The biorefinery in New York: woody biomass into commercial ethanol

By T. E. Amidon

Abstract: This paper reports the application of ESF Biorefinery concepts and current technology to New York State industry. This is a planned application linking at least three industrial companies to reduce the time to practice. A wood-based biorefinery is being erected in New York. Identifying the strengths of the participating companies and required competencies of the wood-based biorefinery is the first step in making the biorefinery a reality. Some components will have additional details added to explain the opportunity envisioned. Potential utility of water based hemicellulolose extraction applications to both the paper industry and the wood fuel industry are discussed.

BIOREFINERY IN NEW YORK

We are embarking on enhancing the speed to application of a new technology by erecting a virtual enterprise from multiple companies with much to gain in their core businesses from the parts of the novel technology that look easy to them. New York is leading nationally by establishing the first wood-based biorefinery with multiple companies operating in the state.

The biorefinery is past the stage of attracting attention in New York and is a concept to be implemented. With the enthusiasm of the participating companies and encouragement from the state and federal governments, the biorefinery envisioned at SUNY ESF is moving towards reality. The first wood-based biorefinery will utilize wood as the main raw material. The main products involving pulp mill applications are cellulose for fiber/pulp/paper; hemicelluloses / extractives for ethanol and chemicals, and lignin for energy. In green electric power applications, the main products are hemicelluloses and extractives for ethanol and chemicals and the rest cellulose and lignin for electricity (energy).

Central New York is strategically located for the first wood-based biorefinery. As the bulk of the industrial activities and a large fraction of portable fuel use in the United States is concentrated in the east, production of liquid bio-fuel ethanol in New York has a distinct advantage and strategic importance to the national economy. Based on the regional statistics provided by DOE [4], the Northeast alone accounts for about 17% of the total US transportation fuel consumption and 80% of total US fuel oil consumption for heating buildings. Securing the woody raw materials locally also ensures that the energy consumption for the raw material transportation is minimized. Producing ethanol in New York reduces the transportation distances to fuel distribution centers in the Northeast USA. Therefore, New York is ideally suited for the first wood-based biorefinery.

WOOD, A PREFERRED RAW MATERIAL SOURCE OF BIOREFINERY

Ligno-cellulosic biomass is the most abundant organic chemical on earth, with an annual produc-
tation in the biosphere of about 170 billion metric tons [1]. Forests account for 42.9% of the annual carbon production and Savanna and grasses account for 11% of total biomass production. When measured in energy terms, the amount of carbon synthesized by plants is equivalent to about ten times the world’s total energy available of 323 EJ [1]. Dedicated energy crops: agricultural forest and/or agriculture biomass can further increase the biomass availability.

Renewable forest material is carbon neutral, i.e., utilizing forest material will not create a carbon imbalance over an extended (5 ~ 50 years [5]) time frame. Utilizing renewable carbon (as illustrated in the Figure 1) eliminates an additional carbon dioxide burden to the environment and thus acts favorably to reduce CO₂ emissions and, therefore, to GHG driven global climate change. Therefore, managed forests have significant potential to reduce greenhouse gas emissions by conversion of the forest material into liquid fuels, electricity and other products. There is growing awareness to utilize otherwise non-renewable carbon. While agriculture crops and perennial grasses are annually renewable and thus more efficient in carbon turnover (by a factor of 5 ~ 50 than wood), they are seasonal in nature. Wood resource availability is little affected by seasons and thus is a preferred resource for continuous industrial operations.

Using the forest as the resource for an industrial base is not new.

"... forests can be made to produce fifty times their present volume of end products and still remain a permanently self-renewing source for raw materials..."

Only forests - no other raw material resource can yield such returns. The forest can, and so must, end the chronic scarcity of material goods that have harassed man’s experience since the beginning of history.” From The Coming Age of Wood, by Egon Glesinger, 1949 [6].

Putting Egon Glesinger’s vision into action is still a work in progress and this paper presents another developmental step.

