Technology and Economic Risks Associated with the Forest Biorefinery

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Commodity industries such as forestry are characterized by a low R&D intensity, and have transformed from process innovation research to enterprise efficiency research (e.g. achieved through optimization of the supply chain). Investments in enterprise efficiency naturally “align” to existing products, and thus commodity industries and especially those that are capital intensive can create inertia against a model of “punctuated equilibrium” (where punctual innovations result in new products which add significant value to company performance). This innovation challenge is obviously complex for industry sectors such as pulp and paper, which especially in recent years, must respond to stock market metrics in the short term.

There is little argument over whether the North American forestry industry is in crisis. The corporate strategy for many forestry companies in recent years has centered on company mergers and continuous belt tightening. Merger activity has undoubtedly been critical, however it is clear that this is not enough – a new business model is essential. Recent mill closures are permanently removing production and creating price optimism for the near-term, but this too is not a sustainable solution for the cyclical and increasingly global pulp and paper industry.

With this backdrop, the forestry industry leadership has begun to discuss the need for “transformative changes”. Options for successful transformative change are not obvious, and they require the courage necessary to take short-term action for longer-term objectives while in economic crisis.

The Forest Biorefinery

In the 27 January 2006 Science Magazine, Art Ragauskas and his colleagues at Georgia Institute of Technology stated that “in essence, the modern biorefinery parallels the petroleum refinery: an abundant raw material consisting primarily of renewable polysaccharides and lignin enters the biorefinery and, through an array of processes, is fractionated and converted into an array of products including transportation fuels, co-products, and direct energy.”

The forest biorefinery pathway possibilities are large in number, and will depend on many factors such as wood species, production levels, technology in place, and where the mill is located. Forest feedstocks such as woodwaste can be gasified into synthesis gas and transformed into chemicals. Hemicellulose can be extracted from wood chips and converted through enzymatic and chemical transformations. Methanol or DME can be produced via synthesis gas from the gasification of black liquor, and via the Fischer Tropsch Process and otherwise, other fuel products can be made such as diesel, naphtha, and LPG. Pulp and paper mill wastewater is potentially an ideal source of PHB due to high carbon and low nitrogen and phosphorus content. Each of these options implies process technology risks, for example related to limited process yields, process thermal efficiencies, materials of construction, gas cleaning requirements, etc.

On the product side, a company might employ a strategy to enter into the supply chain for biofuels, might pursue a strategy to joint venture with a specialty chemicals company and supply an existing hydrocarbon supply chain with “green product”, or might elect to produce a new fibre reinforced "green plastic" whose market has yet to be developed. Otherwise, products can be made and sold directly within the industry such as resins or dry strength agents.

Developing the forest biorefinery will require bold and fast-track research to reduce and eliminate the risks associated with the biorefinery, and enable its full-scale implementation in retrofit at old existing pulp and paper mill sites.

How can a company mitigate technical and economic risks associated with the implementation of the forest biorefinery, and convince investors that the investment will provide an attractive return? The answer to this question is not obvious, and poses a complex multidisciplinary process engineering problem. It will require that systematic product and process design methodologies be applied. The overall goal is clear: improve each facility bottom-line through a capital cost effective program that systematically considers technology risk factors, and uncontrollable risk factors such as changing energy prices, feedstock prices and currencies. This presentation surveys a strategy for achieving this objective.

Product Design Considerations

Using design criteria which are based on business principals incorporating likely prices for feedstocks and products, an important characteristic of the forest biorefinery will be process flexibility. If the forestry industry is to accept the challenge of manufacturing multiple products, it should be able to achieve targeted returns for the biorefinery under a range of volatile market and economic conditions. This will require flexible processes, so that mills can adjust how carbon is consumed to produce pulp and paper, bioenergy, green chemicals or structural material products. The concept of reduced carbon yield for pulp and paper production is contrary to the industry culture, but herein lies the hidden opportunity. At the same time, a given mill may manufacture products that are global (pulp and paper), regional (green power) and local (specialty products) - thus providing an added robustness for maintaining attractive margins.

