WHAT ON EARTH DO WE NEED?

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RESEARCH NEEDS FOR THE PULP AND PAPER INDUSTRY ENCOMPASS BROAD AREAS FROM ENERGY TO CORE PAPERMAKING TECHNOLOGY TO PROCESS CONTROL AND EQUIPMENT.

THE THIRD PAPER INDUSTRY RESEARCH NEEDS Workshop was sponsored by TAPPI Foundation, hosted by North Carolina State University, and attended by more than 70 paper industry technical professionals, representing a wide cross section of expertise and experience related to this industry's technology. This meeting continued the efforts of TAPPI and the pulp and paper industry's technical leaders to periodically assess the state of science and technology in the industry and set forth a list of its high-priority research needs. The results of these efforts should be useful to industry scientists as well as their associates in universities and institutions and others who may not be as familiar with the pulp and paper industry.

The first of these workshops was held in Orono, ME, in July 1988; it was organized and hosted by the Department of Chemical Engineering of the University of Maine and received funding from the National Science Foundation. TAPPI assumed the responsibility for sponsoring and funding the second workshop, which was held in Syracuse, NY, in May 1992 and was hosted by the College of Environmental Sciences and Forestry of the State University of New York. Proceedings of both of these earlier workshops are available from TAPPI.

WORKSHOP STRUCTURE

The current workshop participants were selected to form teams of knowledgeable professionals in eight areas of emphasis:

- Energy
- Environmental issues
- Fibrous raw material
- Papermaking processes
- Pulping and bleaching
- Recycling
- Sensors and process control
- Surface and structure treatment.

Each team member was asked to review the report of the 1992 workshop, update his or her thinking, and submit new thoughts for review by other team members prior to the meeting. At the workshop, each team deliberated for 1-1/2 days to arrive at a prioritized list of the industry's research needs for the assigned area of emphasis. The results of their efforts are presented first in this article. A further summation of the top ten overall research needs for the pulp and paper industry is shown in **Table I.**

ENERGY

The Energy Committee listed and ranked the highest-priority energy research needs it had identified; these were forwarded for full conference consideration. Because many members of the Energy Committee have been and continue to be intimately involved with the industry's "Agenda 2020" vision process, the research gaps identified by that process were used as a starting point for identifying and prioritizing research needs. However, there is one significant difference between the Agenda 2020 focus and the focus of the Paper Industry Research Needs Workshop. The workshop was clearly meant to identify fundamental research needs that can be effectively addressed by university researchers; the Agenda 2020 portfolio covers the spectrum of needs from fundamental research to commercial demonstration. The Energy Committee's results reflect this difference in focus.

The Energy Committee's priorities are listed as follows. Some major messages about each research priority are provided.

- Fuel production and enhancement that significantly increases land productivity and optimizes systems for raw material acquisition and processing

Author's note: This article is comprised of excerpts from Paper Industry Research Needs, *a 114-page summation of a workshop that was sponsored by TAPPI Foundation. The workshop was held April 22–24, 1996, in Raleigh, NC.*

- Fuel conversion and electricity production to improve performance of existing powerhouse assets and to ensure the timely introduction of next- generation technologies
- Manufacturing efficiency and heat recovery that measurably improves the energy efficiency of pulp and papermaking operations and examines and facilitates the development of process alternatives
- Environmental implications, which include (a) physical and chemical treatment technologies for high-concentration streams resulting from close up, (b) examination of the fundamental chemistry of ash and sludge, and (c) a fundamental understanding of the chemistry of closed mills
- Wider use of renewable resources, which include developing energy- efficient processes to use recovered paper.

Significantly enhanced land productivity will be necessary to improve the industry's practices in fuel production and enhancement. Enhanced land productivity includes the returning of essential elements to the soil to ensure sustained soil productivity while at the same time increasing extraction of biomass for primary products and energy. Also included is increasing multiple use and public acceptance of managed plantation systems.

With respect to fuel conversion and electricity production, the industry must exhaust all possibilities for improving performance of existing powerhouse assets. This can be accomplished by significantly increasing fundamental knowledge of biomass and black liquor combustion; greatly reducing downtime and maintenance costs through improved materials, fabrication techniques, and corrosion prevention measures; and increasing understanding and control of process variability.

