Systematic methodology for identifying promising forest biorefinery products

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Abstract: The forest biorefinery may well offer a unique opportunity for the pulp and paper industry to improve its business performance, however a thorough understanding of market challenges at the early planning stages is essential for pursuing successful forest biorefinery business strategies. By first assessing the commercial aspects of biorefinery implementation and integrating a business plan as the driver for process design, pulp and paper companies will set up strategies that are more likely to be successful over the longer term, and will more readily attract shareholders. This paper introduces a systematic product design methodology to assist pulp and paper mills in identifying promising biorefinery opportunities, and highlights the complex challenges associated with using a product-driven mentality as the basis for decision-making.

The North American pulp and paper industry has been impacted by many factors, including the rise in the Canadian dollar, rising energy costs, and competition from larger, more efficient production facilities being built in emerging pulp and paper nations. With few exceptions, the result has been that the global competitiveness of the industry has declined. In order to respond to market conditions, the North American pulp and paper industry has developed a belttightening culture that focuses on cut-and-slash activities, mergers and acquisitions (M&A), and minimum capital spending. New and innovative investment strategies are critical for the pulp and paper industry [1].

There are many initiatives emerging globally to address these issues. The US Agenda 2020 program [2] proposes to enhance the potential of existing industry assets through the innovative development of new wood products by identifying new market functionalities for fibre and focusing on taking advantage of forest biorefinery opportunities. Defined by Peter Axegård [3] as the “full integration of the incoming biomass and other raw materials, including energy, for simultaneous production of fibres for paper products, chemicals and energy”, the forest biorefinery could be integrated in retrofit to existing pulp and paper facilities. The National Renewable Energy Laboratory (NREL) [4] defines a broad range of possible biorefinery by-products by classifying them as building-block chemicals, added-value chemicals and bio-fuels. By successfully manufacturing added-value products from near zero-value biomass feedstocks, pulp and paper mills can potentially expect a significantly increased return on assets. But success at this challenge is not certain. Understanding the complexity of the array of biorefinery products and making use of the available methods to evaluate product opportunities is crucial.

The North American forest industry has not yet embarked on the biorefinery opportunity in a substantial manner, in large part due to the uncertainties and risks concerning product development, process development, and business success. How can mills that have concentrated on pulp and paper commodity products evolve into forest biorefinery facilities offering a complex range of products? To optimize the response to the biorefinery opportunity, pulp and paper mills need to develop specific and unique strategies for maximizing the value of their current assets. Taking into account their core business, companies must structure their decisions in order to identify and mitigate technological, economic and commercial risks, to avoid bad investment strategies and to allocate efforts on profitable biorefinery products that are viable into the longer term. Rather than being used as a survival strategy, if implemented wisely, the forest biorefinery could trigger a change in corporate culture and management, and result in an industry transformation and significantly improved industry profitability.

Objective

The objective of this paper is to propose a practical methodology that mills can use to systematically explore biorefinery business opportunities, and define a strategic plan as an essential deployment step to implement the biorefinery in existing pulp and paper production facilities.

Business approach to biorefinery product and process design

The forest biorefinery is more than a capital spending project that will incrementally impact day-to-day operations at a pulp and paper mill. An overall business approach is required to address the set of implications from its implementation. Business projects are classically developed by defining specific strategies and tactics which reflect a vision, a mission, and a set of objectives. Managing a project from ideas generation to the business model definition and project implementation can maximize stakeholder interest by capturing the overall value of the project, Fig. 1.
As a project management tool, Cooper [5] proposes the application of the Stage Gate concept in order to plan major developmental activities and incremental support activities. This systematic approach can be useful to optimize the value chain of new products. Drawing from this approach and adapting it to the Porter Value Chain [6], the overall methodology proposed here comprises 4 major steps, Fig. 2: project definition, project feasibility, project elaboration and project development. Each of these steps combines incremental activities that can be linked to Stage Gating, and can be adapted to the biorefinery context.

