

## Biorefinery R&D Domains

This section presents a brief description of the 12 R&D domains identified as critical to the establishment of an effective Canadian forest biorefining industry.

### 1. Product opportunity analysis

Depending on the biorefinery product made (e.g. biofuels, commodity organic green chemicals, specialty green chemicals, pharmaceuticals...), Canadian pulp and paper mills may or may not have a competitive advantage over other countries, industry sectors, and pulp and paper companies. It is critical to underline the competitive factors particular to Canadian mills and thereby maximize the biorefinery opportunity. A generic product design methodology must be defined based on a strategy of diversification, and must account for a wide perspective including for example product mix definition, strategic market analysis, opportunities associated with targeted sectors, and competitive analysis.

### 2. Forest feedstock

Forest residue recovery methods are well established in the Nordic countries, but they have been developed for cut-to-length harvesting systems (i.e., branches and tops left in the cutover). These systems require investigation to test their suitability under more heterogeneous stand and harvesting conditions found in Canada. Full-tree harvesting systems still dominate in central and western Canada, resulting in debris piles left along the road or on roadside landings. Efficient recovery methods must be developed for these ideal biomass opportunities. Energy chips or loose debris have a low-bulk density and legal loads are difficult to achieve. Comminution, compaction and new transportation methods must be developed to increase the payload of relatively low-valued forest-origin biomass. Detailed assessments of available biomass volumes and economically-viable volumes must be made for specific forest management areas. Economic assessments of mobile conversion facilities to improve the economics of transporting raw, low-value biomass vs. bio-liquids produced at remote forest locations.

### 3. Thermochemical pathways

There is no material benefit, other than possibly liquor splitting, to using a black liquor gasifier over a modern recovery boiler if the gas produced is simply going to be incinerated in a boiler. To realize any advantages of black liquor gasification for kraft mills, the gas must be used either to produce power in a gas turbine or to produce synthesis products. Other gasification strategies may prove to be more flexible and less risky. Gasification of hog fuel and forestry residuals or pyrolysis oil derived from forestry residuals. There are many gasification systems using woody biomass as feedstocks. However, all of them either burn the gas in a boiler or kiln to produce heat, or in an internal combustion engine to produce power. None are currently using the gas to produce power in a gas turbine or to produce synthesis products. The substitution of biomass fuels for fossil fuels in kraft mill lime kilns has only been accomplished at a few mills around the world. In Canada, crude tall oil (CTO) has been used to replace between 25% and 100% of the fossil fuel demand at a few mills. However, availability of CTO is a barrier to widespread adoption of this option. Pilot wood waste gasifiers have been constructed in Europe to produce gas that could be used as fuel in lime kilns. These gasifiers were technical successes and some of them are still in operation. However, the capital costs make this option unattractive economically for most companies. Pulverized, dry wood waste, sawdust and mixtures of wood wastes are also used successfully in a few mills in Europe. Other alternatives for using non-fossil fuels in the lime kiln need to be explored.

#### **4. Bioproducts from effluent and solid wastes**

Among biodegradable polymers, polyhydroxyalkanoates (PHAs) possess thermoplastic and elastomeric properties similar to traditional petrochemical plastics. PHB is one of the most common forms of PHA and is accumulated in bacteria when cell growth is restricted by a carbon rich, nutrient-limited environment. P&P mill wastewater is potentially an ideal source of PHB due to high carbon and low nitrogen and phosphorous contents. Disposal or boiler ash is costly for pulp and paper operations. It may be possible to negate this cost and even generate profit by finding productive uses for this stream. One possibility is to produce alkali for use in bleaching from the ash. A second possibility is to look at options for its use as a nutrient replenishment for either forestry or agriculture operations. Additional options could include use as a feedstock to other industries such as the cement industry.