ENVIRONMENTAL

Pulp and paper companies deal with every aspect of the environment: air, water, trees, plants, wildlife, and the land itself. These companies have accepted their responsibility to protect natural resources by carefully managing their forests and by operating pulp, paper, and wood-product mills in a safe, environmentally sound manner. As a result, environmental control processes are used in almost every phase of pulp manufacture, papermaking, and converting.

Although air pollution, water pollution, and solid waste are often regarded separately, they are not independent. Unless an integrated problem-solving process is used, changes to correct water problems could, for example, worsen effects in other areas such as air and solid waste.

The Environmental Discussion Group identified research needs in six categories: water, air, solid waste, products, forestry, and public perceptions and regulation. Fundamental research, applied research, or development work will be needed to provide a basis for decisions in all of these areas. The following is a list of the top-ranked environmental research needs:

- **Water.** (a) Establish scientifically valid methodologies to assess the fate of residual compounds (especially bioaccumulating compounds) discharged in mill effluents and the effects of these compounds on human health and the environment. (b) Develop scientifically valid methods to conduct genetic risk assessment. (c) Develop techniques for increased closure of mill systems, and to the extent practical, move toward the minimum-impact mill. (d) Validate biomarker tests and bioassay methods as predictors of effects on human and ecological health.
- **Air**. (a) Assess the amount, chemical characteristics, and potential environmental and human health impacts and develop controls for volatile organic compounds (VOCs) and hazardous air pollutants (HAPs) released from pulp, paper, and wood manufacturing facilities. (b) Eliminate odor from industry manufacturing facilities. (c) Characterize the industry's overall effects on the CO_2 and O_2 cycles.
- **Solid waste**. Develop alternative methods for beneficial reuse of residual solids.
- **Products**. Improve recyclability of paper products through modification of inks, coatings, adhesives, sorting processing, etc.
- **Forestry**. (a) Provide scientific validation for listing of threatened and endangered species through research in (1) basic taxonomy and demography of listed and candidate species, (2) habitat relationships and trends, (3) effects of forest management alternatives, and (4) population variability analysis. (b) Optimize forest management practices to minimize cumulative watershed effects. (c) Use real-time simulation through dynamic modeling of all mill systems for improved environmental performance.

FIBROUS RAW MATERIAL

Worldwide, the pulp and paper industry produces over 260 million metric tons of paper and paperboard each year. The United States is the single largest producer, accounting for over 30% of world capacity. The U.S. pulp and paper industry achieved its position and size primarily on the basis of a relatively abundant and economically available virgin wood-fiber resource. To continue to

1. To develop techniques for increased closure of mill systems, reducing liquid effluent discharges, and to the extent practical, moving toward the minimum- environmental-impact mill.

2. To develop a fundamental understanding of the physical and chemical properties of pulps as they are affected by pulping and bleaching processes.

3. To develop genetic engineering tools that will allow manipulation of tree characteristics such as fiber properties, growth rate, disease and pest resistance, cold tolerance, herbicide resistance, etc.

4. To develop a fundamental understanding of the processes that control the distribution of fibers in paper and board so that advances can be made toward producing perfectly formed products.

5. To improve the knowledge of moisture diffusion in paper and paper products and the understanding of the effects that moisture movement has on their performance.

6. To improve the understanding of the effects of recirculating pulping and bleaching filtrates through the kraft chemical recovery process.

7. To develop methods for growing fibers with physical and chemical properties best suited for pulping, bleaching, and recycling, and for end-use requirements.

8. To establish methodologies to assess the fate of residual compounds discharged in mill effluents and their effects on human health and the environment.

9. To find better ways to control the process of delignification of wood and separation of fibers.

10. To develop improved methods to separate fibers from contaminants in recycling processes.

I. Overall top ten research needs for the pulp and paper industry

dominate, the U.S. industry must continue to have access to an abundant and economically available fiber supply.

It appears that sufficient wood should be available to maintain a pulp and paper industry based on wood-derived fiber. This does not mean, however, that there are not significant problems or research needs in the area of wood-based raw material for the U.S. pulp and paper industry. Often, wood is not growing close to or is not available to major wood-processing or paper-consuming locations. Also, wood use in pulp and paper competes with wood use for lumber, composites, and fuel.