One of the major challenges of project management is combining process and product design activities. In some industry sectors, research and development for future product innovations are considered essential business activities because of their major impact on longer-term profitability. When diversifying a product range, initial product design work can be limited to identification of the physical form and functions of products. However to reach a higher level of profitability and optimize the choices of products and processes that should be developed in an initiative as far-reaching as the biorefinery, a more complete definition of the market and its forces, the competition, and of the current internal assets is necessary. Specifically, research and development activities at successful large companies have moved from being process-centric to product-centric [7]. In order to optimize project decision making, product design should drive process design. As an example, DuPont performs “rapid market analysis” [8] which considers product life cycle needs and identifies opportunities on the market in order to estimate the economic potential of new products, with minimum consideration given to the process flowsheet and other process design activities.

Combining product and process design for the biorefinery

Generally speaking, much of the effort invested to date in defining biorefinery projects has targeted process design innovations, which focus on how to directly implement rather than how to strategically implement biorefinery projects. Given the wide array of possible product opportunities and the implied enterprise transformation and capital costs, this may be too entrepreneurial an approach. The development of a methodology to drive biorefinery decision making is needed, with particular attention given to product and process design. There are many possible approaches that might be taken. In the approach proposed here, the result of the product design step provides the product basis for the process design step, which in turn employs, to a great extent, systems analysis of new processes using process integration tools [9]. Multi-criteria decision-making (MDCM) can be employed to combine the set of outcomes from the process analysis, Fig. 3. By using this model, pulp and paper mills can optimize their choices regarding product development (the chosen range of products) as well as optimize process design (the best process for the chosen products).

Typically, product and process designs are applied at a facility level in order to optimize one product or one process. In the biorefinery context, it would be strategic to identify and then eliminate product options for the corporation, and then identify those that might be considered by a specific company or mill. Assessing the factors that impact the product choice from a general perspective (pulp and paper sector) to a specific case (one specific company or mill) will assist pulp and paper companies in selecting the best opportunities in the large set of biorefinery options, Fig. 4. Furthermore, reconciliation between the specific product choices and process design options is a critical step in order to formulate a viable business plan and move forward to address process design. Product design might be considered as the methodology to identify what products should be produced in the biorefinery, whereas process design identifies what products could be produced.
PRODUCT DESIGN APPROACH

Facing a complex array of product opportunities, each mill needs to define its own “best choice” product, based, for example, on market attractiveness, the mill potential to target this market, and its capacity to fulfill large or specific demands. In order to simplify this approach, production scenarios can be developed. Consider one example reported [10], where scenarios are defined relative to the scale of input and the flexibility of process. The marketing field proposes a large scope of interesting tools that could be employed for evaluating each scenario opportunity. Determining the general marketing environment, the risks inherent to the project, the competitive forces that could impact the product selection, and ultimately the success of the biorefinery are all points that can be tackled through the application of these marketing tools [11].

In the methodology proposed here, four tools were chosen for product selection, Fig. 5. At the generic level, SWOT (strengths, weaknesses, opportunities and threats) and competitive analyses are proposed. More specifically, the competitive analysis provides an assessment of the competitive position of the pulp and paper sector with regards to each product opportunity, and is systematically conducted at three levels: Canada versus other countries, the pulp and paper sector versus other industry sectors, and one specific company or mill versus others. The output of the competitive analysis is a refined set of product options that mills should consider further. These results are then examined using the production scenarios developed. The outcome of this analysis is a list of the most promising production scenarios from a market point of view.

At this point, a company- and/or mill-specific analysis of the investment that a mill could allocate to product development is critical. Regarding its current product mix, Fig. 6 [11], each mill needs to identify the potential free room for new biorefinery products. Products such as ethanol positioned in a “rapid growth” phase and products such as specialty organic chemicals in an “introduction” phase will not require the same investment or implicate the same level of risk as current pulp and paper products. The Boston Consulting Group (BCG) matrix, Fig. 7, by positioning products relative to their market share and market growth, can help to characterize the current investment strategy and define pertinent re-allocation of product investment: reinvest versus abandon, etc. Finally, an evaluation of the (potential) product market positioning should be made, taking into account the mill’s competitive position and other considerations such as the size of investment required relative to profit margins and the projected ROI. This market analysis will be conducted using the marketing mix incorporating definitions of product, price, place relative to the supply chain and promotion for each potential biorefinery opportunity. Identifying market penetration scenarios regarding the slate of new products and the local market opportunities (synergies, supply chain, etc.) will be useful in order to maximize the chance to increase profitability. The interpretation of the market scenarios by the 4 P’s is essential to develop a successful strategy for spreading products on the market.

