Wood Utilization Research and Product Development Capacity in the United States: A Review

by

Paul V. Ellefson, Michael A. Kilgore,
Kenneth E. Skog and Christopher D. Risbrudt

January 2010

STAFF PAPER SERIES NUMBER 207

Department of Forest Resources

College of Food, Agricultural and Natural Resources Sciences
and the Agricultural Experiment Station
University of Minnesota
St. Paul, MN

Department of Forest Resources
University of Minnesota
115 Green Hall
1530 N. Cleveland Avenue North
St. Paul, MN 55108-6112
Ph: 612-624-3400
Fax: 612-625-5212
Email: forest.resources@umn.edu
http://www.cnr.umn.edu/FR/publications/staffpapers/

Wood Utilization Research and Product Development Capacity in the United States: A Review

by

Paul V. Ellefson, Michael A. Kilgore,
Kenneth E. Skog and Christopher D. Risbrudt[a]

January 2010

[a] Professors, respectively, Department of Forest Resources, University of Minnesota, and Project Leader and Director, respectively, Forest Products Laboratory, Forest Service, U.S. Department of Agriculture. Research supported by the University of Minnesota's Department of Forest Resources and MN Agricultural Experiment Station, and the Forest Products Laboratory, Forest Service, U.S. Department of Agriculture, Madison, WI.

Contents

Contents (continued)

Tables

Figures

WOOD UTILIZATION RESEARCH AND PRODUCT DEVELOPMENT CAPACITY IN THE UNITED STATES: A REVIEW

Abstract

Public and private research focused on wood utilization and product development in the United States is an important source of innovation required for sustaining the worldwide competitive position of the wood-based industry. Because of the research community's diversity, the exact magnitude of investment in wood utilization research is subject for much conjecture. However, in 2008 an estimated 400 to 500 wood utilization research projects were implemented by 150 to 200 federal, state and private entities. Investments in publically implemented projects were in the range of $110 to $120million, while, by some estimates, investments in projects sponsored by private concerns exceeded $2.5 billion in the same year. Scientists and supporting staff engaged by public research organizations was in the range of 900 to 1,000 in 2008. For research conducted by private concerns, scientists and engineers approached 8,000 in number. To experienced administrators, conditions necessary for a successful research enterprise focused on wood utilization and product development include clarity in purpose and well-defined client groups, effective governing boards and advisory committees, visionary and enthusiastic administrators, talented and risk taking scientists, satisfied research clients and customers, and research contributions that add to the scientific foundation considered necessary to enhance the efficient use of wood.

INTRODUCTION

The United States annually consumes more than 555 million cubic meters of roundwood equivalent and requires the services of the nation's wood-based manufacturing industry that contributes more than $116 billion in gross value added to the nation's economy (1.3 percent of national total) (Howard 2003). Furthermore, the nation's wood-based industry employs nearly 1.2 million persons. In order to sustain its worldwide competitive status, it is imperative that innovations occur within the industry. An especially important means of doing so is through long-term sustained investments in wood utilization research and product development. Investments in research and development are critical to gains in available timber supplies and to the more efficient use of wood as a raw material. Likewise, they are essential to long-term enhancement of environmental quality and to nationwide advances in economic and social welfare generally.

Objectives and Scope

Programs focused on wood utilization research and development are typically very diverse in terms of the many organizations responsible for them, the variety of public and private research missions being promoted, the breadth of issues and problems being dealt with, and the far-reaching

range in the magnitude of investments made therein. However, just as monitoring of forests is necessary to ensure future growth and sustainability, monitoring the status of research and development involving wood utilization is important to ensuring future strength and capacity of the wood-based industry. With such an interest in mind, the intent of this review was to obtain a better understanding of the wood utilization research and development landscape in the United States, namely (1) the range of public and private organizations engaged in such research, (2) the major strategic project-level research directions of concern to relevant research and development enterprises, (3) the type and magnitude of resources being invested in wood utilization research and development, and (4) the organizational, management, and performance measures that are important to the success of research entities engaged in wood utilization research and development.

Definition and Data Issues

Wood utilization research and product development is an important segment of the nation's research community generally. Unfortunately, there is no central clearinghouse for the ongoing collection, interpretation, and analysis of organizational and administrative information that is specifically devoted to such research. As occurs with many research and development sectors, periodic in-depth reviews, such as presented here, must often suffice. Although this review generated important information that should be useful to administrators of wood utilization research in the United States, its shortcomings need to be acknowledged.

The lack of uniformity in the definition of various concepts and processes involving wood utilization research and development is a challenge to preparation of a comprehensive, accurate and consistent description of research capacity. Exactly what is meant by "research," "development," "research capacity" and the "wood-based industry?" Although many definitions have been suggested for these descriptors (see Appendix Table 1), as used here *research* is the planned search for new knowledge useful in developing a new product or service, a new process or technique, or a significant improvement to an existing product or process, while *development* is the translation of research findings into a new product or process or a significant improvement to an existing product or process. Research and development includes the conceptual formulation, design, and testing of product alternatives, construction of prototypes, and operation of pilot plants. Not included are routine activities involving quality control, product testing, and market research (National Science Foundation 2009a). *Research capacity* is the magnitude of the ability to develop, advance, and disseminate science and technology, while the *wood-based industry* is a manufacturing sector composed of three major groups, namely wood products, paper and allied products, and wood furniture products (Ellefson and Kilgore 2010, National Research Council 2004).

Documentation of wood utilization research capacity in the United States is also challenged by the frequent necessity to separate programs involving wood utilization research (or forest products utilization research) from other types of research programs. The former is very often intermingled within forest research programs generally or is presented as part of broader research programs that encompasses various industrial sectors (construction, packaging, transportation) or many overarching technologies (biotechnology, modeling, simulation). Combining the description of various types of research oftentimes occurs in reports issued by public agencies (for example, National Science Foundation industrial reports) and by private concerns (for example, corporate annual reports). For purposes of this review, the scope of research and product development (see previous definitions) involving wood utilization is limited to harvesting, wood properties, manufacturing and processing, products and testing, and economics and marketing (U.S. Government Accountability Office 2006).

The review is also challenged by the reality that much of the information required to portray wood utilization research capacity is not always common to a single year, although most of the information presented herein reflects conditions occurring during the period 2007-2008. Also of concern is that information reported by many public agencies (such as the National Science Foundation, U.S. Department of Commerce's Census Bureau, U.S. Department of Agriculture's Cooperative State Research, Education and Education Service) adheres to rules designed to avoid disclosure of confidential information. Such rules can result in less than a full description of certain parameters important to describing research capacity. For purposes of this review, estimates were often made in such cases. These and previously described shortcomings aside, the review is offered as a reasonable description of the capacity for undertaking wood utilization and research and product development in the United States.

Prior Reviews and Assessments

Reviews of forestry and wood products research capacity in the United States have been modest in number, especially reviews of wood utilization research and product development. Most often reviews of the latter have focused on the development and subsequent advocacy of agendas that set forth specific issues or problems in need of research. Although the importance of setting forth research agendas should not be overlooked, there are times when a more comprehensive review of research capacity is in order. In the last 10 years, two such reviews are notable and deserving of special attention here.

In 2005, the wood utilization research capacity of federal agencies in the United States was reviewed by the U.S. Government Accountability Office. The review was reported in "Wood Utilization: Federal Research and Product Development Activities, Support, and Technology Transfer." Among the review's findings were (U.S. Government Accountability Office 2006):

- Wood utilization research and development encompasses a broad spectrum of activities, most notable harvesting, wood properties, manufacturing and processing, products and testing, and economics and marketing.

- Twelve federal agencies engage in activities involving wood utilization research and development, although only the U.S. Department of Agriculture's Forest Service and Cooperative State Research, Education, and Extension Service have activities in all five of the a-for-mention research areas.

- Scientists informally coordinate their research activities, although more formal mechanisms have been established through legislative provisions, agency rule-making, joint ventures and memorandums of understanding.

- During fiscal years 2004 and 2005, 12 federal agencies made available more than $54 million annually for wood utilization research and product development, measured either in budget authority or expenditures. The Forest Service was responsible for about half these funds.

- The only federal agency directly employing scientists and support staff to carry out research was the Forest Service, namely 175 full-time equivalent scientists and support staff.

- Transfer of technologies developed as a result of research activities relies on both scientists and technology transfer specialists.

Forestry and forest products research capacity in the United States was also reviewed (2002) by the National Research Council, the findings of which were reported in "National Capacity in Forestry Research." Major findings of the review include (National Research Council 2002):

- Forestry research is performed by a wide variety of organizations, including university forestry departments, schools, and colleges and a wide variety of federal agencies such as the National Science Foundation, Environmental Protection Agency, National Aeronautics and Space Administration, Departments of Energy, Defense, Interior, and Agriculture.

•The U.S. Department of Agriculture's Forest Service research programs involved $229.1 million and engaged a research staff involving 743 scientist years organized into133 research work units. Of the agency's 2001 budget, $26.8 million (12 percent) was directed to research involving forest products. Although a variety of disciplines engage in forest products research, only 13 forest products technologists were employed by the agency in 1999, a decline from 63 in 1985 (not necessarily a loss of expertise as much as an increase in specialization and an evolution of classification methods by the agency).

•Forestry research by various other federal agencies in 1999 was as follows: U.S. Department of Agriculture's Agricultural Research Service – $1.9 million, National Science Foundation – $15.9 million, U.S. Department of Defense – $12.8 million, and National Aeronautics and Space Administration – $13.4 million.

•University schools and colleges perform a substantial amount of research, probably equaling or exceeding that of the efforts of the Forest Service. Residing at 53 universities that have forestry programs, university faculties engaged in forestry research is estimated to have exceeded 700 full-time equivalents in 1993-1994 (1,459 total number of faculty).

•Forest industry is estimated to employee one to several hundred scientific persons focused primarily on forest health, water quality, fish and wildlife, ecosystem management and timber productivity. In 2001, forest industry invested (through the Sustainable Forestry Initiative) $72.2 million in research, 80 percent of which was for internal company research activities.

•High priority emerging topics for forestry research are human and natural resource interactions; ecosystem function, health, and management; forest systems on various scales of space and time; forest monitoring, analysis, and adaptive management; and forest biotechnology. Addressing these topics will require research into certain foundation areas, including biology, ecology, silviculture and forest genetics; forest management, economics and policy; and wood and materials science.

•Important factors enabling forestry and forest products research organizations to perform useful research are continuity through time allowing for adequate and consistent resources to maintain and improve operations, availability of up-to-date facilities and equipment, access to skilled and competent scientists, managers, and staff, and focus on high-priority goals and needs.

The aforementioned are examples of reviews that focus in a major way on the ability of the research community to develop, advance, and disseminate science and technology involving wood utilization and development. In addition to these examples, other recent and noteworthy reviews of research capabilities involving wood utilization (directly or indirectly) are: *research capacity* – "Privately Initiated Forestry and Forest Products Research and Development: Current Status and Future Challenges" by Ellefson and Ek (1996); "The Status of Forestry and Forest Products Research Undertaken in the United States: A Review and Assessment" by MacKay and others (1996); "U.S. Forest Products Research: Trends and Outlooks" by Hodges and Harris (1988); *research priorities* – "Forest Products Industry Technology Roadmap: 2010" by the American Forest and Paper Association (2010); "Wood Science and Technology: A National Needs Assessment Workshop" by the Society of Wood Science and Technology (2009a); "Exploring Research Priorities for North American Hardwood Industry" by Brinberg and others (2008); "Nanotechnology for the Forest Products Industry: Vision and Technology Roadmap" by the American Forest and Paper Association (2004); *research internationally* – "A Worldwide Research Update" by Brashaw and others (2009); "Forest Products Research and Development Organizations in a Worldwide Setting: A Review of Structure, Governance, and Measures of Performance of Organizations Outside the United States" by Ellefson, and others (2007a 2007b); "Forest Research Institutes in the World: Results of a IUFRO Survey" by von Teuffel (2007); "Forestry Research Undertaken by Private Organizations in Canada and the United States: A Review and Assessment" by Ellefson (1995); *research management* – "The Structure of Business R&D: Recent Trends and Measurement Implications" by Inklaar and others (2004); "Measuring Research and Development Expenditures in the U.S. Economy" by the National Research Council (2004); and "Planning and Managing Forestry Research" by Lundgren and others (1994).

RESEARCH AND DEVELOPMENT CAPACITY: PUBLIC SECTOR

Public Research Organizations Generally

Wood utilization research and product development is undertaken by a number of public organizations in the United States, ranging from state agricultural experiment stations to research entities within various agencies and laboratories of the federal government, and from university forestry schools and colleges to state government-sponsored research centers and institutes. Defining the sector-wide magnitude and direction of such research can be challenging, although the Current Research Information System (CRIS), sponsored by the U.S. Department of Agriculture, can provide noteworthy insight on the subject.[1] In 2007, CRIS reported well-over 600 research projects (involving an investment of $172,360,000) focused on wood products, paper and pulp products, other forest products, and forests and forest products generally (Cooperative State Research, Education and Extension Service 2005, 2009). A more focused review of these projects suggests that less than half are actually devoted to investigation of subjects pertaining to wood utilization (for example, development of topsaw sawing optimization systems, modification of cellulose fiber ultrastructure, biosynthesis of methanol from biomass derived carbon dioxide), and of those only 258 are government or government-sponsored projects (Table 1). Major characteristics of these 258 research projects follows.

Sponsored Programs and Grants

A variety of public laws and public agencies authorize the sponsorship of wood utilization research on a continuing basis. Examples are the Hatch Act, McIntire-Stennis Act, National Science Foundation Act, Forest and Rangeland Renewable Resources Act, and state laws authorizing state agricultural experiment stations. Of the 258 projects devoted primarily to wood utilization research,

[1] The CRIS system is a documentation and reporting system for ongoing and recently completed research and education projects in agriculture, food and nutrition, and forestry. Although exceptions exist, the reporting system is focused primarily on the research activities of public agencies and organizations. Organizations contributing information to CRIS are *U.S. Department of Agriculture*: Agricultural Research Service, Cooperative State Research, Education, and Extension Service, Economic Research Service, Forest Service, Rural Business-Cooperative Service; *State Institutions*: State Agricultural Experiment Stations, 1862 Land Grant Institutions, 1890 Land Grant Institutions and Tuskegee University, 1994 Land Grant Institutions (Tribal Colleges), Cooperating Schools of Veterinary Medicine, State Forestry Schools, Cooperative Extension Service; *Other Participants*: CSREES Competitive Grants, Small Business Innovation Research Grants, and Cooperative Agreement Recipients.

Table 1. Wood Utilization Research and Product Development Projects Implemented by Government Organizations in the United States, by Project Characteristic. 2007.

Project Characteristic	Number of Projects	Percent
Type of Project		
Grant or Award Authority	89	34
Sponsored Program Authority	169	66
Total	258	100
Entity Conducting Project Research		
Federal Government Agency	45	17
College or University	207	80
Other Public Agency	6	3
Total	258	100
Regional Location of Project (administrative)		
North	126	49
South	94	36
West	38	15
Total	258	100
Financial Magnitude of Grants or Awards		
Less than $100,000	4	6
$100,001 to $250,000	15	23
$250,001 to $500,000	32	49
$500,001 to $750,000	14	22
More than $750,000	0	0
Total	65	100
Research Emphasis of Projects		
Basic (50 percent or more)	93	36
Applied (50 percent or more)	132	51
Developmental (50 percent or more)	23	9
Less than 50 percent in each category	10	4
Total	258	100
Subject of Investigation (CRIS Classification)		
Wood and Wood Products	194	75
Paper and Pulp Derived Products	41	16
Other Forest Products and Conditions	23	9
Total	258	100
Research and Product Development Focus		
Harvesting and Transportation	9	4
Wood Properties	50	19
Manufacturing and Processing	84	32
Products and Testing	75	29
Economics and Marketing	41	16
Total	258	100

Note: Included are active projects (2007) identified by the Current Research Information System (CRIS) in subject of investigation categories: wood and wood products (0650), paper and pulp derived products (0660), other products of the forest (0680), and trees, forests and forest products, general (0699). Fields of science included are biochemistry and biophysics (1000), chemistry (2000), physics (2010), engineering (2020), mathematics and computer science (2080), statistics econometrics and biometrics (2090), and economics (3010).

Source: Cooperative State, Research, Education and Extension Service 2009.

two-thirds (169 projects) operate under such authorities with the remaining 89 projects supported by special grants (for example, National Research Initiative Competitive Grants, Small Business Research and Development Enhancement Act). Colleges and universities are responsible for implementing 80 percent of the projects, while agencies within the federal government oversee 45 projects (17 percent). Six projects (3 percent) are implemented by an assortment of independent government centers (for example, Minnesota's Natural Resources Research Institute, North Dakota's Energy and Environmental Research Center). As for the regional distribution of projects (primary administrative location), nearly half were in the North, followed by the South and West, namely 49 percent, 36 percent and 15 percent, respectively.

Grants and special awards for wood utilization research were reported by 65 of the projects – a total of nearly $26,191,000. Nearly half of these grants were in the range of $250,000 to $500,000, while only four projects were supported by an amount less than $100,000 (Table 1). No project reported a grant of more than $750,000. Approximately 60 percent of grants were directed at a specific subject of investigation (for example, investigation of fiber-based approaches for connecting wood structure to mechanical properties), with the remainder were awarded to research centers or research programs generally (for example, Sustainable Wood Housing Innovations Program, North Carolina State University). Examples of grants by size of funding in 2007 are as follows:

- *Less than $100,000*: Durable wood-based products-composites from recycled wood and plastic materials. Louisiana State University. $67,707
- *$100,001 to $250,000*: Modeling wood strands using intra-ring properties. Virginia Polytechnic Institute and State University. $211,349
- *$250,001 to $500,000:* Property evaluation of genetically engineered aspen wood with down-regulated lignin enzymes. North Carolina Stare University. $421,688.
- *$500,001 to $750,000*: New England Wood Research Program. University of Maine. $728,545.

Basic and Applied Research

Wood utilization research can assume an assortment of approaches, depending on the clarity of the problems being addressed. The most common research emphasis of the 258 projects reviewed here was to focus on investigations that would acquire new knowledge directed toward a specific aim or objective (applied research). Fifty-one 51 percent of the projects each reported half or more of project research efforts to be so oriented (for example, wood-adhesive curing and cross-linking reactions, Pennsylvania State University: 25 percent basic, 50 percent applied, 25 percent development)(Table 1). Research undertaken to gain fuller knowledge of an underlying phenomenon

without necessarily any particular application in mind (basic research) was the second most common research orientation, namely 36 percent or 93 of the 258 projects (for example, development of cellulose nano-crystals, Forest Service's Forest Products Laboratory: 75 percent basic, 25 percent applied, 0 percent development). A modest number of projects – 23 projects or 9 percent of the total – each devoted more than half their research to development activities, namely drawing on exiting knowledge that was directed at producing new materials, products or processes (for example, synthesis of amphiplhilic hydrogels and semi-inter-penetrating networks, State University of New York at Syracuse: 0 percent basic, 50 percent applied, 50 percent development). In some cases (10 projects), research emphasis was fairly uniform between basic, applied, and development (for example, research involving biosynthesis of methanol from biomass derived from carbon dioxide, University of Minnesota: 40 percent basic, 40 percent applied, 20 percent development).

Subjects of Investigation

Research and development focused on wood utilization can focus on a wide variety of subjects. Focusing on aforementioned CRIS categories, three-quarters of the 258 projects devoted attention to wood and wood products, while only 16 percent concentrated on subjects involving paper and pulp derived products (Table 1). The remaining 23 projects (9 percent) focused on a variety of other forest products and forest conditions relevant to wood utilization. A more focused assessment of subjects investigated reveals that 84 of the 258 projects focus on manufacturing and processing (32 percent of total) and on product development and testing (75 projects, 29 percent of total). Fifty projects (19 percent) engaged in wood properties research, while economics and marketing were the focus of 41 projects (16 percent of total). Very few (nine) of the projects addressed problems involving harvesting and transportation of timber. A more descriptive display of the nature of wood utilization research undertaken by the projects is as follows (with examples) (categories adapted from U.S. Government Accountability Office 2006):

Manufacturing Processes (84 projects): Focus on better ways to extract, reduce and convert virgin raw materials into useful products and the development of technologies to allow re-use of materials and products. Examples are "Evaluation of optimizing water removal processes during paper manufacturing," University of Minnesota; "Evaluation of design and operation of residential and nonresidential wood buildings," Forest Service (Forest Products Laboratory), U.S. Department of Agriculture.

Products and Testing (75 projects): Focus on development of test methods and data evaluation applied to wood and wood fiber. Examples are "Evaluation of factors affecting the durability of engineered wood composites," Mississippi State University; "Evaluation of lateral buckling and vibration damping of wood composite I-joists," Virginia Polytechnic Institute and State University.

Wood Properties (50 projects): Focus on the study of basic physical, chemical and mechanical properties of wood and wood fiber to determine the suitability of wood for various uses. Examples are "Isolation, characterization and modification of xylan hemicellulose," State University of New York at Syracuse; "Evaluation of lognocellulosics as precursors of high performance biopolymer structures," North Carolina State University.

Economics and Marketing (41 projects): Focus on evaluation of supply and demand trends, market opportunities, and harvest and production costs. Examples are "Evaluation of central hardwood forest product markets," Purdue University; "Evaluation of fuels and value-added institutes from pyrolysis oils," Mississippi State University.

Harvesting and Transportation (nine projects): Focus on development of cost-effective, environmentally acceptable, and safe forest harvest and transport operations. Examples are "Evaluation of efficiency in wood harvest," University of Idaho; "Evaluation of status of the Mississippi wood supply chain," Mississippi State University; "Evaluation of opportunities for improving efficiency of resource harvesting and utilization," Forest Service (Forest Science Laboratory, West Virginia), U.S. Department of Agriculture.

State Research Performing Organizations

State government organizations are very active participants in the conduct of research involving wood utilization and product development. They do so via a diverse organizational landscape, ranging from state-sponsored universities and colleges to specially authorized research centers and institutes. A major portion of state implemented research projects are funded directly by state governments, although an important portion of project funding is provided corporations, foundations and various federal agencies and programs.

State government organizations implemented 106 of the 258 projects previously identified as implemented by government generally in 2007. Involved was an investment of more than $32.2 million, the leading source of which was state government appropriations, namely 43 percent or about $13.8 million (Table 2, Figure 1). The projects engaged nearly 271 staff years of personnel, 80 percent of which were scientists and supporting professionals. Regionally, 82 percent of the funds invested by these state implemented research projects occurred in the North and South, with a similar regional distribution for project personnel (87 percent). During the period 2003 through 2007, there has been a general upward trend in funding (current dollars) for 27 of the 106 projects for which data is available for each year in the period (Table 3). Federal government support has nearly doubled during the 5-year period, with large increases occurring in the form of grants and cooperative agreements.

Table 2. Funding and Staff of Wood Utilization Research and Development Projects Implemented by State Government Organizations in the United States, by Source of Funding and Regional Location of Performing Projects. 2007.

Funding Source and Staff	Regional Location of Performing Projects			Total
	North	South	West	
Project Funds (current dollars)				
State Government Appropriations [96]	5,714,318	6,193,225	1,938,459	13,846,002
Corporations & Industrial Organizations [55]	1,040,937	1,644,056	252,026	2,937,019
Foundations, Professional Societies, Local Governments & Individuals [61]	1,418,935	1,302,892	772,147	3,493,974
Royalties, Interest Earnings, and Sale of Products [46]	715,613	72,042	1,211,829	1,999,484
Federal Government				
• Hatch Act of 1887 [10]				
• McIntire-Stennis Cooperative Forestry Research Act of 1962 [41]	214,405	73,484	10,468	298,357
• Grants and Cooperative Agreements [69]	724,493	978,866	205,663	1,909,022
Total	2,195,733	4,293,903	1,259,386	7,749,022
	3,134,631	5,346,253	1,475,517	9,956,401
Total Funding [106]	12,024,434	14,558,468	5,649,978	32,232,880
Project Personnel (staff years) (106 projects)				
Scientist Years	29.3	33.4	10.6	73.3
Professional Years	62.7	59.4	21.5	143.6
Technical-Clerical Years	22.2	28.3	3.5	54.0
Total Staff Years	114.2	121.1	35.6	270.9

Note: Numbers in brackets [] are number of projects. Included are 106 projects reporting funding and staff levels in 2007 to the Current Research Information System (CRIS). Subject of investigation categories are wood and wood products (0650), paper and pulp derived products (0660), other products of the forest (0680), and trees, forests and forest products, general (0699). Fields of science included are biochemistry and biophysics (1000), chemistry (2000), physics (2010), engineering (2020), mathematics and computer science (2080), statistics econometrics and biometrics (2090), and economics (3010).
Source: Cooperative State, Research, Education and Extension Service 2009.

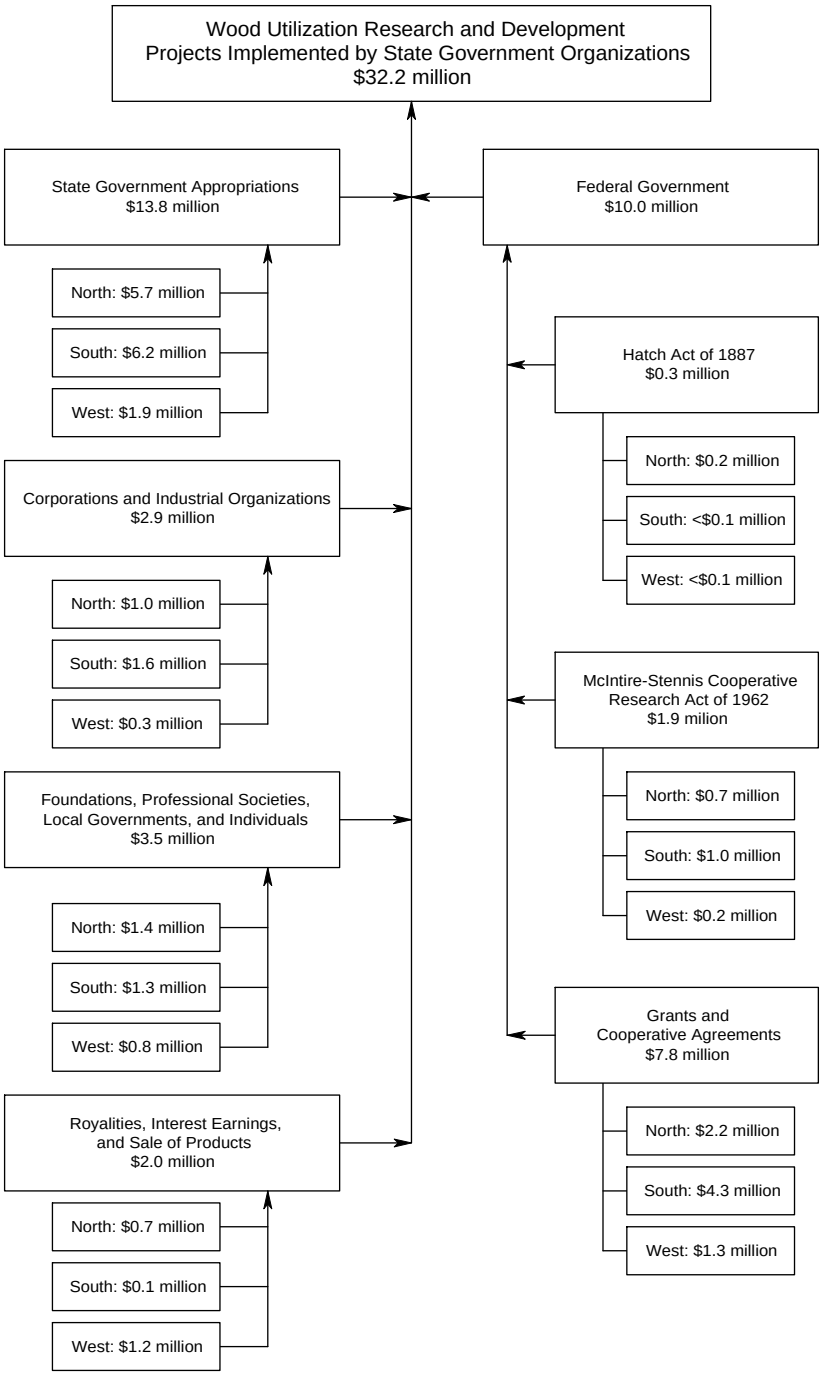


Figure 1. Funding of Wood Utilization Research and Development Performed by State Governments in the United States. 2007.

Table 3. Funding of Wood Utilization Research and Development Implemented by State Government Organizations in the United States, by Source of Funding and Regional Location of Performing Projects. 2003 through 2007.

Funding Source	Year (current dollars) (27 projects)				
	2003	2004	2005	2007	2007
State Government Appropriations	4,050,789	4,230,790	3,706,192	4,012,486	3,927,015
Corporations and Industrial Organizations	1,139,120	1,365,686	1,575,903	2,323,819	1,930,312
Foundations, Professional Societies, Local Governments and Individuals	397,420	668,883	989,149	764,754	940,395
Royalties, Interest Earning, and Sale of Products	305,049	552,274	579,397	395,745	469,868
Federal Government					
• Hatch Act of 1887	84,714	108,218	100,109	96,964	73,018
• McIntire-Stennis Cooperative Forestry Research Act of 1962	442,354	370,196	431,883	447,434	479,858
• Grants and Cooperative Agreements	639,801	615,316	1,295,280	1,528,824	1,859,543
Total	1,166,869	1,093,730	1,827,272	2,073,222	2,412419
Total All Funding Sources	7,059,247	7,911,363	8,677,913	9,570,026	9,680,009

Note: Data for only those projects (27 projects) for which information is available for each year during the period 2003 through 2007.
Source: Cooperative State, Research, Education and Extension Service 2009.

A more focused description of state sponsored and state financed wood utilization and research and development follows, with special attention to state agencies and departments, university research services, and specially established research organizations.

Agencies and Departments Generally

Although their central mission may not embody research and development, a myriads of state government agencies at times engage in investigations and inquiries that involve wood utilization problems (for example, departments of natural resources, economic and community development, pollution control and environmental protection). Exactly which state agencies actually carry-out such activities are not known; the same for the focus of their inquires (for example, recycling of wood-based products, extending the life of wood in service, wood-based economic development), the magnitude of their efforts and whether such activities are being conducted within an agency or are being delegated to other public or private organizations. When undertaken, the sophistication

of their research activities may be questionable, yet their intent to seek information that will solve problems involving some aspect of wood utilization is likely to be sincere. Not to propose that all the following example organizations are actively engaged in research, they are illustrative of agencies that may well engage in some form of research focused on wood, wood-based products, or wood products marketing (Ellefson and others 2002):

> California's Energy Commission; Idaho Forest Products Commission; Pennsylvania Hardwoods Development Council; Kentucky Wood Products Competitiveness Corporation Board; Georgia Forestry Commission's Office of Forest Products Utilization; Illinois Department of Commerce's Division of Energy and Conservation; Kentucky Department of Agriculture's Division of Secondary Wood Products; Louisiana Economic Development Council; Maryland Department of the Environment's Division of Waste Management; New Jersey Department of the Environment's Division of Solid and Hazardous Waste; Oregon Department of Economic Development's Division of Industry Development; Vermont Department of Economic Development; and Washington Department of Economic Development's Division of Energy and Housing.

University Research Services Generally

State governments establish public colleges and universities with the intention of providing citizens with the wide range of benefits that can result from advanced programs involving teaching, research and service. As part of their at large responsibility (and obligation) to a public university, university faculty and staff may well carry-out wood utilization research that is in addition to that performed in response to the research requests of federal and state agencies, public and private corporations, private foundations and institutes and state agricultural experiment stations. The nature and magnitude of these at-large research activities have not been fully documented, although a listing of university-sponsored forest products programs provides some insight. Consider the following, along with an estimate of the number of full-time faculty, research fellows and research assistants specializing in forest products, wood science, engineering and harvesting, economics and marketing (Society of Wood Science and Technology 2009b):

Auburn University (13)
Clemson University (three)
Iowa State University (three)
Louisiana State University (13)
Michigan State University (six)
Michigan Technological University (five)
Mississippi State University (22)
North Carolina State University
Oregon State University (25)
Pennsylvania State University (eight)
Purdue University (five)
Southern Illinois University (one)
State University of New York at Syracuse (12)
University of Georgia (eight)
University of Idaho (six)
University of Kentucky (7)
University of Maine (50)
University of Massachusetts (six)

University of Minnesota (25)
University of Tennessee (14)
University of Washington (12)
University of Wisconsin - Madison (4)
University of Wisconsin-Stevens Point (six)
Virginia Polytechnic Institute & State University (27)
Washington State University (18)
West Virginia University (10)

Research and Development Organizations

State governments also promote wood-utilization research by establishing research organizations and subsequently assigning them the task of conducting research on important public problems. Examples of such organizations are agricultural experiment stations (for example, Michigan Agricultural Experiment Station, Texas Agricultural Experiment Station), colleges and universities (for example, Department of Wood Science and Engineering, Oregon State University; Department of Forest Products, Mississippi State University) and special centers and institutes (for example, Biobased Materials Center, West Virginia University).