The Fibrous Raw Material Committee prepared a list of the highest research priorities by first creating a vision statement for the future. The vision statement is as follows: The forest products industry will have in place the technology to achieve a managed, sustainable, high-quality, and diverse fiber supply available at costs that allow the industry to remain competitive in world markets.

The highest-priority research items identified to achieve the vision are as follows, in order of rank:

- Develop methods to grow fibers with physical and chemical properties best suited for pulping, bleaching, recycling, and end-use requirements
- Identify silvicultural practices and develop tree-harvesting systems that are economically feasible and environmentally sensitive and that meet sustainable forestry criteria
- Develop genetic engineering tools for inserting specific genes (e.g., for growth rate, disease/pest resistance, cold tolerance, fiber properties, herbicide resistance, branch size and angle) into the genome of selected forest trees
- Develop an understanding of the biochemistry and physiology of the tree-growth process
- Develop techniques to predict fiber properties of standing trees (e.g., fast techniques for scanning wood for fiber transverse dimensions)
- Determine the suitability of various types of tree harvesting and transport equipment for meeting sustainable forestry and economic goals/objectives
- Develop mass-propagation techniques for increasing the numbers of superior trees
- Develop technologies to provide fiber with minimum variability to the mill
- Improve the yield of available resources in harvesting and in primary processing of the woody material
- Capitalize on natural variability within species to achieve desirable fiber properties

- Perform research on forest-health improvement through timber salvage, thinning, utilization, and forest rejuvenation.

PAPERMAKING PROCESSES

The Papermaking Processes Group identified the following as areas for top-priority research:

- **Moisture diffusion and its effects.** There is still a need to develop a fundamental understanding of moisture diffusion and its effects on paper structure and properties—e.g., how to control dimensional stability, curl, and cockle.
- **Wet-end chemistry**. Practical furnishes for most paper grades consist of a wide range of particle sizes plus some dissolved or colloidal substances. Chemical additives are used to control process conditions, prevent fiber agglomeration, agglomerate colloidal particles, etc. The chemicals also interact.
- **Limits to speed**. Because papermaking is so capital intensive, the rate of (acceptable-quality) production per unit time is critically important to the economic success of operations. Increasing the production speed usually pays greater returns than increasing the machine width.
- **Perfect formation**. Small-scale uniformity of paper is essential to good printing results; virtually all paper and board products are printed. Small-scale uniformity of paper is also essential to providing maximum runnability and strength in large samples and products.
- **Modeling pressing**. Fundamental modeling of pressing will define and expand knowledge of the process, which is critical to finding novel and more effective solutions. Effects of the web structure and the felt or felts (if any); heat; and mass transfer by mechanical, hydrostatic, hydrodynamic, and other means should be considered.
- **Stability of paper surfaces**. Improved understanding of how the pressure and temperature history influence the behavior of paper surfaces when brought in contact with water may assist in developing more stable surfaces over a wide range of dimensions that affect print quality.
- **Bonding**. Fiber-to-fiber bonding is necessary to produce strength and stiffness. Increased bonding reduces the light-scattering surfaces inside the sheet and thus its light-scattering power, whiteness, and opacity.
- **Nonimpact "printability."** New, less expensive coating materials are needed to control dot spread and give rapid drying while trapping dyes near the surface to yield high print density. New coating materials must have reasonable application rheologies, be relatively nonabrasive, and provide surface strength and resistance to marring.
- **"Baked" papers and boards**. Combinations of heat, moisture, pressure, and chemicals could potentially give added strength and moisture stability at equal density or bulk. The fundamentals of such processes and reactions must be understood if suitable treatments to obtain bulky, strong, tough, and bright products are to be developed.
- **Rupture and structure**. Better understanding of rupture phenomena, the events preceding it, and the paper structure is needed to improve paper and board products. This knowledge might allow computer-aided design and other modeling methods to be used in development of paper and board products.

