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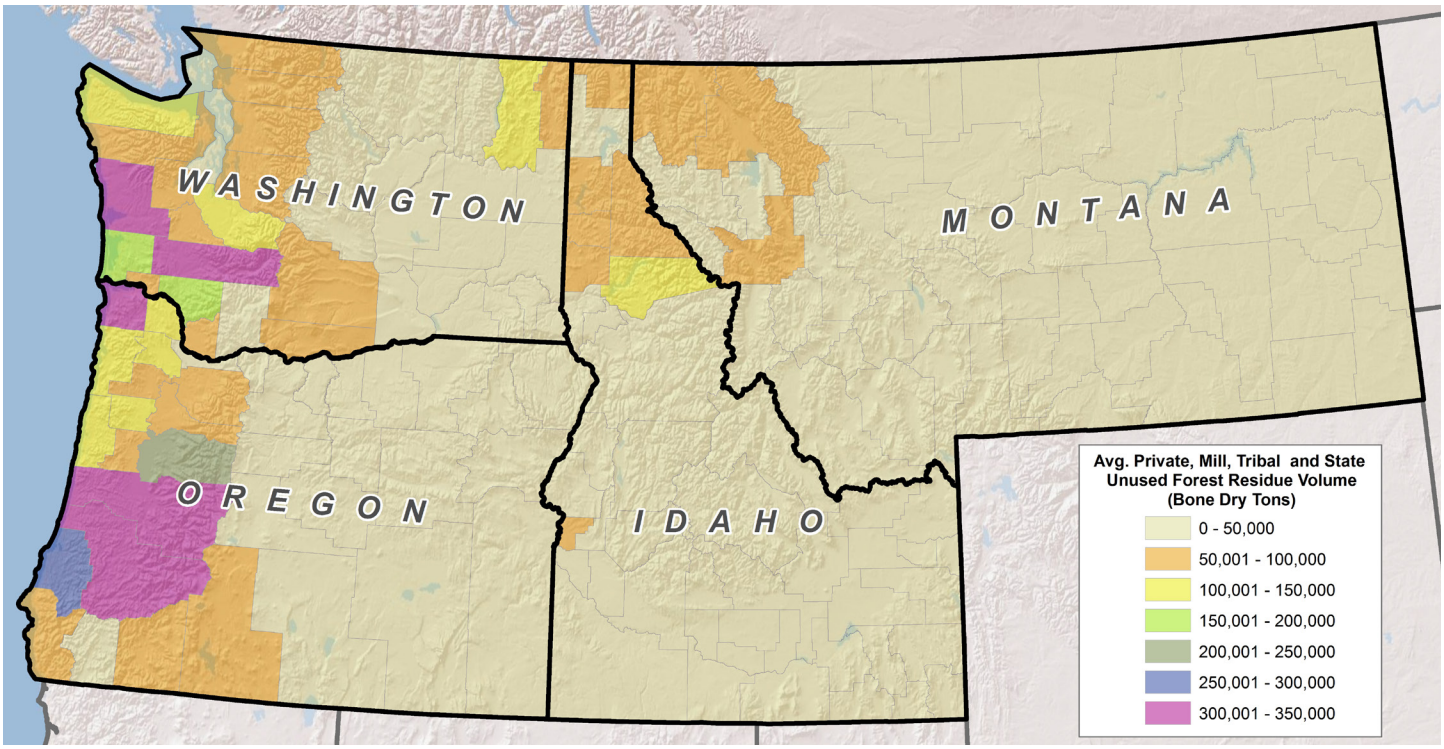

Forest Inventory and Utilization Data

One of the services provided by NARA affiliate, The University of Montana's Bureau of Business and Economic Research (BBER), is publically available forest industry data. Much of the information they provide and compile contributes to NARA's efforts to produce supply chain, environmental and economic sustainability analyses, models and GIS applications useful to an emerging wood-based biofuels industry in the Pacific Northwest. Listed below are two sources of information provided through the BBER's Forest Industry Research Program that may be of interest to our readers.

2011 Idaho Forest Products Industry Census

Recently, the BBER, in conjunction with the Interior West Forest Inventory and Analysis (IW-FIA) Program of the US Forest Service, conducted a census of Idaho's timber processors that operated during calendar year 2011. Through a written questionnaire or phone interview, timber-processing and residue-utilizing facilities provided information about their 2011 operations. The information provided includes:

- Plant location, production, capacity, and employment
- Log lengths, small- and large-end diameters
- Volume of raw material received, by county and ownership
- Species of timber received and live/dead proportions
- Finished product volumes, types, sales value, and market locations
- Volume, utilization, and marketing of manufacturing residue

View tables and figures articulating the findings here

Timber Harvest Data for WA, OR, MT, ID and CA

The data is compiled from information provided by multiple agencies and spans years 2002 to 2011. Harvest volumes can be accessed by county level and are segregated by land ownership (federal, state, tribal, industry).