Thirty-seven of the 258 wood utilization research and development projects previously identified were implemented by state research and development organizations – all of which were located at state universities and colleges (12 different institutions). Most frequently responsible for such projects were the State University of New York at Syracuse – 12 projects, and Louisiana State University and the University of Minnesota – four projects each. As for the diversity of subjects investigated by the 37 projects, the following examples are illustrative: investigation of water removal processes in papermaking (University of Minnesota); hydrogen production from wood-based feedstocks (State University of New York at Syracuse), development of reverse supply chain systems for decommissioned preservative-treated wood (Louisiana State University), analysis of multi-functional fibrous materials via manipulation of nanoscale phenomena (Cornell University), improved pole treatments through the use of super-critical fluids (Oregon State University), and evaluation of opportunities to promote export of wood products (University of Washington) (complete listing in Appendix Table 2). As for the exploratory nature of the research conducted by state-sponsored projects, 21 of the projects were 50 percent or more basic research (16 were 100 percent basic research), seven were 50 percent or more applied research (one was 100 percent applied research), four were 50 percent or more development (none were 100 percent development), and four were less than 50 percent in each category.

State governments also promote wood utilization research by establishing special centers and institutes at colleges and universities. The following are examples:

•Auburn University: Alabama Center for Paper and Bioresource Engineering.
•University of Idaho: Wood Products Laboratory.
•University of Kentucky: Wood Utilization Research Center
•University of Maine: Center for Furniture Craftsmanship; Advanced Engineered Wood Composites Center; Forest Bioproducts Research Institute.
•University of Minnesota: Forest Products Management and Development Institute; Center for Sustainable Enterprise Development.
•Mississippi State University: Southern Climatic Housing Research Center; Formosan Termite Center; Lucas Advanced Biodeterioration Research Center; Franklin Furniture Institute.
•State University of New York at Syracuse: Brown Center for Ultrastructure Studies, Renewable Materials Institute, Tropical Timber Information Center, Wood Engineering Laboratory, Szwarc Polymer Institute; Empire State Paper Research Institute; Cellulose Research Institute; Wood Utilization Service.
•North Carolina State University: Furniture Manufacturing and Management Center.
•Oregon State University: Center for Wood Utilization Research, OR Wood Innovation Center, Utility Pole Research Cooperative.
•Purdue University: Wood Research Laboratory.
•University of Tennessee: Forest Products Center.
•Virginia Polytechnic Institute and State University: Center for Load Design; Center for Forest Products Marketing and Management; Sardo Pallet and Container Research Laboratory; Wood-based Composites Center; Sloan Foundation Forest Industries Center; Sustainable Engineered Materials Institute.
•University of Washington: Center for International Trade in Forest Products.
•Washington State University: Wood Plastic Composite Information Center.
•West Virginia University: Biobased Materials Center; Appalachian Hardwood Center.

In addition to the aforementioned centers and institutes, state governments also sponsor – again, primarily through universities – special facilities and equipment that are important to wood utilization research. Examples are universities with nanotechnology user centers that enable researchers to address issues involving wood and wood-based lignocellulostic materials at the nanoscale level (for example, lignocellulosic nanofibrillar and cellular morphology, application of intense light sources and neutron scattering tools, characterize lignocellulosic surfaces in terms of bonding sites). More than 25 universities have nanoscience user facilities that are relevant to wood utilization research. Examples are the University of Illinois (Center for Microanalysis of Materials), University of Wisconsin (Material Science Center), Pennsylvania State University (National Nanotechnology Infrastructure Network), Colorado State University (NSF Engineering Research Center for Extreme Ultraviolet Science), Duke University (Free Electron Laser Laboratory), Louisiana State university (Center for Advanced Microstructures and Devices), Cornell University (High Energy Synchrotron Source Center), North Carolina State University (Harold Ade Research Center), Oregon State University (Oregon Nanoscience and Microtechnologies Institute), and Purdue University (Birck Nanotechnology Center) (American Forest and Paper Association 2004).

Federally Sponsored and Financed

Formula-funded Programs. The federal government is an important sponsor of wood utilization research undertaken by organizations operating under the auspicious of state governments. Among the most common federal-state linkages for such research are formula-funded programs which are administered by the Cooperative State Research, Education and Extension Service (CREES) under authorities such as the Hatch Act of 1887, McIntire-Stennis Cooperative Forestry Research Act of 1962, and the Agricultural Research at 1890 Land-Grant Institutions Act. In addition to these major formula-funded programs, the federal government also supports state-implemented wood utilization research through a wide variety of special grants and cooperative agreements.

Hatch Act. Annually distributed according to a statutory formula, Hatch Act funds are provided to State Agricultural Experiment Stations for research focused on a broad array of problems, including wood utilization research (Cooperative State, Research, Education and Extension Service 2000). Exactly what portion of the funds are devoted to the latter has yet to be determined. However, in 2007 the CRIS system reported 30 Hatch Act supported projects focused of wood utilization research, all of which were implemented by state universities and colleges (15 different institutions). The institutions most frequently responsible for these projects were Purdue University – four projects, three each at Michigan State University, University of Tennessee and Virginia Polytechnic Institute and State University, and two each at Auburn University, University of California (Davis), the University of Georgia, University of Minnesota, Washington State University and West Virginia University. The remaining five projects were sponsored by five different colleges or universities. For 10 of the 30 projects for which information was available, funding in 2007 was $298,357, 72 percent of which occurred at state universities and colleges located in the North, 25 percent in the South and 3 percent in the West (Table 2).

Projects supported by Hatch Act funds conducted research focused on a wide variety of wood utilization subjects as the following examples illustrate: near-infrared spectroscopic evaluation of woody biomass process streams (University of Maine), optimizing the engineering properties of biomass for use as biorefinery feedstock (University of Georgia), evaluation of central hardwood forest products markets (Purdue University), biosynthesis of methanol from biomass derived carbon dioxide (University of Minnesota), improvement of bacterial cellulose applications to pretreated lignocellouse (Virginia Polytechnic Institute and State University) and evaluation of engineered interface for wood-polymer composites (University of Tennessee) (complete listing see Appendix Table 3). As for the exploratory nature of the research being conducted, 11 Hatch Act projects were 50 percent or more basic research (none were 100 percent basic research), 15 were 50 percent or

more applied (two were 100 percent applied research), one was 50 percent or more development (none was 100 percent development), and seven were less than 50 percent in each category.

McIntire-Stennis. McIntire-Stennis funds are an annual source of support used to conduct research on a wide range of forest resource problems, including timber production, watershed and wildlife management, range and recreation management, and the ". . . utilization of wood and other forest products." Eligible institutions are land-grant colleges, agricultural experiment stations, and other state-supported colleges and universities offering graduate education in the sciences basic to forestry and forest products. The funds are distributed to states according to a statutory formula that considers the area of nonfederal commercial forest land, volume of timber annually cut from growing stock, expenditures for forestry research from nonfederal sources, and a base amount of funding distributed equally among all states (Cooperative State, Research, Education and Extension Service 2002).

The CRIS system reported 62 McIntire-Stennis research projects in 2007. Of the 23 universities and colleges receiving such support, the universities and colleges with the most projects were Mississippi State University – 13 projects, University of Maine – eight projects, Virginia Polytechnic Institute and State University – five projects, and four each at the University of Georgia and West Virginia University. Two universities had three projects each and six had two projects each. For 41 of the 62 projects for which information was available, funding in 2007 was $1,909,022, 51 percent of which occurred at state universities and colleges in the South, 38 percent in the North, 11 percent in the West (Table 2).

The subjects investigated by McIntire-Stennis supported projects in 2007 varied widely as the following examples illustrate: evaluate opportunities for enhancing the yield Southern pine sawtimber by integrating lumber production systems. (Auburn University); assess emerging issues in furniture design (Purdue University); investigate the physical properties of wood and paper that affects permeability and waving (University of Maine); develop accelerated tests for evaluating wood preservatives in above ground use (Mississippi State University); develop integrated experimental protocols for wood-based composites (Oregon State University); and investigate the cause of copper tolerance of brown rot decay fungi (West Virginia University) (complete listing see Appendix Table 4). Of the projects reviewed, applied research was the focus of 31 (eight were 100 percent applied research), 21 of the projects were 50 percent or more basic research (four were 100 percent basic research), and eight were 50 percent or more development (none were 100 percent development). Only nine of the projects were less than 50 percent in each category.

Grants and Cooperative Agreements. The federal government also provides state research performing organizations with grants and cooperative agreements focused on wood utilization research. These grants and agreements are provided by a variety of federal agencies, including the Departments of Agriculture, Defense, Energy, Health and Human Services, and the National Science Foundation. Example grants and cooperative agreements are:

•National Science Foundation: Heat and mass transfer in wood, wood composites, and building envelopes; multifunctional fibrous materials via manipulation of nanoscale phenomena.

•U.S. Department of Defense: Nanotechnology of lignocellulosics; structure, design and functioning of catalytic bioprocessing.

•U.S. Department of Energy: Wood-adhesive curing and crosslinking reactions; heteronuclear nmr in wood chemistry occurring in lignin during pulping and bleaching.

•U.S. Department of Agriculture: Development of optimal sawing system for small-scale sawmills; investigation of environmentally friendly wood adhesives from renewable natural resources.

In 2007, federal agencies provided 69 state research performing projects with $7,749,022 through various types of grants and cooperative agreements (Table 2). These funds were distributed regionally among projects as follows: South – 56 percent, North – 28 percent and West – 16 percent.

The federal government also sponsors state-implemented Wood Utilization Research Centers (WURC) that are responsible for developing new and innovative technologies involving wood. Affiliated with 14 university partners, the nation's 12 centers currently focus on three overarching themes, namely: enhance the global competitive position of the wood products manufacturing industry (for example, develop new products, improve manufacturing processes); utilize wood as a reliable source of energy (for example, economical biofuels production, conversion of woody biomass into electricity); and enable more efficient manufacture and consumption of wood products (for example, improve durability and service life of wood, enhance wood recycling processes) (Cooperative State Research, Education and Extension Service 2006). Within these themes, the projects and objectives of each center varies widely from the development of new products from wood plastic composites, to the design of recycling systems for reuse and recycling of decommissioned treated wood, and from extending the timber resource through improved harvesting and transportation systems to evaluating potential approaches to the restructuring of various

segments of the wood-based industry. This diversity in research emphasis reflects regional differences in problems involving wood utilization (Table 4).

Table 4. Research Objectives of Wood Utilization Research Centers in the United States, by Center. 2005-2006.

University of Alaska, Wood Utilization Research Center (2004-2005): Evaluate potential approaches to the restructuring of Alaska's forest industry, determine potential products from Alaska tree species possessing unique properties, assess the chemical composition of birch bark as a value-added product, determine potential nontimber forest products from forest and related plant species, document traditional and current uses of special forest products in Alaska native communities, and define potential marketing strategies for value-added Alaskan wood and special forest products.

Inland Northwest Forest Products Research Consortium (universities of Idaho and Montana, and Washington State University) (2009): Characterize the unique physical, mechanical, and chemical properties of the small-diameter timber resource; evaluate the capabilities of the regional forest industry to harvest and process the changing timber resource; develop new harvesting and processing systems to deal with small-diameter timber under increasingly stringent environmental constraints; develop new products and processing technologies to enhance the value of the changing timber resource; and determine potential for using currently non-merchantable wood as biomass for energy.

Louisiana State University, Wood Utilization Research Center (2008): Determine technologically feasible solutions for using wood fibers and used plastics to manufacture durable building materials, and develop recycling systems for reuse and recycling of decommissioned treated wood and the chemicals used to preserve such wood.

University of Maine, Wood Utilization Research Center (2006): Improved utilization of biomass for bioproducts, environmentally friendly wood protection, new products from wood plastic composites, nanotubes from renewable resources, biodegradation and bioprocessing, reduction of air pollution associated with wood drying, and producing better wood composites by understanding strand placement.

Michigan State University, Wood Utilization Research Center (Hardwood Utilization Research Program) (2009): Increase the utilization of hardwoods (environmentally benign exterior applications, reuse and recycling wood products), expand opportunities utilize sawdust from furniture manufacture, analysis of economic and social forces affecting timber supply and demand, development of biotechnological means for producing value-added wood products, develop polymorphic markers for identifying strains of wood rot, and investigate o-dihydroxyphenyl groups in the black locust polyphenols.

University of Minnesota (Duluth), Wood Utilization Research Center (2007): Development of a rural bridge in-situ control and monitoring system, assess condition of residential wood-framed wall systems, development of prototype, ready-to-assemble engineered residential building/structure, utilization of paper mill black liquor/soap fraction wastes, and assess biomass for energy from Minnesota' s brush lands.

Mississippi State University, Wood Utilization Research Center (2007): Timber harvesting and transportation, lumber manufacturing and processing, wood-based composite materials, protection and preservation of wood, wood chemistry, and economic evaluation and technology transfer.

Table. 4 (continued).

North Carolina State University, Wood Utilization Research Center (2009): Applied research aimed at improving efficiency of the machine-tool-workpiece interface, especially machine-tool dynamics (high speed machining and thin kerf sawing), tool materials and wear mechanisms (carbide grade treatments and performance), surface character and quality (identification and monitoring of surface defects), process monitoring and control systems (sensor evaluation of surface quality monitors), abrasive machining processes (model and evaluate machine abrasive processes), and appropriateness of new machine technologies (drilling, diamond wire sawing, carbide brazing, sandblasting wood carvings)

Oregon State University, Wood Utilization Research Center (2007): improving products and processes to enhance global competitiveness of Oregon's wood products industry (business systems innovation in the global forest products sector, improvement of wood and log quality to enhance value, management of bio-based product manufacture to reduce energy use), discovering new knowledge for future business opportunities (treatability differences in Douglas-fir wood from different regions, science involving nanocrystalline cellulose electro-optic devices, 3-dimensional micron-scale characterization of adhesive bondlines), extending the timber resource through improved harvesting, transportation and manufacturing (material tracking system for sawmill analysis, opportunities to reduce wood transportation costs, incorporating wood density and elasticity prediction for improved wood allocation to sawmills, and in-forest log segregation based on acoustic measurement of wood stiffness by harvesting equipment).

Virginia Polytechnic Institute and State University, Wood Utilization Research Center (2009): bionspired design of interfaces in wood-plastic composites, and evaluation of novel rheological tools for xylem structure-property determinations.

University of Tennessee, Wood Utilization Research Center (2005): Investigate new approaches to monitor and model extruded composite properties, evaluate wood-polymer composites to determine the effect of copolymar architecture on interfacial structure and adhesion with amorphous polymers, and assess characteristics of wood-polymer interface using mechanical and spectroscopic methods.

West Virginia University, Wood Utilization Research Center (2009): Value recovery through merchandising hardwood log products, increase use of low-quality wood in the upland hardwood region, utilization of oak logging residues in the upland hardwood region, condition assessment of logs using ground penetrating radar, application of advanced technologies (production of cellulose nanocrystals from hardwoods), and transforming veneer-mill residues into value-added composites.

Source: Websites of individual wood utilization research centers; Cooperative State, Research, Education and Extension Service 2009; and U.S. Government Accountability Office 2006.

Wood Utilization Research Centers are funded by various grant programs, most notably the U.S. Department of Agriculture's Special Grant Program for Wood Utilization Research which is administered by the Department's Cooperative State Research, Education and Extension Service. Funding proposals prepared by centers are evaluated by peer-review processes and the performance of research centers is evaluated annually. In 2005, the total federal budget authority for the 10 wood utilization centers operating in that year was $5,664,000 (since 2005, two additional centers were formed). The latter was distributed as follows (U.S. Government Accountability Office 2006):

University of Maine – $ 698,000
Michigan State University – $ 698,000
University of Minnesota (Duluth) – $ 216,000
Mississippi State University – $ 1,148,000
North Carolina State University – $ 269,000
Oregon State University – $ 698,000
Inland Northwest Consortium – $ 496,000
University of Tennessee – $ 406,000
University of Alaska – $ 586,000
West Virginia State University – $ 451,000

Special Grant Program awards granted by CSREES to wood utilization research centers operating in 2008 totaled more than $6,835,000. These grants were distributed to centers as follows (fiscal granting year 2008) (Cooperative State, Research, Education and Extension Service 2009):

University of Maine – $ 526,460
University of Minnesota (Duluth) – $ 163,130
Louisiana State University – $67,707
Mississippi State University – $ 679,832
North Carolina State University – $ 592,193
Oregon State University – $ 2,324,620
Inland Northwest Consortium – $ 1,001,244
University of Tennessee – $ 413,348
Virginia Polytechnic Institute and State University – $ 1,066,539

The number of researchers and supporting staff at wood utilization centers probably is probably in the range of 100 to 150 persons, although staffing information is sketchy and often not commonly available for some centers. Even though not all persons are assigned full-time to a center, the following are illustrative of center staffing in 2007-2008: Oregon State University – 18 persons, West Virginia State University – nine persons, University of Tennessee - eight persons, North Carolina State University – eight persons, University of Minnesota Duluth – four persons, Michigan State University – 13 persons, Inland Northwest Consortium – 32 persons, University of Maine – 28 persons, and Louisiana State University – four persons, and Mississippi State University – 27 persons.

Privately Sponsored and Financed

Private organizations also support state research performing organizations. Sixty-one projects received financial support from an assortment of foundations, professional societies, and individuals.

Another 55 projects were supported in whole or part by corporations and various industrial organizations such as trade associations and special interest organizations. As for the magnitude of investments made by such organizations in 2007, the former sponsored nearly $3.5 million of research funds while the latter provided more than $2.9 million in funding to state organizations implementing wood utilization research projects (Table 2). Examples of research undertaken with private financial support at state research performing organizations in 2007 are:

> *Private Foundations and Individuals*: Durability and protection of wood products (Michigan State University), multifunctional fibrous materials via manipulation of nanoscale phenomena (Cornell University), investigation of environmentally friendly wood adhesives from renewable natural resources (Oregon State University), biofuels production from cotton gin waste and recycled paper sludge (Virginia Polytechnic Institute and State University).
>
> I*ndustrial Organizations*: Modification of the cellulose fiber chemical and physical ultrastructure (North Carolina State University), development of accelerated test methods for evaluating wood preservatives for use in above ground applications (Mississippi State University), lignin biosynthesis, biodegradation and derivative plastics (University of Minnesota), and engineered interfaces for wood-polymer composites to improve utilization of undervalued hardwood resources (University of Tennessee).

Federal Research Performing and Sponsoring Organizations

Research Performing Organizations

A number of federal agencies perform research involving the utilization of woody materials. Although so engaged, the preponderance of these agencies would probably not consider wood utilization as a major nor central focus of their research interests. An example is the U.S. Department of Agriculture's Agricultural Research Service which has researched the energy potential on a native woody shrub called the guayule plant. Interest in the latter is the plant's ground-up stems and branches (bagassee) which are a potential source of energy. Such modest research efforts aside, two federal entities are known to have an important role in research focused on wood as a material, namely the U.S. Department of Energy's National Laboratories and the U.S. Department of Agriculture's Forest Service.

National Laboratories, U.S. Department of Energy. The U.S. Department of Energy (Office of Science) is the steward of 17 national laboratories that perform research and development on a wide array of problems, ranging from solar and nuclear energy to genome biology and

biosecurity sensing and analysis. Special features of these laboratories are the wide scope of their research, the massive infrastructure established to undertake such research, and the extensive multidisplinary teams of scientists that are gathered together to research important national problems. National laboratories are all capable of addressing important problems concerning the utilization of wood. Problematic, however, is at which national laboratories is research involving wood utilization and development actually being conducted, the nature and relevance of their research to problems involving wood utilization, and the magnitude of the research focused on wood utilization (U.S. Department of Energy 2009).

Research relevant to wood utilization is surmised here to vary widely among national laboratories. In some cases, the research conducted by the latter is very focused and deeply concerned with fundamental physical and chemical properties of materials generally. In such cases, the results of research are not unique to wood as a material. In other cases, however, research programs at national laboratories are more applied and more relevant to promoting better understanding of wood and woody materials. For example, at the Lawrence Berkeley Laboratory's Department of Building Technologies (Division of Environmental Energy Technologies), research is undertaken to develop efficient technologies for buildings, especially research that enables increases in energy efficiency and improvements in the comfort, health and safety of building occupants. At the Oak Ridge National Laboratory's Division of Biological and Environmental Sciences, research focuses on lignocellulosic feedstock options and their implications for ecosystem services and social and economic benefits, while the Biofuels and Renewable Energy Program (Division of Energy and Environment) at the Idaho National Laboratory, research is focused on harnessing the physical and chemical properties of diverse cellulose residues to ensure more cost-effectively produced biofuels and other value-added products. At the Ames Laboratory's Division of Materials Sciences and Engineering, investigations are focused on bioinspired hierarchical self-assembling polymer-inorganic nanocomposites and the evaluation of growth, control and modification of novel materials. Other national laboratories known to engage in research involving some aspect of wood utilization are the Brookhaven National Laboratory (fungal decay mechanisms as they involve woody materials), and the National Renewable Energy Laboratory (woody biomass material to ethanol).

Research and development involving wood utilization appears to be most relevant at nine of 17 national laboratories operated by the U.S. Department of Energy, namely:

Ames Laboratory, (Ames, Iowa)
Argonne National Laboratory (Argonne, IL)
Brookhaven National Laboratory (Long Island, NY)

Idaho National Laboratory (Idaho Falls, ID)
Lawrence-Berkeley National Laboratory (Berkeley, CA)
Oak Ridge National Laboratory (Oak Ridge, TN)
National Renewable Energy Laboratory (Golden, CO)
Pacific Northwest Laboratory (Richland, WA)
Sandia National Laboratory (Albuquerque, NM)

Within the above nine national laboratories, 21 organizational entities (divisions, programs, centers) appear to have research initiatives that are especially relevant to understanding the science and potential uses of wood and woody materials (see Appendix Table 5). Although not to be construed as all focusing directly on woody materials, the 21 units engage the services of more than 1,200 scientists and engineers. Using the name of the organizational entity as an indicator, the most common focus of wood-relevant research at the nine national laboratories is nano-technologies, energy technologies, material sciences and biological sciences. To be appreciated is that the 21 organizational entities considered relevant to wood utilization research are part of much larger organizational structures, each of which operates with very large physical facilities, a very large number of scientists and engineers, and an extremely diverse range of subject matter being investigated. In 2009, the nine national laboratories employed more than 15,000 scientists and engineers and more than 16,000 support staff. The combined 2008 budget of the laboratories was nearly seven billion dollars (U.S. Department of Energy 2009).

As is the case with universities, national laboratories also offer nanoscience technologies that facilitate research and development involving wood. Notable in this respect are the Argonne National Laboratory (advanced photon source), Brookhaven National Laboratory (national synchrotron light source), Lawrence Berkeley National Laboratory (advanced light source), National Renewable Energy Laboratory (surface analysis), Pacific Northwest Laboratory (Environmental Molecular Sciences Laboratory), and the National Institute for Standards and Technology (NIST) (SURF III synchrotron) (American Forest and Paper Association 2004).

Forest Service, U.S. Department of Agriculture. The Department of Agriculture's Forest Service plays a significant role in wood utilization and development research. In 2005, the agency invested $27.2 million in such research, engaging the services of 173.8 full-time-equivalent (FTE) staff. Of the latter, approximately half were scientists (87.7 FTE staff) with the remaining portion being support staff (86.1 FTE staff). Over the 10-year period 1995 through 2005, the agency's annual budgetary authority increased $3.4 million (decreased $1.6 million in real 2004 dollars). The agency's wood utilization research and product development efforts were distributed over six Forest Service units in 2005, as follows (FTE staff, budget thousand dollars) (U.S. Government Accountability Office 2006):

Work Unit	Budget Authority	Scientists	Support Staff	Total Staff
Forest Products Laboratory (Madison, WI)	$19,213	59.6	57.3	116.9
Northern Research Station (Newtown Square, PA)	2,596	9.0	10.0	19.0
Pacific Northwest Research Station (Portland, OR)	2,644	9.3	7.0	16.3
Pacific Southwest Research Station (Albany, CA)	164	1.0	2.0	3.0
Rocky Mountain Research Station (Fort Collins, CO)	300	0.1	0.0	0.1
Southern Research Station (Asheville, NC)	2,262	8.7	9.8	18.5
Total	$27,179	87.7	86.1	173.8

The Forest Service's wood utilization and product development research is concentrated at the agency's Forest Products Laboratory, namely 68 percent of 2005 budgetary authority and 67 percent of the agency's wood utilization research staff (20 research projects located at the Laboratory). With a mission of promoting healthy forests and forest-based economies through the efficient and sustainable use of our wood resources, the Laboratory focused research on 16 different problems areas in 2005 (Appendix Table 6), of which the following five (rank order) lead in budgetary authority: engineering properties and structures ($2.4 million), fiber processes and paper performance ($2.2 million), chemistry and pulping ($1.9 million), timber demand and technology assessment ($1.5 million), and microbial and biochemical technology ($1.5 million)(U.S. Government Accountability Office 2006). After extensive program reviews in 2006 and 2008, the Forest Products Laboratory in 2009 refocused research and development on five areas (Forest Service 2006a and 2006b, 2009):

•Underutilized Woody Biomass – supported by two research work units and a technology transfer unit, namely Engineered Composites Sciences (five research staff), Institute for Microbial and Biochemical Technologies (six research staff), and State and Private Forestry Technology Marketing Unit (six staff).

•Nanotechnology – supported by two research work units, namely Performance Enhanced Biopolymers (seven research staff), and Durability and Wood Protection Research (seven research staff).

•Forest Biorefinery and Biomass Utilization – supported by four research work units and a technology transfer unit, namely Analytical Chemistry and Microscopy Laboratory (six research staff), Economics and Statistics (10 research staff), Fiber and Chemical Science Research (seven research staff), State and Private Forestry Technology Marketing Unit (six staff), Durability and Wood Protection Research (seven research staff).

•Advanced Structures Research – supported by four research work units and a technology transfer unit, namely Advanced Housing Research Center; Durability and Wood Protection Research (seven research staff); Engineering Properties of Wood, Wood-based Materials and Structures (eight research staff); Engineering Mechanics and Remote Sensing Laboratory (13 research staff); and State and Private Forestry Technology Marketing Unit (six staff).

•Advanced Composites – supported by three research work units, namely Advanced Housing Research Center, Engineered Composites Sciences (five research staff), and Engineering Mechanics and Remote Sensing Laboratory (13 research staff).

In addition to the Forest Products Laboratory, the Forest Service also conducts wood utilization research at five other units (see Appendix Table 6). At these units, four research projects account for 22 percent of the agency's wood utilization research budgetary authority: human and natural resource interactions ($2.6 million, Pacific Northwest Research Station), utilization of southern forest resources ($1.2 million, Southern Research Station), eastern forest use in a global economy (Northern Research Station, $1.1 million), and efficient use of Northern forest resources (Northern Research Station, $1.1 million).

Research Sponsoring Organizations

Federal Research Sponsorship Generally. The federal government both sponsors and carries out research focused on problems involving wood utilization. As described above, this sponsorship enables a wide range of research that is performed by state governments, especially by colleges, universities and specialized centers. In addition to state governments, federal agencies also support wood utilization research that is conducted by a wide array of other public (for example, national laboratories) and private organizations (bio-based fuel manufacturers). Although they do not employ full-time scientists and support staff to conduct wood utilization and product development research, at least 11 federal departments or agencies are known to sponsor such research. Examples of such departments are the U.S. Department of Agriculture's National Resources Conservation Service which provides funding for research on bio-based fuels and methods for their production, the U.S. Department of Housing and Urban Development which provides grants for research on residential housing materials (including the use wood), and the U.S. Department of Agriculture's Cooperative State Research Education and Extension Service which provides grants and formula-funding for a wide range of wood utilization research (Table 5). The full extent of the wood utilization research sponsored by such organization has not been fully documented (U.S. Government Accountability Office 2006).

Table 5. Federal Agencies Sponsoring Wood Utilization Research in the United States, by Agency, Authorizing Law, and Description of Research. 2006.

Agency	Authorities	Research Subjects
U.S. Department of Agriculture – Cooperative State Research, Education and Extension Service	Various Program Statutes, Land Grant University Statutes, Formula Grant Statutes, and Other Research Statutes	Grants and formula-funding for a broad range of wood utilization research.
U.S. Department of Agriculture – National Resources Conservation Service	Biomass Research Development Act of 2000	Grants for research on bio-based fuels and methods for their production.
U.S. Department of Energy	Energy Policy Act of 1992; Biomass Research Development Act of 2000	Grants for research on energy-efficient processes in energy-intensive industries, including pulp, paper and wood products.
U.S. Department of Homeland Security – Coast Guard	Department of Transportation Appropriation Act of 2002	Grant to conduct wood utilization research at a specific university
U.S. Department of Housing and Urban Development	Housing and Urban Development Act of 1970	Grants to conduct research on residential housing materials, including wood.
U.S. Department of Defense – Army, Corp of Engineers, Office of Navel Research	Defense Appropriations Act of 2005	Grants to conduct wood utilization research at specific universities.
U.S. Department of the Interior – Bureau of Indian Affairs	Snyder Act of 1921	Grants awarded to support wood product development.
National Science Foundation	National Science Foundation Act of 1950	Grants for wood utilization research involving engineering, chemistry, biology and social sciences (excluding product development)
U.S. Department of Transportation	Various Transportation and Appropriations Acts, including 1991, 1992	Grants for research on the use, design and performance of timber and wood products in bridges and related structures.

Source: U.S. Government Accountability Office 2006.

The financial support for wood utilization research by federal research sponsoring agencies is substantial. In 2005, the financial support of 11 federal departments or agencies approached $23 million and was distributed by agency as follows (U.S. Government Accountability Office 2006):

U.S. Department of Agriculture
    Cooperative State Research Education and Extension Service – $5,820,000
    Natural Resources Conservation Service – $ $4,627,000
U.S. Department of Defense
    Army Research – $1,050,00
    Army Corps of Engineers – $2,395,000
    Office of Navel Research – $1,424
U.S. Department of Energy – $6,233,000
U.S. Department of Homeland Security
    Coast Guard – $351,000
U.S. Department of Housing and Urban Development – $225,000
U.S. Department of the Interior
    Bureau of Indian Affairs – $276,000
U.S. Department of Transportation – $441,000
National Science Foundation – $4,242,000

Small Business Innovative Research. The Small Business Innovation Research (SBIR) program of the U.S. Department of Agriculture makes competitively awarded grants to qualified small businesses to support advanced high-quality research related to important scientific problems and opportunities in agriculture and natural resources. SBIR Phase I grants are limited to $80,000 and a duration of eight months, while SBIR Phase II grants are limited to $350,000 and a duration of 24 months (open only to previous Phase I awards). Participation by university faculty or government scientists in SBIR projects is strongly encouraged.

In 2009, the CRIS system reported 18 projects as recipients of SBIR grants (Cooperative State, Research, Education and Extension Service 2009). Support for the projects ranged from $75,000 to Custom Materials, Inc. (Elliot City, MD) for purposes of investigating wood-based advanced ceramic materials, to $350,000 to Restoration Technologies, LLC (Silver City, NM) for purposes of evaluating engineered wood chip composite erosion control material. The average SBIR grant was about $223,000, with half the grants in the range of $295,000 to $350,000; the remainder in the range of $75,000 to $80,000. Except for one, all grants involved only applied research. As for the subjects of investigation, the following are examples: Assess formation of structural core material from wood residuals and recycled fiber (West Mountain View International, LLC; Vancouver, WA); evaluate paper conservation by new mass de-acidification techniques (IFT, Inc., Richmond, CA); and investigate nano-biocides for wood-based construction materials (Nanodynamic Life Sciences, Inc. Pittsburgh, PA) (complete listing in Appendix Table 7).