PULPING AND BLEACHING

North America grows large quantities of wood fiber for paper and board products. The equipment and processes used to convert wood to separated pulp fibers and to bleached fibers are capital and energy intensive and can be a source of environmental emissions. Environmental concerns have created major research needs related to changing the way that pulp is bleached and using the raw material base more effectively. Overall, the industry's needs in pulping and bleaching are to (a) learn how to more efficiently prepare and effectively use higher-yield pulps, (b) understand and improve the properties of pulps, (c) reduce emissions to the environment, and (d) use less water.

The Pulping and Bleaching research team identified the following as top- priority research needs:

- Understand pulp properties as affected by pulp chemistry and pulp bleaching processes
- Understand the effects of recirculation of pulping and bleaching filtrates to recovery (system closure)
- Develop lower-capital pulping and bleaching processes
- Develop low-odor pulping technologies
- Improve high-yield, lignin-containing pulps
- Understand the relationship between the fiber supply characteristics and the pulping and bleaching responses
- Develop or improve sensors for pulping and bleaching processes
- Decrease energy demand in mechanical pulping
- Develop alternatives for separate bleach filtrate processing
- Improve process stability through uniformity, sensors, controls, and models.

RECYCLING

The recycle of fibers has been practiced in the United

States since the founding of the paper industry in 1735. In those days, paper was produced from rags and cotton linters. With the invention of wood digestion to produce papermaking fibers in the 19th century, the industry grew rapidly in size. Beginning about 1900, a number of mills were built that relied on recycled fiber as their primary source of material. A support business of brokers developed to facilitate the supply to the mills of printer waste, trimmings from converting operations, and other industrial operations, plus used corrugated boxes from retail markets. The term associated with these materials was *secondary fiber.*

Given a choice, a papermaker would prefer to use virgin fiber because of its more consistent uniformity and lack of contamination with nonpapermaking materials. Straight economics made this part of the industry grow to a size that required the recovery of about 20% of available discarded paper. The paper industry is capital intensive and has a relatively large economy of scale. Recycled fiber operations can be built economically at lower production rates. The fact that recycling operations are virtually odor free allows mills to be located in metropolitan areas that are close to both the raw material supply and the consumer.

In 1990, the paper industry set a goal to increase the recovery rate to 40% of all paper manufactured by the end of 1995. This goal was adopted in response to public concern about landfill availability and limited reuse of a major renewable resource. At the time the goal was set, economics were not an overriding concern; however, fiber reuse must be an economic requirement if the industry is to continue as the fifth largest industry in the country. The goal was met at the end of 1994 and has been replaced with a goal of 50% recovery by the year 2000. This is a remarkable goal, considering the fact that about 10% of paper manufactured is nonrecoverable (e.g., archival papers, wallpaper, personal and sanitary products, and remote end-use locations).

The Recycling Committee identified the following as top-priority research needs:

- Improved separation techniques of fiber and contaminants
- New technologies for removing or neutralizing (or both) microstickies from all process waters
- Recovery of fillers in recycled fiber
- Recovery and sorting of discarded paper
- Enhanced reuse and recirculation of process water.

SENSORS AND PROCESS CONTROL

Numerous R&D opportunities for sensors and process control systems were identified that address needs in the pulp and paper industry, from timber harvesting through paper manufacturing and converting. Useful suggestions were received from other workshop committees as a result of their discussions of needs in specific process areas. More than 100 specific needs involving new or improved sensors, control methods, or both were tabulated.

Needs were ranked using the criteria of benefit to the industry, inadequacy of the current state-of-the-art, precompetitive nature of the developmental work needed, and time frame for development beyond three years. Seven top-priority needs in sensors and process control research were identified. They are presented here in order of importance to the industry:

- Improved measurement of chemistry during pulping, in both batch and continuous digesters, to include extent of delignification, cellulose degradation, and hemicellulose content
- Sensors, actuators, and control approaches to improve small-scale (3- mm) uniformity of paper in both machine and cross-machine directions, including high-resolution measurement of basis weight, moisture, and caliper over a high percentage of surface area with a goal of 100% surface coverage
- Measurement of wood-chip characteristics, including moisture (especially with frozen chips), size and size distribution, species, age, acidity, and presence of contaminants
- In-process measurement of pulp-fiber characteristics, such as degree of refining, drainage potential, coarseness, conformability, and strength, to improve control of pulping, stock preparation, and papermaking
- Improved control and stability of wet-end operations by measuring colloidal properties in dilute furnish prior to web formation
- Improved sensors for pulp consistency that can distinguish fibers from fillers and are insensitive to changes in process conditions and raw materials
- Prediction of printability of paper with on-line paper measurements.

