

# **A THERMOCHEMICAL BIOREFINERY (TCB) INTEGRATION STRATEGY FOR PULP AND PAPER MILLS AND THE STATUS AND RESULTS OF AN OPERATING TCB PILOT PLANT**

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## **ABSTRACT**

TRI (ThermoChem Recovery International) has been commercializing the thermochemical biorefinery platform in the Pulp and paper industry for over four years. The first part of this presentation will be to review the integration of the thermochemical biorefinery platform strategy in a pulp and paper mill and provide an update of two pulp and paper biorefineries currently in engineering design.

TRI has constructed a biomass gasification process demonstration unit (PDU) at Southern Research Institute's Carbon to Liquids Research Center located at Durham NC. The PDU is designed to process 4 dry tons per day of biomass to syngas. It includes biomass storage and feed, gasification using a proprietary indirectly heated gasification technology, and gas clean-up. The PDU is designed to be integrated to any number of downstream catalytic processes to produce fuels and chemicals. It is currently integrated to Emerging Fuels Technologies (EFT) Fischer-Tropsch process. A number of trials have been run on various biomass feedstocks. The second part of this presentation will provide a review the status of the PDU, test results to date and future test plans.

## **INTEGRATED BIOREFINERY**

The integrated thermochemical biorefinery, when hosted at a pulp and paper mill provides the opportunity to

- Increase mill revenues via the processing of biomass feedstocks to high value fuels and chemicals
- Lower operating costs through the integration of the biorefinery with the mill for maximum thermal efficiency
- Significantly reduce the carbon footprint of the mill site
- Utilize a phased approach to take advantage of both solid biomass and black liquor.

The thermochemical biorefinery can be feedstock flexible, provides finished product optionality and can be integrated into the host in a number of configurations. The platform also takes advantages of all of the strengths built into the host pulp and site such as

- Biomass growing, harvesting, transporting expertise
- Expertise in processing biomass to finished products as well as production of steam, power and bi-products
- Infrastructure already in place

## **THERMOCHEMICAL BIOREFINERY PLATFORM FACTS**

The Thermochemical platform biorefinery utilizes technologies that have been proven for over fifty years. The basic process blocks of the biorefinery are

- Biomass preparation (storage, handling, sizing and drying)
- Biomass gasification to produce synthesis gas (syngas)
- Syngas clean-up
- Catalytic gas to liquids process and/or
- Energy production plant
- Energy recovery and integration with the mill

The Thermochemical biorefinery platform is exothermic and, therefore, integrates thermally very well with an endothermic pulp and paper host.

## FEEDSTOCK AND FINISHED PRODUCT OPTIONALITY

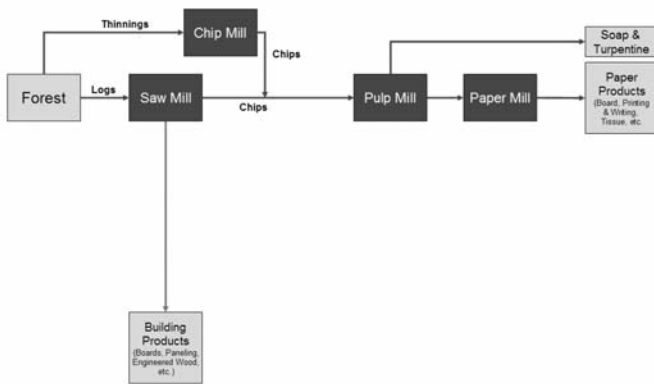
The Thermochemical biorefinery platform is ideal for use in a forest products biorefinery as it is uniquely configured for high-performance integration with pulp and paper facilities and is capable of handling a wide variety of cellulosic feedstocks, including woodchips, forest residuals, agricultural wastes and energy crops, as well as mill byproducts (spent liquor). The syngas produced through gasification of the biomass feedstocks can be used to replace fossil fuel, produce steam and electricity or used as a feedstock for a downstream process to produce renewable fuel and chemicals. Such products include Fisher Tropsch liquid fuels and waxes, methanol, ethanol, acetic acid and other biochemicals

