The Pathway to Our **Bio-Future**

With no end in sight to growing global pressure on the world's supply of oil, other types of technologies and fuels will play an essential role in easing the energy cost burden in the production of pulp and paper.

By Eric J. Connor

The reliability, affordability and environmental impact of energy supplies have become the most critical issue for the world economy. While most of the initial response has been investment in producing ethanol from corn, there is common consensus that there is simply not enough corn to meet renewable energy needs. Given that consensus, as we look forward, the conversion of cellulosic biomass to fuels will be required.

The U.S. Energy Policy Act of 2005 set an objective of generating 1 billion gallons per year of transportation grade biofuels from lignocellulosic sources by 2015. A primary source of cellulosic feedstocks is the pulp and paper industry —the world's largest non-food biomass collection system. Recently, the U.S. paper and forest products industry made a commitment to increase the development of biomass fuels, with the long-term goal of developing a network of integrated "forest products biorefineries."

Forest products biorefineries represent an emerging opportunity that will have a dramatic impact on future U.S. energy supplies and on the forest products industry itself. Baltimore, Maryland-based ThermoChem Recovery International (TRI) estimates that by using existing technology and moving the industry to forest products biorefineries, the U.S. pulp and paper industry could produce nearly half of the transportation fuels amount targeted by the DOE, resulting in a new high-value revenue stream for the industry while reducing dramatically its dependence on fossil fuels.

- Pulp and paper mills are ideal sites for biorefineries for the following reasons:
- Efficient growers, harvesters, transporters and processors of biomass.
- Usually located near substantial sources of biomass.
- Familiarity with producing power from biomass: currently mills produce 60% of their power from wood residuals and spent liquors.
- Employ highly trained workforce capable of operating energy and biorefinery systems.
- Highly efficient integration, matching mill thermal needs with biorefinery waste heat and energy

Future mills, *Integrated Forest Biorefineries*, will import regional biomass instead of purchased energy. They will expand the industry's mission from simply manufacturing low margin paper products to creating new revenue streams by producing "green" power and creating new, high-value products such as biofuels and biochemicals, all while improving the efficiency and profitability of their core paper-making operations.

Gasification Technology

By deploying biomass gasifiers, the pulp and paper industry will be able to process not only the spent liquor, but also any other biomass on-site and any biomass that can be economically transported to a mill, such as forest and agricultural residuals, for gasification. This gasification system will produce a synthesis gas (syngas) for the replacement of fossil fuels, the production of biofuels and biochemicals, and the generation of green electricity, process steam and heat for pulp and paper production.

Steam Reforming of Spent Liquor and Biomass

There are a number of gasification technologies available. For purposes in this article, we will employ the method of gasification used by TRI, which is based on the company's proprietary indirectly-heated steam reforming.

Superheated steam reacts endothermically (consumes heat) with the carbonaceous components of the biomass to produce hydrogen and carbon monoxide fuel gases (synthesis gas or syngas):

$$H_2O + C + \text{Heat} \rightarrow H_2 + CO \text{ (steam reforming reaction)}$$

Water-gas shift reactions also occur simultaneously with the steam reforming reactions to yield additional hydrogen and carbon dioxide:

$$H_2O + CO \rightarrow H_2 + CO_2 \text{ (water-gas shift reaction)}$$

A Phased Approach to Implementation of the Integrated Forest Biorefinery

The following is one proposed path for converting an existing pulp and paper mill to a fully integrated biorefinery—carbon neutral and energy independent—producing a number of value-added products as well as traditional paper products. Process engineering and mass and energy balances developed by TRI, in concert with a key client and engineering consultants, form the basis for this model.

The Current Mill

Figure 1 is a simple block flow diagram of a pulp and paper mill. For illustrative purposes we have established an energy and mass balance for a typical integrated paper mill. It is an average mill producing 1,000 TPD of finished product. This mill uses as its fiber feedstock wood chips that are produced at wood products mills and off site chip mills. It uses steam, electricity, and chemicals to convert the wood chips to cellulose and the cellulose to paper products. This mill provides for a portion of energy requirements by burning spent liquor and woody residual biomass, but it also imports both natural gas and electricity. The natural gas is burned in a boiler to produce additional process steam and in a lime kiln as part of its chemical recovery process.