SURFACE AND STRUCTURAL TREATMENT

Most grades of paper are manufactured with some sort of surface treatment, and very few grades are sold to the final consumer without undergoing conversion. The majority of all paper produced passes through some form of conversion process—printing, bag making, lamination, corrugating, or coating—in short, any one or more of a wide variety of processes subsequent to papermaking. As

it is produced, paper has a relatively rough surface that is not suitable for fine printing or further processing. These converting processes dictate the need for surface treatment of some type. In the manufacture and conversion of paper, there are two main opportunities to treat the paper surface: (a) at a size press location on the paper machine or (b) at a coating station, on or off the paper machine.

Both surface treatment systems customize paper and board for different end uses. These treatments generally change surface structure and surface chemistry. In other cases, the surface treatment is aimed at broadening the applicability of paper in end use. These processes have in common rheological and fluid-dynamic concerns that accentuate at limiting speeds. The objective of surface treatments is to enhance the printing properties of paper and board for processes such as offset lithography, gravure, flexography, inkjet, and toner-based electrophotographic/electrostatic processes. Surface treatments effectively regulate ink penetration, setting, spreading, and adhesion.

The following were identified as top-priority research needs in the surface and structural treatment area:

- Develop computational methods for analysis of sizing and coating processes, including the effects of coating/paper interface deformation, interaction of the coating with the porous substrate, and the effects of solid particles on rheology
- Develop robust constitutive models for coating suspensions
- Develop methods to predict water absorption in surface treatment applications
- Understand the fundamentals of coating consolidation
- Understand the relationship between moisture, temperature, pressure, and calender nip

AVAILABLE EXECUTIVE SUMMARIES AND TECHNICAL PAPERS

In 1991, the Research Funding Program was initiated, with the first annual US$ 250,000 program to provide seed grants for up to US$ 40,000 for research proposals. Since that date, US$ 1,558,443 in seed grants have been awarded to 41 individuals from 33 universities.

When the research proposer finishes his/her research at the end of the year, he submits an executive summary relating to his experience/research. The TAPPI Foundation has 19 executive summaries available on the Internet. Many of these include more detailed information. If you are interested in a copy of the executive summary or if additional information is denoted on the following list, please contact the TAPPI Foundation at +1 770 209–7211 for individual copies. There will be a small charge for duplication and postage.

EXECUTIVE SUMMARIES ON THE INTERNET

The following summaries may be found on the Internet at http://www.tappi.org:

• Bhavik R. Bakshi of the Department of Chemical Engineering, The Ohio State University, "Integrated Data Analysis and Information Extraction From Measured Data in Millwide Information Systems."

• Douglas W. Bousfield of the Department of Chemical Engineering, University of Maine, "The Behavior of Clay Pigments During Coating at High Solids and High Speeds."*

• Leif A. Carlsson of the Department of Mechanical Engineering, Florida Atlantic University, "Micro-Model for Paper."*

• Pierre Carreau of the Centre for Applied Polymer Research, Ecole Polytechnique, "Rheological Properties of Coating Colors: Viscoelastic and Extensional Effects at Very High Deformation Rates."

• Hseuh-Chia Chang of the Department of Chemical Engineering, University of Notre Dame, and Cyrus K. Aidun of the Institute of Paper Science and Technology, "Air Entrainment in Coating and Size-Pressing."

• Richey M. Davis of the Department of Chemical Engineering, Virginia Polytechnic Institute, "A Fundamental Investigation of the Stabilization and Structure of Paper Coating Suspensions Using Well-Defined Polymeric Dispersants."*

• David B. Dusenbery of the School of Biology, Georgia Institute of Technology, and Ronald J. Dinus of the Forest Biology Group, Institute of Paper Science and Technology, "The Use of Nematode, Caenorhabditis Elegans, For Biomonitoring Heavy Metals in Pulp and Paper Effluents and Sludge."*

• Warren T. Ford of the Department of Chemistry, Oklahoma State University, "Oxidations of Lignin Model Compounds Catalyzed by Metallophthalocyanine."*