## 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.

### THE CURRENT MILL

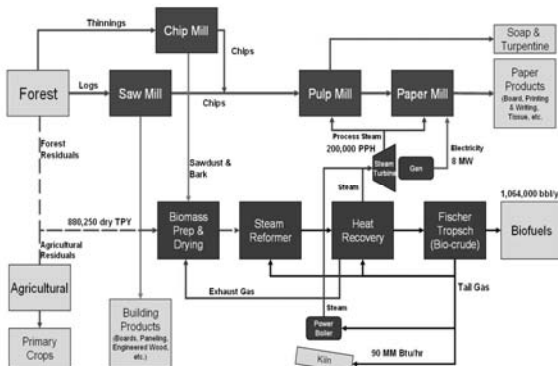
Provided below is a simple block flow diagram of a pulp and paper mill. For illustrative purposes we have established an energy and mass balance for a typical integrated paper mill. It is an average mill producing 1,000 TPD of finished product. This mill uses as its fiber feedstock wood chips that are 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.



## INTEGRATED FOREST BIOREFINERY-PHASE ONE

### *Integrated Forest Biorefinery-Phase One*

A Biomass to Syngas to Gas-to-Liquids (GTL) Plant integrated into the Pulp and Paper Mill



The implementation of Phase One provides the opportunity to;

- Leverage the existing mill infrastructure by installing a new manufacturing process in a way that minimizes risk to the pulp and paper mill,
- Take advantage of available biomass resources currently unused, and
- Increase the mill product mix by producing fuels and chemicals

The first phase of biorefinery 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 the block flow diagram shown above. The feedstock for this biorefinery is biomass including both forest and agricultural residuals.

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.

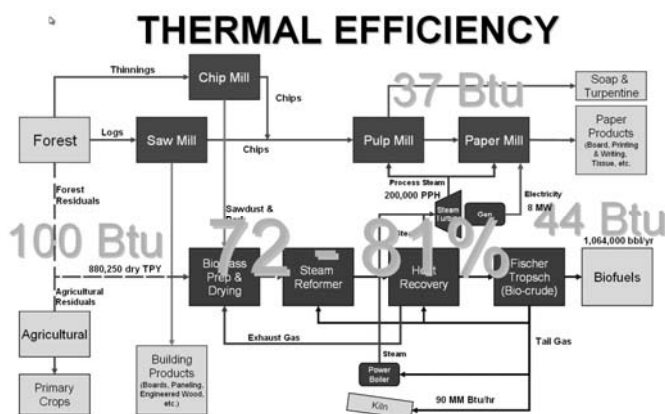
The gas-to-liquids plant technology we have chosen for this example is the Fischer-Tropsch (FT) process, a very mature and known technology that produces “drop in” hydrocarbon fuels with ready markets. The syngas is compressed and fed into the FT process, which is a catalytic process using a slurry bed 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. 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 flared or recycled at additional capital cost. 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. The exothermic heat and energy from the biorefinery was sized 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 880,000 dry tons per year of biomass. Its outputs are the 200,000 pph of steam used for paper making and 90 mm Btu per hour of tail gas for the lime kiln. The biorefinery also produces about 1,000,000 barrels per year of FT straight chain hydrocarbon liquids that can be taken by any petroleum refinery for direct blending or manufacture of refined petroleum liquids. 1,000,000 barrels per year is 42,000,000 gallons per year. The Btu value of FT liquids is 135,000 Btu’s per gallon compared to 76,000 Btu’s per gallon for ethanol. So the ethanol equivalent production of the biorefinery is 74,600,000 gallons per year.

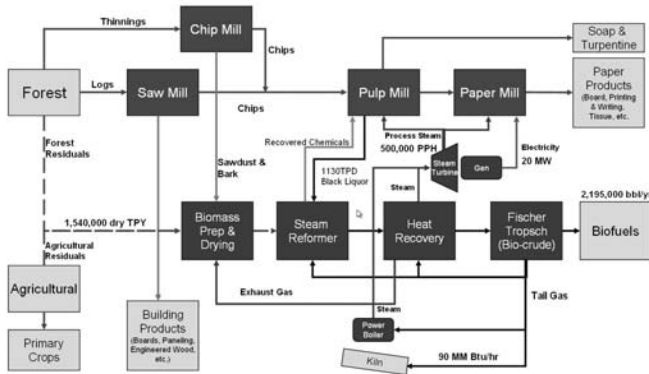
## INTEGRATED FOREST BIOREFINERY-PHASE ONE



In the example shown above for every 100 Btus of biomass fed to the biorefinery, 44 Btus of FT liquids are produced. 37 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 81%. This synergistic integration of a paper mill, a biomass to syngas process, and a gas-to-liquids plant producing carbon neutral transportation fuels is the paradigm of the future. The economics of this paradigm are compelling.