A Biomass to Syngas to Gas-to-Liquids Plant Integrated into the Mill

The first phase of biorefinery implementation includes the installation of a biomass to syngas to gas-to-liquids plant at the paper mill, which is represented by the blue boxes in Figure 2. The feedstock for this biorefinery is biomass including both forest and agricultural residuals.

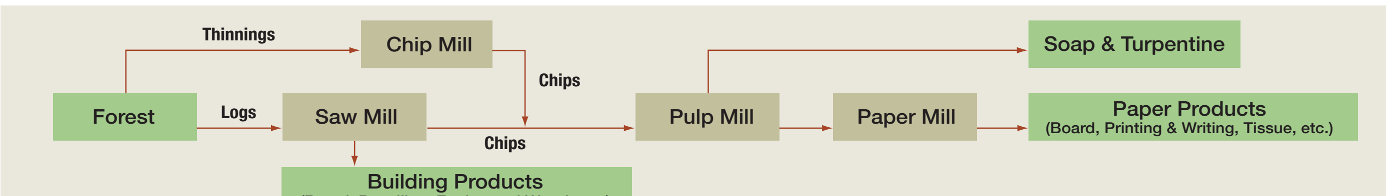

Figure 1.

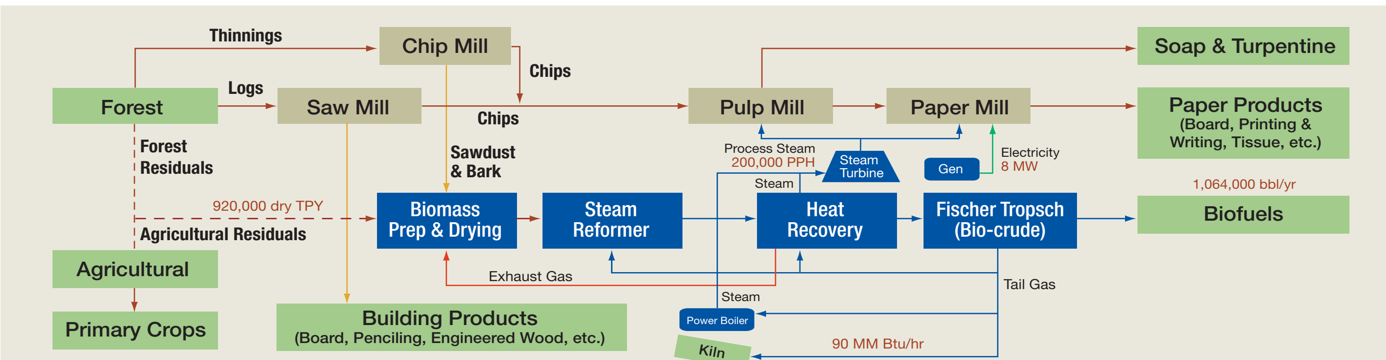

Figure 2.

The biomass is dried and sized prior to gasification. The biomass is fed into the fluidized bed steam reformer through a screw feed system and is gasified to produce synthesis gas with the correct hydrogen to carbon ratio required for the gas to liquids plant. The synthesis gas then goes through a conventional heat recovery and gas clean-up train prior to the gas-to-liquids plant.

The gas-to-liquids plant technology we have chosen for this biorefinery is the Fischer-Tropsch (FT) process—a very mature and known technology. The syngas is compressed and fed into the FT process, which is a catalytic process using a slurry bed reactor. In the reactor, the hydrogen and the carbon monoxide in the synthesis gas comes into contact—under pressure and temperature—with the catalyst to form straight chain hydrocarbon molecules that range from very light gases to heavy waxes. The hydrocarbons are removed from the reactor vessel, distilled to fractions that include gasoline, naphtha, diesel, and waxes, and stored prior to shipment to a refinery for further processing, distribution and sale.

