



Forest Biorefineries: Reality, Hype or Something in Between?

Existing chemical pulp mill infrastructures could be feasibly adapted to co-produce ethanol and other biorefinery fuel products from wood feedstocks.

By Stephen S. Kelley, Ph.D.

Even before President Bush mentioned “ethanol from wood chips,” in his televised State of the Union address last month, the pulp and paper industry was running forest biorefineries. A modern pulp and paper mill, in fact, is a biorefinery— we buy feedstocks and manufacture a suite of products, and we use the entire feedstock. Currently these products are pulp and paper, which have moderate to high value, and process heat and power, which has relatively low value.

Any discussion about the “forest biorefinery” is essentially an examination of how to increase the overall value of this suite of products. Can we take some of the wood sugars and convert them to specialty chemicals or materials? Can we use a feedstock not suitable for high quality pulp to produce commodity fuels? Can we make products more valuable than process heat from pulping or paper making residues?

Two questions should be answered at the outset of a serious discussion about forest biorefineries. First, is there enough biomass available on a sustainable basis to have a national impact? Second, what is the non-renewable energy balance for fuels produced from biomass?

The first question has been clearly answered in a 2005 study by the U.S. Department of Energy (DOE) and the U.S. Department of Agriculture (USDA) that determined there is more than 1.3 billion dry tons of forest and agriculture biomass available, on a sustainable basis, for production of fuels and energy. These 1.3 billion tons of biomass have the energy equivalence of 3.5 billion barrels of oil, which is about 75% greater than our current domestic oil production of 2.0 billion barrels. There is enough sustainable biomass to make a difference.

The second non-renewable energy balance question has been recently addressed by a very complete study in the journal *Science* that found fuel ethanol made from corn has a favorable non-renewable energy balance, i.e., it takes less non-renewable energy to make ethanol from corn than is contained in the ethanol. This study also concluded that production of fuel ethanol from cellulose has a very favorable energy balance and a very positive greenhouse gas balance.

With both of these national policy questions answered, the next set of questions should focus on technology options for making fuel ethanol or other energy products from biomass. Before exploring several of these technology options below, this article first considers some implications of making products from wood feedstocks.

BASIC CONSIDERATIONS

The pulp and paper industry buys wood by the ton, roughly 42% which is oxygen. If we are selling fuels or chemicals, we need to carefully consider process yields and how much of this oxygen is contained in the final product. Ethanol can only be made from the carbohydrate portion of wood, so the lignin and extractives cannot produce the main product. Also, the maximum theoretical yield of ethanol from six-carbon sugar, such as glucose in cellulose, is 67%, while the actual yield may be closer to 60%.

The overall process becomes even more challenging if hardwood feedstocks are used. The fermentation of five-carbon sugars from these feedstocks, such as xylose, is not a commercially proven process, although great strides are being made in that direction.

Fermentation and distillation of ethanol requires process heat, which can be generated with the non-fermentable lignin and extractives, and sugar-deficient biomass feedstocks. A 50% yield of ethanol from raw biomass would be more or less in the same ballpark as yields from many chemical pulping

processes, but would be much lower than processes that produce transportation fuels from crude oil.

Finally, and a very important consideration, process yield is only one aspect of an economical process. The yield of ethanol from wood may be modest relative to the yield of ethanol from corn grain, but wood is a much less expensive feedstock than corn grain, and the residual wood components can be used for relatively high quality process heat. Thus, ethanol from wood may actually be a more commercially attractive process than ethanol from corn.

FOUR BIOREFINERY SCENARIOS

A forest biorefinery offers many options for producing ethanol from woody biomass, although three scenarios have attracted most attention. The first scenario is known as “value prior to pulping.” The second scenario involves total hydrolysis of the biomass to sugars. The third scenario is gasification and the production of a variety of potential fuel products. Yet a fourth scenario, production of pyrolysis oils with subsequent conversion to fuels, is also discussed below.

Scenario 1. Value prior to pulping involves extracting some of the hemicellulose sugars from wood to produce ethanol, and then sending the extracted wood chips on to the digester. This scenario has several very attractive features including the continued production and sale of pulp and paper products, potential improvements in the pulping and bleaching process itself, and production of a value-added product—ethanol—from sugars that would have otherwise gone into the recovery boiler.

Commercial feasibility of this scenario still needs to be verified with trials demonstrating that high quality pulp can actually be produced from the extracted wood chips, and that the complex mixture of wood sugars, including xylose-rich streams, can be successfully fermented to produce ethanol. Ongoing work in this regard is showing significant promise.