### INTEGRATED FOREST BIOREFINERY-PHASE TWO

Replacing the Tomlinson Recovery Boiler with Spent Liquor Gasification



Implementation of Phase two provides the opportunity to utilize more available biomass plus the black liquor from the pulp mill to make significantly more fuels and operate the mill. In a sense this phase makes 1 plus equal 3.

The second 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. It is an old, unsafe, inefficient technology.

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 500,000 pph. To match this heat sink about 1,500,000 dry tons per year of forest and agricultural residual biomass is fed to the biorefinery, which now produces 2,200,000 barrels per year of carbon neutral transportation fuels. This is 164,000,000 gallons per year on an ethanol equivalent basis.

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

## **THERMOCHEMICAL BIOREFINERIES IN DEVELOPMENT**

### **FLAMBEAU RIVER BIOFUELS**

This thermochemical biorefinery is being sited at Flambeau River Papers, Park Falls Wisconsin pulp and paper mill. The project has been awarded a \$30 million grant from the Department of Energy as a demonstration biorefinery.



The biorefinery will process 1000 dtpd of woody biomass to produce

- ~19 million gallons per year of FT liquids and waxes
- 5.3 MW of green electricity
- Steam and hot water exported to the paper mill, shutting down 2 natural gas boilers.

The key process blocks are biomass preparation, biomass gasification, syngas clean-up, catalytic conversion of the syngas to FT liquids, and steam and electricity generation.

The appropriation grade scope and estimate is underway and pilot plant testing using northern Wisconsin biomass has been completed.

### **NEWPAGE CORP; PROJECT INDEPENDENCE,**

The endothermic host for this thermochemical biorefinery is the NewPage Corp pulp and paper mill at Wisconsin Rapids Wisconsin. The project has been awarded a \$30 million grant from the Department of Energy as a demonstration biorefinery.



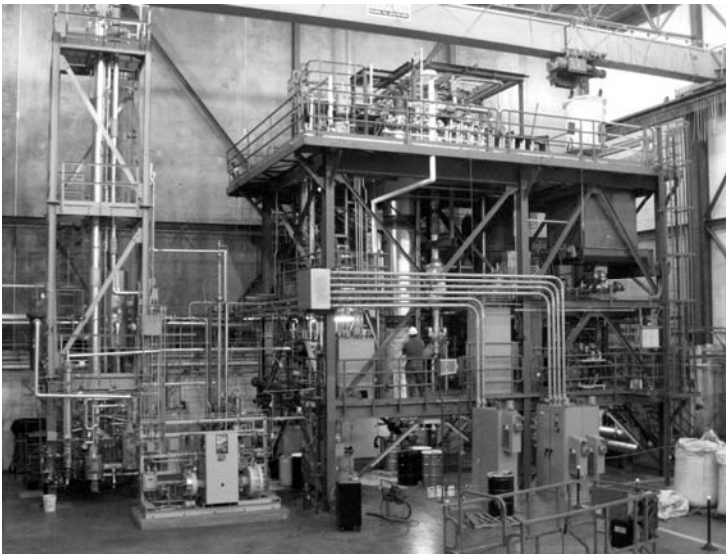
The biorefinery will process 500 dtpd of woody biomass to produce

- ~5.5-8.5 million gallons per year of FT liquids and waxes
- Up to 92 MMBtu's hour of tail gas for fossil fuel replacement in the pulp mill lime kiln
- Steam and hot water to be used by the mill to replace steam and hot water currently being produced by burning coal.
- The key process blocks are biomass preparation, biomass gasification, syngas clean-up, catalytic conversion of the syngas to FT liquids, tail gas generation for the lime kiln, and steam and hot water generation for the mill.