View timber harvest data for five western states here

View additional regional reports relevant to the timber industry here

NARA Contributions

NARA partially funds the BBER's Forest Industry Research Program. They provide NARA data needed to understand how forest resources are being used and how much wood residuals are available. The map highlighted in this newsletter relied upon data from the BBER and is instrumental for planning a regional supply chain.

To meet this task, the BBER continually updates the primary mill residue and capacity information for the 4-state region, consults with other NARA members, and has conducted extensive logging utilization fieldwork to provide residue estimates. To date they have measured more than 1700 felled trees at 73 logging sites across the NARA 4-state region.

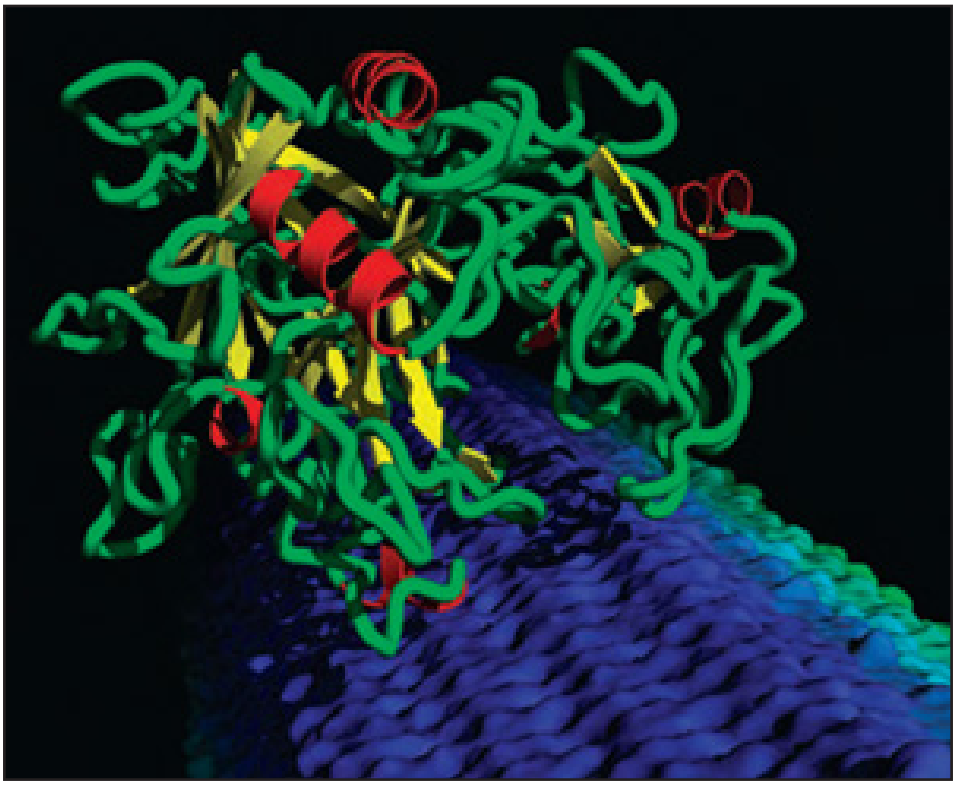

Illustration of cellulase enzyme attached to cellulose

Improving simple sugar yields from wood residuals

Materials built from simple sugar molecules are the foundation of plant systems. Many plants, like corn, use these sugar-based materials to store energy in the form of starch. We then use these materials for food and increasingly as fuels and chemicals. Simple sugars are also used in structural plant materials that humans cannot digest. Some organisms, like fungi and termites, have the proper enzymes, commonly referred to as cellulases, to free up the simple sugars in these fibrous materials. The emerging cellulosic biofuels industry is spurring research and commercial efforts to improve and refine these cellulase enzymes.

Cellulases are enzymes that break down (hydrolyze) cellulose into simple sugars. Cellulose is an abundant structural molecule found in most plants and composed of linked carbohydrates. Cellulases are an essential tool used in the NARA conversion process. When added to pretreated wood, they bind to cellulose and break it into sugar molecules. This cleaving process is called "enzymatically hydrolyze" and is essential to the production of sugars that will be later fermented into the isobutanol alcohol used to make biojet fuel.

Essentially, high sugar yields from wood depends on proper conditions to aid the cellulase enzyme. But getting cellulases to perform their task efficiently is a real challenge. First, lignin and hemicellulose molecules surround the cellulose in wood and effectively block cellulases from binding to cellulose. To partially alleviate this blockage and make the cellulose accessible to the cellulase enzymes, a pretreatment step is required. Second, even if the pretreatment process exposes the cellulose, cellulase can nonspecifically bind to non-sugar molecules like lignin, effectively preventing them from functioning.

Nonspecific Binding to Lignin

One strategy used to relieve the effects of cellulases binding to lignin is to simply increase the amount of cellulase. This option works fine, however, purchasing or processing cellulase is expensive. Other strategies involve removing the lignin by extensive washing or chemically treating the lignin molecule so that cellulase does not bind. These options can also be expensive and environmentally unsound.