Scenario 2. The second scenario is the total hydrolysis of wood to produce a high quality sugar feedstock that can then be fermented to produce ethanol. This scenario is similar to the approach being taken by the DOE Office of the Biomass Program for the total conversion of corn stover to ethanol.

In this scenario, biomass feedstock is converted to sugars, which can then be fermented, while the lignin is used for process heat. The pulp and paper industry offers several advantages for deployment of this technology. This process could be integrated into a pulp mill with excess batch digesters where the hydrolysis would take place. Pulp mills typically have an existing feed collection infrastructure, a boiler, and wastewater treatment facilities, which would save 15-20% (or more) of the capital needed for a greenfield ethanol production plant.



This scenario would not necessarily require modification to the current pulping process, and could be used to produce ethanol from relatively low quality, inexpensive biomass residues. The major challenge for this scenario is the need to develop enzymatic or chemical processes that can convert cellulose and hemicelluloses to fermentable sugars in very high yield, and depending on the wood feedstock the need to develop technology for fermentation of five-carbon sugars.

Scenario 3. Gasification is an alternative approach to extracting sugars as a feedstock for ethanol production. This technology involves the production of synthesis gas (carbon monoxide and hydrogen) that can be used for both high efficiency power production and production of liquid fuels. One of the most attractive aspects of gasification for the forest biorefinery is that syngas can be made from almost any feedstock, regardless of composition, e.g., wood, limbs, bark, salvage materials or spent pulping liquors. A gasifier could be integrated with the heat and power demands of a mill.

Gasification of spent pulping liquors is currently being demonstrated at three pulp mills in North America—Weyerhaeuser at New Bern, N.C., Georgia-Pacific at Big Island, Va., and Norampac at Ontrario, Canada. The technology is also being developed and demonstrated by a consortium of companies in Pitea, Sweden.

The gasification systems being demonstrated differ in their process details, but all of them face a significant challenge in the area of cost effective, high quality refractory materials that can withstand high temperature, corrosive environments. But progress is being made to find and implement improved refractory materials and boost on-stream time.

If spent kraft pulping liquors are used as a gasification

feedstock, recovery of the pulping chemicals must still be demonstrated. Syngas can also be produced directly from biomass without the same demands on refractory materials imposed by black liquor gasification. In all cases, the syngas has to be cleaned up to remove sulfur, nitrogen, and organic tars.

But clean syngas can be used to produce a variety of fuel products. Some very large-scale commercial processes can be used to convert it to a crude hydrocarbon mixture, also known as Fischer-Tropish Liquids (FTL), methanol, ammonia, or through a series of intermediate products to acetic anhydride. Demonstration projects have also shown that syngas can be used to produce ethanol via fermentation or mixed alcohols via chemical catalysis.

If FTL is the desired product, none of the oxygen is retained in the final hydrocarbon mixture. Oxygen in the biomass is lost as water or carbon dioxide, lowering final product yield. Methanol is currently made from syngas, but the majority of methanol is produced from natural gas derived syngas at very large scales, making competition from biomass difficult. Methanol or its derivatives, such as dimethyl ether (DME), are not currently accepted as transportation fuels in North America. Production of fuel ethanol from syngas, either by fermentation or chemical catalysis, has been demonstrated at the pilot scale, but is not yet a commercial technology.

Scenario 4. Fast pyrolysis also could be used to produce fuels from wood. In this scenario, wood biomass is converted to liquid pyrolysis oil using a fast pyrolysis process to maximize yield. Pyrolysis oil can then be used directly as a fuel or as a petroleum refinery feed.

In the petroleum refinery, pyrolysis oil is viewed as a unique form of crude oil that can be used with or without pretreatment, and then converted into a final product using fluid-bed catalyst or hydrocracking technology existing in most refineries. In this model, the pyrolysis oil conversion plant could be associated with a pulp and paper mill, operated as a stand-alone facility. The yield of pyrolysis oil is related to lignin contents of the wood feedstock, so bark rich feeds would be most attractive.

All forest biorefinery options have technology challenges that must be overcome. However, many of these challenges are currently being addressed in a variety of projects, many which leverage significant investments from state and federal government, and other industries. Government policies, such as the recently enacted Energy Policy Act of 2005, with its \$1.27 credit for ethanol from cellulose feedstocks, can also encourage the development and deployment of forest biorefineries. ■

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