The appropriation scope and estimate and pilot plant testing are complete. Corporate approvals are underway.

### **THERMOCHEMICAL BIOREFINERY PROCESS DEMONSTRATION UNIT**

A biomass gasification process demonstration unit (PDU) has been constructed at Durham NC and is currently operational. The PDU is capable of processing solid biomasses and black liquor.



The process scope of the PDU includes

- Biomass feed
- Biomass gasification
- Primary gas clean-up
- Syngas compression and secondary gas clean-up
- FT liquids production

The process is capable of providing high value, clean syngas to essentially any downstream catalytic process, syngas fermentation process, of gas turbine.

## **Biomass Feed System**

The Biomass feed system is designed to handle a wide range of biomasses

- 230 cubic feet day bin with live bottom
- Weigh screw feed to first stage piston
- 3- Stage hydraulic piston system to feed biomass while preventing back flow of gasifier gases.
- Lump breaker
- High speed biomass injection auger

## **Steam reformer and carbon trim cell**

The steam reformer and carbon trim cell are a proprietary two stage gasification system capable of processing 4 tons per day on a dry basis

- Steam reformer
  - Indirectly heated steam reformer
  - Superheated steam fluidizing media
  - Engineered bed materials
- Carbon trim cell
  - Conversion of carry over char to trim the H<sub>2</sub>:CO ration
  - Fluidized with steam and oxygen

## **Syngas Clean-up**

The syngas clean-up train is sized to process a 10% slipstream of the syngas produced from the gasification system and includes the following:

- Primary gas clean-up
  - HRSG to cool the syngas to ~ 500 degrees F
  - Venturi scrubber for removal of particulate
  - Gas cooler for condensation of residual steam
  - Proprietary solvent extraction of tars
  - Scrubber for removal of any sulfur compounds
- Secondary gas clean-up
  - Syngas compressor to take the syngas from 25 psig to 440 psig required for the GTL system
  - Scrubbers to remove HCN and NH<sub>3</sub>

- Packed guard bed trace H<sub>2</sub>S and COS
- Particulate Filters

## **Fischer Tropsch Reactor**

The FT system is based on Emerging Fuels Technology fixed bed technology

- Three tube FT reactor with cobalt based catalyst
- Tube length identical to commercial scale reactor to facilitate scale-up
- Forms heavy fraction (HFTL), medium fraction (MTFL) and light fraction (LFTL)
- Exothermic heat is removed via steam generated in reactor cooling jacket

## **PDU STATUS**

The process demonstration unit has run over 4000 hours combined gasifier and biomass feed systems. It has operated over 1000 hours through gas clean-up and FT liquids production.



The process consistently produces a high quality syngas on a sustained basis for feed to the FT reactor.

The PDU produces high quality FT liquids and waxes.

Mass and energy balances created from the pilot plant runs are the basis for scaling both the Flambeau River Biofuels and NewPage biorefinery projects.

## **FUTURE SCHEDULE FOR THE PROCESS DEMONSTRATION UNIT**

- CLIENT ONE
  - Alternate woody biomass pilot trials; first quarter 1020
- CLIENT TWO
  - Sweet sorghum pilot trial; first quarter 2010

- Switch grass pilot trial; first quarter 2010
- CLIENT THREE
  - Refuse derived fuel (RDF) bench tests; first quarter 2010
  - RDF feeder test; first quarter 2010
  - RDF pilot trial; all of second quarter 2010

## **BIOREFINERIES- OUR BIO-FUTURE**

Industry leaders, such as Flambeau River Biofuels and NewPage Corp, investors, policy-makers and others now understand the vital role to be played by biorefineries as we move from a fossil fuel-based energy economy toward a bio-based one. When properly located and operated, the potential of an integrated forest biorefinery to be huge: a very attractive and synergistic business opportunity for both the co-located pulp and paper mill and for the biorefinery itself.

- Biorefineries are a key pathway to our Bio-future, displacing fossil fuels and supplying clean, renewable and carbon neutral energy.
- Biorefineries fit very well at pulp and paper mills because of their inherent ability to gather and process biomass and create energy from biomass.
- The thermochemical biorefinery provides excellent thermal integration with the host site, syngas optionality, and excellent economics.