• Craig L. Hill of the Department of Chemistry, Emory University, "A New Environmentally Benign Catalytic, Biomimetic and Selective Approach for Bleaching Wood Pulp Based on Polyoxometalates."*

residence time on pore structure, surface strength, ink receptivity, and surface profile
- Develop a comprehensive model to predict sheet properties from given raw material and process parameters
- Identify methods to predict and eliminate nonuniformities in macroscopic fiber network formation that impact coating quality and appearance
- Develop a fundamental understanding of the inter action between the pigment, binder, and other additives to produce coating liquid formulations with optimum coating rheology, high scattering coefficient, and other desirable end-use attributes
- Develop a fundamental understanding of the hydrodynamic and colloidal interaction between suspended solid particles in coating liquid
- Analyze the fundamental impact of substrate formation on coating consolidation and final coating characteristics
- Develop robust methods to detect and monitor particulate and air- bubble-concentration gradients.

SUMMARY

TAPPI and TAPPI Foundation welcome your comments and feedback on the industry needs that are presented here. Feel free to fax any comments to Pat Stiede at TAPPI Foundation, fax: +1 770 446-6947.

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• Julia A. Kornfield of the Department of Chemical Engineering, California Institute of Technology, "Effects of Closing White Water Streams on the Dispersal and Reflocculation of Wood Pulp Fiber Suspensions."

• Jules (Jaye) Magda of the Department of Chemical and Fuels Engineering, University of Utah, "A Critical Examination of the Role of Ink Surface Hydrophobicityin Flotation Deinking."*

• Vijay Modi of the Department of Mechanical Engineering, Columbia University, "Control of VOC Vapor Emissions in Web Offset Lithography."*

• C. D. Mote Jr. of the Department of Mechanical Engineering, University of California–Berkeley, "Equilibrium Displacement and Stress Distribution in a Two Dimensional, Axially Moving Web Under Transverse Loading."

• Noel C. Perkins and William W. Schultz of the Mechanical Engineering and Applied Mechanics Department, University of Michigan, "The Mechanics and Modeling of Wet Paper Forming."

• Robert L. Powell of the Department of Engineering, University of California–Davis, "Studies of the Fluid Mechanics and Rheology of Pulp Suspensions Using Nuclear Magnetic Resonance Imaging."*

• M. K. Ramasubramanian of the Office of Sponsored Programs, North Carolina State University, "Mechanics of the Creping Process."

• Nick V. Sahinidis of the Department of Mechanical and Industrial Engineering, University of Illinois at Urbana-Champaign, "Development of Novel Modeling and Optimization Approaches for Scheduling the Operation of Paper Production Plants."*

• John F. Scamehorn and Sherril D. Christian of the Institute of Applied Surfactant Research, University of Oklahoma, "Fundamental Study of the Flotation Deinking Process."

• Richard J. Spontak of the Department of Materials Science and Engineering, North Carolina State University, "Characterization and Viscosity Modification of Virgin and Thiocyanate-Treated Black Liquor and Aqueous Hydroxpropylcellulose Solutions."*

AVAILABLE TECHNICAL PAPERS

The following technical papers, which are not on the Internet, may be obtained from the TAPPI Foundation:

• Cyrus K. Aidun and Georges M. Fadel of the Department of Mechanical Engineering, Georgia Institute of Technology, "Investigation of Air/Sheet Dynamics in the Dryer."

• Richard C. Benson and Sinan Müftü of the Department of Mechanical Engineering, University of Rochester, "Air Bar Stabilization of a High Speed Paper Web."

• David C. S. Kuhn of the Department of Chemical Engineering and Applied Chemistry, University of Toronto, "Development of a Rapid Method for Measuring the Wet Flexibility of Pulp Fibres."

• Jeffrey D. Lindsay of the Institute of Paper Science and Technology, "Fundamentals of Three-Phase Pulp Suspension Flows."

• Arthor J. Ragauskas of the Department of Chemistry, Institute of Paper Science and Technology and Leslie T. Gelbaum of the Department of Biotechnology, Georgia Institute of Technology, "Application of ^{17}O and ^{2}H NMR in Bleaching Technology."

*Additional information available