RESEARCH AND DEVELOPMENT CAPACITY: PRIVATE SECTOR

Private Research Organizations Generally

Private entities also engage in research and development focused on the utilization of wood. The manner in which they organize and subsequently pursue their interests ranges from the use of company-employed scientists (for example, Neenah Paper, Inc.), to research undertaken by formal consortiums of interested private parties (for example, Herty Advanced Materials Development Center), and from scientific inquiries undertaken by cooperative ventures involving a variety of both public and private entities (for example, the Franklin Furniture Institute, Mississippi State University), to consulting organizations that carry out very specialized research and testing procedures (for example, Integrated Paper Services, Inc.). Also known to engage in wood utilization research is an assortment of private nonprofit foundations, institutes and centers (for example, Center for Paper Business and Industry Studies, Institute of Paper Science and Technology, American Society for Testing and Materials), and a variety of affiliates owned by wood-based manufacturing companies (for example, Weyerhaeuser's Optiframe Software LLC [focus on construction industry] and Catchlight Energy [converting biomass into low-carbon fuels]).

Comprehensive documentation of research projects implemented by private organizations is sparse. Eighteen wood utilization research projects were reported by the CRIS system as being implemented by private concerns in 2007. Example companies so engaged are NanoDynamics Life Sciences, Inc., (Pittsburgh, PA), West Mountain View International, LLC (Vancouver, WA), and the Technical Association of the Pulp and Paper Industry, Inc.(Timber Lake, GA). The 18 projects entailed an investment of more than $4.0 million, nearly all of which was provided by the Small Business Innovation Research (SBIR) program of the U.S. Department of Agriculture (Appendix Table 7) (Cooperative State Research, Education and Extension Service 2009). In addition to actually conducting research, private organizations also sponsor wood utilization research. As previously described, 61 wood utilization research projects implemented by state governments received financial support ($3.5 million) from an assortment of foundations, professional societies, and individuals in 2007. Another 55 projects were supported ($2.9 million) in whole or part by corporations and various industrial organizations such as trade associations and special interest organizations (Tables 2 and 3) (Cooperative State Research, Education and Extension Service 2009).

Although important in their own right, the aforementioned estimates of wood utilization research are in all likelihood an inadequate basis from which to judge the extent of wood utilization research that is carried out or sponsored by private organizations. Unfortunately, a more complete sector-wide documentation of the magnitude and direction of wood utilization research engaged in

by the latter is not available. In large measure the information void stems from the lack of a comprehensive central information reporting system, reluctance of private entities to fully disclose (for proprietary reasons) the nature of their research efforts, the inclination of reporting sources to be overly inclusive of topics considered within the scope of research (technical, marketing, accounting, consumer surveying), and the frequent merging of information about wood utilization research with research generally or with research involving forests, forest resources, forestry in general or environmental sciences.

Wood-based Manufacturing Companies

Important insights about wood utilization research carried out by enterprises operating within the wood-based manufacturing industry can be gained from the National Science Foundation's annual reporting (since the early 1950s) of research carried out by industry (National Science Foundation 1990). Although the specific portion of the industry's total research that is devoted specifically to wood utilization is not reported by the later, wood-based company annual reports suggest that a very large portion (in some cases, all) of the research and development reported annually by such companies involves some aspect of wood utilization – probably more than 95 percent (see Appendix Table 8). With this caveat in mind, the information reported by the National Science Foundation, and presented in what follows, probably represents a fairly reasonable basis for assessing wood utilization research and development carried out by the wood-based manufacturing industry.

Industry-wide Research Patterns

Wood-based manufacturing industries in the United States invested an estimated $2.4 billion in research and development in 2006 (0.1 percent of total for all U.S. manufacturing industries), a very large portion of which was in all likelihood focused on wood utilization and development (Table 6). Over the eight-year period 1999 through 2006, industry-wide research and development investments averaged about $2.1 billion per year, although annual investments have fluctuated from 11 percent increases (2002 to 2003, 2005 to 2006) to a 14 percent decline (2003 to 2004). As described below, 86 percent of the industry's 2006 research and development investments were made by companies operating within the paper manufacturing group (National Science Foundation 2009a) (millions of current dollars).

Major Industry Group	1999	2000	2001	2002	2003	2004	2005	2006
Wood Products	70	105	182	145	151	167	220	195
Paper Products	1,768	1,929	1,903	1,859	2,078	1,648	1,771	2,030
Wood Furniture Products	84	96	102	88	102	140	136	140
Total (million)	$1,922	$2,130	$2,187	$2,092	$2,331	$1,955	$2,127	$2,365

Research and development investments similar in magnitude to those made by the wood-based industry occur in a number of nonwood-based manufacturing industries. For example (2006), the electrical equipment and components industry – $2.3 billion, plastics and rubber products industry – $2.2 billion, and the electrical equipment and appliances industry – $2.3 billion. However, the wood-based industry's research and development investments pale in comparison to industries such as the pharmaceuticals and medicine industry – $38.9 billion, computer and electronics industry – $56.8 billion, and the aerospace products and parts industry – $16.4 billion (National Science Foundation 2009b, National Science Board 2008).

The funding for research and development undertaken by wood-based manufacturing companies originates primarily from company and nonfederal sources (for example, joint ventures and state governments). In 2006, an estimated 96 percent of the $2.4 billion invested in research by the industry was from these two sources, with the remaining 4 percent provided by the federal government (nearly all of which focused on development activities). The industry's paper products group received nearly all of the industry's federal funding ($210 million to $215 million of an estimated $228 million). For comparison, of the total funding of research and development by companies in all manufacturing industries, 10 percent originated from federal sources, with the aerospace products industry (27 percent) and the electro-medical and control instruments industry (43 percent) on the high side. Industries with federal funding emphasis similar to that occurring among wood-based manufacturing companies in 2006 were the nonmetallic mineral products industry (8 percent) and the basic metals industry (5 percent) (National Science Foundation 2009b).

The ratio of research and development investments to company domestic sales is a commonly used benchmark for judging the importance of research and development to an industry. In 2006, the overall ratio for companies performing research and development within the wood-based industry was about 1 percent, with the industry's major groups performing as follows: wood products group – 0.85 percent, paper products group – 1.39 percent, and wood furniture group – 0.76 percent (Table 6). In 2006, the ratio for all manufacturing companies in the United States was 4.0 percent, although the portion of sale devoted to research and development in some industries was substantial: computer

Table 6. Research and Development Activities of Private Wood-based Manufacturing Companies in the United States, by Major Industry Group. 2006.

Wood Products Manufacturing Group	Paper Manufacturing Group	Wood Furniture Manufacturing Group
R&D Expenditures Total - $195,000,000	R&D Expenditures Total - $2,030,000,000	R&D Expenditures Total - $140,000,000
Distribution of Companies by R&D Expenditures	Distribution of Companies by R&D Expenditures	Distribution of Companies by R&D Expenditures
Less than $200,000 – 277 companies	less than $200,000 –26 companies	Less than $200,000 – 171 companies
$200,000 to $999,999 – 29 companies	$200,000 to $999,999 – 14 companies	$200,000 to $999,999 – 89 companies
$1 million to $9.9 million –20 companies	$1 million to $9.9 million – 9 companies	$1 million to $9.9 million –62 companies
$10 million to $99.9 million – 3 companies	$10 million to $99.9 million – 2 companies	$10 million to $99.9 million – 14 companies
$100 million or more -- no companies	$100 million or more – one company	$100 million or more – 7 companies
Portion of Domestic Sales = 0.76 percent	Portion of Domestic Sales = 1.39 percent	Portion of Domestic Sales = 0.76 percent
Distribution of R&D Expenditures by Type of Research [329]	Distribution of R&D Expenditures by Type of Research [52]	Distribution of R&D Expenditures by Type of Research [343]
Basic Research – $ 7,000,000	Basic Research – $ 21,000,000	Basic Research – $ 2,000,000
Applied Research – $72,000,000	Applied Research – $439,840,000	Applied Research – $30,000,000
Development – $ 116,000,000	Development – $ 1,577,000,000	Development – $ 108,000,000
Distribution of R&D Expenditures by Size of Company	Distribution of R&D Expenditures by Size of Company	Distribution of R&D Expenditures by Size of Company
5-49 employees – $ 4,485,000	5-49 employees – $ 46,690,000	5-49 employees – $ 3,220,000
50-249 employees – $ 7,605,000	50-249 employees – $ 79,170,000	50-249 employees – $ 5,460,000
250-999 employees – $ 15,999,000	250-999 employees – $ 166,460,000	250-999 employees – $ 11,480,000
1,000-9,999 employees – $ 47,580,000	1,000-9,999 employees – $ 495,320,000	1,000-9,999 employees – $ 34,160,000
10,000+ employees – $ 119,340,000	10,000+ employees – $ 1,242,036,000	10,000+ employees – $ 85,680,000
Distribution of R&D Costs by Type of Cost	Distribution of R&D Costs by Type of Cost	Distribution of R&D Costs by Type of Cost
Wages of R&D Personnel – 46 percent	Wages of R&D Personnel – 38 percent	Wages of R&D Personnel – 55 percent
Employer Fringe costs for R&D Personnel – 12 percent	Employer Fringe costs for R&D Personnel – 12 percent	Employer Fringe costs for R&D Personnel – 8 percent
Materials and Supplies – 10 percent	Materials and Supplies – 23 percent	Materials and Supplies – 17 percent
R&D Depreciation – 3 percent	R&D Depreciation – 5 percent	R&D Depreciation – 2 percent
Other Costs – 29 percent	Other Costs – 22 percent	Other Costs – 18 percent
Distribution of Companies by R&D Performing Area	Distribution of Companies by R&D Performing Area	Distribution of Companies by R&D Performing Area
Biotechnology – 3 percent	Biotechnology – 2 percent	Biotechnology – less than 1 percent
Software Development – 2	Software Development – 32 percent	Software Development – 6
Materials Synthesis and Processing – 56	Materials Synthesis and Processing – 21 percent	Materials Synthesis and Processing – 14
Other Areas – 39	Other Areas – 45 percent	Other Areas – 79
Scientists and Engineers	Scientists and Engineers	Scientists and Engineers
Total – 1,710	Total – 3,767	Total – 2,246
Portion of Total Employees – 1.60 percent	Portion of Total Employees – 2.13 percent	Portion of Total Employees – 1.30 percent

Note: Number in brackets is number of companies. In some cases, estimates were made for nondisclosed information (data source avoiding disclosure of confidential company information) and for separation of information describing combined (multiple) industries.
Source: National Science Foundation 2009a.

and electronics industry – 10.8 percent, pharmaceuticals and medicine industry – 13.6 percent. More aligned with the wood-based industry in 2006 were the textiles and apparel industry – 1.4 percent, fabricated metals industry – 1.4 percent, and the electrical equipment and component industry – 2.5 percent (National Science Foundation 2009a).

Research and development is not universally performed by companies operating in the wood-based industry. In some cases, the investments of individual companies therein are very modest or not all. In 2006, 23 percent of 936 surveyed companies indicated they did not investment in research and development. Of the 77 percent that did make such investments, 65 percent invested some – but less than $200,000 –, while only 3 percent of reporting companies invested at least $10 million but less than $100 million. As indicated below (and in Figure 2), only eight companies invested $100 million or more in research and development during 2006 (National Science Foundation 2009a).

	Research and Development Investments (companies)						
Major Industry Group	None	Some but Less than $200,000	$200,000 to $999,999	$1 million to $9.9 million	$10 million to $99.9 million	$100 million or more	Total Comp-anies
Wood Products	77	277	29	20	3	0	406
Paper Products	14	26	14	9	2	1	66
Wood Furniture Products	121	171	89	62	14	7	464
Total	212	474	132	91	19	8	936

Investments in research and development by wood-based companies are more likely to be made by companies considered large in size, with size being defined by number of employees. In 2006, more than 61 percent of research and development investments made by wood-based companies engaged in such activities occurred in companies with 10,000 or more employees, while small companies (less than 250 employees) accounted for but 6 percent of the total (Table 6). When compared to all manufacturing industries in the United States, the proportion for each of these categories is nearly the same, namely 61 percent and 9 percent respectively. As for the industry's major groups, the portion of research and development attributable to large companies (10,000 plus employees) was identical for wood products, paper products and wood furniture products, namely 61 percent each. In absolute magnitude, however, companies with 10,000 or more employees in the paper product group accounted for the largest portion of industry-wide research and development investments in 2006, namely $1.2 billion or 52 percent (National Science Foundation 2009a).

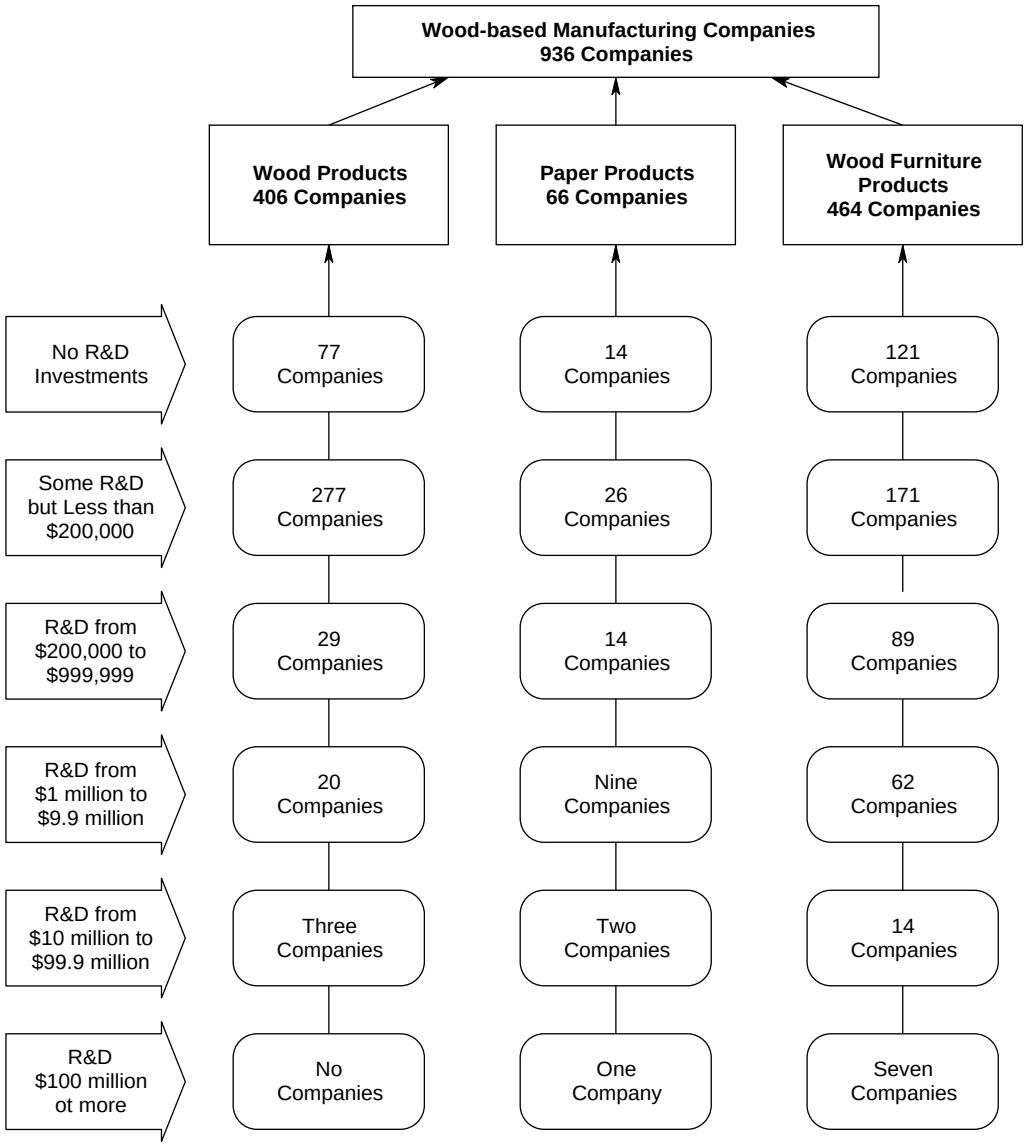


Figure 2. Research and Development Performing Wood-based Manufacturing Companies in the United States. 2006.

Company investments in research and development are distributed among various cost categories (Table 6). For wood-based manufacturing companies in 2006, the wages of research and development personnel (for example, scientists, engineers, technicians, secretaries) accounted for 46 percent of such investments. The remaining 54 percent was distributed as follows: materials and supplies (17 percent), personnel fringe costs (for example, health plans, retirement plans) (11 percent), depreciation of property and equipment (3 percent), and various other costs (for example, company overhead, utilities, taxes, books, periodicals) (23 percent). For the most part, this industry-wide distribution was uniform across the industry's major groups. The notable exception was the wood furniture group where over half (55 percent) of research and development funds were wages paid to company personnel. For all manufacturing industries in the United States, a slightly lesser portion of research and development costs were accounted for by wages (44 percent), while for other cost categories the distribution was very similar to that occurring in the wood-based manufacturing industry (National Science Foundation 2009a).

Research and development engaged in by wood-based companies can focus on a wide variety of subjects, of which biotechnology, software development, and materials synthesis are but three major categories. In 2006, about 2 percent of the industry's companies were engaged in biotechnology research, namely the use of scientific and engineering data and techniques for the study and solution of problems concerning living organisms (Table 6). Across all the industry's major groups, this proportion of companies varied only slightly with the high percentage (3 percent) occurring among companies in the wood products manufacturing group. As for software development as a focus of research (formulation of programs, applications and routines to be used by computers, excluding those used for internal company use), a relatively large portion – 32 percent – of companies engaged in paper and related manufacturing were engaged in software development. For the same research emphasis, the proportion of wood product and wood furniture companies were far less for each, namely 2 percent and 6 percent, respectively. Research involving materials synthesis and processing (formulation and manipulation of new materials) was the focus of about 30 percent of companies industry wide. However, the proportion varied from a high of over half (56 percent) of the companies in the wood products group to a low of 14 percent of companies in the wood furniture manufacturing group. About two of 10 companies in the paper group were engaged in such research. Unfortunately for purposes of making comparisons, the research performing category labeled "other" is very large, namely averaging nearly 54 percent. In 2006, the research subject distribution for all manufacturing companies in the United States was as follows: biotechnology – 5 percent, software development – 18 percent, materials synthesis and processing – 33 percent, and other areas – 44 percent.

Research and development performed by wood-based manufacturing companies is heavily skewed toward development, namely the translation of research findings into new products or processes or significant improvements to existing products or processes (including the design of prototypes) (Table 6). Of the $2.4 billion invested in 2006 by wood-based companies performing research and development, 76 percent focused on development activities. Particularly notable in this respect was the paper and wood furniture segments of the industry, where development investments exceed three-fourths of each group's total research and development investments. Applied research (translation of basic research toward new knowledge that has specific commercial objectives with respect to products, services, processes, or methods) accounted for 20 percent of industry-wide research and development in 2006 ($777 million of $2,365 million), with applied research emphasis among the industry's major groups distributed as follows: wood product manufacturing – 37 percent ($72 million), paper product manufacturing – 22 percent ($440 million), and wood furniture manufacturing – 21 percent ($9 million). Research pursuing new scientific knowledge that may not have specific or immediate commercial outcomes – basic research – was a modest $30 million for the wood-based industry in 2006, the largest portion of which – $21 million – occurred in the paper products manufacturing group. For purposes of comparison, the 2006 distribution of research and development investments among basic, applied and development for all manufacturing industries in the United States was: basic – 4 percent, applied – 20 percent and development – 76 percent (National Science Foundation 2009a).

Wood-based manufacturing companies employ a variety of scientists and engineers to implement their research and development programs.[2] In 2006, an estimated 7,723 full-time equivalent scientists and engineers were so engaged by the industry – a modest 1.1 percent of all such persons so engaged in 2006 by all manufacturing companies in the United States (Table 6). The paper manufacturing segment employs the largest portion of the industry's scientists and engineers and had the largest portion of total employees considered scientists and engineers, namely 49 percent and 2.1 percent, respectively. In terms of direct financial support per scientist or engineer in 2006, the paper products segment was the leader with an estimated $221,087 per scientist followed by the wood products segment and the wood furniture products segment with $169,946 and $136,923 per scientist, respectively. In 2006, the national average for all manufacturing industries was $233,737 per full-time equivalent scientist or engineer (National Science Foundation 2009a).

[2] Scientists are defined as persons engaged in scientific work that requires knowledge (gained either formally or by experience) of physical, biological, mathematical, statistical, or computer concepts which has been acquired through completion of a 4-year college program or equivalent. Not considered scientists are persons engaged in routine activities involving quality control, product testing, and market research (National Science Foundation 2009b).

The number of scientists and engineers employed annually by wood-based companies during the period 2000 through 2006 was about 8,350, with 1,420, 5,240 and 1,690 being the average per year for the wood products, paper products, and wood furniture products groups, respectively. As indicated by the following, the number of scientists employed over this seven-year period have remained fairly stable (National Science Foundation 2009b).

Major Industry Group	2000	2001	2002	2003	2004	2005	2006
Wood Products	700	1,600	2,000	1,550	1,100	1,278	1,710
Paper Products	5,346	4,990	4,396	7,088	4,976	6,116	3,767
Wood Furniture Products	1,685	1,872	1,373	1,248	1,622	1,810	2,246
Total	7,731	8,462	7,769	9,886	7,698	9,204	7,723

Longer term assessment of full-time equivalent scientists and engineers employed by the wood-based industry is difficult to evaluate because the information source (National Science Foundation) changed the definition of the industry's major groups in the mid-1990s. Recognizing this inconsistency in reporting, company employed researchers (full-time equivalents) industry-wide increased quite dramatically in the decade of the 1970s, becomes fairly stable in the decades of the 1980s and 1990s, and subsequently experiences a modest decline through 2006 (estimate for 1990) (National Science Foundation 1990):

Year	Lumber, Wood Products and Wood Furniture Industry	Paper and Allied Products Industry	Total Wood-based Industry
1960	700	2,400	3,100
1970	1,100	2,900	4,000
1980	2,200	7,500	9,700
1990	1,500	6,800	8,300
2000	-	-	7,731
2006	-	-	7,723

Research and development entities operated by wood-based manufacturing companies were located in all 50 states in 2006 (Table 7). In any specific state, the total research and development investment made by companies varied considerably between major groups of the industry as described below (the amount for some states is not available so as to avoid disclosure of confidential company information) (National Science Foundation 2009a):

- Wood Products Manufacturing Group: Investment of less than $500,000 in each of 24 states and an investment of $500,000 or more in each of 19 states.

•Paper Products Manufacturing Group: Investment of less than $500,000 in each of eight states and an investment of $500,000 or more in each of 38 states.

•Wood Furniture Products Manufacturing Group: Investment of less than $500,000 in each of 23 states and an investment of $500,000 or more in each of 24 states.

Although physically located in a particular state, wood-based company research and development entities very often engage in research that is regional and, in some cases, national and international in scope. Focusing only on the state location of such entities, the industry's research and development presence can be considerable in some states (Table 7). Of 38 states for which information is available, research investments by paper product companies in only five states accounted for 72 percent of the paper group's total for those states: $427 million in Ohio, $205 million in Wisconsin, $79 million in Texas, $69 million in Georgia, and $36 million in Washington. Although more modest in amount, wood furniture manufacturing companies made research and development investments of $32 million in Michigan, $13 million in Indiana, $11 in North Carolina, $7 million in Wisconsin, and $6 million in California. The most notable state locations of the wood products segment of the industry were Pennsylvania and California, where companies in 2006 invested $28 million and $22 million, respectively, in wood products research and development. Although confidential information for some states makes judgements about research magnitudes somewhat suspect, states in which total company investments in research and development might be considered quite modest (less than $500,000 each in three or fewer of the industry's three major groups) were Alaska, Delaware, Hawaii, Kansas, Montana, North Dakota, New Mexico, South Dakota, West Virginia and Wyoming.

Wood-based manufacturing companies are not indifferent to having research and development performed by organizations outside the United States. In 2006, five wood product companies reported investing $8 million ($1.6 million per company) in research performed by organizations located in foreign countries. Two companies in the industry's paper product group reported investing $32 million ($16 million per company) in research carried out by such organizations, while six companies in the industry's wood furniture group committed $2 million ($0.3 million per company) to research conducted by foreign-based organizations. Although substantial, these amounts are very modest compared to foreign research services sought by other manufacturing industries in the United States. For example, the transportation equipment industries and the chemicals industry invested an average of $77 million per company and $43 million per company, respectively, in research and development carried out by organizations located in other countries. Nationally, the average for all manufacturing industries was $20 million per company (National Science Foundation 2009a).

Table 7. Research and Development by Wood-based Manufacturing Companies in the United States, by State and Major Industry Group. 2006.

Wood Products Industry Company R&D Expenditures in State		
Less than $500,000	$500,000 or more	Confidential
AK, AL, CO, CT, HI, ID, KS, LA, ME, MO, MS, MT, ND, NH, NJ, NM, NV, RI, SD, UT, VA, VT, WV, WY	AR ($1 million), AZ ($1 million), CA ($22 million), FL ($4 million), GA ($11 million), IA ($12 million), IL ($1 million), IN ($1 million), KY ($1 million), MI ($7 million), NE ($1 million), NY ($1 million), OR ($7 million), PA ($28 million), SC ($2 million), TN ($4 million), TX ($4 million), WA ($2 million), WI ($12 million)	DL, MA, MD, MN, NC, OH, OK
Paper Products Industry Company R&D Expenditures in State		
Less than $500,000	$500,000 or more	Confidential
AK, HI, MT, ND, NM, SD, WV, WY	AL ($4 million), AR ($4 million), AZ ($1 million), CA ($36 million), CO ($6 million), CT ($19 million), FL ($10 million), GA ($69 million), IA ($3 million), ID (($8 million), IL ($19 million), IN ($6 million), KY ($2 million), LA ($2 million), MD ($17 million), ME ($12 million), MI ($10 million), MO ($8 million), MS ($1 million), NE ($1 million), NC ($11 million), NH ($3 million), NJ ($22 million), NV ($1 million), NY ($11 million), OH ($427 million), OK ($4 million), OR ($5 million), PA ($22 million), RI ($1 million), SC ($32 million), TN ($21 million), TX ($79 million), UT ($3 million), VA ($15 million), VT ($2 million), WA ($36 million), WI ($205 million)	DL, KS, MA, MN
Wood Furniture Products Company Industry R&D Expenditures in State		
Less than $500,000	$500,000 or more	Confidential
AK, AR, AZ, CT, DL, FL, HI, ID, KS, LA, MD, ME, MT, ND, NH, NM, NV, RI, SC, SD, VT, WV, WY	AL ($1 million), CA ($6 million), GA ($1 million), IL ($2 million), IN ($13 million), KY ($2 million), MA ($3 million), MI ($32 million), MN ($5 million), MO ($2 million), MS ($3 million), NC ($11 million), NJ ($1 million), NY ($2 million), OH ($1 million), OK ($1 million), OR ($1 million), PA ($4 million), TN ($3 million), TX ($1 million), UT ($1 million), VA ($2 million), WA ($2 million), WI ($7 million)	CO, IA, NE

Note: Information available from data source for some states is confidential so as to avoid disclosure of confidential company information.
Source: National Science Foundation 2009a.

Company Research Programs

The research and development programs of individual wood-based companies can provide additional insight to corporate interest in research. Consider as examples, the research programs of 26 public companies for which information is readily available (company annual reports, 10 -K reports to US Securities and Exchange Commission) (Table 8) (see Appendix Table 8). Although varying considerably from company to company, the 26 wood-based manufacturing companies invested $788 million in research and development programs in 2008 (average of $30 million per company), or about one-third of the industry's total investments for such purposes ($2.4 billion in 2006) (Table 6). Leading in research and development investments in 2008 were Kimberly-Clark Corporation ($297.0 million), Avery Dennison Corporation ($94.0 million), Furniture Brands International, Inc. ($88.1 million) and Weyerhaeuser Company ($64.0 million). In absolute magnitudes, such leaders pale in comparison to research and development investments made in 2005 by General Electric ($2.4 billion), 3M Corporation ($1.1 billion) and Dow Chemical Corporation ($1.0 billion) (Technology Review 2005). Although declining in 2008, companies that have experienced consistent growth (current dollars) in research and development investments from 2003 through 2007 are Avery Dennison Corporation, Flexsteel Industries, Inc., Packaging Corporation of America and Weyerhaeuser Company. Notable declines over the same period have occurred for International Paper Company, Nashua Corporation and MeadWestvaco Corporation.

Research and development expenditures as a proportion of a wood-based company's sales averaged 0.8 percent for 22 companies for which information was available (Table 8). Such a level was somewhat less than the 1 percent reported for all wood-based manufacturing companies and considerably below the 4.0 percent of all manufacturing companies in the United States (Table 6). Leading among the example wood-based companies in this measure were Furniture Brands International, Inc.(2.9 percent), Herman Miller, Inc. (2.4 percent), Kimberley-Clark Corporation (1.6 percent), and Avery Dennision Corporation (1.4 percent).[3]

[3] Governments use direct (specific development projects) and indirect (cost-share, tax relief) incentives to foster research and development by companies (Martin and Scott 2000). Tax relief can take the form of a tax allowance, exemption-deductions, or tax credits (reduction in tax liability). An important example of the latter is the federal research and experimentation tax credit (established by the Economic Recovery Act of 1981, as amended) which enables companies to take a 20 percent credit for qualified research above a base amount for activities undertaken in the United States. In 2003, 10,400 companies claimed $5.5 billion in tax credits, including most wood-based manufacturing companies with research programs (for example, Avery Dennison Corporation, Bemis Company, International Paper Company, Weyerhaeuser Company). At least 32 states have similar research and development tax credits (National Science Board 2008).

Table 8. Research and Development Expenditures by Public Wood-based Manufacturing in the United States, by Company. 2003-2008 by Company. 2003-2008.

Company	Year (million dollars)					
	2008	2007	2006	2005	2004	2003
Advanced Environmental Recycling Technologies, Inc.	0.3 [*]	0.3 [*]	0.3	0.1	-	-
Avery Dennison Corporation	94.0 [1.4]	95.5 [1.5]	87.9	85.4	81.8	74.3
Bemis Company	25.9 [0.7]	26.0 [0.1]	25.0	24.0	21.0	21.4
Buckeye Technologies, Inc.	8.2 [1.1]	8.2 [0.1]	8.3	9.2	9.4	9.3
Flexsteel Industries, Inc.	3.1 [0.8]	3.3 [0.8]	3.3	3.0	2.9	2.7
Furniture Brands International, Inc.	88.1[2.9]	80.7 [3.8]	72.7	65.9	-	-
Georgia-Pacific (Koch Industries)	-	-	-	-	61.0	64.0
Graphic Packaging Holding Company	8.0 [0.2]	9.2 [*]	11.4	9.9	9.6	7.4
Herman Miller, Inc.	38.8[2.4]	38.8 [2.0]	42.1	36.7	-	-
IFCO Systems North America, Inc.	5.6[0.8]	4.8 [0.7]	-	-	-	-
International Paper Company	22.0[0.1]	24.0 [0.1]	45.0	63.0	67.0	71.0
Kimball International, Inc.	16.0[1.3]	16.0 [1.4]	17.0	15.0	16.7	17.6
Kimberley-Clark Corporation	297.0[1.6]	276.8 [1.5]	301.2	319.5	279.7	-
Koppers, Inc.	2.8[0.2]	2.8 [0.1]	2.5	2.8	2.2	-
MeadWestvaco Corporation	61.0[0.9]	62.0 [0.9]	65.0	50.0	74.0	80.0
Nashua Corporation	0.7[0.3]	0.8 [0.3]	0.6	0.6	2.1	2.5
Neenah Paper, Inc.	6.5[0.1]	6.4 [0.6]	3.5	2.2	1.5	2.1
Packaging Corporation of America	6.9[0.3]	7.6 [0.3]	6.9	6.8	6.1	6.1
Rayonier, Inc.	5.0[0.4]	5.0 [0.4]	6.0	6.0	7.0	9.0
Rock-Tenn Company	0.3[*]	0.7 [*]	0.8	-	-	-
Schweitzer-Mauduit International, Inc.	8.3[1.1]	8.0 [0.1]	7.3	9.0	9.3	8.3
Smurfit-Stone Container Corporation	3.0[*]	3.0 [*]	4.0	9.0	8.0	5.0
Sonoco Products Company	15.9[0.4]	15.6 [0.3]	12.7	14.7	15.4	14.2
Universal Forest Products	3.7[0.2]	3.2 [0.1]	4.1	-	-	-
Wausau Paper Company	2.5[0.2]	2.6 [0.2]	2.1	1.9	1.9	2.2
Weyerhaeuser Company	64.0[0.8]	71.0 [0.4]	69.0	61.0	55.0	51.0

Note: No entry indicates information not available or company not part of wood-based industry. Number in brackets indicate research and development expenditures as a percent of company sales. An asterisk indicates less than 0.1 percent.