The biorefinery is exothermic, meaning it gives off energy as it makes the FT hydrocarbon liquids. The exothermic heat from the FT process has to be removed, resulting in the manufacture of process steam and hot water that can be used by the paper mill replacing steam and hot water made through the burning of natural gas.

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The FT gas-to-liquids process also releases a tail gas that is made up of unreacted synthesis gas and light, non-condensable hydrocarbon gases. In a conventional FT plant this tail gas is recycled or flared. When integrated into the paper mill, this tail gas is used to replace natural gas and other fuels used to make paper.

This paper mill uses 200,000 pph of steam produced from natural gas and burns natural gas in its lime kiln to calcine lime. TRI sized the exothermic heat and energy from the biorefinery to match the heat and energy sink provided by the paper mill. In other words, the waste energy from the biorefinery is enough to produce 200,000 pph of steam and replace 90 MMBtu per hour of natural gas with tail gas in the lime kiln.

The input to this phase one biorefinery is about 900,000 dry tons per year of biomass. The plant's outputs are the 200,000 pph of steam used for papermaking and 90 MMBtu per hour of tail gas for the lime kiln.

The biorefinery also produces about 1,064,000 barrels per year of FT straight chain hydrocarbon liquids that can be taken by any petroleum refinery for the manufacture of petroleum liquids. To put quantities into perspective, 1,064,000 barrels per year of FT liquids equals 44,688,000 gallons per year. The Btu value of FT liquids is about135,000 Btu's per gallon compared to 76,000 Btu's per gallon for ethanol. So the ethanol equivalent production of the biorefinery is 79,380,000 gallons per year. This biorefinery is power self sufficient and exports 8 MW of electricity to the mill.

The process can make a barrel of FT liquids for under $25.

Thermal Efficiency

The historic petroleum industry paradigm regarding the manufacture of FT liquids is the minimum size plant that can be cost-effectively built and operated to produce about 20,000 barrels per day. The petroleum industry design includes a number of reactors in series to maximize the amount of FT liquids made and minimize the amount of tail gas, which is flared as wasted energy.

When TRI integrates the FT process, or other exothermic catalytic process, to the pulp and paper mill the FT process does not need to have high conversion efficiency because the paper mill will use the exothermic heat and the tail gas provided by the gas-to-liquids process to offset fossil and other fuels needed by the paper mill to make paper.

For example, for every 100 Btus of biomass fed to the biorefinery, 44 Btus of FT liquids are produced. In turn, 28 Btus of exothermic heat and tail gas from the gas-to-liquids plant are used by the paper mill. So, very high thermal efficiencies are possible—as high as 71%, including all parasitic loads in the biorefinery. This synergistic integration of a paper mill, a biomass to syngas process, and a gas-to-liquids plant producing carbon neutral transportation fuels, is TRI's paradigm of the future. The economics of this paradigm are compelling.

Replacing the Thomlinson Recovery Boiler With Spent Liquor Gasification

The second implementation phase of the integrated forest biorefinery at this mill eliminates the chemical recovery boiler, which burns black liquor from the pulp mill to produce steam and electricity and recover the cooking chemicals for re-use.

In Phase Two, the biorefinery is increased in size to process the organics in the black liquor to syngas and to recover the cooking chemicals for reuse by the pulp mill. The syngas from the black liquor is cleaned-up and fed to the gas-to-liquids plant to produce more transportation fuels.

With the chemical recovery boiler gone, the steam it was generating for the paper mill is gone as well, increasing the process steam need by the paper mill from the biorefinery to 700,000 pph. To match this heat sink, about 850,000 dry tons per year of forest and agricultural residual biomass is fed to the biorefinery, which now produces 1.5 million barrels per year of carbon neutral transportation fuels. This is 112 million gallons per year on an ethanol equivalent basis.

