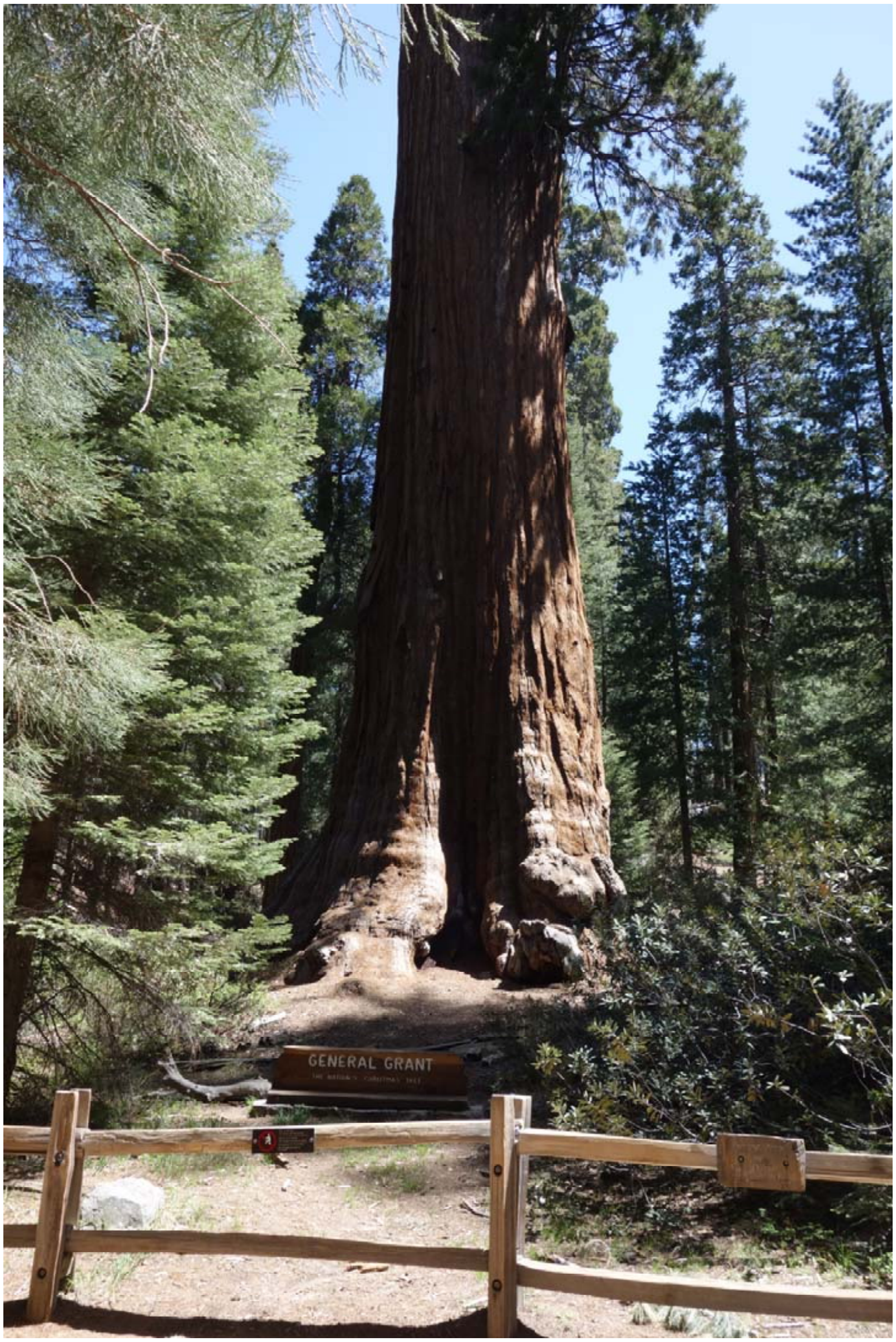

Lignin 2021

A pivotal year

By Jack Miller

BioBased Markets

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On the cover:

The General Grant Tree, a giant sequoia in California's Kings Canyon National Park, is one of the largest trees in the world. It stands 267 feet tall, and lignin makes this possible

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1. Acknowledgments

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I would also like to thank North Carolina State University for the photo of dried lignin on page 25.