Developing a biorefinery technology based on wood is imperative to the development of a bio-based energy economy, whether the final intent is the use of forest biomass, woody biomass crops, perennial grasses, or agricultural residues. These feedstocks should enjoy “life cycle” energy benefits compared to alternative biomass resources such as dedicated agricultural crops and offer continuity over agricultural residues.

1) Development of fast-growing woody species that can be used year-round as the biorefinery feedstock. These feedstocks must be self-sustaining and ready for pretreatment and separation scenarios for woody biomass that provide at least three major process streams for the biorefinery: cellulose, hemicelluloses and lignin.

2) Efficient pretreatment and separation scenarios for woody biomass that provide at least three major process streams for the biorefinery: cellulose, hemicelluloses and lignin.

3) Creation of a value-added portfolio of fuels, chemicals, and materials from each of the three biorefinery process streams that mimic the diverse product slate characteristic of today’s petroleum refineries. Although cellulose fiber is profitably exploited by the paper industry, the hemicelluloses and lignin components of wood are generally underutilized.

At SUNY ESF, we have been actively engaged in developing the competencies and filling the gaps between the commercial biorefinery and technology requirements. The learning has currently been taken to bench and pilot scale and we are planning the industrial scale applications that this paper presents. The current progress proposed for application is a result of work from more than 12 faculty members in four different faculties/ departments at ESF. The research support has been provided by the Empire State Paper Research Institute (ESPRI) and the financial support for some of the pilot plant work has been provided by the VPP (Value Prior to Pulp) consortium of eight companies from the AF&PA.

**MATCHING CHALLENGES WITH EXPERTISE**

Success of the biorefinery will rely on the competencies of participating companies and individuals to match the operational requirements of a forest based biorefinery. Since the inception of the hot-water based wood biorefinery concept at SUNY ESF, we have been working towards the reality of such a biorefinery process application. The challenges and competencies are matched to companies or industry sectors that can easily adapt to the process requirements, if they are not already possessed, to ensure a high probability of success:

1) The competencies in wood growing, procurement, chipping / pretreatment, chemical processing are found in the Pulp and Paper Industry;
2) The competencies of willow biomass growing, harvesting and burning are found among Farmers and in the Wood Fuel Industry;
3) The competencies of fermentation of sugars to products and marketing are found in the Ethanol Industry.

These matches between needs and competencies are found in New York:

1) Conventional Wood Processing for Pulp and Paper in Ticonderoga, New York;
2) Biomass Willow growing and burning - New York Field Trials in Tully, New York and Lyon Falls, New York;
3) Fermentation of sugars to products and marketing in Fulton, New York at the Northeast Biofuels facility.

The match of expertise from each participating company reflects the major objectives of the first wood-based biorefinery: cellulose for fiber/pulp/paper, hemicelluloses / extractives for ethanol and chemicals, and lignin for energy [10]. In the green electrical power case the cellulose and lignin are both used for energy. Locating the companies / facilities that match the required competencies of a wood biorefinery completes the first step toward erecting the first wood-based biorefinery in New York.
PLAN OF ACTION
With the required competencies identified, the companies are coordinated to erect the first wood-based biorefinery in New York. The reality of the SUNY ESF style biorefinery is well under its way of implementation. The following actions are scheduled for immediate implementation in 2006:

1. Extraction and separation of wood sugars at ESF Pilot, Syracuse, New York;
2. Burning of extracted wood at Lyonsdale, New York;
3. Ethanol from wood sugars at ESF Pilot, Syracuse, New York;

And in the coming two years, implementing

5. Extraction and separation of wood sugars at Ticonderoga, New York;
6. Burning of extracted wood at Lyonsdale, New York;

And in the third year

8. Commercial scale extraction and separation of wood sugars at Ticonderoga, New York and shipping to Fulton, New York;
9. Commercial extraction and burning at Lyonsdale, New York and shipping wood sugars to Fulton, New York;

The plan has been set in motion by all the participating partners who see economic benefit in their business models. This development will be a success as long as each company continues to see the importance in their profitability. While there is a penalty of added cost due to the transportation of sugars from the extraction sites to the ethanol production site, the unique “three sites” approach is chosen for a speedy implementation of the first wood-based biorefinery. The risks are shared among the participants and the competencies are matched to minimize the risk at each site. The experience learned from the “three sites” can be adapted to improve the overall “structure” and each site is prepared to implement an “independent” wood-based biorefinery.