With the installation of Phase Two of the biorefinery, the mill is fossil fuel and purchase electricity independent. It is a carbon neutral manufacturing site producing paper products and transportation fuels.

Adding a Combined Cycle Generating Plant to Export Electricity

As discussed earlier, TRI's foundation for the design capacity of the biorefinery is based on matching the paper mill heat and energy sink to the waste heat and energy provided by the biorefinery.

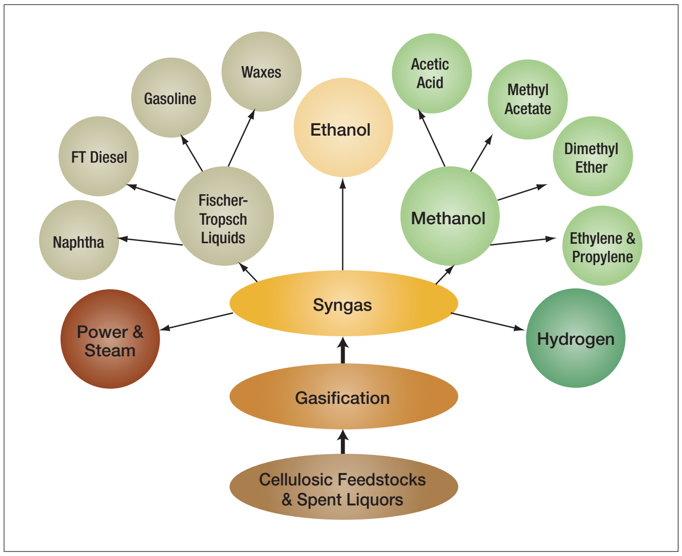
Following the elimination of the chemical recovery boiler, the only way to increase the output of the biorefinery economically is to increase the size of the paper mill heat and energy sink. In Phase Three, TRI accomplished this by adding a combined cycle gas turbine, HRSG, and steam turbine with tail gas as its fuel. The mill would be producing pulp and paper products as well as renewable transportation fuels and exporting "green" electricity to the grid.

The Build-Own-Operate Biorefinery at a Pulp and Paper Mill

TRI believes there is a significant opportunity now for investors to build, own, and operate biorefineries at existing pulp and paper sites in North America and Europe that will work synergistically and economically for the pulp and paper mill owner and the biorefinery owner.

The pulp and paper industry is the world's largest non-food biomass collection system. In North America there are approximately 200 chemical pulp mills and high-yield pulp mills that could economically host Phase One biorefineries of the size described in this article. There are also another 100 large, nonintegrated paper mills with heat and energy sinks large enough to support a biorefinery.

Internationally, TRI conservatively estimates that there are over 450 pulp and paper mills and another 400-500 nonintegrated paper mills that are sound potential sites for biorefineries. In Europe, there is high demand for distributed "green" energy where incentive structures for carbon neutral fuels and electricity have been established.



In North America, forest and agricultural residual-based feedstocks constitute a huge and readily available biomass source for the biorefinery, and the pulp and paper industry is the most qualified industry to take advantage of it. The North American pulp and paper industry has the ideal infrastructure, experience and resources to capitalize on renewable fuels via the biorefinery.

Biorefineries – Our Bio-Future

Industry leaders, investors, policy-makers and others are now beginning to better understand the vital role to be played by biorefineries as we move from a fossil fuel-based energy economy toward a bio-based model. There are, of course, many different biomass conversion technologies and an even wider range of raw materials and finished products to consider. For these reasons, all potential advantages must be factored into the location, design, efficiency and operational flexibility of any proposed biorefinery. When properly located and designed, the potential of an integrated forest biorefinery could be enormous: a very attractive and synergistic business opportunity for both the co-located pulp and paper mill and for the biorefinery itself. ■

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ThermoChem Recovery International was founded in 1996 and is headquartered in Baltimore MD. The company is commercializing proprietary technology for the integrated biomass biorefinery and chemical and energy recovery systems for the pulp and paper and related industries.