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Finally, thank you to all who provided input to this study through interviews, email, and more, and especially my technical advisors:

- Dr. Hasan Jameel, Jordan Family Distinguished Professor, Department of Forest Biomaterials, North Carolina State University
- Dr. Michael Lake of TechLake and Liquid Lignin
- Dr. Michael Paleologou, Senior Scientist, FPInnovations, Chemical Process Group
- Dr. Orlando Rojas, Professor and Canada Excellence Research Chair, University of British Columbia, and Scientific Director Bioproducts Institute

Jack Miller
Biobased Markets
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2. Introduction, Methodology, and Scope

A golfer might tell you that trees are 90% air. They'll say this as you are about to hit a shot with a tree in the way, and of course, they're joking. We know that trees, and other plants, are composed of cellulose, hemicellulose, and lignin. In trees, cellulose is typically around 45% of the dry mass, hemicellulose 25%, and lignin 25%, though this varies depending on the species, with lignin content ranging from 15% to 40%.[1, 2]

Cellulose is a complex carbohydrate polymer composed of glucose molecules, while hemicelluloses are shorter-chain carbohydrates that primarily include C5 sugars such as xylose, and some C6 sugars such as glucose. Lignin is a complex aromatic macromolecule that is essentially the "glue" that holds the cellulose and hemicellulose fibers together.

In five or ten years, when we look back, we likely will see that 2021 was a pivotal year for lignin.

Nature produces approximately 20 billion tonnes of lignin each year,[3, 4] but historically, lignin was the undesirable part of the biomass. Most lignin has long been derived as a by-product in pulp and paper production. In a pulp mill, wood chips are broken down with heat and chemicals in a digester, removing most of the lignin and hemicellulose and creating a pulp primarily composed of strong cellulose fibers. The pulp then goes to the paper mill to produce brown kraft[5] paper for

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[1] Miller J. Lignin: Technology, Applications and Markets, RISI, 2017.

[2] Novaes E. et al. *Lignin and Biomass: A Negative Correlation for Wood Formation and Lignin Content in Trees*; Plant Physiology, Oct. 6, 2010. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2949025/

[3] Dessbesell L. et al. Global lignin supply overview and kraft lignin potential as an alternative for petroleum-based polymers. Renewable and Sustainable Energy Reviews, Volume 123, 2020, 109768, ISSN 1364-0321, https://doi.org/10.1016/j.rser.2020.109768.

[4] Smolarski N. High-value opportunities for lignin: unlocking its potential. Frost and Sullivan, 2012. https://www.greenmaterials.fr/wp-content/uploads/2013/01/High-value-Opportunities-for-Lignin-Unlocking-its-Potential-Market-Insights.pdf

[5] Kraft is the German word for "strong"

grocery bags or containerboard for corrugated boxes. These products are brown because some of the residual lignin remains in the pulp. To produce white paper, the pulp is bleached to remove the remaining lignin.

Table 2.1

Megatrends Impacting Lignin Markets

Sustainability:
circular bioeconomy
legislative: biofuel mandates
utilize waste biomass
stronger, lighter materials > material reductions
better gas mileage
less reliance on oil-based products
don't compete with food

Economic:
use cheaper feedstocks, i.e., agricultural residues
stronger, lighter materials > less material, lower cost
use the entire biomass
optimize all value streams

Source: Biobased Markets

Today several megatrends have combined to drive interest in lignin (Table 2.1), and 2021 may well be a pivotal year for development of lignin-based products and markets. As biorefineries emerged to produce cellulosic ethanol, they originally used corn. Concerns about fuel competing with food gave rise to second generation (2G) biorefineries that produce ethanol from agricultural residues such as corn stover, but many of these biorefineries failed. While the process worked, the economics did not. Now we are seeing a new generation of biorefineries that seek to optimize the full value stream: cellulose for specialty cellulose, nanocellulose and biocomposites; ethanol from cellulose and C6 sugars; chemical building blocks and bioplastics from C5 sugars; lignin and value-added lignin derivatives.

At the same time, pulp and paper mills are embracing the concept of the circular economy, and are also seeking value-added product streams as paper markets decline: nanocellulose and cellulose specialties, and of course, lignin.

The objective of this report is to explore the growing interest in lignin from the converging worlds of biorefineries and pulp mills and their customers, to examine the different forms of lignin, and to review the state of the industry and provide and forecast to 2030. This report covers the various forms of lignin, including lignosulfonate, kraft lignin, and a range of biorefinery lignins, and includes profiles of more than 70 mills, biorefineries, and technology providers.