WHY BIOREFINERY NOW
Table 1 shows the national targets set by NRC for the bio-based products in the United States of America. While most liquid fuels and chemicals are currently not bio-based, a dramatic increase is being pursued. To meet the national targets, we must begin acting today to secure the success of the bio-based industry.

To lessen the nation’s dependence on petroleum, bio- or plant-based chemical and fuel industries must be quickly begun so that the evolution of an integrated bio-based industry can be accomplished while it is still possible without resorting to crisis driven actions. This urgent need to begin has been the main driver for the speedy implementation of the ESF wood-based biorefinery.

WHY - PAPER INDUSTRY
The involvement of the paper industry in the biorefinery is not only for national energy security strategic reasons, but for the success and survival of the industry as well. Traditionally, the paper industry utilizes cellulose for paper and lignin for energy. Despite the combination of paper and energy, the paper industry has had low profitability for over 15 years. The paper industry must look to other initiatives to change the overall profitability and enhance their ability to survive.

The Kraft process is the most widely used chemical pulping technology utilizing wood. Up to 20% of wood weight, in the form of hemicelluloses, is removed from the fibers during Kraft cooking. The degraded hemicelluloses, in the black liquor, have a heating value of 13.6 MJ / kg which is about half that of lignin at 25 MJ / kg [11]. Therefore, a potentially higher value use of hemicelluloses would be to extract them as monomers or oligomers prior to pulping, followed by conversion to higher value-added products such as ethanol, polymers and chemicals.

By inserting a new process in front of the digesters to extract hemicelluloses, which can then be converted to ethanol, PHA’s, and other bioproducts, and recovering acetic acid, one can enhance the overall energy efficiency of the Kraft process. The estimated profit increase for a complete paper industry application is $3.3 Billion per year [12]. Total production was estimated at 1.9 Billion gallons of ethanol and 600 Million gallons of acetic acid can be produced for an industry-wide application [12].

WHY - WOOD BURNING INDUSTRY
The wood burning industry has marginal economics and only the lowest cost and quality wood is affordable. Evolutionary change is possible in the wood burning industry using the SUNY ESF biorefinery concept. Wood costs presently range from approximately $40 to $80 per dry ton, or $0.02 - $0.04 / dry pound. Extraction can be achieved at 15% of mass recovered with two thirds as wood sugars and the remaining one third as acetic acid/extractionives. Presently, sugars can be priced at a minimum of $0.07 / pound and acetic acid / extractives at $0.30 / pound, which renders $0.07 × 2 + $0.30 × 3 = $0.146 per pound for the mass recovered. The extraction produces value for the 300 pounds recovered from one ton of wood at $43.80 which equates to half to all of the wood cost. Therefore, the residue can then be burned with cost reduction that is likely to be greater than the mass lost.

WHY - WOOD SUGAR ETHANOL PRODUCTION IN FULTON NEW YORK
While corn has been the current choice for ethanol in the U.S.A., there is limited supply in New York. The limited production of corn in New York is largely dedicated to dairy use. Most commodity corn is shipped from the American Mid-West. Therefore, local corn is limited as raw material for ethanol in New York and much of the corn to be used has a significant transportation cost to be absorbed.