#### **5. Products from hemicellulose**

The sugars in hemicellulose could be used to produce a range of products if the hemicellulose is extracted prior to pulping. Potential products range from fuels to artificial sweeteners, to biopolymer feedstocks. Hemicellulose can also be used as a dry bonding agent in paper, enabling ultra-high levels of mineral filler, leading to a new class of papers. Conversion of hemicellulose sugars to ethanol is a potential route. However, fermentation by means of conventional yeasts will not convert pentose sugars, a major constituent of hemicellulose. Work is needed to identify novel methods to transform the sugars present in hemicellulose into high value added products. The optimization, integration and impact of the prehydrolysis step must be studied to determine its effect on the pulping process and pulp properties. This should be done for both chemical and mechanical pulping processes.

#### **6. Products from lignin**

Lignin separation in a kraft mill, where the capacity of the recovery boiler is limiting, offers the possibility to increase production. As a first step, the separated lignin could be used to replace fossil fuel in either the lime kiln or power boiler. Successful experiments have been performed with a mixture of fuel oil and lignin, as a fuel in the lime kiln. Pelletized lignin has been used as a solid fuel. As a next step, lignin could be sold as a fuel or chemical. It is currently used in binders, dispersants, emulsifiers, and sequestrates. Most commercial lignins are water soluble lignosulphonates from sulphite pulping processes. Kraft lignins are not water soluble and are usually sulfomethylated to make them water soluble and useable for commercial applications. The ultimate objective should be to develop additional high value end uses for kraft lignins.

#### **7. Products from extractives**

It may be possible to convert both the fatty and rosin acids present in crude tall oil (CTO) into a diesel fuel via catalyzed esterification with an alcohol such as methanol. Forestry slash is potentially a large source of extractives. As part of a comprehensive program to recover and derive value from slash, extractives could be collected and diverted to diesel production facilities. High conversion efficiencies, separation of desired components, and ensuring residuals from the process are usable in the lime kiln will be essential.

#### **8. Products from condensates**

Wood lignin contains methoxy groups which release methanol under kraft pulping. The majority of the methanol ends up in the mill foul condensates. The average 1000 tpd softwood mill has about 7 to 8 tonnes of methanol per day in this stream. Methanol in hardwood mills would be slightly higher.

Possible uses for this stream include its use in ClO<sub>2</sub> generation to displace purchased methanol and the potential to produce value added products, such as formaldehyde, power, or transportation fuels.

## **9. Phyto-chemical products from bark, branches and foliage**

Softwood knots and branches have been shown to be rich sources of lignins, which are antioxidants and have a purported wide range of health benefits. They are typically sourced from seeds, such as flax or sesame, or the oils from these seeds. Work required includes characterizing the potential of mill knotters reject streams, and developing extraction and purification methods in the lab.

## **10. Integrating novel products with existing product lines**

Each new process and product must be integrated into existing pulp mills, at least in the short and medium term scenarios. Each case will be different and will require analysis to evaluate the impact of the new process or product on existing mill operations, including pulp or paper quality and production rate, steam and power use and generation capability, effluent treatment operation, corrosion resistance of existing mill components pressed into new duties, etc. Mass and energy targeting at the facility level, production flexibility analysis, as well as supply chain modeling and life cycle assessment at the product level will be critical systems analysis tools. There will also be activities in integrating new, over-the fence operations into existing mill support systems, such as steam power, fresh water and effluent treatment, and other logistical considerations.

## **11. Conversion of uncompetitive pulp mills**

For some existing pulp mills, economic conditions may prevent achieving an attractive return on investment when producing pulp for sale. In such cases, it may be more attractive to redeploy the existing assets to produce products other than pulp or paper. One possibility is the production of ethanol or other biofuels from hydrolyzed sugars. In this case the cellulose would be hydrolyzed with enzymes to produce large quantities of glucose which could be converted to biofuels. By-product streams such as lignin and unfermentable sugars would have to be processed efficiently into novel products to achieve value.

## **12. Integrating pulp mills with other industries**

It may be possible to identify high growth industries that would benefit from being partially integrated with pulp and paper operations. One example is the production of biodiesel from agriculture derived oils (canola or soy). Such a process requires significant industrial infrastructure which is already available on pulp mill sites. Kraft pulp mills may be able to utilize the glycol by-product for black liquor viscosity control. Other examples of potential symbiosis should be explored.