Source: Appendix Table 8, company annual reports, and filings with U. S. Securities and Exchange Commission.

The intent of research and development programs implemented by wood-based companies varies considerably, depending on the type of technology a company needs in order to succeed in the marketplace. Some companies firmly believe that their ". . . research and product development capabilities have played an important role in establishing a reputation for high quality, superior products" (Schweitzer-Mauduit International, Inc.). Review of the research intentions of 21 of the 26 wood-based companies (see Appendix Table 8) suggests that companies consider their research programs to be important for a number of reasons, including support for the implementation of company business strategies generally, development of new and improved products and processes required in order to remain competitive in the marketplace, reduce the cost of manufacturing products and distributing them to customers, and seek solutions to sensitive environmental problems associated with the manufacture of certain products. Companies also appear to use their research programs as a way of building customer loyalty by providing technical support based on the findings of research activities. They also make known their reliance on a parent organization for their research needs (for example, IFCO Systems North America, Inc. ". . . engage in ongoing product improvement efforts through parent company research programs, we do not have separate research and development expenditures).

When research intentions are actually made known by wood-based companies, such often tend to describe research and development intentions generally – only occasionally is there a specific focus on wood utilization. However, an appreciation of the latter can be gained by example (see Appendix Table 8 for more detail).

- *Buckeye Technologies, Inc*. "Focus on developing new products, improving existing products, and enhancing process technologies to further reduce costs and respond to environmental needs . . . focus on advanced products and new applications to drive future growth"
- *International Paper Company*. "Direct research and development activities to short and long-term technical assistance needs . . . and to process, equipment and product innovations."
- *Kimball International* ". . . development of manufacturing processes, major process improvements, new product development and design, information technology, and wood related technologies."
- *Nashua Corporation.* "Direct research toward developing new products and processes and improving product performance, often in collaboration with customers."
- *Rayonier, Inc.* "R&D efforts in performance fiber business directed primarily at developing existing core products and technologies."
- *Schweitzer-Mauduit International, Inc*. ". . . dedicated to developing paper product innovations and improvements to meet the needs of customers."
- *Verso Paper Company*. ". . . work with customers in developing and modifying products to accommodate their evolving needs and to identify cost saving opportunities within company operations.

•*Weyerhaeuser Company*. "Research is a strategic business investment to help the company and its customers achieve sustainable competitive advantage by creating and preserving options in the face of uncertainty about the future competitive environment."

Wood utilization research and development is identified as an interest of the research programs implemented by 22 of the 26 companies reviewed. Specifically mentioned in the research goal or mission statement of these companies is some aspect of wood utilization, such as "new product development or improvement," "improvement of pulping, bleaching and chemical recovery processes," "develop new products and enhance existing technologies," "develop new engineering systems for homes," "create a successful foundation for new products," and "focus on recyclable products to replace waxed packaged products." In only two cases is research involving forest management identified within a mission statement, namely International Forests Products Ltd. (INTERFOR) (applied research and development in the areas of environment and forest management) and Rayonier, Inc. (research on genetic tree improvement and applied silvicultural programs with the intent of identifying management practices that will improve financial returns from timber assets).

The research and development programs of the 26 companies reviewed here often involves collaborative initiatives as frequently occurs in other countries (Nakamura and others 2003). For example, prior to 2008 MeadWestvaco Corporation cooperated with India's Council on Scientific and Industrial Research (CSIR), especially "research which focuses on sustainable packaging solutions, process innovations related to biomass conversion and packaging innovations utilizing advanced materials." Similarly, International Paper Company has a one-third interest in ArborGen, LLC, a joint research and development venture with other forest products and biotechnology companies. Wood-based companies also have seen fit to establish research programs at facilities in countries other than the United States. Although the number of companies doing so appear modest, some probably involve research and development focused on wood utilization:

•Brazil – MeadWestvaco Corporation, Schweitzer-Mauduit International, Inc.
•Canada – Graphic Packaging International Corporation, International Forest Products Ltd.
•China – Avery Dennison Corporation
•France – Georgia-Pacific (Koch Industries), Schweitzer-Mauduit International, Inc.
•Germany – Neenah Paper, Inc.
•India – Avery Dennison Corporation
•Peoples Republic of China – MeadWestvaco Corporation
•Philippines – Schweitzer-Mauduit International, Inc.

Table 9. Private Organizations Engaged in Wood Utilization Research and Development in the United States, by Organization Characteristics. 2009.

Organization	Research Mission-Objectives	Major Focus	Wood Utilization Research and Development Interest	Resources
Applied Paper Technology, Inc. (Atlanta, GA)	Help customers improve the predictability of their paper, paperboard, or converted product	Research, testing, information dissemination	Coated paperboard, and fine paper	Seven staff
APA-The Engineered Wood Association (Tacoma, WA)	Develop and maintain markets through excellence in product promotion, quality assurance, and technical support.	Research, testing, information dissemination	Engineered wood product manufacturing.	---
Center for International Trade in Forest Products (CINTRAFOR) (Seattle, WA)	Undertake and apply research on technical, environmental, economic, social and resource problems that impede international trade in forest products.	Research, information dissemination, education	International trade in forest products.	10 staff
Center for Paper Business and Industry Studies (Atlanta, GA)	Identify, develop, and support research on business, management, and social science issues that are of critical interest to the global forest products industry.	Research, information dissemination, education	Pulp and paper industry.	Six staff
CleanTech Partners (Middleton, WI)	Help businesses implement new and emerging technologies that will reduce energy consumption, create jobs, and protect the environment	Equity financing, business counseling	Commercialization of technologies in forest product companies.	Seven staff
Consortium of Universities for Research in Earthquake Engineering (CUREE) (Richmond, CA)	Advance research, education and technologies involving earthquake engineering	Research, information dissemination, education, collaboration	CUREE-Caltech Woodframe Project.	27 staff (research-advisory)
Herty Advanced Materials Development Center (Savannah, GA)	Through innovation, unlock commercial opportunities in wood fiber and ensure production into new markets and industrial products.	Research, testing, pilot-scale production, product commercialization	Pulp, paper, board, and advanced composites.	---

Source: Company web sites and annual reports.

Table 9 (continued).

Organization	Research Mission-Objectives	Major Focus	Wood Utilization Research and Development Interest	Resources
Institute of Paper Science and Technology (IPST) (Atlanta, GA)	Provide new knowledge and technology through research and transfer technology considered important to the technical needs and competitive position of industry.	Research, information dissemination, education, collaboration	Global pulp, paper, and related industries.	10 staff
Integrated Paper Services (Appleton, WI)	Provide timely research, test data, and interpretive analysis.	Testing, research	Pulp, paper and allied industries.	11 staff
National Association of Home Builders Research Center (Upper Marlboro, MD)	Source for reliable, objective information and research on housing construction and development issues.	Research, testing, information dissemination, education, collaboration	Residential construction and housing industry.	Four mgt staff and others
Polymers Center of Excellence (Charlotte, NC)	Assist in the development of emerging polymer technologies and provide timely, cost-effective technical support for such technologies.	Product design, testing, education	Packaging and consumer product industries.	20 staff
Resource Information Systems, Inc. (Bedford, MA)	Create high quality information about the global forest products industry.	Research, information dissemination	Pulp, paper, and timber industries	---
Sardo Pallet and Container Research Laboratory (Center for Unit Load Design)	Provide research, technical assistance, and continuing education programs directly applicable to the pallet and container industries.	Research, information dissemination, education	Pallet and container industry	Eight staff
Southern Research Institute (Birmingham, AL)	Innovative solutions to industry problems involving life sciences, engineering, energy, and the environment.	Research, information dissemination, education	Wood materials and mechanics, chemistry and physics of materials, biomass energy technologies	---

Philanthropic foundations affiliated with wood-based companies also support research and development focused on wood utilization. In most cases, however, the focus of such research is on grants for the education of future scientists to be engaged in such research (for example, the International Paper Company Foundation) or grants for the construction of research facilities (or equipment) that will be involved in wood utilization research. Examples of companies with a foundation (or foundations affiliated with a company) that are known to provide grants for forestry, forest products and environmental purposes are MeadWestvaco Corporation, Bemis Company, Kimberly-Clark Corporation, Champion Enterprises, Louisiana-Pacific Corporation, Masco Corporation, and Furniture Brands International (Ellefson and Kilgore 2010). Unfortunately, a comprehensive review of wood-based corporate philanthropic activities is not available (last comprehensive review by Ellefson and Stone 1984).

Research Service Organizations

A variety of private nonprofit organizations actively engage in wood utilization research and development, as do many private enterprises that seek a profit from the research services they provide (Table 9). Although they may be involved in research activities, these organizations typically engage in wide variety of closely related activities, including testing of materials (for example, APA-The Engineered Wood Association), development of product and process standards (for example, National Association of Home Builders Research Center) and lending financial support required in order to implement the findings of research (for example, CleanTech Partners). In some cases, the mission of these organizations is focused directly on wood and woody products (for example, Center for Paper Business and Industry Studies), while in other cases wood utilization is but one modest part of their overall mission (for example, Southern Research Institute). For those organizations for which information is available, the resources devoted to wood utilization research and development ranges from fewer than 10 to more than 100 technical and support staff. Although industry wide information about private research service organizations has not been compiled, the total staff of such organizations is probably in the range of 500 to 1,000 nationwide.

Private for-profit organizations may also engage in some form of research and development focused on wood utilization. The most common of such organizations is consulting firms that respond to the information needs of wood-based enterprises. Although many of these organizations may be only peripherally engaged in research, they do investigate problems posed by a variety of different clients. Since the extent of such organizations has not been documented, the following examples will have to suffice (often wood-based services of larger company consulting portfolio).

•*ABB, Inc*. (Appleton, WI; Portland, OR) – services involving process control systems, instrumentation and energy systems for the paper and composites industries.
•*Abba Makolin Waldron & Associates, LLC* (Neenah, WI) – services involving development of processes, products and materials for the pulp and paper industry.
•*Buckman Laboratories* (Memphis, TN) – services involving development of speciality chemicals for the pulp and paper, packaging and recycling industries.
•*Chempap, Inc.* (Montgomery Center, VT) – services involving strategic planning, merger and acquisitions, advising buyers and sellers in the forest industry.
•*EnteGreat, Inc.* (Birmingham, AL) – services involving manufacturing designs to help in the leveraging of technology required by in the production of pulp and paper.
•*Intota Corporation* (Minneapolis, MN) – services involving wood adhesives used in laminated wood and oriented strand board, especially selection, application, and failure of adhesives.
•*PERFORX* (Atlanta, GA and Portland, OR) – services involving operational planning and performance of large paper converting, panel product and sawmill enterprises.
•*Wood Machining Institute* (Berkeley, CA) – services involving collection, evaluation and dissemination of information about wood machining equipment and cutting tools as applied to operations such as chipping, sawing, planing, shaping, routing, and sanding.
•*Wood Advisory Services, Inc.* (Millbrook, NY) – services involving engineering and construction, building performance evaluations, process and product evaluation, and statistical analysis and experimental design.
•*Wood Resources International* (Bothell, WA) – services involving global wood price trends and global trade in wood and paper products.

Trade and Business Associations

A myriad of private nonprofit interest groups perform an assortment of wood utilization related activities on behalf of their members. In 2006, more than 100 such organizations were identified as representing the wood-based interests of individuals, businesses or other organizations (Zerbe and others 2006). Most of these organizations engaged in activities such as development of industry wide product and process standards and specifications, testing and screening of products for performance and safety adherence, third-party certification of products and processes, sponsorship of education and training for employees of member company, publishing of technical journals and news letters, and various forms of public outreach that are designed to help the general public better understand the industry the organization represents. Some business and trade organizations develop research agendas and actively seek to build alliances that will promote the implementation of such agendas. An example is the American Forest and Paper Association's "Agenda 2020: Forest Products Industry Technology Alliance" which focuses on advancing wood-based technologies through the coordinated efforts of nearly 100 public and private organizations (American Forest and Paper Association 2006).

The extent to which trade and business associations are directly engaged (maintain laboratories, employ scientists, publish research results) in wood utilization research and development is largely unknown. Some have been known to indirectly engage in research via the making of financial grants. For example, during the period 1992-1998, TAPPI (Technical Association of the Pulp and Paper Industry) through the TAPPI Foundation granted $2.2 million (57 awards) for purposes of research involving wood utilization. A relatively small portion of the organization's funding for such purposes came from member dues (about 10 percent); most was provided by other public and private organizations (for example, International Paper Company, James River paper Company, Union Carbide Company, U.S. Department of Education and U.S. Department of Energy) (Alexander and others 2000). The following are offered as examples of trade and business organizations that have a notable interest in wood utilization research and development: Alliance for Environmental Technology (improve the environmental performance of the pulp and paper industry), National Nanotechnology Manufacturing Center (accelerate the commercialization of nano-enabled materials and devices), American Society for Testing and Materials (ASTM) (voluntary development of technical standards for materials, products, systems, and services), National Institute of Building Science (promote effective cooperation between public and private interests seeking energy efficient and environmentally responsible homes and buildings), American Institute of Timber Construction (development laminated industry design and product standards, including quality assurance, inspection, grading, and laminated timber research), and Composite Panel Association (bring together the complete value chain affiliated with the composite panel industry).

RESEARCH ORGANIZATION GOVERNANCE AND ADMINISTRATION

Design Standards and Criterion

The overall arrangement of a research organization is the means by which an organization seeks to accomplish its goals or mission. Organizational structure is not an end in itself. Rather it is the system through which appropriate inputs must go (scientists, facilities) in order to produce outputs (technologies, products, processes) that will sustain the organization's relevance. As for the exact form assumed by an organization, such is largely determined by size and need for coordination, extent of geographic disbursement, and whether few or many products or services are provided. Once such conditions are determined, research organizations most often choose to be either functionally organized (because they are small, geographically centralized, and focus on narrowly defined researchable problems) or divisionally organized (large, geographically disbursed, and focus on a wide range of researchable problems) (McNamara 2009).

Successful public and private research organizations engaged in wood utilization research and development often have common characteristics regarding their organizational structure, management practices and performance measures. Frequently mentioned attributes of an effective research organization are clear intentions, a focus on clients, talented staff, and a passion for judging performance. In more detail, a review of more than 20 references reporting on important attributes of forestry and forest products research organizations identified the following (Ellefson et al. 2007a, 2007b):

- Clear national and regional priorities for investment in high-quality relevant research focused on well-defined client-group needs (research viewed as a long-term strategic investment).
- Periodic critical review of research priorities and subsequent strengthening of research capacity required to address such priorities.
- Comfortably adapt to major changes in research environments (competition for financial resources and professional talent, attention to performance and accountability).
- Relate performance measures to knowledge generated and used by clients (not program inputs such as number of staff or number of publications).
- Organizationally structured along issue or problem lines (risk management, product commercialization, manufacturing systems) rather than along disciplines or products (chemistry, composites, pulp and paper).
- Extensive research networking by scientists and program managers with ample rewards for networking. Foster and participate in formally structured cooperative research activities (alliances, cooperatives, joint ventures).

•Suitable balance between short-term needs of clients and the funding required to support the organization's long-term relevance.
•Promote employee competence, pride and remuneration in accomplishing organizational goals and objectives.
•Beneficiaries of research services clearly identified and, as appropriate, payments made for services received.
•Appropriate blend of research to be publicly funded (imprecise markets, unclear allocation of intellectual property rights, insufficient scale of individual firms, uncertain long-tern sustained funding, public interest in benefitting certain social or economic segments of society) and to be privately funded (a high rate of potential return, low risk of uncertain results, single or small group of clients).
•Acknowledge long-term consequences of inordinate emphasis on private sources of research funding (limited support for research infrastructures, reduced freedom to explore high-risk but large payoff research opportunities, possible compromising research objectivity and neutrality, a diversion of attention away from important long-term research projects).

The organization and administration of wood utilization research and development organizations in the United States can benefit from the experiences of similar organizations located beyond the nation's boundaries. In this respect, especially noteworthy among foreign organizations engaged in wood utilization research is the blurry distinction between public and private sector responsibility for research; public sponsorship, yet private operation and management; wide range of services, in addition to research, available to clients; complex ownership and partnering arrangements; seemingly scrambled yet effective organizational structures; extensive use of subsidiaries and joint ventures; specialized services to a single major group of clients; intense desire to meet the needs of clients; synthesis of existing information as an important service; fees charged for services provided; strategic interest in clients located throughout the world; engagement in educational and degree-granting activities; multiple sources of income and revenue; diverse standards for measuring performance; adept response to broad economic-social changes; and multiple location of physical facilities (Ellefson et al. 2007a, 2007b).

Organizational Structure and Management

Public and Private Position

Public and private enterprises are engaged in wood utilization research and development in the United States. If the former, they are typically authorized by a public governing body, while as a private enterprise they exist because of their success in meeting needs for information as expressed by market systems. Examples of privately sponsored research in the United States are the research programs of the MeadWestvaco Corporation and the National Association of Homebuilders

Research Center, while research carried out by the Forest Products Laboratory (Forest Service, U.S. Department of Agriculture), and the Natural Resources Research Institute, (University of Minnesota Duluth) is government sponsored. Some research organizations are strictly private enterprises that are beholden to markets within which clients must be sought for the services that they are capable of providing (for example, Herty Advanced Materials Development Center). Others are solidly part of government and must rely on government political and administrative processes for financial support and, at times, research direction (for example, Building Technologies Department of the Lawrence Berkeley National Laboratory).

Mission and Strategy

The long-term interests and purposes of an organization are reflected by statements of mission. A review of mission statements developed by 27 wood utilization research and development organizations in the United States revealed the following common categories of purpose: advance science and new technologies ("develop creative concepts and strengthen scientific foundations"), contribute to national needs and concerns ("promote private sector employment"), support technical needs of clients ("create innovative technical solutions for clients), support economic and managerial needs of clients (improve financial returns from company investments"), and promote resource utilization and sustainability ("promote efficient, sustainable use of wood resources"). Although most of the reviewed statements addressed more than one of these categories, dominant were those mission statements that were concerned with strengthening scientific foundations and promoting efficient use of wood resources (Table 10).

Research organization mission statements tend to vary in scope and specificity. For the organizations reviewed here, some were brief and succinct such as ". . . advance the science and technology of wood-based composite materials" of the Wood-based Composites Center (Virginia Polytechnic Institute and State University) and ". . . provide timely research, test data, and interpretative analysis" of Integrated Paper Services, Inc. In other cases, the statements were very comprehensive as with the College of Forestry's Department of Wood Science and Engineering (Oregon State University)". . . advance science, engineering and business to help society use renewable wood and related materials and products in an environmentally sound and sustainable manner; enable the wood industry to be successful in a globally competitive environment through our teaching, research and outreach programs."

Table 10. Organization Mission Statements of Wood Utilization Research and Development Organizations in the United States. 2009.

Centers and Institutes

•*Alabama Center for Paper and Bioresource Engineering*. Mission: Conduct fundamental and applied research in line with industry's research agenda; develop and transfer technology to the industry consistent with the industry's technology vision and to provide timely technical information to the operating sector of the industry.

•*Forest Products Center, University of Tennessee*. Mission: Solve problems for Tennessee forest products producers and provide leadership in research and education to ensure future competitiveness and sustainability of the industry.

•*Natural Resources Research Institute, University of Minnesota Duluth.* Mission: Foster economic development of Minnesota's natural resources in an environmentally sound manner to promote private sector employment.

•*Wood-based Composites Center, Virginia Polytechnic Institute and State University*. Mission: Advance science and technology of wood-based composite materials.

University Colleges and Departments

•*College of Environmental Science and Forestry, State University of New York Syracuse*.

+Department of Chemistry. Mission: Advance chemistry in the service of Mankind's interaction with our environment, focusing on education of future scientists, advancing fundamental knowledge, disseminating chemical knowledge, and developing an awareness of the ethical impacts of the chemical sciences upon society and the environment.

+Department of Construction Management and Wood Products Engineering. Mission: Promote the utilization of sustainable construction practices and renewable wood products through teaching, research and outreach, for a sustainable built environment.

+Department of Environmental Resources and Forest Engineering. Mission: Through teaching, research, and service to advance engineering practices to meet the needs of the world.

+Department of Forest and Natural Resources Management. Mission: Produce and to transmit knowledge about the function and dynamics of forests and related renewable resources; to encourage continual learning about forest and related renewable resources and their role in making people's lives better; and to develop leaders who will manage renewable resources for people on a sustainable basis.

+Department of Paper and Bioprocess Engineering. Mission: Train engineers and conduct research involving the bioprocessing and biofuels industry to produce energy and related chemical products, including pharmaceuticals, from renewable resources.

•*College of Forestry, Oregon State University*.

+Department of Forest Engineering, Resources and Management. Mission: Developing, communicating and teaching the science, knowledge and engineering necessary for the sustainable management of forest, land and water resources that will achieve economic, environmental and social objectives.

+Department of Wood Science and Engineering. Mission: Advance science, engineering and business to help society use renewable wood and related materials and products in an environmentally sound and sustainable manner; enable the wood industry to be successful in a globally competitive environment through our teaching, research and outreach programs.

Source: Organization web sites and annual reports.

Table 10 (continued).

Company Research Programs

•*MeadWestvaco Corporation.* Mission: Using research generated new and emerging technologies, provide for innovative products and manufacturing processes that will reduce the cost of product development and manufacture.

•*Rayonier, Inc*. Mission: Via research and development efforts, further the existing core of company products and technologies and identify and improve resource management practices that will lead to improvement in financial returns from company investments.

•*Smurfit-Stone Container Corporation.* Mission: Use advanced technologies developed through research to assist in product development and all levels of manufacturing and sales processes, from raw material supplies through to finished packaging performance.

•*Weyerhaeuser Company*. Mission: Focus research and development resources on new ways to expand and improve the range of applications for cellulose fibers and on new product opportunities.

Federal Government Organizations

•*Forest Products Laboratory, U.S. Department of Agriculture*. Mission: Promote healthy forests and forest-based economies through the efficient, sustainable use of our wood resources.

•*Lawrence Berkeley National Laboratory, U.S. Department of Energy*. Mission: With a commitment to pioneering science, engage multi-disciplinary scientific teams working together to solve global problems in human health, technology, energy, and the environment and support the acceleration of scientific discovery through the collection and dissemination of scientific and technical works.

Private Service Programs

•*Herty Advanced Materials Center*. Mission: supporting innovation and unlocking commercial opportunities; reduce the risk of product innovation and accelerate good product ideas to great commercial success; leverage Herty strengths in fibers and pilot scale production into new markets and industrial products.

•*Institute of Paper Science and Technology.* Vision and mission: Produce research output that has a significant beneficial impact on the manufacturing and use of pulp & paper and related products; conduct research and transfer technology to support the technical needs and competitive position of our member Companies.

•*National Association of Homebuilders Research Center*. Mission: Advancing housing technology and enhancing housing affordability for the benefit of all Americans; be a source for reliable, objective information and research on housing construction and development issues.

•*Southern Research Institute*. Mission: Create innovative solutions for public and private sector clients in the life sciences research, life sciences contract services, engineering, and environment and energy industries.

Governance and Advice

The exercise of governing authority often determines the extent whether a wood utilization research and development organization will be successful in carrying out its mission. Such authority emanates from many sources, most of which are embodied in notions of power and the charisma of leadership. Although a comprehensive review of governance structures for wood utilization research organization in the United States has not been carried out, example organizations provide some insight. In some cases, an independent governing panel (board, council, committee) is a common expression of governance (for example, Board of Trustees, Herty Advanced Materials Development Center; Board of Directors, Southern Research Institute; Investment Board, CleanTech Partners), while in other cases a research organization is positioned within a larger organization that may – or may not – exercise broad governing responsibilities over a research organization (for example, Forest Products Laboratory within the Forest Service, U.S. Department of Agriculture; NAHB Research Center within the National Association of Homebuilders). Although not common, some research and testing organizations are directly governed by a single executive (for example, Executive Director, Polymers Center for Excellence; Chairman, Integrated Paper Services).

Regardless of whether part of a broader organization or operating as an independent organization, for 16 example organizations (public and private) reviewed here all were guided by an executive officer that exercised significant leadership and authority (director, provost, president, vice president, chief technology officer) (Appendix Figures 1 through 16). Although ultimately responsible for the research programs of their organization, these executive officers commonly delegate governance authority to various subordinates. For example, the President and Chief Executive Officer of Weyerhaeuser Company assigns company research programs generally to a Senior Vice President-Chief Technology Officer for Research and Development who in turn delegates research program authority to six technology-focused vice presidents that are responsible for technologies involving strand technologies, timberland, lumber, marketing, veneer, and bioproducts (Appendix Figure 10).

Formally established advisory bodies (committees, councils) are very common to research organizations, especially public organizations. Nearly all of the 16 example organizations examined here made use of such entities for purposes of seeking scientific advice (guidance on scientific knowledge and procedures), research program advice (guidance on general long-term research directions), research project advice (guidance on design and conduct of specific projects within programs), performance advice (guidance on assessing results and effectiveness of research programs and projects), and managerial operational advice (guidance on the administration and operation of an organization).

Organizational Structure

The organizational structure of research entities can range from those that are carefully arranged (vertically or horizontally) to entities that appear to be organizationally very cluttered. Yet regardless of outward appearance, most research organizations have certain basic internal units that address administrative support functions (accounting, human resource management, communications, public affairs, computer systems), planning and reporting functions (program development, monitoring, evaluation), research and development functions (divisions, sections, programs, branches, subsidiaries), technology transfer functions (publications, workshops, public-private partnerships), testing and inspection functions (materials testing, certification), and educational functions (graduate education, continuing education). Exactly which units are chosen depends on the size of the research enterprise and the nature of its mission.

Wood utilization research organizations in the United States exhibit a modest array of organizational structures (Appendix Figures 1 through 16). Some are vertically structured organizations with many layers of organization and a pronounced chain of command (for example, National Association of Homebuilders Research Center [Appendix Figure 15]), while others are horizontally structured with relatively few layers of organization and a collegial management style (for example, Forest Products Center, University of Tennessee [Appendix Figure 3]). Information and skills structured organizations emphasize fields of knowledge and teams of specialists focused on researchable problems (for example, Lawrence Berkeley National Laboratory [Appendix Figure 12]). Some research units are located within larger diversified organizations that have broader research responsibilities or other business or resource management obligations (for example, Forest Product Laboratory within the Forest Service, U.S. Department of Agriculture [Appendix Figure 11]). Also across the organizational landscape are research alliances, partnerships and joint ventures established by multiple research enterprises or business interests (for example, Catchlight Energy [Chevron and Weyerhaeuser],Weyerhaeuser-Lenzing Group Partnership [research involving development of lyocell-based nonwoven products] [Appendix Figure 10]). Although the aforementioned organizational structures provide a framework for analysis, in reality, few – if any – wood utilization research organizations conform to a single theoretical organizational form.

Wood utilization research entities in the United States are many times a distinct organizational unit located within and responsibility to a college or university system. In some cases, their affiliation with the latter is organizationally modest, even though they enjoy the benefits of the affiliation. The latter can include an educational-employer interface that increases opportunities for student involvement with experienced researchers and administrators, and provides research organizations with an opportunity to employ well-educated, technically competent professionals.

Especially noteworthy for their affiliation with universities are the more than 30 university departments of wood and paper science, the 10 federally sponsored wood utilization research centers, and an array of other centers and institutes, including the Natural Resources Research Institute at the University of Minnesota Duluth's (Appendix Figure 1), and the 12 centers and institutes affiliated with the College of Environmental Sciences and Forestry at the State University of New York (Appendix Figure 5).

Most wood utilization research organizations in the United States carry out research at a single geographic location (a situation that is in marked contrast to conditions in other countries [Ellefson et al. 2007a, 2007b]). In large measure, this narrow geographic focus is driven by an interest in achieving the economies of scale necessary to conduct certain types of research (equipment, libraries, computer facilities, support staff) and by the importance of having researchers concentrated in sufficient number so as to promote useful interaction and collaboration. There are, however, government and business organizations that have more than one location where their research activities are carried out. For example, in 2005 six-wood-utilization work units of the Forest Service, U.S. Department of Agriculture were located in six different states. Similarly, some wood-based manufacturing companies carry out wood utilization research at a number of different locations (within and outside the United States). For example, Avery Dennison Corporation [three states], International Paper Company [at least two states], MeadWestvaco Corporation [two states], Neenah Paper, Inc. [two states] (Appendix Table 8) (U.S. Government Accountability Office 2006).

Strategic alliances and partnerships are fairly common organizational approaches to carrying out wood utilization research. Often operating quite independently from the sponsoring organizations, these arrangements are initiated for a variety of reasons, including bringing together unique research talents, addressing short-term problems in need of research, serving or accessing current or new clients, externalizing risk away from an organization, leveraging resources necessary to address large problems, and–for private sector organizations–avoiding taxes on revenue generated by research programs (Inklaar et al. 2004). The number of alliances and partnerships engaged in wood utilization research probably is in the range of 75 to 100 nationwide, of which the following are examples.

> *Coalition of for Advanced Wood Structures* (CAW). Objectives: Improve the economy and performance of wood structures; coalition members – University of Idaho, Iowa State University, Mississippi State University, NAHB Research Center, The Engineered Wood Association (APA), and the Forest Products Laboratory, Forest Service, U.S. Department of Agriculture.
> *Consortium for Research on Renewable Industrial Materials* (CORRIM). Objectives: develop scientific base of information about the environmental

performance of wood-based building materials; consortium members – universities of Washington, Minnesota, Idaho, and Maine; state universities of New York, Oregon, North Carolina, Pennsylvania, Washington, Mississippi; Purdue University; The Engineered Wood Association (APA); Composite Panel Research Foundation (CPA); Forest Products Laboratory, Forest Service, U.S. Department of Agriculture; American Forest and Paper Association; and 13 U.S. wood-based manufacturing companies.

Herty Advanced Materials Development Center: Objectives: through an innovation and product development network, leverage diverse resources to enable solutions to important problems; network members – Georgia QuickStart, Polymers Center of Excellence, Georgia Institute of Technology Savannah, Synergics Corporation, National Nanotechnology Manufacturing Center, Georgia Centers of Innovation, and Georgia Department of Economic Development (Appendix Figure 13).

Pulp and Paper Education and Research Alliance (PPERA). Objectives: Cooperate in attaining common objectives involving education, research, and service, for the purpose of enhancing benefits to the North American pulp, paper and allied industries; alliance members – universities of Maine, Minnesota, Washington and Wisconsin Stevens Point; state universities of New York, North Carolina; Auburn, Miami, and Western Michigan universities; Georgia Institute of Technology; and the Institute of Paper Science and technology.

National Center for Wood Transport Structures. Objectives: Through research and demonstration, improve the use, durability, and performance of wood transportation structures on primary and secondary roads and the rural transportation infrastructure. Center members: Federal Highway Administration, U.S. Department of Transportation; National Park Service, U.S. Department of the Interior; Forest Products Laboratory, Forest Service, U.S. Department of Agriculture; Institute for Transportation, Iowa State University.

Public-Private Partnership for Advanced Housing Technology (PATH). Research Objective: Conduct research on advanced housing technologies that support housing affordability, durability, disaster resistance, safety, quality, and energy efficiency and environmental sustainability. Partnership members include: Housing Research Institute, Arizona State University; Civil Engineering Program, Clemson University; Massachusetts Institute of Technology; Construction Management Program, Michigan State University; Housing Research Center, Pennsylvania state University; Purdue and Villanova universities; universities of Central Florida, Missouri-Rolla, Southern California; Center for Housing Research, Virginia Polytechnic Institute and state University.