Generic product design of the forest biorefinery

Product platforms

A number of technologies (e.g. hemicellulose extraction, black liquor gasification, fast pyrolysis, etc.) deal with different by-products of pulp and paper processes which are biorefinery feedstocks, such as hemicellulose, precipitated lignin, extracts, and even cellulose. With these feedstocks and technologies, several by-products can be obtained based solely on syngas and sugar platforms, such as proposed by the NREL.

In this methodology, the definition of each product is based on a determination of its functionality and market application(s). Bio-commodities, bio-fuels and fine chemicals, for example, might be categorized by determining the volume-to-value ratio of each product. Bio-fuels such as bio-diesel or bio-ethanol might form their own category, because of the current interest in these products on the market. Commodity chemicals produced in large quantities, such as bio-butanol and intermediate green chemicals (aspartic acid, levulinic acid), might be characterized by an unsaturated market. Specialty chemicals, such as PHA, PHB and PLA, target specific customer groups, and their high performance and quality are considered as competitive criteria. In our study, bioethanol and bio-butanol were chosen as reference products for bio-fuels and bio-commodities, respectively. PHA was cho-
sen as reference product for the specialty chemicals, since there are potential applications within the medical and pharmaceutical industries [12]. The general benefits of using SWOT, Fig. 8, and competitive analyses as primary tools to drive the first reduction in the biorefinery product range will be introduced.

**SWOT Analysis**

Several critical questions related to biorefinery product opportunities can be addressed using SWOT analysis. Does the pulp and paper sector have the necessary strengths to manufacture products facing price volatility and/or supply chain barriers to entry, as in the case of specialty chemicals? Can pulp and paper companies maximize their unique strength of having access to biomass and harvesting know-how? What feedstock synergies are possible for the necessary economies of scale in the development of commodity products such as bio-ethanol and bio-butanol? What sector/company synergies are viable in order to ensure value chain optimization for specialty chemicals? Confronting the characteristics of each product/market combination - market volume, market share, supply chain, potential market development, current suppliers and customers - with the internal strengths of pulp and paper companies determines their capability to consider the product further.

Using the example of (commodity) bio-fuels, pulp and paper mills must ensure a high level of biomass feedstock in order to boost production throughput. Wood access, high pulp throughputs in existing mills and residue volumes appear attractive at first glance - however larger feedstock quantities are not obvious when considering overall balances on a mill-by-mill basis. Furthermore, the level of investment required to develop new processes with high throughputs could be limited by the low investment capability of many pulp and paper companies (this capital requirement can be somewhat mitigated due to the integration of biorefineries with existing mill processes). Threats need to be assessed, such as the competitive environment related to biofuels, e.g. will Brazil export large volumes of low-cost ethanol, from sugar and bagasse?

**Competitive Analysis**

The initial product identification from the SWOT analysis is narrowed via the competitive analysis. Does Canada have the capability to be a world leader in bio-production for export products? Does the pulp and paper industry have an advantage in producing biofuels from the forest compared to petrochemical companies? What are the main factors of competitiveness that a company and/or mill needs to consider relative to other companies/mills?

The different criteria for the competitive analysis must be carefully defined in order to optimize the risk assessment activity and to determine the competitive position for a company to develop products and set appropriate strategies. Our experience is that different companies, indeed different individuals, have quite distinct perspectives on the critical factors that should be considered in the competitive analysis. Many of the key criteria in the competitive analysis should have been considered in the SWOT analysis, however identifying all the most critical criteria and obtaining the data needed for their evaluation is far from obvious. By a definition of the competitive environment (i.e. direct and indirect competitors) at three scales (country, sector and company/mill), a grid of competitiveness criteria can be defined, Fig. 9. The criteria ranking from the most impacting to the least depends on analyzed products, and requires that the complexity of criteria interaction be taken into account.

