develop pulp mills that can run on low lignin (<15%) biomass with efficient heat and power systems •••••••• • Methods to manipulate lignocellulose/wood chemical components •••••• • Maximize carbon in biomass for thermochemical biorefinery technology platform •••• • Develop high hemicellulose, high lignin, and low cellulose biomass sources for thermochemical technology platform • • Biomass with high complex-polysaccharide content	• Flexible biomass fractionation technologies ••••••••• • Efficient processes for production of platform molecules ••••••• • Custom microbes for specific fermentation production ••••• • Sugar conversion platform—multiple products from same sugars—polyhydroxyalkanoates, furfural, propane, butanol, etc. •••• • Catalyst development for syngas and pyrolysis reformation •••• • Low-cost catalytic reactors that can be changed to make different chemicals • Flexible pre-extraction coupled with flexible pulping process • Sensors/systems that can select trees to harvest based on current product needs • Processes based on standard feedstocks: pellets, chips, boles, sugar solutions	• Affordable size reduction techniques ••••••••••• • Solvent and/or enzymatic deconstruction •••• • Supercritical water (SCW) depolymerization ••• • Universal, low-cost, high-volume separation technology ••• • Pulping or other processes that allow separation of lignin in form useful for production of carbon fibers, etc. •• • Physical separation of biomass components •• • Counter-current fractionation of wood components via pH and temperature profiling •• • Cost-effective breakthrough membrane technology • Non-sulfur pulping

Product Features Group—R&D Needs by Technology Objective

Achieve Biomass-Based Packaging Developments That Both Meet Customer Needs And Compete With Non-Renewable Materials (Near-Term ~3 Yrs)	Achieve A 20–50% Improvement Performance/Weight Ratio Paper And Packaging Products (Near-Term ~3 Yrs)
• Bio-based coatings and structures that can function in paper-based packaging like synthetic polymers in thin films in paper packaging designs ● ● ● ● ● ● • Identify surface treatments to reduce water permeability of cellulosics (plasma, inorganic or organic coatings, and texture) ● ● ● ● • Need a material-independent measure of oil and grease barrier ● • All wood—characterize biomass compounds for physical and chemical properties—link with properties of non-renewable materials ● • Need quicker measure of oxygen and moisture barrier in evaluating packaging materials. Go from hours to minutes ● • Develop physical/chemical barriers to prevent or control the transfer of moisture and other vapors • Effective means of replacing air in paper with filler, bio-polymer, etc. • Determine effective impregnation process to achieve barrier properties • How to manipulate the permeability to vapor/moisture transport • New package features: high clarity film/package, high toughness package, "3D" printable images, imbedded ID tagging, anti-microbial • Develop moisture-resistant wood fibers using inexpensive OH and C-OH end group modification • Develop "green" barrier coatings, moisture, air/gas, and water • Biomass composite sheets that require less energy than traditional composites • Find a use for "fiberclay" in coating and sheet strengthening—a byproduct of recycling printing papers • Biomass packaging—develop "formable" paper as alternative to box/bottle/can—bio-based, resealable too • Characterize the "lotus leaf" surface appearance so that it can be mimicked on packaging surfaces	• Improve interfiber bonding by understanding interfacial interactions of fiber and other furnish components at the nanoscale and microscale ● ● ● ● • Understand the structural strength limits of structured/layered materials using nanocrystalline cellulose and lignin derivatives ● ● ● • Develop controlled-porosity base sheets, e.g., vapor injection during forming or drying, to enhance bulk ● ● ● • Develop stronger flute geometries for corrugated boxes: a) linear fluting, b) multi-fluting constructions, c) flute to flute, d) cross-fluting ● ● • Bulking approaches with minimum impact on paper physical properties ● • Basic characterization of nanocrystalline cellulose and contrast and compare to carbon nanotubes ● • Dispersion and alignment of nanomaterials within a pulp stream ● • Develop processes for aligning cellulose nanocrystals ● • Air loading process for fibers before and during web forming, to achieve very high bulk fibers, and find economical blowing agents and stilling agents • Develop structured flexible coatings that increases product strength • Chemical and physical characteristics of basic components of fibers • Use biomimetic nano and microstructures to achieve more efficient (less mass) mechanical, transport, or optical characteristics in paper and paperboard • Improve the durability of paper/board through fiber treatment and/or functionalization • Need to understand (math model and measure) the contribution of coating layer vs. fiber base to stiffness and strength properties • Performance/weight ratio—develop additives to increase tear strength • Use cellulosic ethanol waste by-product to develop new corrugating adhesives for lighter weight of boxes • Utilize/adapt finite element analysis simulations, confirm w. experiments to model structures

Product Features Group—R&D Needs by Technology Objective (cont'd)