Administrator Perspectives

The executives and management staff of wood utilization research and development organizations are often in a position to provide especially noteworthy insight about organization, management and performance measures. With such in mind, the directors (or their deputies) of 32 public and private research organizations in the United States were contacted and asked to provide the following information about the research organization (or units within an organization) for which they were responsible: "Wood utilization research organizations can be organized, managed and performance assessed in many different ways. What organizational, managerial and performance assessing features of your organization enable it to effectively carry out its mission?" Responding administrators were affiliated with independent research centers or institutes, university forest and biobased products departments, federal research organizations, and private manufacturing and research service companies. With only slight paraphrasing, the more discerning replies of 22 responding administrators follow.

Organization and Direction

Research administrators were presented with examples of various subjects involving organizational structure. For example, ownership (public, private, or some combination), governance (board of directors, chief executive office, advisory committees), partnerships (affiliates, subsidiaries, joint ventures), sources of finances (government, private, or some combination) and decision-making processes (centralized, decentralized). Among the respondent's many observations about their own entity's organization was the importance of clarity in purpose and a clear focus on the clients to be served; ability to network with a variety of like organizations and formalized participation in well-crafted joint ventures; workable governing boards and advisory boards with well-defined duties; importance of public funding, especially the financial stability and long-term perspective such often imply; advantages of being a private research organization, especially the ability to quicky respond to a need for research; and the value of being affiliated with (or within) a larger organization that has visibility, respect and political strength. In a more detailed fashion, the administrators noted the following.

Mission and Strategies

> . . . our primary goal is to have a positive impact on science, education and outreach in our field.
> . . . research programs must be defined and subsequently directed toward the future uses of wood fiber and the solution of important national issues involving wood.

. . . as an organization that is primarily public funded, we are allowed to focus on longer term, innovative, and game changing research.
. . . well developed and targeted objectives have been critically important to our organization over the years.
. . . we direct research and development activities to short-term, long-term and technical assistance needs of customers and company operating divisions, and to process, equipment and product innovations.
. . . what an academic institution can offer is what virtually no other research organization can, namely state of the art research that move the boundaries of knowledge outward.
. . . institute's mission is quite different from other university departments in that we exist to apply technological solutions to drive economic development and job creation while doing so in an environmentally sensitive manner.
. . . history of the institute's success is a result of organizational stability over time, well-defined expectations, clear reporting responsibilities, and openness with and respect of staff.

Organization and Structure

. . . having both an executive director and a director is important, since the former understands and connects with industry, while the latter bring sound managerial practices to research and research processes.
. . . as a university center, our strength is in bridging the gaps between the silos (academic departments). Being affiliated with a college brings strong collegiate-level advocacy for resources. If positioned at the university level, the center's support would be significantly diluted.
. . . as a research entity within a larger forest products company, we continually need to project our abilities within the larger company structure. Long-term research is often difficult; managers want and need answers now.
. . . as an academic research entity in the traditional sense, research faculty is a very decentralized and quite autonomous bunch. Each operates as a separate enterprise – works quite well.
. . . as a multidisciplinary research center, we operate under the university's vice president for research and development. Although our researchers are often strongly engaged with academic departments, they are not formally part of any single department.
. . . even though part of a larger organization, very little direction comes from the parent entity. As long as such has some relevance to the parent organization, our scientists and managers are quite free to determine a program's direction and intensity.
. . . an important element of our success is the ability to easily partner with other federal and state entities, academia and private industry. Such is formalized through a variety of cooperative agreements and joint venture authorities.

. . . center operates as a commercial enterprise with R&D areas organized as business units and lead by senior management staff.

. . . structure conditions important to our success are public ownership, a consortium partnership, and a combination of public and private funding mechanisms.

. . . department is 100 percent committed to serving the research function. When this actually happens in word and deed, researchers are served by a proactive structure, rather than a rigid, authoritative, restrictive structure.

. . . organize research work by functional divisions and subdivide the divisions into groups that have a specific focus and emphasize a team approach . . . such contrasts with the individual investigator approach used in many research establishments.

. . . being situated within a larger federal organization is essential for a research organization of our modest size. We would be lost in a bureaucratic maze and invisible to legislators if we were on our own.

Sources of Income

. . . since we are a private organization, we are constantly seeking financial support from the private sector. Since we do both product testing and research, the testing part of our business gives us a greater degree of financial stability that cannot be given to us by our research clients.

. . . external funding is important (90 percent external, 10 percent university). Industrial contracts make up 10 percent of the external funding, with the balance coming from federal grants and contracts.

. . . federal funding of most of our budget gives our organization stability that is difficult to find elsewhere. Because of such funding, our scientists are freed from the constant pursuit of research funds. It also gives us relief from certain pressures that might occur if our organization relied solely on private funding.

Governance and Advice

. . . board of advisors is critical, but if such is to properly function members must be broadly based and understand the nature of research. Members may at times look for quick solutions to current problems, a perspective that conflicts with our organization's research interests, namely focus on extended time lines (longer view), development of a deeper understanding of some topics, and exploration of more profound subjects not always on industry's radar screen.

. . . meeting twice a year, our advisory board identifies key issues for our involvement and then sets clear objectives that are to be achieved before the next meeting.

. . . our for-profit research organization is well-governed by a five-member board of trustees appointed by the governor for five year terms. It understands our mission of accelerating commercialization processes.

> . . . a special management team advises (budgets, direction, client relations) the center's director, while a research quality team (council) informs the International Organization for Standardization (ISO) about research procedures and processes.

Administration and Management

Administrators were also presented with examples of administration and management topics. For example, clients and customers (service, communication, geographically dispersed), leadership (creative, enterprising), research and supporting staff (talented, energized, dedicated), communication (targeted, timely, informative), risk taking (responsive, welcoming), blend of programs (research, service, education), and orientation of research (basic, applied; forestry, forest products; paper products, solid wood products). Among administrators' noteworthy observations was the importance of leadership, especially visionary and enthusiastic leaders; encouraging bold and venturous searches for new knowledge; promoting both applied and basic research, as difficult as such may be; extensive collaboration and interaction; employee access to decentralized decision making processes; and long-term dialog with clients as well as plentiful internal and external communication generally. Responding administrators' observations are noted in more detail as follows.

Clients and Patrons

> . . . each year, we visit dozens of forest products companies and related stakeholders. Being client-centric is the name of our game.
> . . . work to promote a broad set of collaborative arrangements with many technical and political partners. Enables us to have an informal compact of interests that we can draw on to promote our programs, especially financial support.
> . . . critical is the center's substantive interaction with industry and industry associations. We want the center to be viewed by industry as a valuable resource. The bottom line – the center needs industry.
> . . . never underestimate the importance of gaining and keeping the trust of commercial and industrial clients and partners.
> . . . research results are important to us. As a forest products company, we derive a competitive advantage by protecting our trade secrets, patents, trademarks and other intellectual property rights, and by using them as required to support our company's businesses.

Scientists and Staff

> . . . scholarship of research is the prerogative of the researcher's creative endeavor. Research decision making within our organization is decentralized. The administration does not stand in the way of this creativity and curiosity.

. . . key to our success is the vision and enthusiasm of its director. A good director possesses unparalleled, keen strategic vision. This leadership and sense of direction, when combined with principal investigators that excel in the execution of projects, enable our research programs to be very effective.

. . . talented scientists and support staff are absolutely essential; without dedicated people we would be nowhere.

. . . critical to the center's operation is a customer orientated staff that provides a rapid response to customer needs.

. . . researchers are encouraged to be bold and venturous, and, as such, many have established 'centers' that allow them to be entrepreneurial, exercise leadership, establish a research identity, and develop a constituent base.

. . . so as to avoid financial or other conflicts of interest, period ethics training of all staff and annual disclosure of finances by scientists and senior managers.

. . . scientific staff is given much freedom to select and carry out independent and innovative research. They must, however, demonstrate how their work will contribute to the overall success of the research organization.

. . . believe that our teams and individual researchers should be given the freedom to pursue their programs with some independence, and are given good latitude for moving ahead while following our organization's basic policies regarding in program implementation.

Planning and Administration

. . . success rests on staying relevant which requires periodically reviewing our research agenda. Such is a challenge since so many different groups attempt to shape the focus of our research.

. . . collaboration of faculty, students and staff is strongly encouraged. Doing so has lead to quality research that flows from faculty research experiences, staff technical and managerial support, and new and innovative ideas brought forth by very bright graduate students.

. . . as a private research organization, we are very sensitive to protecting a client's intellectual property.

. . . decentralized decision-making is the center's management philosophy. Initiative, creativity and risk taking are valued by our center's entrepreneurial environment.

. . . research projects have become much more targeted. Cost-effectiveness is promoted when we are able to take advantage of the significant cost difference between academic and for-profit research.

. . . although our research combines basic and applied research, all basic research is conducted with an eventual applied objective that is supportive of our strategic plan. Such a strategic approach is very important to fulfilling our mission of creating economic development opportunities through commercialization of new technologies and products.

. . . as a small research unit within a large forest products company, we do a lot of contracting with consultants.

. . . managerial conditions of importance to us are talented research and support staff, good communication, and decentralized decision-making.
. . . have yet to really figure out how to maintain a balance between fundamental research and the applied research that many of our clients desire.
. . . within our organization, we have frequent communication about the research enterprise, including facilities, equipment and staff support/sharing.
. . . close integration of research involving forest resources, timber harvesting and the manufacture of wood-based products has been a plus for us. In addition, we make a special effort to incorporate engineering and business disciplines into our research efforts.
. . . institute does not have a direct responsibility for teaching although many of our researchers do teach courses on campus. We make extensive use of undergraduates and graduate students on research projects, but not on projects that require client confidentiality.
. . . consideration is being given to a number of new administrative approaches, including establishing a technology commercialization entity for new businesses; offering companies a propriety interest in our public research enterprise; offering scientists temporary employment with private enterprises (ability to transfer technologies, enhance scientist experiences); establishing with companies, jointly operated pilot plants; encouraging scientists to start businesses utilizing their research (not unlike universities); taking temporary equity positions in startup companies; and collaborating with venture capital companies to create new businesses using newly-developed technologies.

Performance and Appraisal

Research program administrators were presented with examples of performance measures for research programs. Examples included: clients are satisfied, organization is efficient and profitable, scientific contributions are being made, products and services are numerous (publications issued, tests conducted, conferences sponsored), achievements are being recognized (publicly and professionally), and operations are being conducted in professional and ethical manners. Respondents made special note of the importance of using a wide range of performance measures; periodic intense scrutiny of scientist performance and the performance of research programs generally; active engagement of clients in review processes and clear responses to their sentiments; reinforcing high-expectations for prospective and current employees; and the importance of documenting and evaluating products traditionally viewed to be the results of investments in research (publications, patents). More detailed sentiments of responding administrators follow.

Process and Procedures

. . . research program quality and relevance is annually reviewed at liaison meetings with representatives of academia and the forest products industry. Business-oriented management processes and principles guide these reviews.

. . . an annual attainment report is submitted to our parent organization, a report that allows for comparisons with other research entities and locations. Every five years a major review is conducted by external reviewers from industry, academia and other government organizations.

. . . as a way of assessing the desire of external groups to cooperate with our organization, we keep track of trends in the number and dollar value of cooperative agreements.

. . . not everyone in our organization wishes to perform at 100 percent – and that is ok. However, those that do perform at 100 percent have the greatest chance of promotion and future employment.

. . . each year, research scientists are required to produce a minimum of three research accomplishments (for example, patents or publications) and to prepare at least two proposals for external funding. In addition, research scientists are evaluated by a peer panel review system every 3-5 years.

. . . organization has a results orientation that tries to move things from the laboratory to demonstration and then to commercialization. We do not insist on publication of results because many of the things we work on involve trade secrets or know-how that our commercial partners want to protect.

Measures and Standards

. . . performance is measured by many standards, including success in securing externally funded competitive grants and contracts; graduation of talented graduate students; and publication of research results in high quality journals.

. . . success or failure is based upon whether the industry sees the center's research results as value-added contributions. To the point, the center's research must be relevant to industry and communicated to it.

. . . high quality published and publishable research are the most important performance measures.

. . . extracurricular grants-contracts and refereed publications are the primary standards against which performance is judged. Our unit is viewed as successful because we are very productive in all program areas for which we are responsible, namely teaching, research, extension, and service.

. . . key measures of performance are grants and contracts awarded, publications and patent activity, commercialization of new technologies, and the number of students engaged and supported by our research.

. . . an effective research organization must meet the needs of industry, looking for research opportunities that add value to industry and, subsequently, being able to gather the resources required to address these research opportunities.

. . . meeting the information needs of clients is very important. If some public or private organization does not find our information useful or profitable, strategic research directions are re-evaluated.

. . . important performance information includes the number of manufacturers assisted in creating new materials-based products, extent of new innovative capital expenditures made by industry without help, and new jobs created as a result of our for-profit commercialization ventures.

. . . performance is measured against tangible goals largely focused on having an impact on the tangible parts of our mission (economic development, job creation, and environmental solutions).

. . . high expectations are set when hiring new people. These expectations continue to be reinforced.

. . . as an academic institution, performance measures include, peer recognition, external reviews, and qualitative measures that are aligned with a faculty member's appointment (teaching, research, extension).

. . . as a private center, focus is on customer communication, making sure that customers get the research and testing they expected. If customers return for more work, it is a great sign that they were satisfied. Customer surveys also help.

. . senior management holds the scientific staff accountable for being entrepreneurial and for deploying research. The latter occur through partnerships with industry, academia, NGOs and others.

. . . in a university setting, primary performance measures are refereed publications, extramural research dollars, non refereed publications, technical presentations, student teaching and advising, stakeholders served, outreach and extension successes, and influence at national, regional, and state levels.

. . . our bottom line is whether our research-generated products and processes contribute to our company's bottom line. Forest products companies such as ours periodically take an economic hit – so does our research.

. . . although federally funded, scientists are required to compete in the "marketplace" of ideas by submitting two grant applications per year. Such provides a feel for the relevancy of ideas and research directions.

. . . success of the institute is measured by the extent of funding from external sources, impact of research (measured by patents, publications), reputation of research teams (honor s, awards), and students participating in the program.

. . . important measures of performance outcomes are publications, conferences attended, patents granted, scientist recognition and the like. It is via such measure that our research organization's scientific credibility is maintained.

. . . feedback on client satisfaction with the information that is produced by our research programs is periodically sought and evaluated.

. . . important performance measures are scientific outcomes valued by clients as measured by repeated service requests and client enterprise expansion; numerous products and services, including completed graduate students, refereed publications, presentations, service reports, and national recognition for achievements.

SUMMARY AND OBSERVATIONS

The wood-based manufacturing industry in the United States contributes more than $116 billion in gross value added to the nation's economy and employees nearly 1.2 million persons. Maintaining its worldwide competitive status depends in large measure on having ready access to a dependable flow of innovations that can arise from investments in wood utilization research and product development. In a broader sense, these innovations – and the research from which they commonly arise – are essential to long-term enhancement of environmental quality and to nationwide advances in economic and social welfare generally. With such in mind, a 2008-2009 review of research and development involving wood utilization was undertaken, the broad intent of which was to identify public and private organizations that are engaged in such research and the type and magnitude of resources they invest in wood utilization research, and to describe the strategies and objectives that guide their research investments and how their success as research entities relates to organizational design, management practices and measures of performance.

The diversity and complexity of the wood utilization research and product development community in the United States poses important challenges to preparation of a comprehensive description of its participants, magnitude and strategic directions. A single central clearing house for the gathering and interpretation of such information does not exist. In addition, there are concerns over definitions, scope of manufacturing and service industries to be regarded as wood-based, and the ofttimes intermingling of wood utilization research within forest research programs generally or its inclusion in broader research programs that encompasses various industrial sectors (construction, packaging, transportation) or many overarching technologies (biotechnology, modeling, simulation). Rules designed to avoid disclosure of confidential information often results in less than a full description of certain parameters, and in many cases information available for describing research capacity in not common to a specific year. Such shortcomings aside, this review is offered as a reasonable description of wood utilization research and development capacity in the United States.

Public Sector Research

Wood utilization research and product development is undertaken by a number of public organizations in the United States, ranging from state agricultural experiment stations to research entities within various agencies and laboratories of the federal government, and from university forestry schools and colleges to state government-sponsored research centers and institutes. In 2007, more than 250 government-sponsored projects were devoted to wood utilization research (identified with the aid of the U.S. Department of Agriculture's Current Research Information System [CRIS]).

Authorized by various public laws and agency directives, two-thirds of the projects were financed on a continuing basis (the remainder by special government grants). Most of the projects were implemented by colleges and universities (eight of 10 projects); three-quarters focused research on wood and wood products (16 percent paper and pulp-derived products). Slightly more than half of the projects (51 percent) emphasized applied research. Regionally, nearly half the projects (49 percent) were located in the North while 36 percent were located in the South. When made available to the projects, about half the grants and special awards were in the range of $250,000 to $500,000.

State Sponsorship and Implementation. State governments are very active participants in the conduct of wood utilization research and product development. In 2007, they were responsible for the implementation of 106 of the 258 projects previously identified as being implemented by government generally. Leading as a source of funding for such projects in 2007 were state government appropriations, namely $13.8 million or 43 percent of the $32.8 million total funds, followed by federal funding sources, namely $10.0 million or 31 percent of the total. Private organizations also support state research implementing organizations. Of the 106 state-implemented projects, 61 received $3.5 million in financial support from an assortment of foundations, professional societies, and individuals, while 55 received $2.9 million from companies and trade associations.

Excluding Wood Utilization Research Centers, the 106 state-implemented projects engaged nearly 271 staff years of personnel, 80 percent of which were scientists and supporting professionals. Regionally, 82 percent of the funds were implemented by research projects located in the North and South, with a similar regional distribution for project personnel (87 percent). Twenty-seven state colleges and universities are known to engage in research involving wood utilization, involving an average of 11 researchers at each entity. Also actively engaged in wood utilization research are more than 35 state-sponsored centers, institutes and laboratories. More than $6.8 million and the talents of an estimated 100 to 150 persons were also engaged in research at 10 university-sponsored (federally funded) Wood Utilization Research Centers.

Federal Sponsorship and Implementation. Federal government agencies also engage in research focused on wood utilization and product development. As for research performing agencies, the U.S. Department of Energy's National Laboratories and the U.S. Department of Agriculture's Forest Service are most prominent. Although not to be construed as all focusing directly on woody materials, 21 units at nine of the former's national laboratories engage in research relevant to wood utilization, notably nano-technologies, energy technologies, material sciences and biological sciences. The financial and human investment in wood utilization research by these units is not clear, although combined they engage the services of more than 1,200 scientists and engineers.

The U.S. Department of Agriculture's Forest Service plays a very significant role in wood utilization and development research. In 2005, the agency invested $27.2 million in such research, engaging the services of nearly 174 full-time-equivalents (FTE) staff. Of the latter, approximately half were scientists (nearly 88 FTE staff) with the remaining portion being support staff (more than 86 FTE staff). Over the 10-year period 1995 through 2005, the agency's annual budgetary authority increased $3,452,000 (but decreased $1,586,000 in real 2004 dollars). The agency's wood utilization and product development research is concentrated at the agency's Forest Products Laboratory, namely 68 percent of 2005 budgetary authority and 67 percent of the agency's wood utilization research staff. In 2009, the Laboratory's research focused on underutilized woody biomass, nanotechnology, forest biorefinery and biomass utilization, advanced structures research, and advanced composites.

Federal agencies also sponsor research that is conducted by private organizations and other units of government. At least 11 federal departments or agencies are known to do so, examples of which are the U.S. Department of Agriculture's National Resources Conservation Service which provides funding for research on bio-based fuels and methods for their production, the Department's Cooperative State Research Education and Extension Service which provides grants and formula-funding for a wide range of wood utilization research, and the U.S. Department of Housing and Urban Development which provides grants for research on residential housing materials. The financial support for wood utilization research by these 11 agencies is substantial, namely $23 million in 2005. Also notable is the U.S. Department of Agriculture's Small Business Innovation Research (SBIR) program which competitively awards grants to small businesses to support advanced high-quality research, including wood utilization research. Eighteen small business projects were granted ffinancial support in 2008, 14 of which received a total of about $3.7 million.

Private Sector Research

Private organizations engage in and sponsor wood utilization research and product development. In 2006, wood-based manufacturing industries in the United States invested $2.4 billion in research and development, most, if not all, involved the utilization of wood and the development of products therefrom. Of this total, most (90 percent) originated from company sources with a modest sum (about 10 percent) coming from federal research and development contracts. Over the eight-year period 1999 through 2006, industry-wide research and development investments averaged about $2.1 billion per year, although annual investments have fluctuated widely. In 2006, the paper manufacturing group was dominant, namely accounting for 86 percent

of the industry's research investments (followed at a distinct second by the industry's wood products group with 8 percent).

Large wood-based companies are more likely to invest in wood utilization research. In 2006, 73 percent of nearly 1,000 companies each invested none or less than $200,000 in wood utilization research, while only 3 percent each invested $10 million or more. Research and development performed by the industry is heavily skewed toward development, namely 76 percent of industry-wide investments. Judged by the level of research investments as a percent of sales, the wood-based industry (wood, pulp, paper, paper products, printing) is considered a low-technology industry, far behind high technology industries such as pharmaceutical, aeronautical, and medical industries.

Wood-based manufacturing companies employ a variety of scientists and support staff. In 2006, more than 7,700 full-time equivalent scientists and engineers were so engaged. The paper manufacturing segment of the industry employed the largest portion (nearly 3,800) and had the largest portion of total employees considered scientists and engineers, namely 49 percent and 4 percent, respectively. Trends in the total number of scientists employed over the eight year period 2000 through 2006 are not noticeable, although significant increases occurred in the wood products and wood furniture industries during this period, while substantial declines occurred in the industry's paper products segment (5,346 to 3,767).

In 2008, $788 million was invested in research and development programs by 26 public wood-based manufacturing companies. Averaging $30 million per company, the total was about one-third of the industry's total investments for such purposes ($2.4 billion in 2006). Leading investors were Kimberly-Clark Corporation ($297 million), Avery Dennison Corporation ($94 million), Furniture Brands International, Inc. ($88 million) and Weyerhaeuser Company ($64 million). Companies experiencing consistent growth (current dollars) in research and development investments from 2003 through 2007 were Avery Dennison Corporation, Flexsteel Industries, Inc., Packaging Corporation of America and Weyerhaeuser Company. Notable declines over the same period have occurred for International Paper Company, Nashua Corporation and MeadWestvaco Corporation.

Wood utilization research and development was specifically identified as a focus for research and development by 22 of the 26 companies reviewed here. Examples of stated research interests in wood utilization are "new product development or improvement," "improvement of pulping, bleaching and chemical recovery processes," "develop new products and enhance existing technologies," "develop new engineering systems for homes," "create a successful foundation for new products," and "focus on recyclable products to replace waxed packaged products."

Collaborative initiatives involving joint ventures and subsidiaries are used by some companies as a way of pursuing such outcomes. Although not common, many collaborative initiatives involve research programs at facilities located in countries other than the United States (eight foreign countries).

Privately sponsored research service organization and trade and business associations also conduct and sponsor wood utilization research. A definitive assessment of the type and magnitude of their programs has not been made. In most cases, the research programs of such organizations are complementary to a wide variety of closely related activities, including testing of materials, development of product and product standards, and providing financial and technical support required to implement the findings of research.

Organization and Management.

The wood utilization research and product development community is far from being a single unified and highly structured system. Although the threads that give it a common interest are wood fiber and the pursuit of investigations to advance the use of wood fiber, the manner in which the community's research enterprises are organized and managed are most often unique to an organization's mission. In the United States, the latter ranges from advancing science and new technologies to contributing to national needs and concerns, and from supporting technical and managerial needs of clients to promoting resource utilization and sustainability (strengthening scientific foundations and promoting efficient use of wood tend to dominate as research missions). To accomplish these intents, most wood utilization research projects in the United States are affiliated with government research organizations which are authorized by a public governing body, whereas private research enterprises exist because they successfully meet information needs expressed by market systems. In reality, most wood utilization research organizations in the United States exhibit public as well as private operational characteristics.

Certain organizational structures seem to prevail among organizations engaged in wood utilization research. Common are vertical structures that have many layers of organization and a pronounced chain of command, horizontally structures with relatively few layers of organization and a collegial management style, information and skills structures emphasizing fields of knowledge and teams of specialists, research units within larger diversified organizations having broader research responsibilities or other business or resource management obligations, and research alliances, partnerships and joint ventures established by multiple research enterprises or business interests. Although the aforementioned organizational structures provide a framework for analysis, in reality,

few – if any – wood utilization research organizations conform to a single theoretical organizational structure.

Although appearing to be organizationally cluttered, most organizations engaged in wood utilization research have certain basic internal units that address important functions (support, planning, research, technology transfer, testing, education, out reach). In most cases, these units are overseen or governed by a lead executive with the advice and counsel of a governing board or an advisory body. The latter are typically organized to provide either technical advice or managerial advice. Most research organizations in the United States carry out research at a single geographic location, a condition often required in order to achieve the economies of scale necessary to conduct certain types of research and to concentrate researchers in sufficient numbers so as to promote useful interaction and collaboration. Noteworthy in this respect is the frequency with which wood utilization research organizations are administratively or geographically associated with a college or university system. The nation's 10 Wood Utilization Research Centers are examples.

Strategic alliances and partnerships are fairly common organizational approaches to carrying out wood utilization research. Typically they are established for reasons such as bringing together unique research talents, addressing short-term problems in need of research, serving or accessing current or new clients, externalizing risk away from an organization, leveraging resources necessary to address large problems, and – for private sector organizations – avoiding taxes on revenue generated by research programs. The number of alliances and partnerships engaged in wood utilization research probably is in the range of 75 to 100 nationwide.

Executive managers of wood utilization research and development organizations are often in a position to provide especially noteworthy insight about the organization, management and performance of research entities. With such in mind, the directors (or their deputies) of 32 public and private research organizations in the United States were contacted (22 responded) and asked what organizational, managerial and performance assessing features of their organization enable it to effectively carry out its mission. Summarized responses are as follows.

> *Organizational Considerations*: Clarity in purpose and a clear focus on the clients to be served; ability to network with a variety of like organizations; workable governing boards and advisory boards; public funding and the financial stability such can often ensure; chartered as a private organization and the program flexibility such can lead too; and the value of being affiliated with (or within) a larger organization that has visibility, respect and political strength.

Administration and Management: Visionary and enthusiastic organizational leaders; talented researchers encouraged to be bold and venturous; decentralized decision making processes; extensive collaboration among researchers; focused, long-term dialog with clients; and plentiful internal and external communication generally.

Performance and Appraisal: Satisfied clients and customers; profitable and efficient organization; important scientific contributions; numerous high-quality products and services; publicly and professionally recognized achievements; and professional and ethical conduct of operations. From a process perspective, use a wide range of performance measures, periodic intense scrutiny of scientist performance and the performance research programs generally, active engagement of clients in review processes, reinforcing high-expectations for prospective and current employees, and documenting and evaluating products traditionally viewed to be the results of investments in research (publications, patents).

LITERATURE CITED

Alexander, S., B. Crouse, D. Cooper, C. Franklin and others. 2000. A Six Year Review of TAPPI Research Funding Program. TAPPI Journal 83(4):61.

American Forest and Paper Association. 2004. Nanotechnology for the Forest Products Industry: Vision and Technology Roadmap. Washington, DC: American Forest and Paper Association.

American Forest and Paper Association. 2006. Forest Products Industry Roadmap: Agenda 2020 Technology Alliance. Washington, DC: American Forest and Paper Association.

American Forest and Paper Association. 2010. Forest Products Industry Technology Roadmap: Agenda 2020 Technology Alliance. Washington, DC: American Forest and Paper Association.

Brashaw, B. K., V. Bucur, F. Divos, and others. 2009. A Worldwide Research Update (and earlier reviews). Forest Products Journal 59(3):7-14.

Brinberg, D., E. Kline, D. Alderman, and others. 2008. Exploring Research Priorities for North American Hardwood Industry. Forest Products Journal 58(3):6-16.

Cooperative State, Research, Education and Extension Service. 2000. Administrative Manual for Hatch (Experiment Station) Act as Amended. Washington, DC: U.S. Department of Agriculture, Cooperative State, Research, Education and Extension Service.

Cooperative State, Research, Education and Extension Service. 2002. Administrative Manual for the McIntire-Stennis Cooperative Forestry Program. Washington, DC: U.S. Department of Agriculture, Cooperative State, Research, Education and Extension Service.

Cooperative State, Research, Education and Extension Service. 2005. Manual of Classification for Agricultural and Forestry Research, Education and Extension: Classification used in the Current Research Information System. Revision VII. Washington, DC: U.S. Department of Agriculture, Cooperative State, Research, Education and Extension Service.

Cooperative State Research, Education and Extension Service. 2006. Strategic Wood Utilization Research Centers: Strategic Plan 2005-2001. Washington, DC: U.S. Department of Agriculture, Cooperative State, Research, Education and Extension Service.

Cooperative State, Research, Education and Extension Service. 2009. Current Research Information System: 2008. Washington, DC: U.S. Department of Agriculture, Cooperative State, Research, Education and Extension Service.

Ellefson, P. V. 1995. Forestry Research Undertaken by Private Organizations in Canada and the United States: A Review and Assessment. In: The Role of the Private Sector in Forestry Research: Recent Development in Industrialized Countries by Forestry Department, United Nations Food and Agriculture Organization. Pg. 73-139. Rome, Italy: United Nations Food and Agriculture Organization, Forestry Department.

Ellefson, P. V., and A. R. Ek. 1996. Privately Initiated Forestry and Forest Products Research and Development: Current Status and Future Challenges. Forest Products Journal 46 (2): 37-43.

Ellefson, P. V. , and M. A. Kilgore. 2010. United States Wood-based Industry: A Review of Structure and Organization. Staff Paper No. 206. St. Paul, MN: University of Minnesota, Department of Forest Resources.

Ellefson, P. V., and R. N. Stone.1984. U.S. Wood-based Industry: Industrial Organization and Performance. New York, NY: Praeger Publishers.

Ellefson, P. V., R. J. Moulton and M. A. Kilgore. 2002. An Assessment of State Agencies that Affect the Use and Management of Forests. Journal of Forestry 100 (6): 35-41.

Ellefson, P. V., M. A. Kilgore, K. E. Skog, and C. D. Risbrudt. 2007a. Forest Products Research and Development Organizations in a Worldwide Setting: A Review of Structure, Governance, and Measures of Performance of Organizations Outside the United States. FPL-GTR-172. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Ellefson, P. V., M. A. Kilgore, K. E. Skog, and C. D. Risbrudt. 2007b. Forest Products Research and Development Organizations: Organization, Governance, and Measures of Performance in a Worldwide Setting. Forest Products Journal 57(10): 6-13.

Forest Service. 2006a. Strategic Framework of Forest Products and Utilization Research and Development (FPURD). Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Forest Service. 2006b. USDA-Forest Service, Forest Products Utilization Research: An External Review. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Forest Service . 2009. USDA-Forest Service, Forest Service: Research Areas of Focus. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Hodges, D. G., and T. G. Harris. 1988. US Forest Products Research: Trends and Outlooks. Forest Products Journal 38(7/8): 26-32.

Howard, J. L. 2003. U.S. Timber Production, Trade, Consumption, and Price Statistics: 1965-2002. FPL-RP-615. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Inklaar, R., R. H. McGuckin, B. Van Ark, and S. M. Dougherty. 2004. The Structure of Business R&D: Recent Trends and Measurement Implications, Paper prepared for the 2004 IARIW Conference, August 2004, Cork, Ireland. Washington, DC: National Science Foundation. International Union of Forestry Research Organizations. 2007. Forest Research Management in an Era of Globalization. Bethesda, MD: Society of American Foresters.

International Union of Forest Research Organizations. 2010. Organization of Global Network for Forest Science Cooperation. Vienna, Austria: International Union of Forest Research Organizations.