Methodology

This report was written by Jack Miller, Founder and Principal Consultant, Biobased Markets, a unit of Market-Intell LLC. Jack has more than thirty years' experience in market research and marketing strategy related to paper and paperboard. Since 2009, his focus has been on markets for bio-based products such as nanocellulose, biocomposites, and lignin.

He is a member of the Advisory Board of Sweetwater Energy, a biorefinery company, and is also a member of the Advisory Board of Applied Bioplastics, a supplier of plant-based plastic alternatives. Jack is the author of *Lignin: Technology, Applications and Markets* published by RISI in 2017. He is also the author of *Nanocellulose: Technology, Applications and Markets* published by RISI in 2014; *Nanocellulose Producers, Products and Applications, A Guide for End Users*, published by TAPPI in 2017; *Nanocellulose Challenges and Opportunities: End User Perspectives,* published by TAPPI in 2018, and *Nanocellulose: Packaging Applications and Markets* published by RISI in 2019. He has also presented on cellulose nanomaterials and lignin at webinars and conferences in the United States, Canada, Europe, South America, and Asia, as well as at conferences on packaging, composites, nonwovens, adhesives, textiles, and other nanomaterial applications.

This study is the product of extensive primary and secondary research.

Primary research includes direct input from more than 40 mills, biorefineries, research centers and technology providers. This includes interviews conducted by Biobased Markets, by telephone and email. In addition, draft profiles were sent to more than 50 key players for review and validation, and close to 50% have responded and provided input. Primary research included direct input from the following:

- Andritz AG
- Avantium N.V.
- BioProducts Institute
- Blue BioFuels, Inc.
- CellMark AB
- CH-Bioforce
- Chemtex Global Corporation
- Clariant AG
- CMPC
- FPInnovations
- Futurity Bio-Ventures Ltd.
- G+E GETEC Holding GmbH
- Graanul Biotech
- GranBio Technologies
- Klabin S.A.
- LignoPure
- Liquid Lignin Company
- MetGen Oy
- North Carolina State University
- Ørsted A/S
- Praj Industries Ltd.
- Pure Lignin Environmental Technology, Ltd.

- Ren Com AB
- RenFuel AB
- Sainc Energy
- Sappi Limited
- Svensk Etanol Kemi AB (Sekab)
- Södra
- Stora Enso
- Suzano S.A.
- Sweetwater Energy
- Techlake
- University of British Columbia
- University of Maine
- University of North Carolina
- UPM Biochemicals
- US Forest Service
- Valmet Oyj
- Versalis S.p.A.
- Wageningen University

Secondary research includes an extensive review of patents, technical journals, conference presentations, magazine articles, and websites. Sources are referenced in the footnotes, as well as in Tables and Figures, many with live hyperlinks to the source material.

This study also builds on research conducted by Jack Miller in conjunction with the 2017 study *Lignin: Technology, Applications and Markets.*

This is a market study, not a technical journal, but it necessarily includes some technical discussion. Some may find it too technical while others may find it not technical enough. I have tried to strike a balance.

I thank technical advisors, Michael Paleologou of FPInnovations, Orlando Rojas of the University of British Columbia, Hasan Jameel of North Carolina State University, and Michael Lake of Techlake and Liquid Lignin for their support with technical details. These advisors not only answered questions and provided input, but also reviewed sections of the report and suggested valuable edits. For those who want further technical research, a Bibliography is provided in Chapter 14.

Scope

The scope of this study is global. It covers kraft lignin, lignosulfonates, and biorefinery lignins. It includes discussion of biorefineries that have a reasonable likelihood of producing and recovering lignin and lignin-based chemicals. Lignocellulosic biorefineries that are primarily designed for biofuels, bio-diesel, etc. are generally not within the scope of this report.

Notes

More than 200 discrete sources are referenced, with active hyperlinks provided where possible, and underlined in blue type.

This report uses both terms: “ton” and “tonne.” A ton, sometimes called short ton, is 2,000 pounds. A tonne, or metric tonne, is 1,000 kilograms, 2,204.6 pounds. We will generally use “tonne” except where the source uses the term “ton.”

The symbol “$” is used to mean US dollars (USD or US$) unless otherwise noted. The symbol € is used to mean euros. Other currencies except Canadian dollars (CAD) are converted to US$. Currency symbols and abbreviations are defined in the Glossary.