Lignin: Technology, Applications, and Markets

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Jack Miller
Principal Consultant, Market-Intell LLC
Associate Consultant, RISI

Marina Faleiros
Senior News Editor, RISI

Market-Intell LLC
Thank you

Technical advisors:

• Joseph J. Bozell, Professor of Biomass Chemistry in the University of Tennessee’s Center for Renewable Carbon
• Hasan Jameel, Distinguished Professor, North Carolina State University
• World L-S Nieh, National Program Lead, Forest Products and Wood Utilization, U.S. Forest Service
• Michael Paleologou, Research Leader – Biorefinery, FPInnovations
Thank you

- Adrian van Heiningen, University of Maine
- Anders Larsson, Manager LignoBoost and Innovations, Valmet
- Bernard de Galembert, Innovation and Bioeconomy Director, Confederation of European Paper Industries (CEPI)
- Blaine Kunkel, CEO, BlueGoose Biorefineries
- Caio Falcão, Strategy and Business Development Manager, Suzano
- Fabio Figliolini, R&D Innovation Manager, Suzano
- Gurinder Minhas, Managing Director, Performance BioFilaments Inc.
- Hasan Jameel, Distinguished Professor, North Carolina State University
- Hou-min Chang, Professor Emeritus, North Carolina State University
- Joseph Bozell, Professor, University of Tennessee Knoxville
- Lani O'Flynn CEO/Vice president, Pure Lignin Environmental Technology Ltd.
- Mats Nytorp, Business Director, Lignin, Domsjö Fabriker
- Michael Lake, CTO, Lignin Enterprises, LLC
- Michael Paleologou, Research Leader – Biorefinery, FPIInnovations
- Mike Rushton, Chief Operating Officer, Fibria Innovations, Inc.
- Peter Axegård, Vice President, Bioeconomy Strategy, Innventia
- Richard Gosselink, Coordinator Wageningen UR Light Platform, Wageningen University
- Soydan Ozcan, Scientist, Materials Science & Technology Division, Oak Ridge National Laboratory
- Ting-Feng Yeh, Associate Professor, National Taiwan University
- David van Vliet, Adviseur, Structural Reliability, TNO
- Vesa Pykkkanen, CTO, American Process
- World L-S Nieh, National Program Lead, Forest Products and Wood Utilization, U.S. Forest Service
Summary

- Lignin is abundant and cheap
- Lignin competes with oil
- Lignin is complex and heterogeneous, and properties vary widely depending on feedstock and process
- More R&D is needed to develop applications for lignin and lignin-based products

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Introduction to Lignin

• The glue that holds the cellulose in trees together
• Between 20% and 30%, dry weight
• A billion tons potential

Source: http://www.lignoworks.ca/content/what-lignin
Why lignin? Why now?

- Known since early 1900s
- High oil prices in 2000s
- Demand for renewable materials
- Interest and funding for cellulosic ethanol
- Kraft mills recovery limited
- Development of LignoBoost and LignoForce
  kraft lignin recovery

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# Major Market Pulp Expansions 2012-2020 (thousand tonnes)

<table>
<thead>
<tr>
<th>Company (Mill)</th>
<th>Location</th>
<th>Country</th>
<th>Grade</th>
<th>Capacity</th>
<th>Year</th>
<th>Energy output (MW/hr)</th>
<th>Surplus (MW/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eldorado</td>
<td>Três Lagoas</td>
<td>Brazil</td>
<td>BHK</td>
<td>1,700</td>
<td>2012</td>
<td>229</td>
<td>75</td>
</tr>
<tr>
<td>Suzano</td>
<td>Imperatriz</td>
<td>Brazil</td>
<td>BHK</td>
<td>1,500</td>
<td>2013</td>
<td>250</td>
<td>100</td>
</tr>
<tr>
<td>Montes del Plata</td>
<td>Punta Pereira</td>
<td>Uruguay</td>
<td>BHK</td>
<td>1,300</td>
<td>2014</td>
<td>170</td>
<td>80</td>
</tr>
<tr>
<td>CMPC</td>
<td>Guaíba</td>
<td>Brazil</td>
<td>BHK</td>
<td>1,300</td>
<td>2015</td>
<td>175</td>
<td>30</td>
</tr>
<tr>
<td>Klabin</td>
<td>Ortigueira</td>
<td>Brazil</td>
<td>BHK/BSK</td>
<td>1,500</td>
<td>2016</td>
<td>270</td>
<td>150</td>
</tr>
<tr>
<td>OKI/APP</td>
<td>Sumatra</td>
<td>Indonesia</td>
<td>BHK</td>
<td>2,800</td>
<td>2016</td>
<td>n.a.</td>
<td>n.a.</td>
</tr>
<tr>
<td>Fibria</td>
<td>Três Lagoas</td>
<td>Brazil</td>
<td>BHK</td>
<td>1,950</td>
<td>2017</td>
<td>n.a.</td>
<td>130</td>
</tr>
<tr>
<td>Eldorado</td>
<td>Três Lagoas</td>
<td>Brazil</td>
<td>BHK</td>
<td>2,000</td>
<td>2019</td>
<td>n.a.</td>
<td>170</td>
</tr>
</tbody>
</table>

Source: RISI
Kraft vs Lignosulfonate

- Commercial kraft lignin is generally higher in purity; lignosulfonates may contain as little as 75% lignin.
- Lignosulfonate has up to 8% sulfur as sulfate; kraft lignin has 1% to 2% sulfur but it is mostly bonded to the lignin.
- Lignosulfonate is soluble in water; kraft lignin is soluble above pH 11.
- Lignosulfonate is more reactive than kraft lignin towards certain reagents in aqueous solutions at pH < 11.
- Lignosulfonate molecular weight is 20,000 – 50,000; kraft 2,000-3000