Lundgren, A. L., S. J. Josiah, H. M. Gregersen, and D. N. Bengston. 1997. Planning and Managing Forestry Research (Volume I-VI).Vienna, Austria: International Union of Forestry Research Organizations.

MacKay, D. M., Ellefson, P. V., and A. R. Ek. 1996. The Status of Forestry and Forest Products Research Undertaken in the United States: A Review and Assessment. Staff Paper Series No. 117. St. Paul, MN: University of Minnesota, Department of Forest Resources.

Martin, S., and J. T. Scott. 2000. The Nature of Innovation Market Failures and the Design of Public Support for Private Innovation. Research Policy 29:43747.

McNamara, C. 2009. Guidelines for Organizational Design. In: Legal Forms and Traditional Structures of US Business Organizations by C. McNamara. Minneapolis, MN: Authenticity Consulting, LLC.

Nakamura, M., Nelson, H., and I. Vertinsky. 2003. Cooperative R&D and the Canadian Forest Products Industry. Managerial & Decision Economics 24 (2/3): 147-169.

National Research Council. 2002. National Capacity in Forestry Research. Washington, DC: National Academies Press.

National Research Council. 2004. Measuring Research and Development Expenditures in the U.S. Economy. Division of Behavioral and Social Sciences and Education. Washington, DC: National Academies Press.

National Science Board. 2008. Science and Engineering Indicators:2008. Washington, DC: National Science Board, Science and Engineering Indicators.

National Science Foundation.1990. Industrial Research and Development Information System: 1990 (and earlier years). Washington DC: National Research Foundation, Division of Science and Statistics.

National Science Foundation. 2009a. Research and Development in Industry: 2006 (and earlier years). Division of Science and Statistics. Washington DC: National Science Foundation, Division of Science and Statistics.

National Science Foundation. 2009b. Definitions of Research and Development: An Annotated Compilation of Official Sources. Washington, DC: National Science Foundation, Science Resource Statistics.

Society of Wood Science and Technology. 2009a. Wood Science and Technology: A National Needs Assessment Workshop. Monona, WI: Society of Wood Science and Technology.

Society of Wood Science and Technology. 2009b. Directory North American Schools Offering Baccalaureate and Graduate Programs of Study in Wood Science and Technology. Monona, WI: Society of Wood Science and Technology.

Technology Review. 2005. Corporate R&D Scorecard: 2004 by Technology Review. Technology Review 108(9): 56-61.

U.S. Department of Energy. 2009. National Laboratories and Technology Centers. Washington, DC: U.S. Department of Energy, Office of Science.

U.S. Government Accountability Office. 2006. Wood Utilization: Federal Research and Development Activities, Support, and Technology Transfer. GAO-06-624. Washington, DC: Government Accountability Office.

Von, Teuffel, K. 2007. Forest Research Institutes in the World: Results of a IUFRO Survey. In: Forest Research Management in an Era of Globalization. Pg. 9-12. Bethesda, MD: Society of American Foresters.

Zerbe, J., R. Dramm and J. Livingston. 2006. National Forest Products Utilization and Marketing Personnel Directory. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

APPENDICES

Appendix Table 1. Definitions and Scope of Research and Product Development.

U.S. Businesses

Financial Accounting Standards Board . . . research is a planned search or critical investigation aimed at discovery of new knowledge with the hope that such knowledge will be useful in developing a new product or service or a new process or technique or in bringing about a significant improvement to an existing product or process. Development is the translation of research findings or other knowledge into a plan or design for a new product or process or for a significant improvement to an existing product or process whether intended for sale or use. It includes the conceptual formulation, design, and testing of product alternatives, construction of prototypes, and operation of pilot plants. It does not include routine or periodic alterations to existing products, production lines, manufacturing processes, and other ongoing operations even though those alterations may represent improvements and it does not include market research or market testing activities.

U.S. Code of Federal Regulations . . . research involves activities in the experimental or laboratory sense . . . incident to the development or improvement of a product . . . activities intended to discover information that would eliminate uncertainty concerning the development or improvement of a product. Research does not include ordinary testing or inspection of materials or products for quality control (quality control testing), efficiency surveys, management studies, consumer surveys, advertising or promotions, and activities in connection with literary, historical, or similar projects.

U.S. Federal Government

National Science Foundation Survey of Industrial Research and Development . . . Research and development includes the planned, systematic pursuit of new knowledge or understanding toward general application (basic research); the acquisition of knowledge or understanding to meet a specific, recognized need (applied research); and the application of knowledge or understanding toward the production or improvement of a product, service, process, or method (development). Not considered research is quality control; routine product testing; market research; sales promotion, sales service, and other nontechnological activities; routine technical services; and research in the social sciences or psychology.

National Science Foundation Survey of Federal Science and Engineering Support to Universities, Colleges, and Nonprofit Institutions . . . research and development activities comprise creative work undertaken on a systematic basis in order to increase the stock of knowledge, including knowledge of man, culture and society, and the use of this stock of knowledge to devise new applications. Not considered research is routine product testing, quality control, mapping, collection of general-purpose statistics, experimental production, routine monitoring and evaluation of an operational program, and training of scientific and technical personnel.

Source: International Union of Forest Research Organizations 2010, National Science Foundation 2009b.

Appendix Table 1 (continued).

U.S. Bureau of Economic Analysis Survey of Foreign Direct Investment in the US . . . research and development is the planned, systematic pursuit of new knowledge or understanding toward general application (basic research); the acquisition of knowledge or understanding to meet a specific, recognized need (applied research); and the application of knowledge or understanding toward the production or improvement of a product, service, process, or method (development) . . . research includes these activities whether assigned to separate organizational units of a company or conducted by company laboratories and technical groups that are not a part of a separate R&D organization.

Office of Management and Budget Circular A-11 . . . research and development comprises creative work undertaken on a systematic basis in order to increase the stock of knowledge, including knowledge of man, culture and society, and the use of this stock of knowledge to devise new applications.

Statements of Federal Financial Accounting Standards . . . investment in research and development refers to those expenses incurred to support the search for new or refined knowledge and ideas and for the application or use of such knowledge and ideas for the development of new or improved products and processes with the expectation of maintaining or increasing national economic productive capacity or yielding other future benefits.

Department of Defense Research, Development, Test, and Evaluation Budget Activities . . . basic research is farsighted high payoff research that provides the basis for technological progress . . . applied research is the systematic study to understand the means to meet a recognized and specific need . . . development is a systematic expansion and application of knowledge to develop useful materials, devices, and systems or methods.

U.S. Academic and Nonprofit Organizations

Federal Office of Management and Budget, OMB Circular A-21, A-110, A-133 . . . research is systematic study directed toward fuller scientific knowledge or understanding of the subject studied . . . development is the systematic use of knowledge and understanding gained from research directed toward the production of useful materials, devices, systems, or methods, including design and development of prototypes and processes . . . research includes activities involving the training of individuals in research techniques.

International Organizations

OECD, Frascati Manual . . . research and experimental development comprises creative work undertaken on a systematic basis in order to increase the stock of knowledge, including knowledge of man, culture and society, and the use of this stock of knowledge to devise new applications . . . excluded are education and training and administrative and other research support activities . . . basic research is experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundations of phenomena and observable facts, *without any particular application or use in view* . . . applied research is *original* investigation undertaken in order to acquire *new knowledge* . . . however, it is *directed* primarily towards a specific practical *aim or objective* . . . experimental development is systematic work, drawing on *existing knowledge* gained from research and practical experience that is *directed* to producing *new* materials, products and devices; to installing new processes, systems and services; or to *improving* substantially those *already produced or installed*.

Appendix Table 1.

United Nations Statistical Division, System of National Accounts . . . research and development by a market producer is an activity undertaken for the purpose of discovering or developing new products, including improved versions or qualities of existing products, or discovering or developing new or more efficient processes of production . . . research and development is different from teaching and should be classified separately, although there may be interaction between teaching and research which makes it difficult to separate them.

International Union of Forest Research Organizations . . . research is undertaken to enhance the understanding of the ecological, economic and social aspects of forests and trees. Wood utilization research and products development involves major topical areas such as wood quality, mechanical properties of wood and wood-based materials; wood protection; wood processing; composite and reconstituted wood products; properties and utilization of plantation wood; energy and chemicals from forest biomass; forest products marketing and business management; nonwood forest products; sustainable use of forest products; harvesting and transportation engineering; and managerial economics and accounting.

Appendix Table 2. State Government Sponsored and Financed Wood Utilization Research and Development Projects in the United States, by Research Subject and Performing Organization. 2008.

Research Performing Organization	Research Subject and Objective
Cornell University	Analysis of multifunctional fibrous materials via manipulation of nano-scale phenomenon.
University of Idaho	Evaluate efficiency of wood harvesting, manufacturing processes, and construction designs.
Louisiana State University	Assessment of the durability of wood-based products; development of reverse supply chain systems for decommissioned preservative-treated wood; evaluation of wood-natural fiber polymer composites as advanced engineering materials; detoxification of spent treated wood by liquidation and reuse as industrial raw materials.
Michigan State University	Evaluation of the production of biofuels, biomaterials and composites; evaluate thermochemical conversion of woody biomass to fuels and chemicals.
Michigan Technological University	Evaluation of biocides and wood preservatives; assessment of composite production manufacturing systems.
University of Minnesota	Investigation of water removal processes in papermaking; development of environmentally benign adhesives, coatings, composites and industrial chemicals; evaluation of environmentally friendly pulping and bleaching processes; evaluate operation of mass spectrometry core facility.
Mississippi State University	Evaluation of wood drying processes, moisture movement in wood, and management of water pollutants from wood preservation processes.
State University of New York at Syracuse	Assessment of hydrogen production from wood-based feedstocks; analysis of increased maple syrup productivity and profitability; evaluation of processing and manufacturing of pulp and paper products; assessment of bleaching pulp and paper products; analysis of characteristics of paper, paperboard and nonwovens; evaluation of paper transport thermodynamics; assessment of efficiency in the manufacturing and design of forest products; analysis of environmentally benign paper manufacturing processes; analysis of multi-functional fibrous materials via manipulation of nanoscale phenomena; assessment of wood products construction management; assessment of properties of wood drying processes; investigation of the structure-function relationships of a wide variety of materials.
Oregon State University	Evaluation of short-term utilization research supported by grants; assessment of improved pole treatments through use of super-critical fluids.
Pennsylvania state University	Evaluate biofuels, bioproducts and hybrid materials used in production of composites.
University of Washington	Evaluation of opportunities to promote export of wood products; assessment of utilization of Alaska logs and cants in China and Japan; analyze novel yeast strains for improved biofuel production.
University of Wisconsin	Evaluation of the conversion of biomass to higher value coproducts; assessment of efficiencies in wood harvesting, manufacturing, and construction design systems; investigate effectiveness of wood waste products as soil amendments.

Source: Cooperative State, Research, Education and Extension Service. 2009.

Appendix Table 3. State Government Sponsored and Federal Hatch Act Financed Wood Utilization Research and Development Projects in the United States, by Research Subject and Performing Organization. 2008.

Research Performing Organization	Research Subject and Objectives
Auburn University	Analysis of biofuel production from high-volume low-value feedstocks; evaluation of thermochemical conversion of biomass feedstocks indigenous to SE United States.
University of California, Davis	Evaluation of new structures and functions of natural fibers and biobased polymers; evaluation of thermochemical conversion of biomass feedstocks.
Clemson University	Evaluation of cinnamyl alcohol dehydrogenase genes in Tulip-Popular.
University of Georgia	Optimizing the engineering properties of biomass for use as biorefinery feedstock; development of biorefinery processes for energy production.
University of Hawaii	Evaluate means of enhancing the utilization of wood and the development of sustainable and environmentally appropriate solutions to national energy problems.
University of Kentucky	Assess opportunities for the utilization of wood and the development of sustainable and environmentally appropriate solutions to national energy problems.
University of Maine	Evaluate of woody biomass process streams using near-infrared spectroscopic approaches.
Michigan State University	Assess opportunities to enhance the utilization of wood and the development of sustainable and environmentally appropriate solutions to national energy problems; assess opportunities for strengthening partnerships and exchanging information between researchers and end users; assess pyrolysis of lignocellulosic biomass to fuels and chemicals.
University of Minnesota	Evaluate biosynthesis of methanol from biomass derived carbon dioxide; analysis of lignin biosynthesis, biodegradation and derivative plastics.
Pennsylvania State University	Evaluate biofuels, bioproducts and hybrid materials used in production of composites.
Purdue University	Analyze isomerization, hydrolytic and esterification reactions in fixed bed reactors of solid phase catalysts; determine and quantify price trends for hardwood stumpage, logs, and lumber, and the implications of these trends to timber producers and wood products manufacturers; evaluate opportunities for retaining competitiveness of the US furniture industry; analyze biomass feedstock processing and delivery to thermochemical conversion platforms.

Source: Cooperative State, Research, Education and Extension Service. 2009.

Appendix Table 3 (continued).

Research Performing Organization	Research Subject and Objectives
University of Tennessee	Evaluate means of enhancing the utilization of wood and the development of sustainable and environmentally appropriate solutions to national energy problems; evaluate engineered faces for wood-polymer composites; assess the economic impacts of value-added forest products industry development.
Virginia Polytechnic Institute and State University	Assess opportunities to enhance the utilization of wood and the development of sustainable and environmentally appropriate solutions to national energy problems; evaluate ways of improving bacterial cellulose applicable to pretreated lignocellulose for the production of bio-based products; analyze biofuels production from cotton gin waste and recycled paper sludge.
Washington State University	Assess opportunities to enhance the utilization of wood and the development of sustainable and environmentally appropriate solutions to national energy problems; evaluate pyrolysis of biomass to produce second generation biofuels and chemicals.
West Virginia University	Evaluate biofuels potentials in the Application Region; investigate opportunities to increase the success of the primary processing and manufacturing sectors of the wood products industry.

Appendix Table 4. State Government Sponsored and Federal McIntire-Stennis Act Financed Wood Utilization Research and Development Projects in the United States, by Research Subject and Performing Organization. 2008.

Research Performing Organization	Research Subject and Objectives
Auburn University	Evaluate opportunities for enhancing the yield Southern pine sawtimber by integrating lumber production systems; evaluate harvesting and transport of bio-fuels.
University of Arkansas	Analyze economic and policy aspects of wood-based energy markets.
University of Georgia	Assess changing opportunities for GA's forest products industry; estimation of the strength properties of green wood using NIR spectroscopy; analyze current factors affecting forest sector development in the US South; assess modifications in harvesting systems to improve value and biomass.
University of Idaho	Investigate xylem development in conifers by in vitro analysis.
Iowa State University	Analyze bio-based materials and bio-energy from lignocellulosics.
Louisiana State University	Develop a topsaw sawing optimization system; investigate long-term structural performance of borate modified oriented stand boards.
Louisiana Technological University	Evaluate new approaches to log volume estimation.
University of Massachusetts	Assess mill renovation in MA using wood-concrete composites.
University of Maine	Assess the physical properties of wood and paper that affects permeability and waving; evaluate wood thermal properties and volatile organic chemical release; analyze wood degradation mechanisms and pressure infusion involving wood composites fabrication; develop improved adhesive applications systems for wood-based composites; investigate micro- and nanocellulose fiber filled thermoplastic composites; investigate the efficiency, recovery and quality of ME's forest product supply chain; analyze dynamic visualization of strand composite processes; evaluate wood propereties of spruce and fir from precommercially thinned and mature stands.
Michigan State University	Evaluate opportunities to develop novel wood-based products; evaluate the durability and protection of wood products; analyze green nanobiocomposites from wood fibers and polyhydroxyalkanoates bioplastics.
Michigan Technological University	Evaluate hardwood defect images in used in hardwood log bucking.
University of Minnesota	Evaluate biodegradation of microbes with focus on biology, ecology, inhibition and utilization; assess economic development opportunities for the forest products industry; assess bio-based composites derived from renewable resources.

Source: Cooperative State, Research, Education and Extension Service. 2009.

Appendix Table 4 (continued).

Research Performing Organization	Research Subject and Objectives
Mississippi State University	Assess the influence of forest policies on forest resource management and the growth of the forest products industry; evaluate factors affecting the durability of engineered wood composites; analyze the chemical and physical properties of bio-oil; assess wood adhesives from wood resources; develop accelerated tests for evaluating wood preservatives in above ground use; study depletion-migration of biocides in organic and metallic-based wood preservatives; assess the bond durability of engineered wood-based composites; evaluate breakthrough technologies for wood drying; evaluate production of fuels from pyrolysis oils developed from unique auger reactors; evaluate nano-scale property reinforcement for furniture with wood-fiber based composites; assess the status and future of the wood supply system in MS; assess the competitiveness of MS forest resources in the global market-place; evaluate composite lumber and panel alternatives to traditional forest products.
State University of New York at Syracuse	Evaluate chemical and structural changes in decaying wood observed by magic angle spinning NMR; investigate opportunities for new products from biomass with a focus on xylan hemicellulose.
North Carolina State University	Evaluate novel wood-based materials and processes for sustainable housing; investigate heat and mass transfer in wood, wood composites, and building envelops.
Oregon State University	Investigate environmentally friendly wood adhesives from renewable natural resources; develop integrated experimental protocols for woo-based composites.
Pennsylvania Sate University	Investigate wood-adhesive curing and cross-linking reactions.
Purdue University	Evaluate emerging issues in furniture design.
University of Tennessee	Investigate composite materials using advanced analytical tools, including nanotechnology.
Virginia Polytechnic Institute and State University	Investigate nanotechnology coating of wood surfaces; evaluate lateral buckling and vibration damping of wood composite I-joists; assess wood-based nanoparticles for targeted drug delivery; evaluate high-performance bio-based composites produced from low-grade wood fiber; assess improved value streams for the US hardwood industry.
Washington State University	Investigate the nanotechnmology of lignocellulosics.
West Virginia University	Investigate the cause of copper tolerance of brown rot decay fungi; develop optimal sawmilling systems for small-scale sawmills in the Appalachian Region; assess biofuels and bioproducts from biomass and related materials; evaluate harvest-machine interactions in harvesting in Central Appalachian forests.
University of Wisconsin	Evaluate value-added utilization of lignin and hemicellulose from ligncellulosic ethanol production; assess the economic implications of economic shocks, trade liberalization and recycling policies on the global forest sector.

Appendix Table 5. U.S. Department of Energy National Laboratories, by Relevance to Wood Utilization Research and Development. 2009.

National Laboratory	Laboratory Overall Mission and Objective	Laboratory Overall Budget and Staffing	Scientific Programs Potentially Relevant to Wood Utilization Research and Development
Ames Laboratory, (Ames, Iowa)	Create innovative materials, technologies and energy solutions	$25 million; 250 scientists and engineers; 150 support staff	a. Division of Materials Sciences and Engineering (90 scientists and engineers) b. Office of Biological and Support Research (four scientists and engineers) c. Chemical and Biological Sciences Program (18scientists and engineers)
Argonne National Laboratory (Argonne, IL)	Provide scientific solutions required for plentiful and safe energy, healthy environments, economic competitiveness and a secure nation	$540.0 million; 1,000 scientists and engineers; 1,900 support staff	a. Division of Materials Science (200 scientists and engineers) b. Center for Nanoscale Materials (60 scientists and engineers) c. Division of Biosciences (120 scientists and engineers)
Brookhaven National Laboratory (Long Island, NY)	Develop advanced technologies that address national needs and to transfer them to other organizations and to the commercial sector	$454 million; 1,020 scientists and engineers (est); 1,980 support staff	a. Center for Functional Nanomaterials (40 scientists and engineers) b. Department of Biology (35 scientists and engineers)

Note: In some cases, number of scientists, engineers and support staff are estimated.
Source: Website of each laboratory, 2009.

Appendix Table 5 (continued).

National Laboratory	Laboratory Overall Mission and Objective	Laboratory Overall Budget and Staffing	Scientific Programs Potentially Relevant to Wood Utilization Research and Development
Idaho National Laboratory (Idaho Falls, ID)	Develop safe, competitive, and sustainable energy systems	1,225 scientists and engineers; 2,375 support staff	a. Division of Energy and Environment, Program on Biofuels and Renewable Energy (13 scientists and engineers)
Lawrence Berkeley National Laboratory (Berkeley, CA)	Multi-disciplinary scientific teams working together to solve global problems in human health, technology, energy, and the environment	$500 million; 1,360 scientists and engineers (est); 2,640 support staff	a. Division of Environmental Energy Technologies (55 scientists and engineers) b. Division of Materials Sciences (est 100 scientists and engineers) c. Division of Earth Sciences, Department of Ecology–Bioenergy (30 scientists and engineers) d. Division of Physical Biosciences, Department of Synthetic Biology (60 scientists and engineers)
Oak Ridge National Laboratory (Oak Ridge, TN)	Promote scientific and technological innovation in support of national economic and energy security	$1,400 million; 3,000 scientists and engineers (est); 1,300 support staff	a. Center for Nanophase Materials Sciences b. Division of Materials Science and Technology (155 scientists and engineers) c. Division of Biosciences (45 scientists and engineers) d. Division of Environmental Sciences (Bioenergy Science Center; Center for BioEnergy Sustainability) (45 scientists and engineers)

Appendix Table 5 (continued).

National Laboratory	Laboratory Overall Mission and Objective	Laboratory Overall Budget and Staffing	Scientific Programs Potentially Relevant to Wood Utilization Research and Development
National Renewable Energy Laboratory (Golden, CO)	Develops renewable energy and energy efficiency technologies and practices	$380 million; 450 scientists and engineers; 850 support staff	a. Biomass Energy Program (110 scientists and engineers) b. Building Technologies Program
Pacific Northwest Laboratory (Richland, WA)	Advance science focused on energy, environment and national security	$750 million; 1,460 scientists and engineers; 2,540 support staff	a. Center for Nanoscience and Nanotechnology (26 scientists and engineers)
Sandia National Laboratory (Albuquerque, NM)	Improve energy and critical resource security	$2,250 million; 5,720 scientists and engineers; 2,480 support staff	a. Center for Integrated Nanotechnologies (40 scientists and engineers)

Appendix Table 6. Wood Utilization Research and Product Development Program of the U.S. Department of Agriculture, Forest Service, by Research Work Unit and Project. 2005.

Research Focus and Mission	Budget Authority	Scientists	Support Staff
Forest Products Laboratory			
•*Biodeteration of Wood*: Increase wood efficiency of use, protection, and serviceability through research on the nature and control of biodeterioration.	673	2.2	1.1
•*Center for Wood Anatomy*: To develop, accumulate, and disseminate information on the anatomical, biochemical, and physical characteristics of wood species that may affect their utilization and wood quality; to develop new and improved techniques for wood identification.	425	1.0	1.9
•*Wood Adhesives Science and Technology*: Improve the utilization of wood through more efficient fabrication and performance of bonded-wood products.	1,107	3.0	4.5
•*Performance Designed Composites*: To define fundamental relationships between base materials and product performance; to engineer reliable, high-performance composites from wood- and wood-lignocellulosics, including new hybrid composites melding wood and alternative materials.	1,265	6.0	9.5
•*Wood Surface Chemistry*: To improve the durability of wood and wood-based composites.	697	2.0	2.5
•*Chemistry and Pulping*: To develop environmentally benign processes for the production and utilization of wood pulp fibers and the chemical byproducts of pulping processes.	1,877	5.0	3.5
•*Fiber Processes and Paper Performance*: To increase the use of small-diameter and underutilized tree species, recycled fiber, and various biomass resources addressing environmental and energy concerns.	2,231	6.0	6.5
•*Institute for Microbial and Biochemical Technology*: Develop biotechnology for wood and fiber conversion through fundamental and applied research that contributes to efficient utilization and improved health of our forests.	1,474	4.0	6.5
•*Engineering Properties and Structures*: To improve the characterization of the mechanical and physical properties of solid sawn and composite structural products that are important in engineering design; to foster their efficient utilization in wood building systems.	2,445	7.0	2.2
•*Building Moisture and Durability*: To extend the service life of wood products in buildings through improved building design and operation.	875	2.0	1.7

Note: Budget authority in thousands of dollars; full-time equivalent scientists and support staff.
Source: U.S. Government Accountability Office 2006.

Appendix Table 6 (continued).

Research Focus and Mission	Budget Authority	Scientists	Support Staff
•*Condition Assessment and Rehabilitation of Structures*: Develop nondestructive evaluation technologies, structural analysis procedures, inspection methods, and rehabilitation procedures for wood structures.	1,308	3.0	1.9
•*Modified Lignocellulosic Materials*: To develop advanced environmentally friendly composite materials from chemically and physically modified wood-based resources alone or in combination with other materials to extend the use of our forest resources.	1,013	5.0	5.0
•*Wood Preservation and Fire Safety Engineering*: To improve the durability and fire safety of forest products in the context of changing environmental and societal needs.	925	3.0	4.3
•*Statistical Methods in Wood and Fiber Research*: To enhance the integrity and efficiency of research efforts through the development, evaluation, and promotion of modern statistical methods.	638	3.0	2.0
•*Fire Safety*: To develop data, methodologies, and technologies needed to ensure that wood products and wood-based structures do not adversely contribute to the loss of life and property in fires.	775	2.1	2.5
•*Timber Demand and Technology Assessment*: To provide economic information, analysis, and projections indicating how and why the markets and technologies for wood products change over time, implications for natural resources management, and selected broad environmental and social impacts.	1,485	5.4	1.7
Northern Research Station			
•*Efficient Use of Northern Forest Resource*: To develop and deliver knowledge and innovative technology that improves efficiency in forest products conversions to strengthen U.S. worker productivity in global wood products marketplace; increase the value of the timber resource and the economic viability of forest management options.	1,084	3.0	6.0
•*Integration of Forest Operations into Eastern Hardwood Intermediate Cuttings and Structural Retention Treatments*: To improve and integrate forest operations to accomplish intermediate silvicultural treatments in hardwood forests of the Northeast.	248	1.0	1.0
•*Eastern Forest Use in a Global Economy*: To provide economic, market, and wood-use information that will support the health and sustainability of forest-based industries, hardwood forests, and forest communities in the eastern United States.	1,103	4.0	3.0
•*Influence of Markets on Sustainability of Eastern Hardwood Forests*: To examine interrelationships between forest product markets and the structure and sustainability of the eastern hardwood forest.	161	1.0	0.0

Appendix Table 6 (continued).

Research Focus and Mission	Budget Authority	Scientists	Support Staff
Pacific Northwest Research Station			
•*Human and Natural Resources Interactions*: To improve understanding of social and economic values as input to and evaluation of resource management decisions.	2,644	9.3	7.0
Pacific Southwest Research Station			
•*Sierra Nevada Research Center*: Provide assistance to land managers and policy makers by addressing uncertain land and resource management strategies, emphasizing an integrated, eco-regional approach.	164	1.0	2.0
Rocky Mountain Research Station			
•*Southwestern Forest Health Restoration and Wildlnd-Urban Interface Fuels Management*: To understand economics, markets, and utilization opportunities to support the management and restoration of southwestern forests that also contribute to the economic vitality of local and regional communities.	300	0.1	0.0
Southern Research Station			
•*Disturbance and the Management of Southern Pine Ecosystems*: To increase understanding and develop applications of disturbance to sustain the productivity and functions of southern pine ecosystems.	401	1.2	3.0
•*Utilization of Southern Forest Resources*: To define and describe the fundamental raw material characteristics influencing the sustainable and environmentally sound use of southern forest resources.	1,183	4.0	4.8
•*Forest Products Conservation:* To enhance sustainable forest resource use through improved product, processing, and recycling analysis.	479	3.0	1.5
•*Forest Operations Research to Achieve Sustainable Management:* To provide the science integrating ecological and engineering disciplines to achieve economically and ecologically viable forest operations which are necessary for sustainable and socially acceptable forest resource management.	200	0.5	0.5

Appendix Table 7. Federal Small Business Innovation Grants Sponsored and Financed Wood Utilization Research in the United States, by Research Subject and Performing Organization. 2008.

Research Performing Organization	Research Subject-Objectives and Funding
Auburn Machinery, Inc. (Greene, ME	Evaluate of opportunities for converting sawmill waste into high value products using total solution recovery strategies ($296,000).
Custom Materials, Inc. (Ellicott City, MD)	Analysis of wood-based advanced ceramic materials ($75,000).
Restoration Technologies, LLC (Silver City, NM)	Assess engineered wood cup composite erosion control materials ($350,000).
Newman Machine Company, Inc (Greensboro, NC)	Investigate recycling of surface contaminated wood via waste stream remediation ($79,500).
IPM Development Company (Marylhurst, OR)	Evaluate systems for in-transit detection of bio-invasive fores insects in inter-modal wood shipping containers ($80,000)
Nanodynamic Life Sciences, Inc (Pittsburgh, PA)	Investigate nanobiocides for wood-based construction materials ($349,902).
Quintek Measurement Systems, Inc (Knoxville, TN)	Develop models of engineered wood quality using genetic algorithms and neural networks ($346,000)
Merichem Chemicals and Refinery Services, LLC (Houston, TX)	Investigate non-leachable born-based wood preservatives for ground contact and exterior applications ($79,947).
West Mountain View International, LLC (Vancouver, WA)	Assess formation of structural core material from wood residuals and recycled fiber ($296,000).
Forest Concepts, LLC (Federal Way, WA; Auburn, WA)	Development of marketing and logistics systems for roundwood component kits and materials (Phase I:$79,359, Phase II: $296,000); evaluate woody-biomass collection systems ($296,000); Evaluate benefication of chipped and shredded woody biomass ($80,000).
Biopulping International, Inc. (Madison, WI)	Investigate a novel process for converting wood chips into improved compost boards, chemicals, and fuels ($349,914)assess novel cost-effective production of high quality papers ($295,619).
IFT, Inc (Richmond, CA)	Evaluate paper conservation by new mass de-acidification techniques ($296,000).
Plant Polyphenols, LLC (Alexandra, LA)	Investigate the structure and physiological properties of procyanidins made from Douglas-fir bark and tea leaves (($80,000).
Compost Wizard, Inc (Locust Grove, GA)	Evaluate pine mulch for erosion and sediment control practices ($296,000).

Source: Cooperative State, Research, Education and Extension Service. 2009.

Appendix Table 8. Research and Development Programs of Wood-based Manufacturing Companies in the United States, by Company and Program Characteristics. 2008.

Advanced Environmental Recycling Technologies, Inc. *Program Intent*: ". . . research expenditures focus on product development and improvement." *Annual Investments*: 2008–$323,000, 2007–$266,000, 2006–$286,000, 2005–$110,000, 2004–$97,000, 2003–78,000.

Avery Dennison Corporation. *Program Intent*: ". . . research, design and testing of new products and applications . . . [company] has access to unparalleled research and development resources." Among research areas are basic research into polymer physics and rheology; development of laboratory equipment and instrumentation for basic research in polymer synthesis; advanced analytical instrumentation and custom-designed equipment; development of materials performance testing methods; pilot plant testing of new solvents and hot melt adhesive film coatings. *Research Facilities*: California, China, Georgia, India, Ohio (roll material group). *Annual Investments*: 2008–$94.0 million, 2007–$95.5 million, 2006–$87.9 million, 2005–$85.4 million, 2004–$81.8 million, 2003–$74.3 million.

Bemis Company. *Program Intent*: "Company uses state-of-the-art research laboratories to produce innovative solutions and patented materials . . . work with a variety of polymer resins, adhesives, inks and solvents to create unique materials . . . experiment with different process technologies to reveal superior performance characteristics . . . our technological expertise differentiates us from our competitors and illustrates the substantial value that [out company] brings to customer relationships and the industry." *Annual Investments*: 2008–$25.9 million, 2007–$26.0 million, 2006–$25.0 million , 2005–$24 million , 2004–$21 million, 2003–$24 million. Investment by research area: 2008–flexible packaging $18 million, pressure sensitive materials $7 million, 2007–flexible packaging $20 million, pressure sensitive materials $6 million; 2006–flexible packaging $20 million, pressure sensitive materials $5 million; 2005–flexible packaging $19 million, pressure sensitive materials $5 million; and 2004–flexible packaging $17 million, pressure sensitive materials $4 million.

Buckeye Technologies, Inc. *Program Intent:* ". . . focus on developing new products, improving existing products, and enhancing process technologies to further reduce costs and respond to environmental needs . . .focus on advanced products and new applications to drive future growth . . . pilot facilities allow us to produce , test and deliver break-through products to the market place on a cost-effective basis." *Research Facilities*: Tennessee. *Annual Expenditures*: 2008–$8.2 million, 2007–$8.2 million, 2006–$8.3 million, 2005–$9.2 million, 2004–$9.4 million, 2003–$9.3 million.