Corn market price fluctuations are a serious business risk for corn based ethanol in New York, particularly with the incremental transportation cost needed. Sugar source diversification has beneficial short term and long term impact on the business model. Wood sugars that are produced from locally grown woody feed stocks are projected to be lower in cost. The Forestry originated sugars are free-from seasonal effects and can provide buffering for cyclic annual growth events in agriculturally derived sugars. Near Fulton, there are abundant low cost hardwood forests in the adjacent Tug Hill Plateau and excellent biomass willow growing potential on the Lake Ontario Plains. Therefore, wood derived sugars are natural complement for corn derived sugars for ethanol production at Fulton, New York.

PLAYERS
Since the concept of a biorefinery was formed at the Empire State Paper Research Institute and the Faculty of Paper Science and Engineering, SUNY ESF, we have been searching for competent and willing partners to make the biorefinery a reality. Agreements have been put in place by the participants to work closely together to ensure the success of the first wood-based biorefinery in New York. Here are the partners in the SUNY ESF biorefinery:

1) International Paper in Ticonderoga, New York;

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<td>25%</td>
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<td>Materials</td>
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Based on NRC Report - 2000
biorefining

2) Catalyst Renewables, Lyonsdale Biomass in Lyons Falls, New York;
3) Northeast Biofuels in Fulton, New York;
4) SUNY College of Environmental Science and Forestry, SUNY Center for Sustainable and Renewable Energy, Syracuse Center of Excellence in Environmental and Energy Systems;
5) Case-New Holland USA, a critical industrial partner in Biomass Willow harvesting equipment development.

Each partner has one or more defined competencies for the operations of a wood-based biorefinery. With all the required competencies identifiable among the participants, the biorefinery is set to become a reality.

SUNY ESF BIOREFINERY

Salient features of, and technologies required to make the SUNY ESF Biorefinery a success are summarized as following:
1) Use conventional wood chips and preserve structure in process;
2) Low cost woody biomass fractionation;
3) Environmentally preferable system that preserves current uses of residual wood chips;
4) Water is used as the solvent;
5) Easy to clean up sugar extract;
6) Easy separation of valuable co-products;
7) Pentose fermentation commercialization needed;
8) Use membrane and filtration as the main separation technology.

The unique aspect of the ESF biorefinery is the use of water as solvent in extracting hemicelluloses and extractives. Compared with other chemicals, water is not toxic, yet abundant and relatively easy to clean up. Additional chemicals are not required for the subsequent purification of the wood extract components. Equally important is the use of membrane as the main separation / purification technology. As a result, this technology helps to ensure low energy consumption and high product value.

CONCLUSIONS

ESF biorefinery is taking shape in New York. The first wood-based biorefinery will be a collaborative effort of a few companies from different industries. The paper industry, ethanol industry, and wood-fuel industry are crucial participants.

In conclusion: 1) Wood holds great promise as the “Biorefinery” feedstock of choice; 2) Cellulose, Hemicelluloses, and Lignin will all enjoy broad utilization; 3) Advances in separation systems, biotechnology, biomass gasification, silviculture, and agro-forestry will establish the 21st century and beyond as the “Age of Wood”; 4) Future Paper Industry - Cellulose for Paper and Lignin for Energy with Hemicelluloses and extractable such as acetic acid, turpentine, fatty acids etc. for New Materials; 5) Wood burning industry - Lignin as Fuel and all other components for New Materials; 6) Purpose-built Biorefinery - All components available for New Materials.

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REFERENCES


Résumé: La présente communication porte sur l’application des concepts du bioraffinage ESF et de la technologie actuelle à l’industrie de l’État de New York. L’application prévue relie au moins trois entreprises industrielles afin de réduire le temps de pratique. Déterminer les forces des entreprises participantes et les compétences requises pour le bioraffinage du bois représente la première étape qui fera du bioraffinage une réalité. L’utilité possible des applications d’extraction d’hémicellulose à base aqueuse tant à l’industrie du papier qu’à l’industrie du bois combustible fait l’objet de discussion.


Keywords: BIOTECHNOLOGY, BIOMASS, ETHANOL, NEW YORK, HEMICELLULOSE,