The product opportunity analysis might consist of several steps, starting from the set of possible biorefinery products which has been well-defined by many researchers and authors relative to the biorefinery:

- SWOT and competitiveness analyses of the forest industry in a country are critical relative to a) other countries, and then b) other industry sectors. This analysis serves to remove certain products from the list since they can better be addressed by others, and
- From the remaining product list, a systematic product analysis methodology is needed to identify the most interesting products for specific companies and their mills also by a SWOT analysis, and accounting for such considerations as a) quantities that can be produced based on mass and energy balance constraints, relative to scenarios of future product demand growth and supply-demand, b) product "slates" that can be produced from platforms including design-for-flexibility considerations, c) existing supply chains pertinent to the company's mill locations, etc. The goal of this analysis is to identify that an economic hurdle rate can be met for a range of feedstock and product price ranges, reflected in a business model which would show a marked improvement over the existing business model.

Process Design Considerations

There are numerous complex issues that must be addressed at the process design stage, for example the following:

- Improvements to the existing processes must be made by mills, especially in terms of energy management, as they evolve towards the biorefinery, e.g. for certain process configurations which use lignin as the feed material to the biorefinery, mills must optimize process energy efficiency to maximize carbon availability from the mill. A further energy analysis is required to determine, for a given process pathway, how the energy systems are best integrated and optimized between the biorefinery and the existing mill.

- It is important that following the implemented biorefinery, existing pulp and paper operations continue to operate efficiently, and produce target product qualities. This requires plant-wide analysis techniques. For example, how will contaminants distribute between pulp and paper manufacturing and biorefining operations? Will there be greater or less evaporator scaling issues in pulp and paper manufacture? Will sulphur carry-over with lignin as the biorefinery feedstock and require additional processing steps, or require Na/S ratio adjustments in the pulping process?
- Conversion of hemicellulose sugars extracted from wood chips to ethanol is a promising biorefinery route. However, there are critical technology uncertainties. What are the enzyme costs and pentose conversion efficiencies necessary to have an economically attractive pathway? What will the concentration of the produced ethanol be from various wood feedstocks, and what are the purification and concentration requirements and costs for this?
- What are the most attractive hydrocarbon, carbohydrate or other process platforms that a given mill should consider? How can these be designed to offer maximum production flexibility for different biorefinery products across a product slate?
- A biorefinery implementation strategy through incremental process changes is critical, including consideration of business considerations such as “quick win” opportunities, allowing for the time needed to establish quality customers and optimized distribution routes, and maintaining a positive cash flow throughout the total implementation strategy. How can this strategy be identified?

Summary

An objective methodology is needed to evaluate biorefinery options for producing added-value products while preserving the value of the existing processes. Developing a systematic algorithm for analyzing mill biorefinery opportunities this is the focus of the NSERC Design Chair at École Polytechnique. We develop validated process and cost accounting models for case study facilities. Process simulation is used to estimate biorefinery quantities for use in market and supply chain analyses. The simulation can be further used to explore mill-wide optimization, and process flexibility. Energy efficiency analysis techniques (such as thermal pinch) are used to explore the potential for minimizing energy use, thereby maximizing carbon availability to produce biorefinery products. Product analysis tools such as supply chain management (SCM) and life cycle assessment (LCA) are used to explore financial and environmental performance of product mixes. Multi-criteria decision-making (MCDM) methods are employed to systematically raise awareness of decision-makers to the key analysis outcomes, followed by a mathematical weighting of stakeholder values for decision-making.

Corporate social responsibility (CSR) is a concept increasingly being adopted in the forestry industry and elsewhere. It makes particular sense for the pulp and paper industry, which is natural resource-based, and whose mills are often located in rural communities and play an important role in the local society. However, it is not obvious how corporate social responsibility should be specifically defined, and what this definition subsequently entails. This product and process design methodology is critical for the biorefinery pathways being explored in the proposed program, as well as for analyzing other promising pathways which may emerge in the future as further research into the biorefinery takes place. The global methodology including performance indices for comparing process alternatives has yet to be defined, and implies the application of a range of sophisticated product and process analysis tools in order to be able to extract meaningful evaluation metrics.