Flexsteel Industries, Inc. *Annual Expenditures*: 2008–$3.1 million, 2007–$3.3 million, 2006–$3.3 million, 2005–$3.0 million, 2004–$2.9 million, 2003–$2.7 million.

Note: U.S. Securities and Exchange Commission 10-K filings (2008, 2007, 2006, 2005) searched for information about company research and development programs. Although such does not necessarily indicate research and development doe not exist within a company, the search was unable to clearly identify such programs for the following companies: Louisiana-Pacific, Champion Enterprise, Temple-Inland, Clayton-Homes, Plum Creek Timber, Potlatch, Skyline Corporation, Cavalier Homes, Cavco Industries, Liberty Homes, Inc., NewPage Holdings, Cenveo, Inc., Carustar Industries, AbbitiBowater, Inc., Furniture Brands International, American Woodmark, Ethan Allen Interiors, Hooker Furniture, Basset Furniture, Stanley Furniture and Chromcraft. Statements of research intent come from various years 2005 through 2008.
Source: Company annual reports and filings with U. S. Securities and Exchange Commission.

Furniture Brands International, Inc. *Program Intent*: ". . . product development, product engineering and process improvements." *Annual Expenditures*: 2008–$88.1 (est), 2007–$80.7 million, 2006–$72.7 million, 200 –$65.9 million.

Georgia-Pacific (Koch Industries). *Program Intent*: "Perform research into tissue papermaking, tableware manufacturing and tissue and towel dispensing technology in order to improve consumer products in North America and Europe. . ."*Research Facilities*: Research centers in Wisconsin and France. *Annual Investments*: 2004–$61 million, 2003–$64 million, 2002–$65 million.

P. H. Glatfelter Company. *Program Intent:* ". . . significant expenditures for . . . research and development to support our business strategies . . . invest in research and development activities efficiently."

Graphic Packaging Holding Company. *Program Intent*: "Extending shelf life of customer products, reducing production costs, and refining packaging appearance . . . [company] designs, tests and manufactures prototype packaging for consumer product packaging applications . . . designs and tests packaging machinery and engages in product development employing full-size pilot lines . . . company has broad technical expertise in chemistry, paper science, engineering, physics and food science. *Research Facilities*: Colorado, Georgia, Wisconsin, New Hampshire , Louisiana, and Ontario, Canada. *Annual Investments*: 2008–$8 million, 2007–$9.2 million, 2006–$10.8 million, 2005–$9.9 million, 2004–$9.6 million, 2003–$7.4 million, 2002–$5.2 million.

Herman Miller, Inc. *Program Intent*: ". . . design products, systems, and services." *Annual Expenditures:* 2008–$38.8, 2007–$38.8 million, 2006–$42.1 million, 2005–$36.7 million.

IFCO Systems North America, Inc. *Program Intent*: "Engaged in ongoing product improvement efforts (through parent company research programs, as such) do not have separate research and development expenditures. Research focused on improving supply chain planning and asset utilization, automatic warehousing systems, and logistics providers." *Annual Investments*: As of December 2008, capitalized $5.6 million in hardware and associated research and development (2007: $4.8 million).

International Forest Products Ltd. (INTERFOR). *Program Intent*: "Committed to applied research and development in the areas of environment, health and safety, forest management and product and market development . . . conduct product research on our own in Canada and the U.S.. . contribute to and participate in industry research organizations that have made numerous technical developments beneficial to company in areas such as sawing technology, drying techniques, and anti-sapstain applications."

International Paper Company. *Program Intent*: "Direct research and development activities to short and long-term technical assistance needs of customers and operating divisions, and to process, equipment and product innovations. Activities include studies on innovation and improvement of pulping, bleaching, chemical recovery, papermaking and coating processes; packaging design and materials development; reduction of environmental discharges; re-use of raw materials in manufacturing processes; recycling of consumer and packaging paper products; energy conservation; applications of computer controls to manufacturing operations; innovations and improvement of products; and development of various new products. Developments efforts specifically address product safety as well as the minimization of solid wastes." *Research Facilities*: Ohio and Georgia, plus several product laboratories at various locations.

Company has a one-third interest in ArborGen, LLC, a joint research and development venture with other forest products and biotechnology companies. *Annual Investments*: 2008–$22 million, 2007–$24 million, 2006–$45 million, 2005–$63 million, 2004–$67 million, 2003–$71 million.

Kimball International, Inc. *Program Intent*: ". . . development of manufacturing processes, major process improvements, new product development and design, information technology, and wood related technologies." *Research Facilities*: Indiana. Annual Expenditures: 2008–$16 million, 2007–$17 million, 2006–$15 million, 2005–$18.5 million, 2004–$16.5 million, 2003–$17.6 million.

Kimberley-Clark Corporation. *Program Intent*: "directed toward new and improved personal care, tissue, wiping and health care products and nonwoven materials. Place a heavy emphasis on research and engineering disciplines . . . , in fact, [company] invests $800 million each year into the development of new technology and new processes, and are considered the foremost global leaders in each of our core technologies." *Annual Investments*: 2008–$297 million, 2007–$276.8 million, 2006–$301.2 million, 2005–$319.5 million, 2004–$279.7 million.

Koppers, Inc. *Program Intent*: "Committed to R&D, which has yielded a number of promising products based on existing technology and work we have developed . . ." *Human Resources*: Twelve full-time employees in R&D. *Annual Investments*: 2008–$2.8 million, 2007–$2.8 million, 2006–$2.5 million, 2005–$2.8 million, 2004–$2.2 million.

MeadWestvaco Corporation. *Program Intent*: Among company research initiatives is the South Carolina Center for Packaging Innovation which engages in research on emerging packaging technologies, material sciences, marketing, best business practices, and other packaging innovation resources for the company. R&D approach is to work extensively and cooperatively with customers to understand packaging needs and to develop customized solutions that are valuable in the marketplace. Company is also involved in collaborative activities with India's Council of Scientific and Industrial Research (CSIR), especially research which focuses on sustainable packaging solutions, process innovations related to biomass conversion and packaging innovations utilizing advanced materials. *Research Facilities*: South Carolina, North Carolina, Brazil, People's Republic of China. *Annual Investments*: 2008–$61 million, 2007–$62 million, 2006–$63 million, 2005–$50 million, 2004–$74 million, 2003–$80 million.

Nashua Corporation. *Program Intent*: "Direct research toward developing new products and processes and improving product performance, often in collaboration with customers. . . focus primarily on new thermal coating applications. *Annual Expenditures*: 2008–$0.7 million, 2007–$ 0.8 million, 2006–$0.6 million, 2005–$0.6 million 2003–$2.1 million, 2003–$2.5 million.

Neenah Paper, Inc. *Program Intent*: ". . . our research and development program gives us an advantage in customizing base papers to meet customer needs . . ." *Research Facilities*: Georgia, Michigan, Germany. *Annual Expenditures*: 2008–$6.5 million, 2007–$6.4 million, 2006–$3.5 million, 2005–$2.2 million, 2004–$1.5 million, 2003–$2.1 million.

NewPage Corporation. *Program Intent*: "We hold foreign and domestic patents as a result of our research and product development efforts."

Palm Harbor Homes, Inc. *Program Intent*: "Factory built homes are designed after extensive field research and consumer feedback . . . research has developed engineering systems which permit customization of homes and assist product development and enhancement."

Rayonier, Inc. *Program Intent*: "R&D efforts in performance fiber business directed primarily at developing existing core products and technologies, improving the quality of cellulose fiber grades, absorbent materials; and improving manufacturing efficiency and environmental controls and reducing fossil fuel consumption. R&D in timber operations include genetic tree improvement and applied silvicultural programs to identify management practices that will improve financial returns from timber assets." *Research Facilities*: Georgia. *Annual Investments*: 2008–$5 million (est), 2007–$5 million, 2006–$6 million, 2005–$6 million, 2004–$7 million, 2003–$9 million.

Rock -Tenn Company. *Annual Investments*: 2008–$ 0.3 million, 2007–$0.7 million, 2006–$0.8 million.

Schweitzer-Mauduit International, Inc. *Program Intent*: "Dedicated to developing paper product innovations and improvements to meet the needs of customers . . . believe that research and product development capabilities have played an important role in establishing reputation for high quality, superior products." *Research Facilities*: France, Brazil, Philippines, Georgia. *Human Resources*: Employ about 50 research personnel. *Annual Expenditures*: 2008–$8.3 million, 2007–$8 million, 2006–$7.3 million, 2005–$9 million, 2004–$9.3 million, 2003–$8.3 million.

Smurfit-Stone Container Corporation. *Program Intent*: "Technical staff conducts basic, applied and diagnostic research, develops processes and products, and provides a wide range of technical services to company operations. Research program has provided improvements in coatings and barriers, stiffeners, inks and printings. Advanced technology is used to assist all levels of manufacturing and sales processes, from raw material supply through finished packaging performance." *Research Facilities*: Illinois. *Annual Investments*: 2008–$3 million, 2007–$3 million, 2006–$4 million, 2005–$9 million, 2004–$8 million, 2003–$5 million.

Sonoco Products Company. *Program Intent*: "Significant research projects include efforts to design and develop new products for the construction industry and for the film and tape industries . . . enhance performance characteristics of tubes and cores in the textile, film and paper packaging areas . . . and research focused on cost reduction projects, high-value flexible packaging enhancements, rigid plastic container technology and next generation composite packaging." *Annual Investments*: 2008–$15.9 million, 2007–$15.6 million, 2006–$12.7 million, 2005–$14.7 million, 2004–$14.4 million, 2003–$14.2 million.

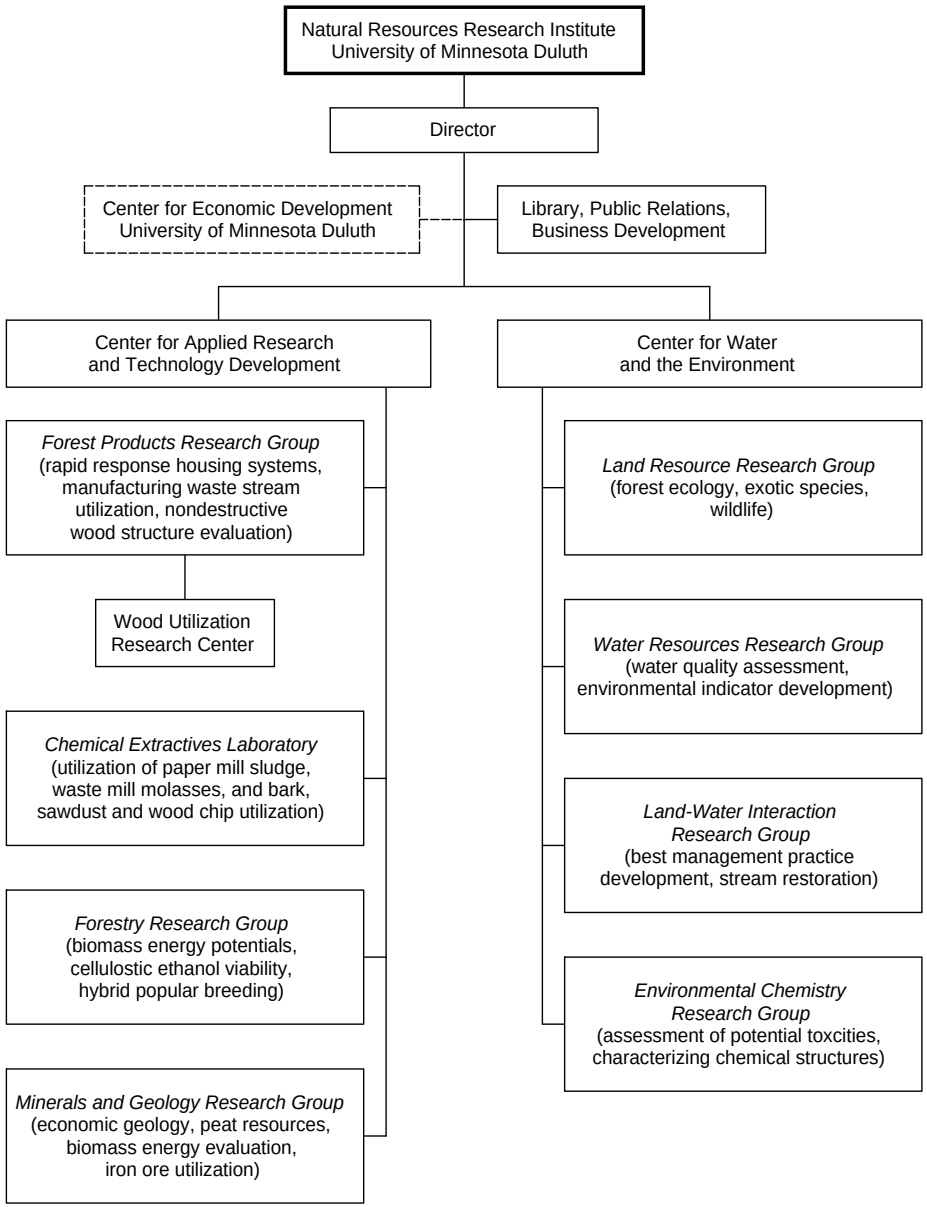
Universal Forest Products. *Annual Investments*: 2008–$3.7 (est) (actual $14.0 million which includes revised tax credits for 2001 through 2006), 2007–$3.2 million, 2006–$4.1 million.

Verso Paper Company. *Program Intent*: ". . . work with customers in developing and modifying products to accommodate their evolving needs and to identify cost saving opportunities within company operations . . . examples of research are high-bulk offset and rotogravure coated groundwood, lightweight grade Nimber Four coated groundwood, ultra-lightweight grade Number Five coated groundwood, and rotogravure coated freesheet."

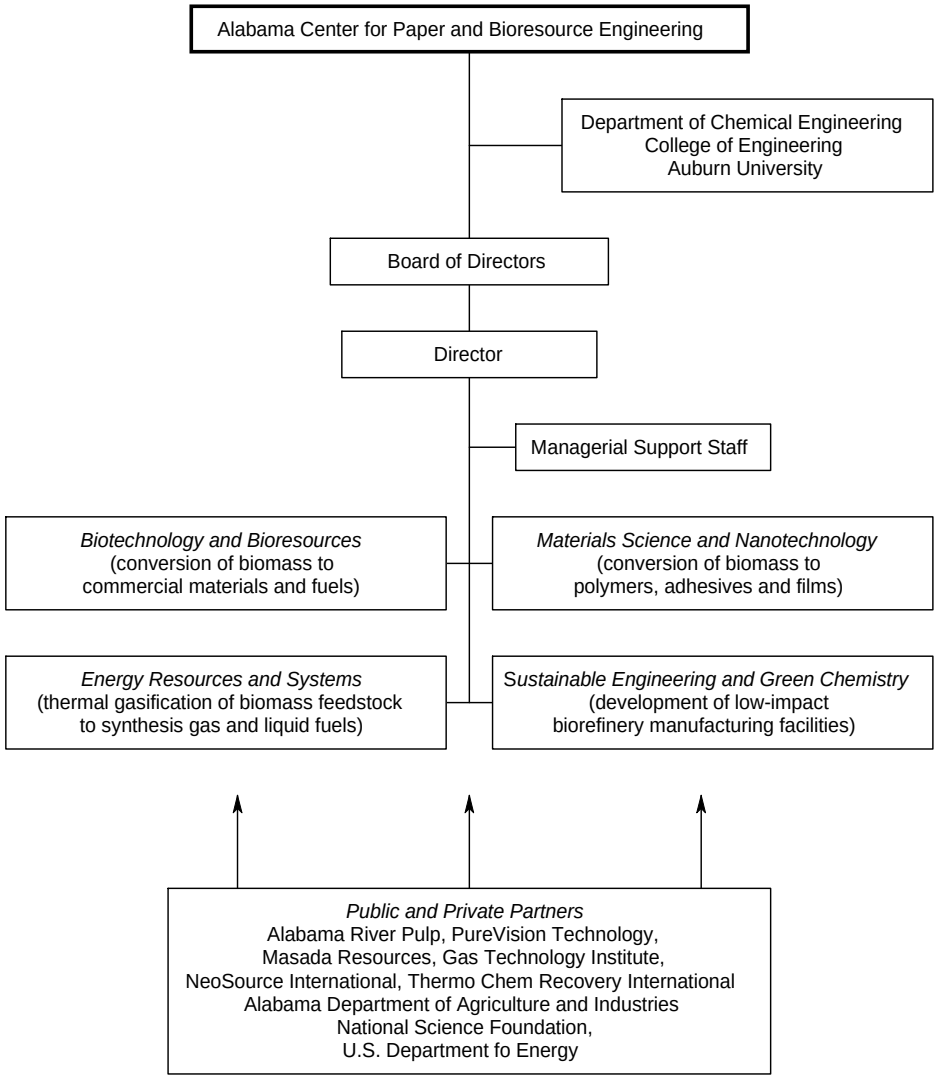
Appendix Table 8 (continued).

Wausau Paper Corporation. *Program Intent*: ". . . research and development experience creates a foundation for successful new products . . . typical products are carrier liners, transfer liners and casting sheets used in advanced composites, labels, tapes, graphic arts and medical markets . . . development of a variety of new release liners, food-packaging/food service papers, and development of color and writing grade papers." *Annual Expenditures*: 2008–$2.5 million, 2007–$2.6 million, 2006–$2.1 million, 2005–$1.9 million, 2004–$1.9 million, 2003–$2.2 million.

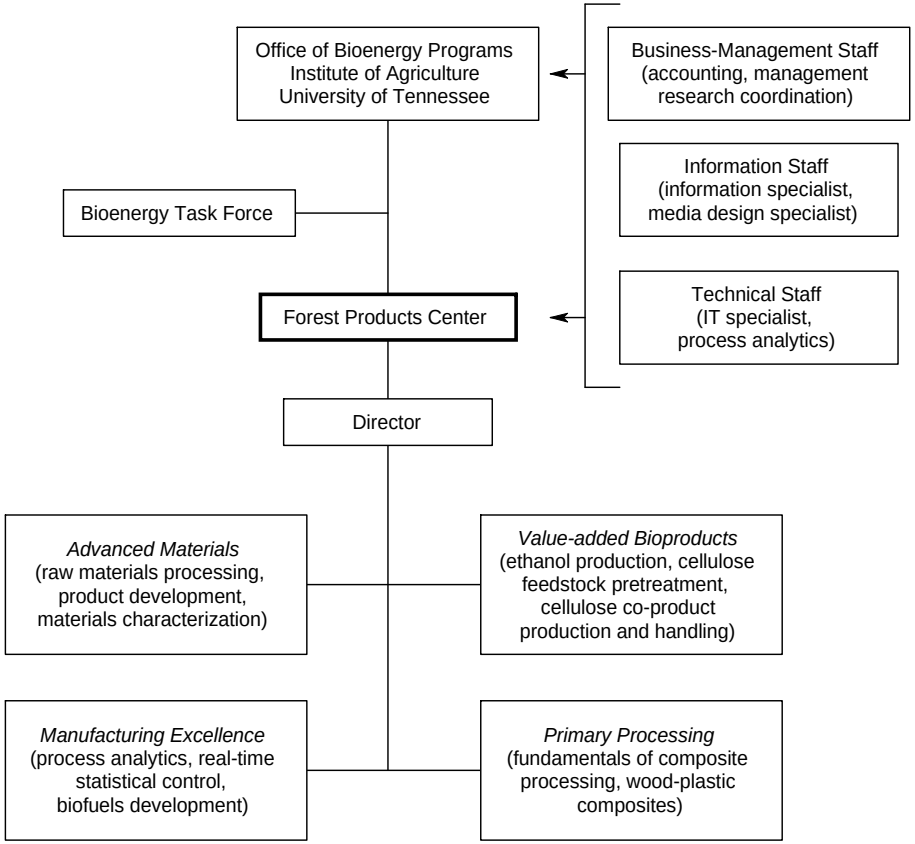
Weyerhaeuser Company. *Program Intent*: "Research is a strategic business investment to help the company and its customers achieve sustainable competitive advantage by creating and preserving options in the face of uncertainty about the future competitive environment. The mission of our research and development is to deliver technology options and solutions that support corporate and business strategies and goals by providing new and improved processes and products; valid, relevant, and timely technical information; technical services to business and operations units; and by acquiring and communicating competitive technology intelligence. Research and development in [containerboard, packaging and recycling] is focused on recyclable products that would replace waxed corrugated package products, and radio-frequency identification for corrugated packages. *Annual Expenditures*: 2008–$64 million, 2007–$71 million, 2006–$69 million, 2005–$61 million, 2004–$55 million, 2003–$51 million, 2002–$52 million.



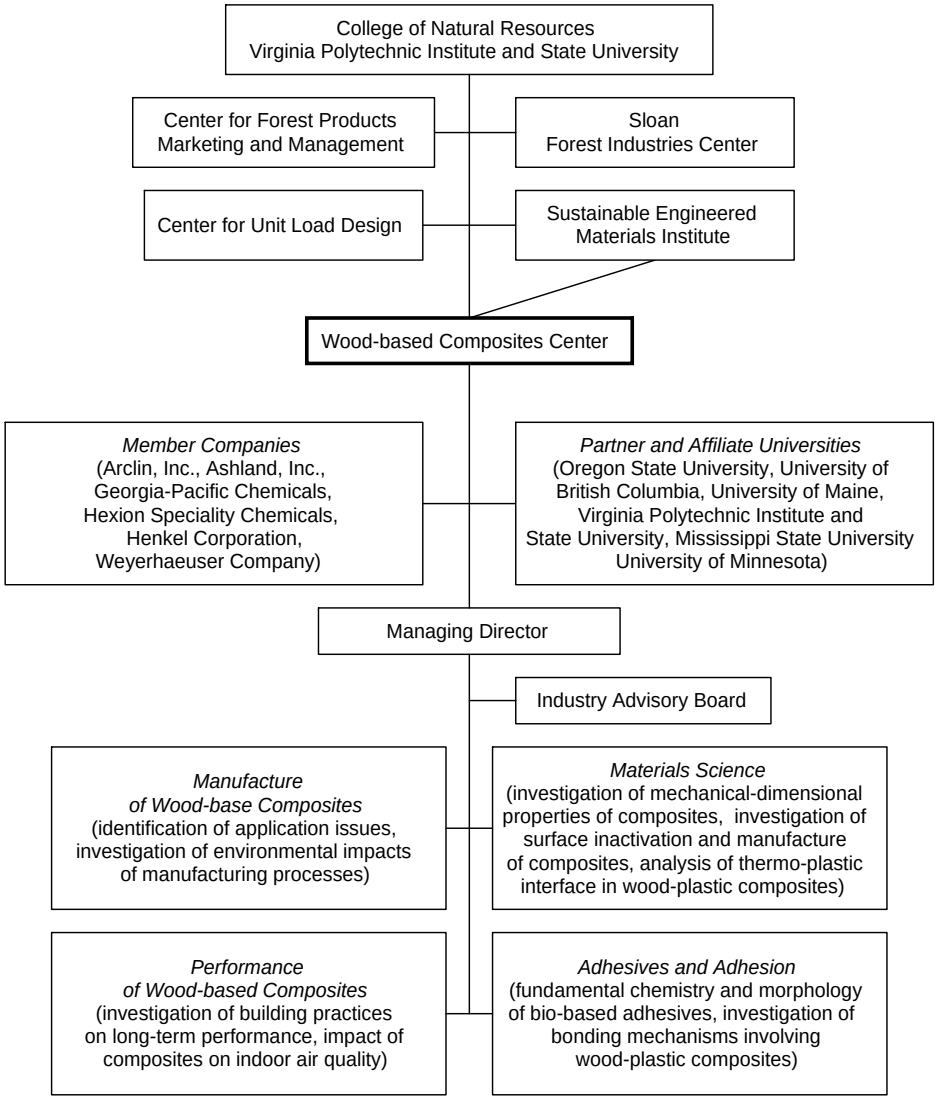
Appendix Figure 1. Natural Resources Research Institute, University of Minnesota Duluth. 2009.



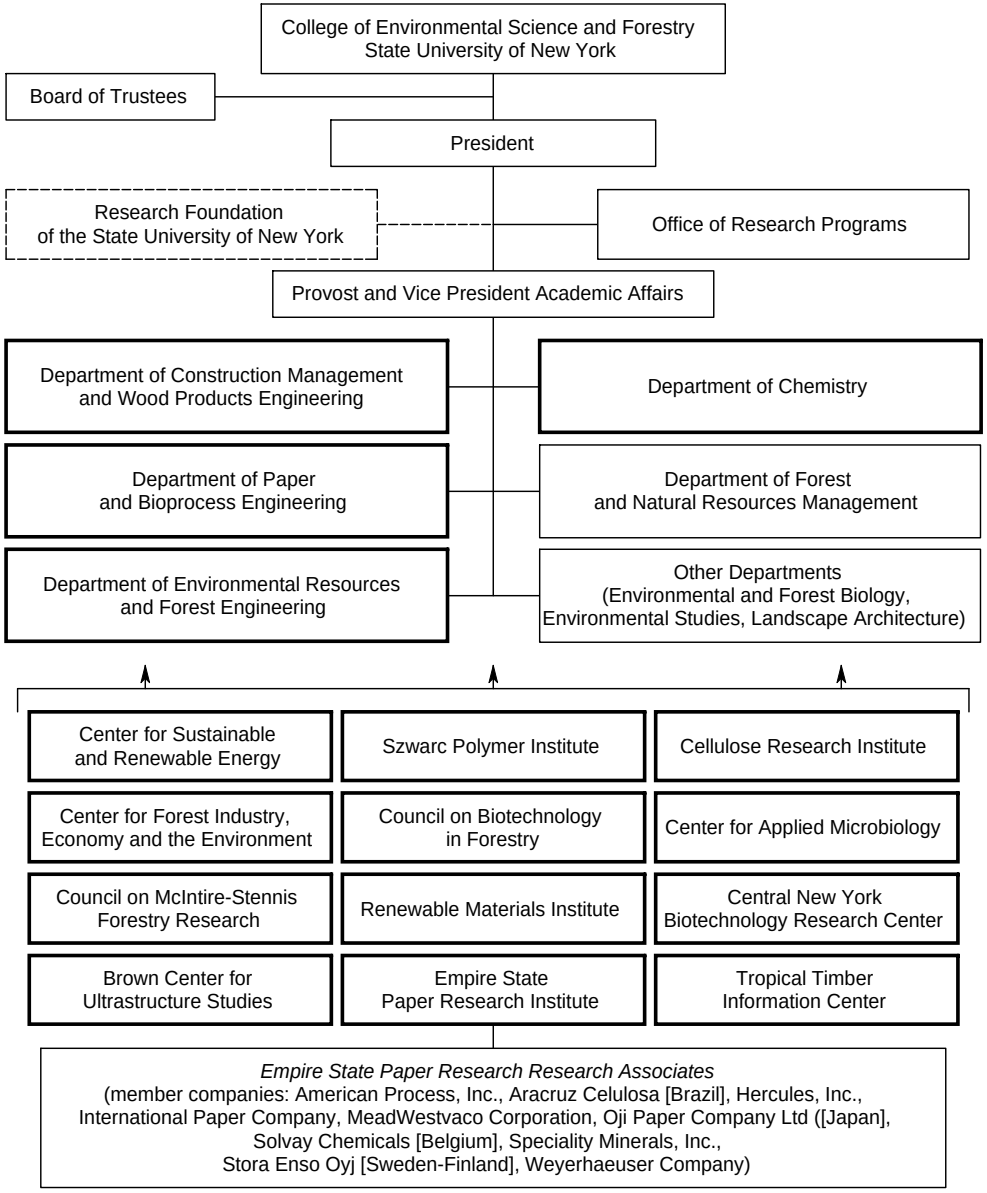
Appendix Figure 2. Alabama Center for Paper and Bioresource Engineering, Auburn University. 2009.



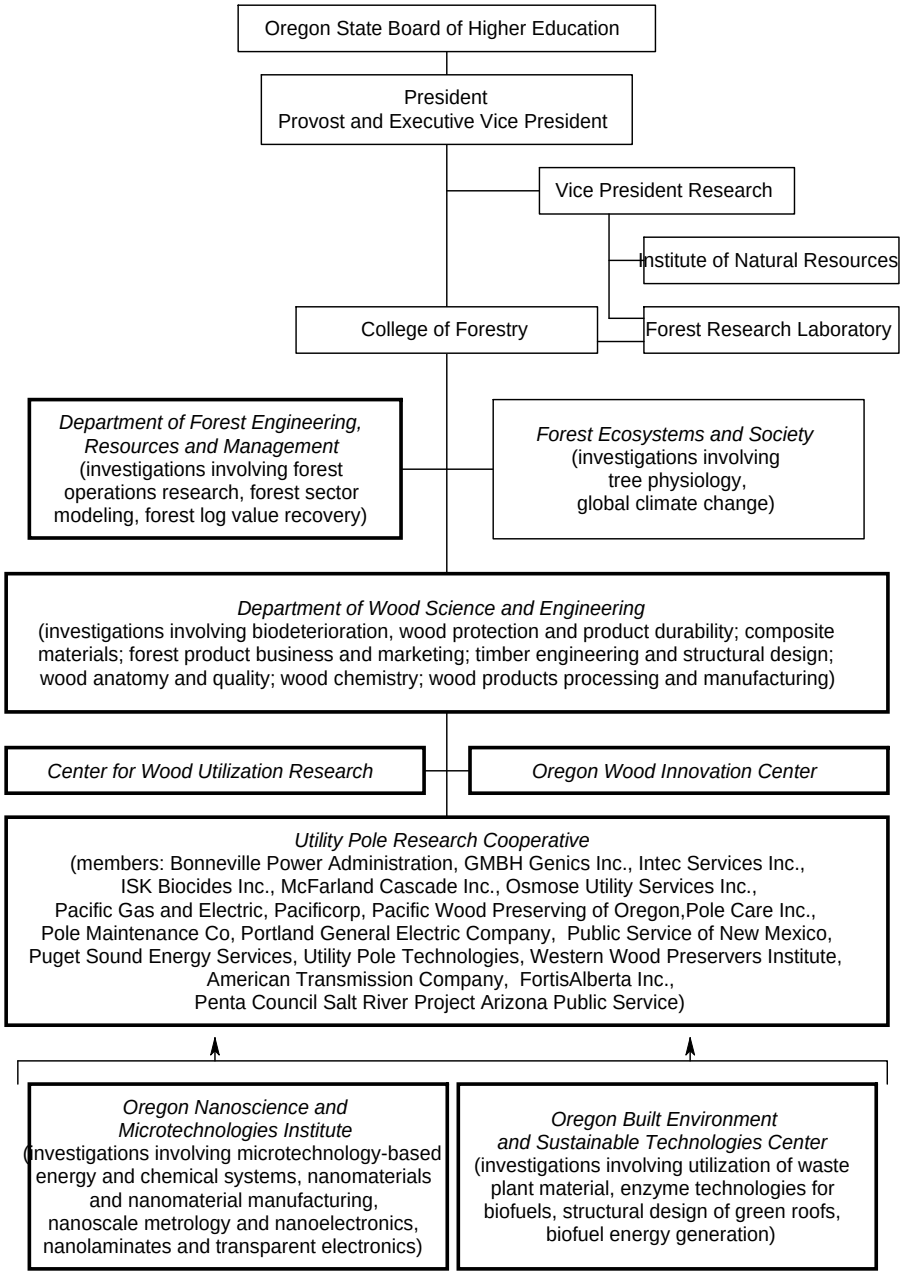
Appendix Figure 3. Forest Products Center, University of Tennessee. 2009.