Source: RISI, Lignin: Technology Applications and Markets

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Biorefinery lignin

- Organosolv
- ASAM
- Aceotsolv
- Formicofib
- Cellulosic ethanol

Lots of low quality lignin but some processes under development have the potential for high quality
<table>
<thead>
<tr>
<th>Segment</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lignosulfonate</td>
<td>Mature, flat</td>
</tr>
<tr>
<td>Kraft lignin</td>
<td>Developing, growing</td>
</tr>
<tr>
<td>Soda lignin</td>
<td>Small, not developing</td>
</tr>
<tr>
<td>Biorefinery</td>
<td>Emerging, struggling</td>
</tr>
</tbody>
</table>

Source: RISI, *Lignin: Technology Applications and Markets*
Recent developments

- Domtar Plymouth, North Carolina, first LignoBoost kraft lignin site, 2013
- Borregaard LignoTech lignosulfonate, Flambeau River Paper, 2015
- Fibria acquires Lignol Innovations, 2015
- Abengoa Bioenergy bankruptcy, 2015
- Startup of West Fraser LignoForce kraft lignin, 2016
- Ingevity spin-off from WestRock, 2016
- Suzano investment at Limeira mill, 2016, sulfonated kraft lignin
## Volume by Segment 2015 (000 tonnes)

<table>
<thead>
<tr>
<th>Segment</th>
<th>Production</th>
<th>Capacity</th>
</tr>
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<tbody>
<tr>
<td>Lignosulfonate</td>
<td>1,100</td>
<td>1,400</td>
</tr>
<tr>
<td>Kraft lignin</td>
<td>75</td>
<td>* 160</td>
</tr>
<tr>
<td>Soda lignin</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Biorefinery</td>
<td>3</td>
<td>250</td>
</tr>
</tbody>
</table>

* includes 40,000 tonnes of sulfonated kraft

Source: RISI, *Lignin: Technology Applications and Markets*
Key players

- Beta Renewables
- Borregaard
- CIMV
- Domsjö Fabriker
- Domtar
- Fibria
- FPInnovations
- Ingevity
- Nippon Paper
- Stora Enso
- Suzano
- UPM
- Valmet
- West Fraser

Source: RISI, *Lignin: Technology Applications and Markets*
# Second Generation Cellulosic Ethanol Plants

<table>
<thead>
<tr>
<th>Company</th>
<th>Location</th>
<th>Country</th>
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<tr>
<td>DuPont</td>
<td>Nevada IA</td>
<td>USA</td>
</tr>
<tr>
<td>Abengoa*</td>
<td>Hugoton KS</td>
<td>USA</td>
</tr>
<tr>
<td>POET</td>
<td>Emmetsburg IA</td>
<td>USA</td>
</tr>
<tr>
<td>GranBio</td>
<td>Alagoas</td>
<td>Brazil</td>
</tr>
<tr>
<td>Beta Renewables</td>
<td>Crescentino</td>
<td>Italy</td>
</tr>
<tr>
<td>INEOS*</td>
<td>Vero Beach FL</td>
<td>USA</td>
</tr>
<tr>
<td>Shengquan</td>
<td>Jinan</td>
<td>China</td>
</tr>
<tr>
<td>Quad County Corn Processors</td>
<td>Galva IA</td>
<td>USA</td>
</tr>
</tbody>
</table>

* Not operating

Source: RISI, *Lignin: Technology Applications and Markets*

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## Second Generation Cellulosic Ethanol Plants

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</tbody>
</table>

* Running at less than 5% of nameplate capacity

* Not operating

Source: RISI, *Lignin: Technology Applications and Markets*
Applications


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The Road Ahead

Source: GAO

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The Road Ahead

Source: GAO

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Transformation takes time

Source: RISI, *Nanocellulose: Technology Applications, and Markets*
Key challenges

- Proof of concept
- Economics
- Low oil prices
- Funding challenges: the Valley of Death
- Applications development
- Market development
- Scale up in production
- Scale up of applications
- Competitive materials

Source: RISI, Lignin: Technology Applications and Markets
Customer needs

- Proof of concept
- Proven value proposition
- Availability of material
- Consistent quality
- Multiple sources of supply
- Assurance of future prices at commercial scale
Eight things customers need to know

• Lignin is abundant and cheap…
• but supply is limited.
• Lignin is environmentally beneficial.
• The price of oil matters.
• Lignin has been known for a long time, but development has accelerated in recent years.
• Lignin is a complex, heterogeneous material.
• Lignin is not a “drop in” material.
• R&D is needed by producers and customers alike.
## Lignin Production Forecast by Segment (000 tonnes)

<table>
<thead>
<tr>
<th>Segment</th>
<th>2015</th>
<th>Forecast</th>
<th>Potential</th>
</tr>
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<tbody>
<tr>
<td>Lignosulfonate</td>
<td>1,100</td>
<td>1,400</td>
<td>3,000</td>
</tr>
<tr>
<td>Kraft lignin</td>
<td>75</td>
<td>200</td>
<td>78,000</td>
</tr>
<tr>
<td>Biorefinery</td>
<td>3</td>
<td>125</td>
<td>60,000</td>
</tr>
</tbody>
</table>

Source: RISI, *Lignin: Technology Applications and Markets*
“We always overestimate the change that will occur in the next two years and underestimate the change that will occur in the next ten.”

--Bill Gates
Thank you

For more information:
www.risi.com/lignin

Jack Miller
Principal Consultant, Market-Intell LLC
Associate Consultant, RISI
jack.miller@market-intell.com

Marina Faleiros
Senior News Editor, RISI
mfaleiros@risi.com

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