Develop Paper With New Features Including Ability For Passive And/Or Active Reaction To Environmental Conditions (Near-Mid Term ~4–5 Yrs)	Develop New Processes To Efficiently And Cost Effectively Disaggregate Biomass Into Basic Components, Below Fiber Level, While Preserving Nano Properties (Mid-Long Term ~6–8 Yrs)
• Photonics—develop new materials to control photon dispersion (color/wave length) • • • • • Control paper surface between micro-nano level with either innovative coating or forming • • • • Characterize the substrate properties needed for printed video screens • • • Explore interactions between paper/ cellulosics and functional polymers like organic semiconductors, enzymes, thermal-sensitive, etc. • • • Basic research in protein penetration abilities to get new sensors suspended in coatings • • Create economically viable conductive ink and smart paper surface and test in lab—pilot in the form of RFID, solar panel, nano-sensors, etc., and compare to printed circuit • • Smart paper—develop edible packaging papers • • Hygienic papers that promote good health care—antibacterial surfaces, • Power transmitting wallpaper, microbial sensing wallpaper, paper with active display elements, package that senses temperature, relative humidity, etc., and history • Develop a recyclable light switch as part of smart paper to handle higher temperatures and moisture applications • Explore functional wet-end additives, e.g., additives that change color when ethylene is present • Bio-based substances for coating/printing solar cells or "photonic" devices (organics) • Paper which can seal itself if punctured/damaged—self-healing • Develop cost-effective coating techniques to apply unique coatings • Exploit the electronic/electrical properties of cellulose nanocrystals • Change in paper properties resulting from energy pulses	• Method and system to manufacture crystalline nanocellulose and microfibrillar cellulose cost effectively for industry and academia • • • • • Separate lignin and hemicelluloses from cellulose while preserving all properties of each stream • • • • New means for generating nanocellulose at high volume for commercial use • • • • Mathematical modeling below fiber level using chemical and physical properties • • • • Injection of wood before harvesting to begin disaggregation in the forest—reduce chemical and energy use • • Need an overall process to remove lignin cost effectively without modifying it chemically. Preserve unique properties—example, can be used for barrier • • Develop new characterization tools for biological nanomaterials (10-Q) • • Grow cellulose vs. trees • Develop a non-water-based process for dissociating or fractionating the structural microcomponents of wood • Develop new and novel separation technologies for wood's basic chemical components and constituents • Investigate enzymatic disaggregation methods—genetically engineered enzymes—for example, plants that express enzymes • Characterize wood polymers for possible coating applications, e.g., xylan, etc. • Mass production of nanocrystalline cellulose at low cost and low environmental impact • Ionic liquids and supercritical fluids to separate biomass elements • Beyond pulping—revisit steam explosion process • Identify catalysts to speed the chemical process in separating components • Fundamental understanding of lignin chemistry to "free" basic components including carbon cycles

Product Features Group—R&D Needs by Technology Objective (cont'd)

Develop New Materials & Processes To Create New Bio-Based Composites For Both Structural Uses & Non-Traditional Uses (Mid-Long Term ~6–8 Yrs)

- Composites with new "surface-engineered" inorganic materials and bio-based polymers ••••••••
- Understand and exploit the self-assembly process and non-covalent interactions in wood •••••
- Interaction of cellulose/lignin materials within plastic and cement materials •••
- Develop technologies to disperse/intermix components to capture the desirable properties of each component in the matrix •
- Develop metrology tools to measure and characterize dispersion of components in a matrix •
- Need improved methods to characterize the shape and size of micro/nano materials •
- Wood fiber material as truly functional filler in building material (strength/toughness)
- Put nanocellulose fibrils on conventional mineral fillers to bond them into composite
- Laminated wood made with biopolymer for wood-based building materials
- Lignin and modified cellulose as a rheology modifier to allow blown film production of paper packages/bags
- Material science gaps linking nano to macro properties (materials structure modeling)
- Develop lignin de-polymerase and re-polymerase
- Product safety and risk analysis for industrial health and consumer protection
- Develop novel biopolymer or proteins for wet end additives/hydrophobic binders/wet strength—Improve modulus and tensile properties
- Use various forms of cellulose as a functional coating
- Develop techniques to cost effectively model the long term performance of unique bio-based materials for surface treatment applications
- Understand lignocellulose fiber/water interactions at the nanoscale
- Continuous film water-based coating application techniques that are less sensitive to base sheet variation
- Characterize paper impregnated with biopolymers for strength and water resistance
- Develop new technology approach on-line to insert new data on paper machine itself—idea for surface treatment (rheology, etc.)
- Develop self-assembly techniques for cellulose, lignin, and other materials—aligned, structured particles

Recovery/Recycle Group—R&D Needs by Technology Objective

Improve Sorting Of Recovered Wood And Fiber	Design Products For Deconstruction Or Recycling	Use Non-Fiber Components Of Recovered Materials More Effectively	Enhance Availability And Use Of Recovered Biomass For Energy	Improve Paper Machine First-Grade Production Rate (Runnability)
• Develop certified document destruction processes which maintain fiber integrity and reduce contaminants ●●●●●● • Improve sorting in recycle paper mills to better separate grades and contaminants ●●● • Detect, sort, and remove wood that contains heavy metals ●●● • Develop dry sorting technology for wood from landfills	• Identify methods and materials for systems approach to wood product design ●●●● • Incorporate recovery into fiber product design ●●●● • Incorporate recovery into wood product design ●●	• Develop techniques for filler separation from paper recycling mill wastes ●●●●● • Develop process to transform recovered filler into useful or saleable product ●● • Identify approaches for beneficial reuse of paper recycle mill residue (sludge) ●	• Recover urban wood wastes (e.g., from construction and clearing) for energy ●●●●●● • Recover paper recycle mill ash and separated sludge for energy ● • Recover energy from pulp/paper mill heavy rejects	• Optimize paper machine water use and quality ●●●● • Develop new techniques that enable recycled fibers to have runnability equivalent to virgin fibers ●●●● • Develop improved process control technologies for contaminants ●● • Increase fiber yield during paper recycling ●