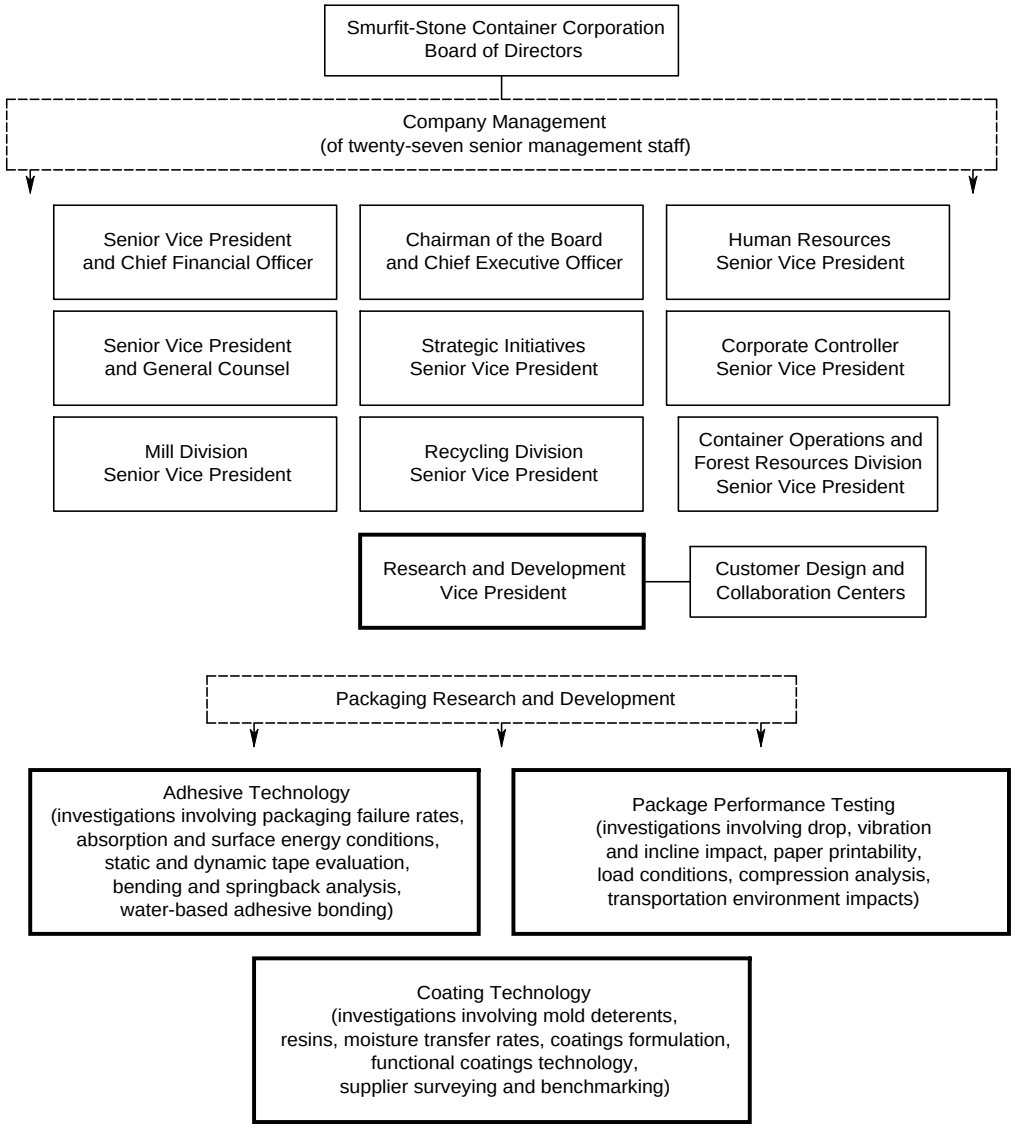
Appendix Figure 4. Wood-based Composites Center, Virginia Polytechnic Institute and State University. 2009.



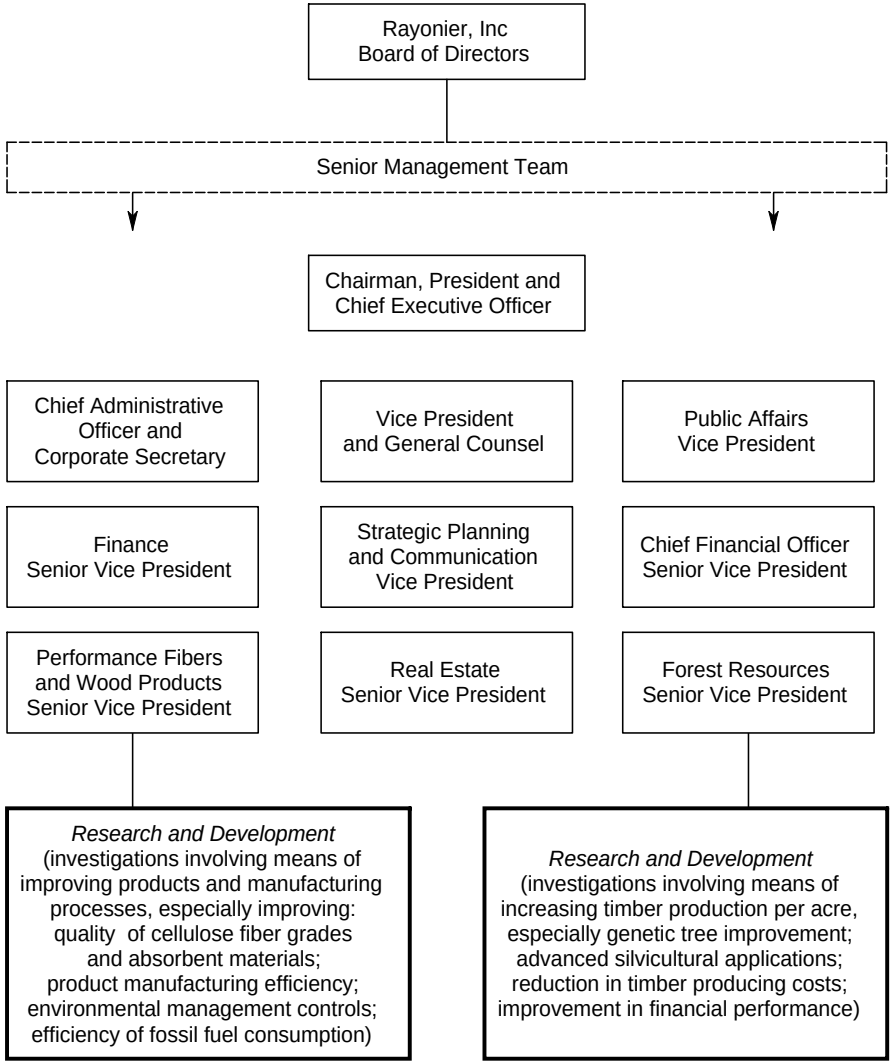
Appendix Figure 5. College of Environmental Science and Forestry, State University of New York Syracuse. 2009.



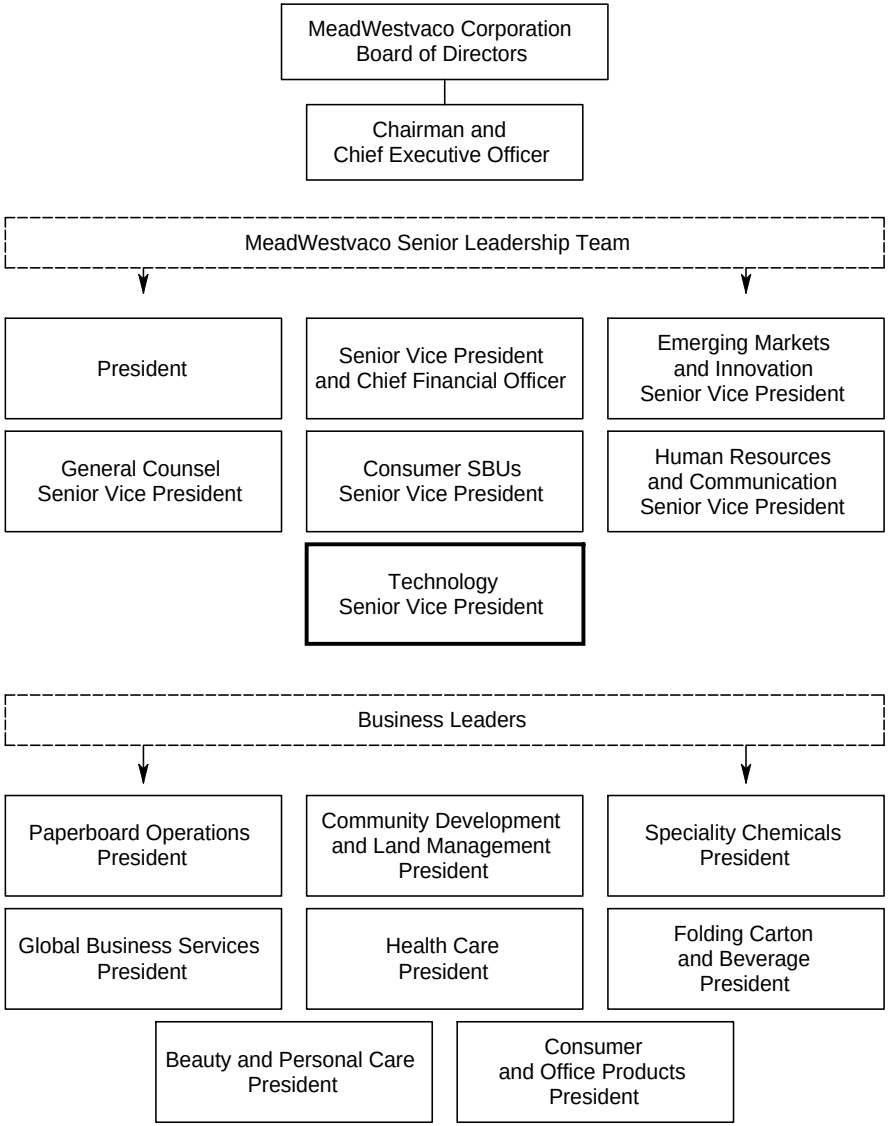
Appendix Figure 6. College of Forestry, Oregon State University. 2009.



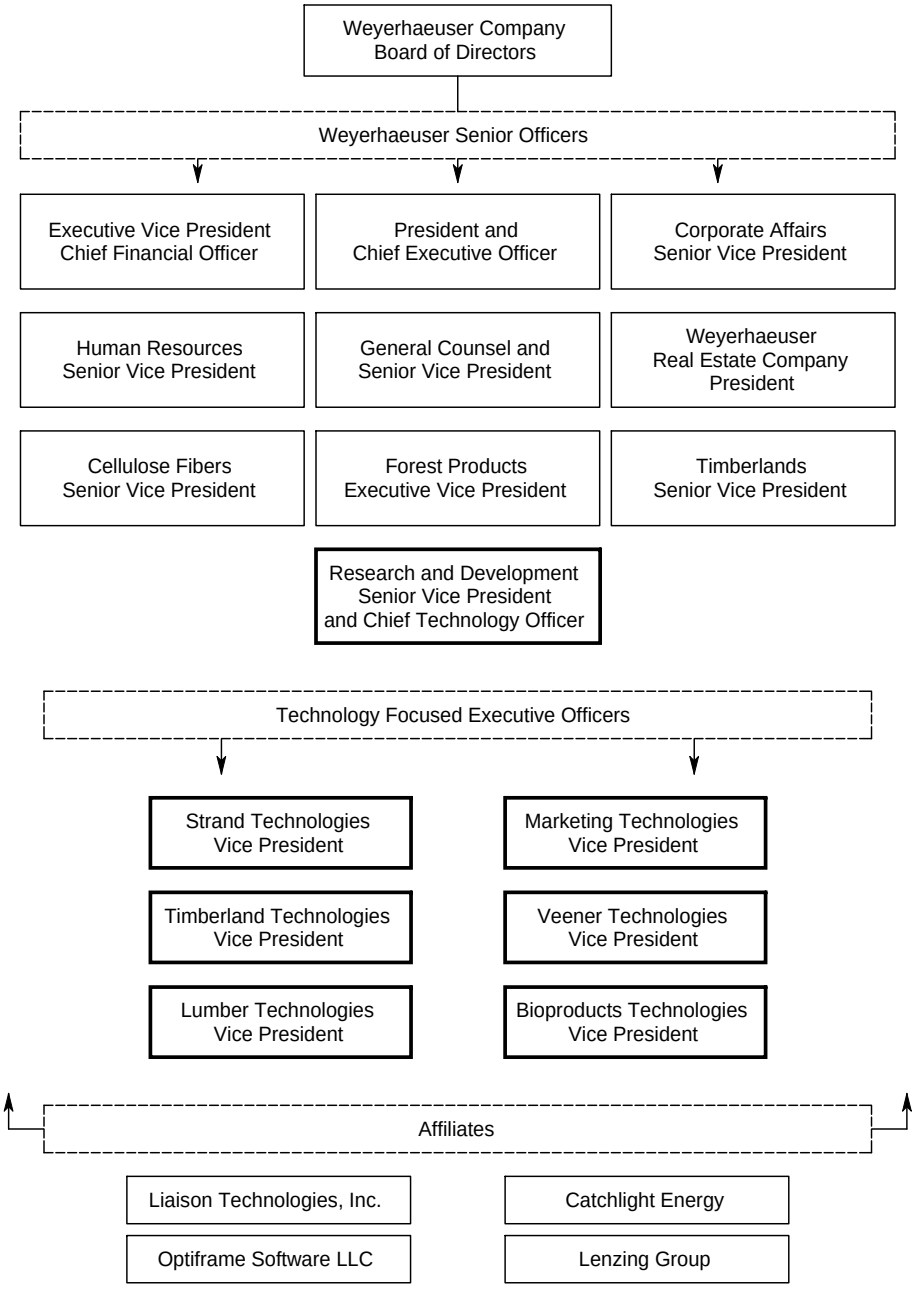
Appendix Figure 7. Smurfit-Stone Container Corporation, Technology-Focused Entities. 2009.



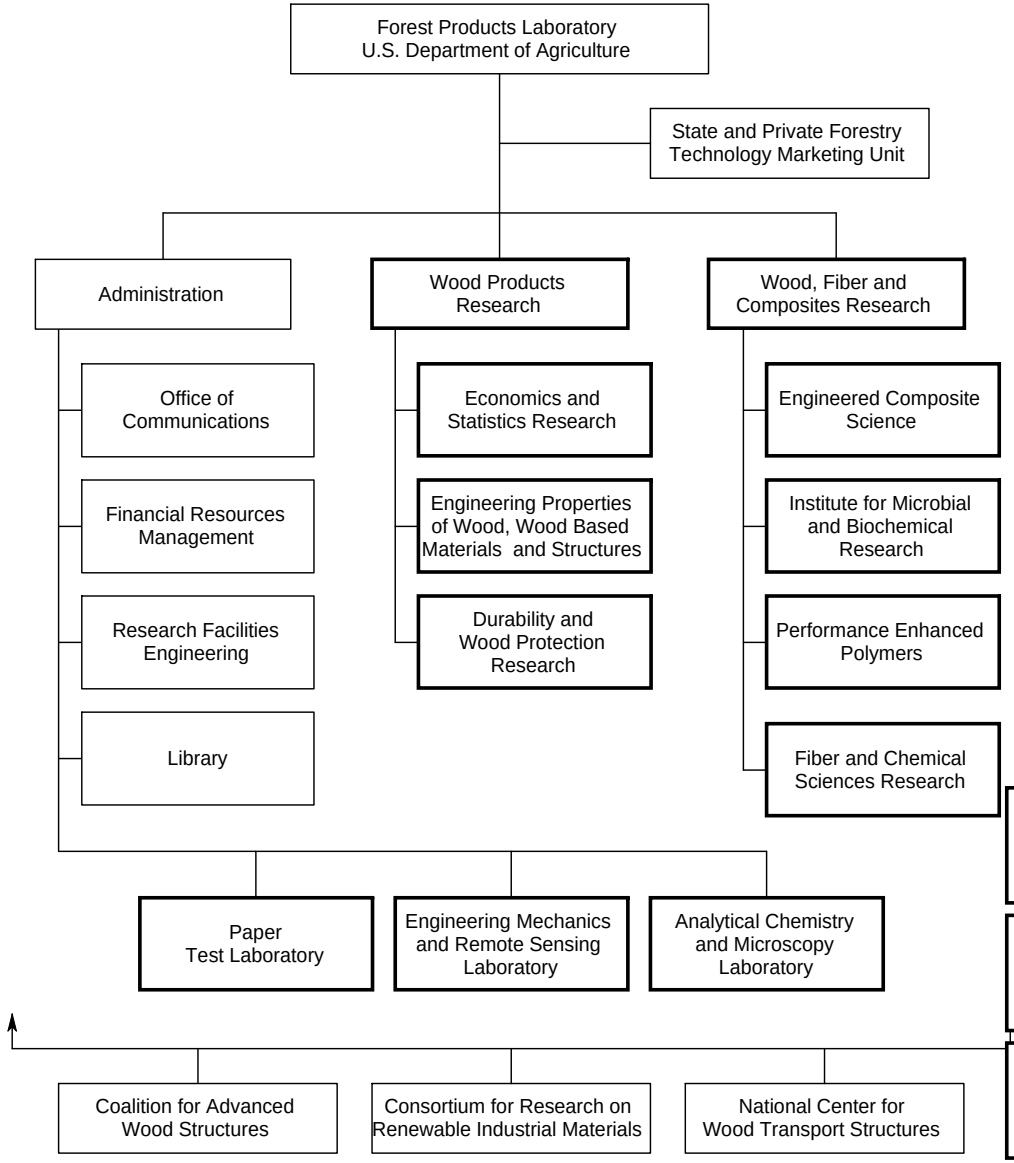
Appendix Figure 8. Rayonier, Inc., Technology-Research Focused Entities 2009.



Appendix Figure 9. Organizational Chart (technology focused), MeadWestvaco Corporation. 2008.

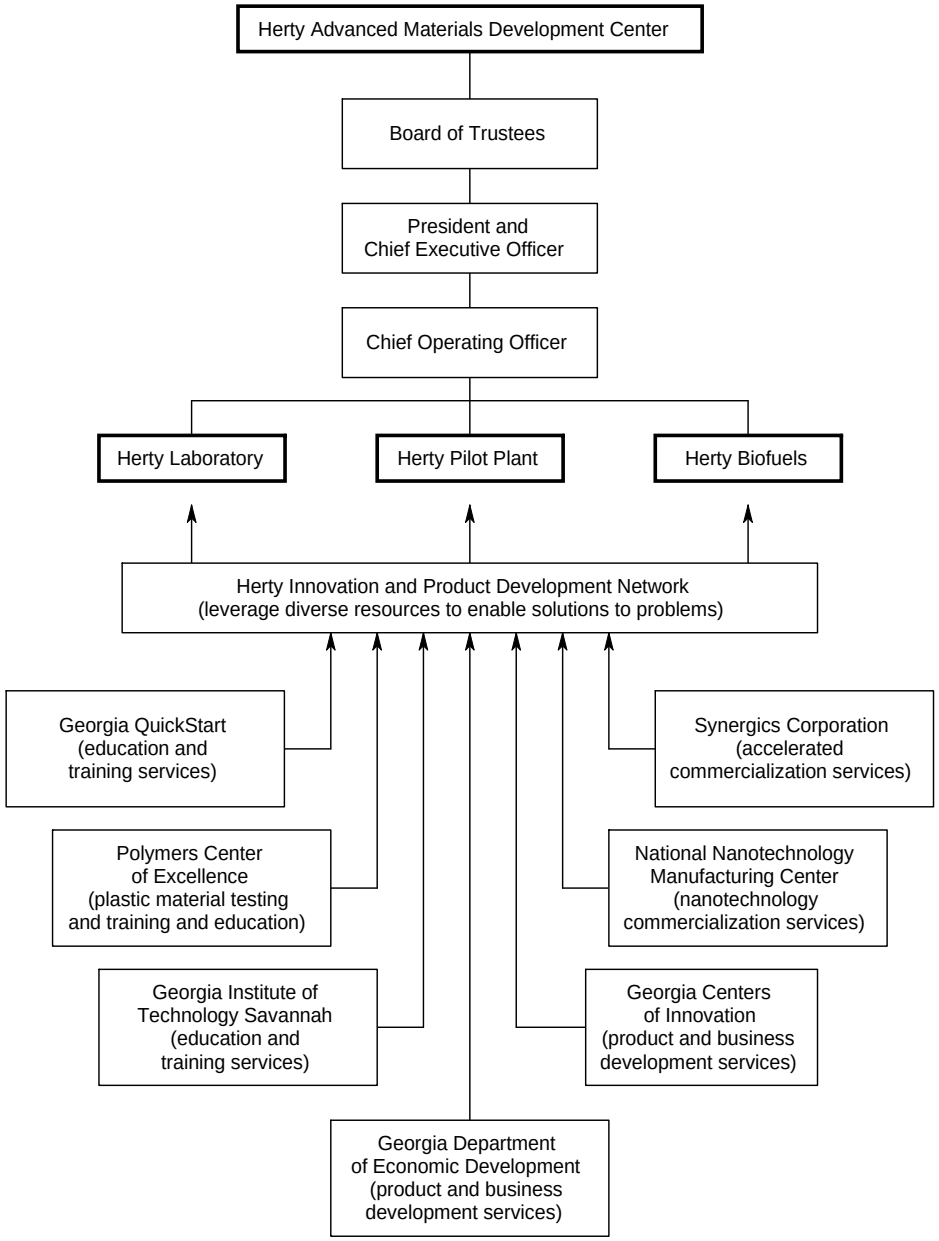


Appendix Figure 10. Weyerhaeuser Company, Technology-Research Focused Entities. 2008.

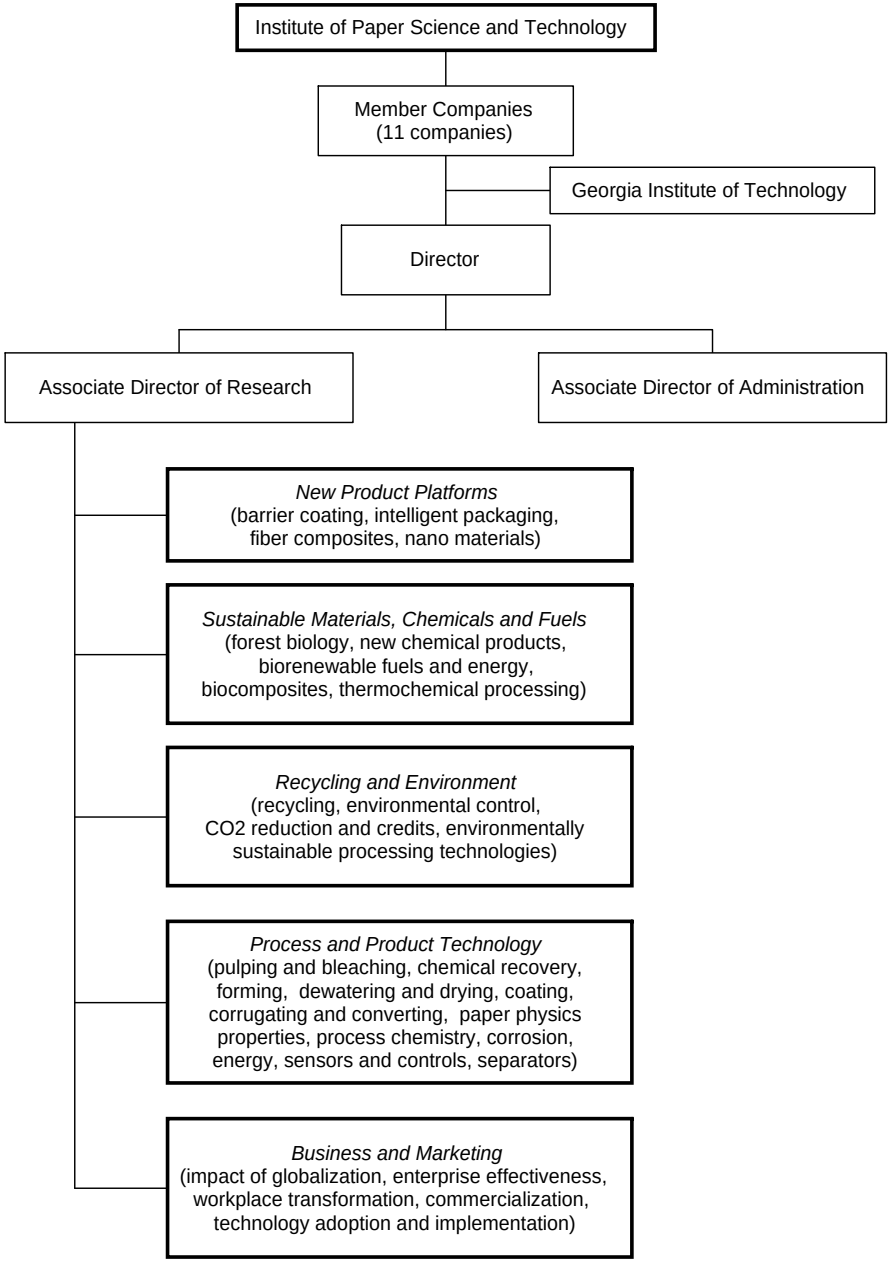


Appendix Figure 11. Forest Products Laboratory, Forest Service, US Department of Agriculture. 2009.

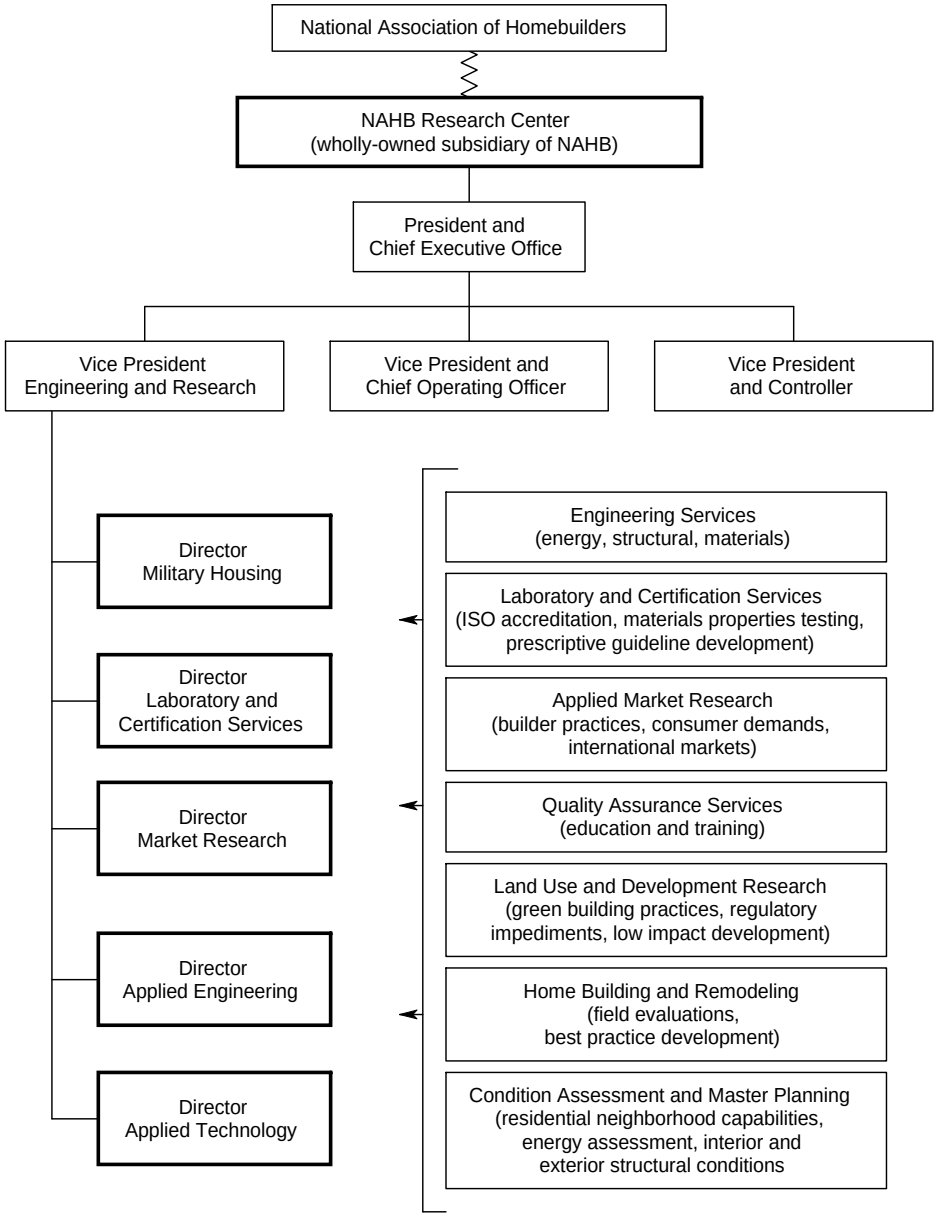
Appendix Figure 12. Department of Building Technologies, Division of Environmental EnergyTechnologies, Lawrence Berkeley National Laboratory. 2009.



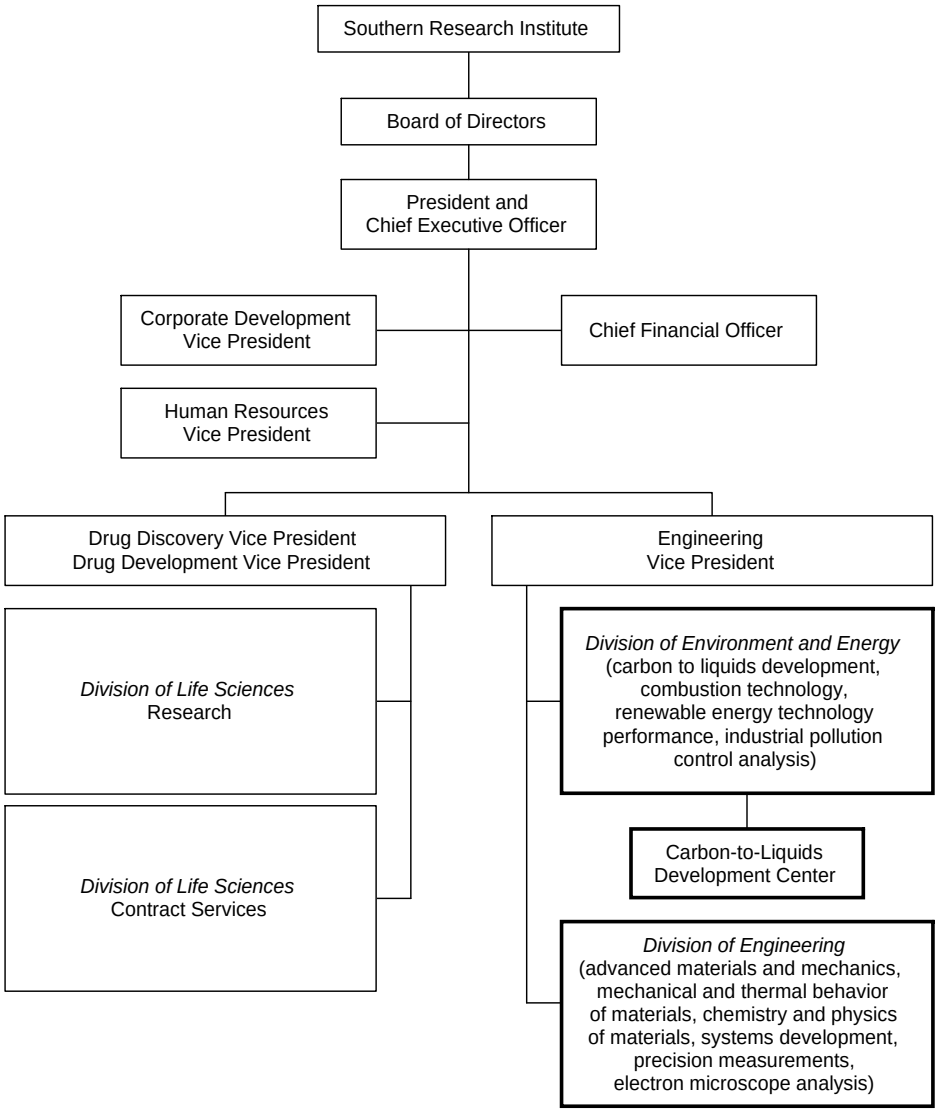
Appendix Figure 13. Herty Advanced Materials Development Center. 2009.



Appendix Figure 14. Institute of Paper Science and Technology. 2009.



Appendix Figure 15. NAHB Research Center, National Association of Home Builders. 2009.



Appendix Figure 16. Southern Research Institute. 2009.