Elevate the pH

Work partially funded by NARA and conducted at the USDA Forest Products Laboratory, a NARA affiliate organization, provides an elegant and inexpensive way to reduce the nonspecific binding of cellulase to lignin and thereby increase the simple sugar yields from hydrolysis. NARA researcher Junyong Zhu, scientific team leader at the USDA Forest Products Laboratory and adjunct professor at the University of Wisconsin-Madison, and his collegues published two papers that describe their findings (see references below).

Traditionally, cellulose hydrolysis using cellulase is performed in solution at a pH range of 4.8 to 5.0. At this pH range, cellulases break down (hydrolyze) pure cellulose at the fastest rate. This is also the pH range recommended by Novazymes, the manufacturer of the cellulase/hemicellulase mix commonly used for cellulose hydrolysis.

What the team at the USDA Forest Products Laboratory discovered is that by raising the pH of the solution to the range of 5.5 to 6.0, they could improve the simple sugar yields from cellulose hydrolysis by up to 70%. A key consideration in this case is that the cellulose contained in wood residuals after pretreatment is not pure. "These results contradict the well-established concept that an optimal pH is 4.8–5.0 for enzymatic hydrolysis using Trichoderma reesi cellulase", says Dr. Zhu. "This pH range is based on optimization by using pure cellulose and is widely accepted and exclusively practiced in numerous laboratories throughout the world."

The higher pH reduces the rate of cellulase activity, but it also dramatically reduces the nonspecific binding of cellulase to lignin, thereby providing a net improvement of cellulase activity. It is believed that the higher pH conditions alter the charge of the lignin and cellulase

surface and thus reduce their binding affinity to each other.

Raising the pH in the system is relatively inexpensive and has the added benefit of placing the hydrolyzed carbohydrates in a pH range that is better suited for fermentation into isobutanol. These findings have been incorporated into the protocols currently in place to develop large-scale conversion of wood residues to biojet fuel.

Lan, T.Q., Lou, H., J.Y. Zhu. (2012) Enzymatic Saccharification of Lignocelluloses Should be Conducted at Elevated pH 5.2-6.2. Bioenerg. Res. 6, 476-485. doi:10.1007/s12155-012-9273-4.

Lou, H., Zhu, J.Y., Lan, T.Q., lai, H., Qui, X. (2013) pH-Induced Lignin Surface Modification to Reduce Nonspecific Cellulase Binding and Enhance Enzymatic Saccharification of Lignocelluloses. ChemPubSoc. 6, 919-927. DOI: 10.1002/ceec.201200859

Co-product development: lignin-based molecules for commercial epoxies

Based on current estimates, a bone-dry ton of forest residue can be converted to 59 gallons of isobutanol. What remains is approximately 1450 dry pounds of "waste product". (Tom Spink presentation at the Idaho Small Log Conference 2013). Approximately 37% of the "waste product" or more technically speaking "co-product residual" is lignin (550 dry pounds) with the remainder being processing acids, unreacted cellulose (polysaccharides), non-fermented sugars, extractives, bark, yeast, and wood ash. The most common commercial use for residual solids is to burn them and produce heat or energy. While this strategy remains a potential option for future conversion sites and depots, NARA researchers are developing new uses for the lignin that may provide a higher value than simple energy production. Creating high-value products from the lignin-rich byproduct is essential to improve profitability of the bio-refinery.

Jinwen Zhang, NARA researcher and associate professor, and Michael Wolcott, NARA co-director and Regents professor, are both affiliated at the Composite Materials and Engineering Center at Washington State University. They lead a team that explores ways to convert lignin into molecules that can used for commercial purposes. Their most recent publication entitled *Use of eugenol and rosin as feedstocks for biobased epoxy resins and study of curing and performance properties*, featured in the journal Polymer International, explores the use of eugenol, a molecule that can be derived from lignin, as a bio-based source for epoxy resins.

For this work, their group developed a method to convert eugenol into a novel epoxy molecule. Epoxies are a class of molecules that contain at least one functional group known as an epoxide. The epoxide feature allows the molecule to bind or "cross link" to other molecules forming a tight bond. Consequently, epoxy molecules possess strong mechanical properties able to withstand wide temperatures and harsh chemical environments. Epoxies are used commercially in a wide range of applications including use as structural adhesives and as an additive to metal coatings.

When treated with commercially available curing agents and with a curing agent derived from rosin (resin from pines), the eugenol epoxy demonstrates similar mechanical properties and thermal stability to bisphenolA (BPA)-type epoxies that have been in commercial use since the late 1950s.

The authors state in the paper, " If the highly selective conversion of lignin to aromatic chemicals such as eugenol can be achieved with mass production and cost effectiveness, lignin will bring great value to the chemical industry". The term "if" looms large here, and making the lignin to eugenol conversion costs competitive with current epoxy resin production is a remaining challenge. This work indicates that a high-grade epoxy can be synthesized from a lignin-based feedstock and represents a potential direction in converting lignin-based molecules into commercial products.

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