The criteria expressed in Fig. 9 must be defined using general sub-criteria in order to focus the study. For example, at the country level, an appreciation of government implication in the development of products plays an important role in the country competitiveness. Using the example of bio-diesel in Europe, government incentives such as “credit at the pump” are boosting demand and pushing industries to develop biodiesel production. Factor interactions need to be considered, e.g. in the example presented, government initiatives encourage the development of production and the growth of demand for biodiesel, however biomass availability is limiting production. A similar situation may well develop for ethanol in North America.

At the sector level, the petrochemical, chemical, pharmaceutical, agricultural and energy sectors might be considered as pulp and paper competitors (or joint venture partners) for certain products. Concerning criteria definition, feedstock differences are critical. Related to the production of bio-commodities, the cost of feedstock will play an important role regarding the competitive position on the market. Government support of the agriculture and other sectors relative to their support of the forestry sector will be critical in this regard.

At the company/mill level, criteria must be defined case by case. The relative performance of one company compared to another for a given biorefinery product or product slate is directly related to their existing mills, including facility sizes, their relative location and supply chain logistics, the processes installed, current production costs, process flexibility, biomass availability, and corporate tax rates.

SWOT and competitive analyses can assist in strategic decision making concerning product development. They can motivate the management of pulp and paper companies to define the needs for
a successful biorefinery strategy, e.g. regarding opportunities for symbiosis and/or joint ventures to create economies of scale, or to enter an existing and mature supply chain as opposed to producing biofuels. Specific strategies are not obvious, and several of them need to be defined in order to guide the decision making of companies.

**BIOETHANOL PRODUCTION**

**The case for bioethanol**

Ethanol is possibly the most common biorefinery product being considered by pulp and paper companies. Before entering into detailed considerations regarding processes for its production from pulp and paper mills, companies should question whether bioethanol is a viable product opportunity for the pulp and paper sector, considering such factors as the volumes required and the strong and competitive market that has yet to fully develop.

The broad consideration of ethanol as a biorefinery product might be characterized by interesting process advancements, coupled with growing demand resulting from government policies regarding transportation fuels in the USA and elsewhere. Biofuels are attractive relative to petrochemical fuels concerning greenhouse gas (GHG) emissions and energy security. Currently confronted with the question of corn supply sustainability and its impact on the food and feed sector [13], government policies are leading to the investigation of processes employing lignocellulose as a feedstock for ethanol production. Consequently, lignocellulosic ethanol production is expected to increase sharply in the next months and years in order to supply ethanol-in-gasoline targets such as E10 and E85, which in Canada alone, would require a production of 3.4 billion litres and 340 billion litres respectively [14].

Is the ethanol opportunity important for the forest biorefinery in Canada? Mills could take advantage of their access to biomass. It has been estimated that Canadian lignocellulosic waste and residues could represent between 2.3 and 10.4 billion litres of ethanol per year [15]. Significant additional quantities of black liquor could be made available for gasification [16], provided that mills implement aggressive energy use reduction programs. From these, a large quantity of energy, bio-based products and bio-fuels, such as ethanol, could be produced.

Nevertheless, pulp and paper mills need to manage their weaknesses. Canadian pulp and paper mills are older and smaller than those in most other pulp and paper producing nations. Mill closures and cut-and-slash strategies have resulted in reduced capability at the mill level. Confronted with a large investment requirement, such as that estimated in the Larson Report [17] for black liquor gasification, many pulp and paper companies seeking to produce ethanol via this route would require substantial financial support in order to invest in several mills and manufacture bioethanol production volumes that would make them competitive. Since the stock market may be reluctant to invest in companies that have not assessed first-hand a full-scale ethanol production plant [17], the pulp and paper sector needs to attract government support and incentives by building business strategies demonstrating the broad benefit of the ethanol biorefinery. With interesting incentives for ethanol producers and consumers, Larson estimates that the internal rate of return could increase to 35% in the case of gasification process. This IRR would undoubtedly attract external investment.

**Competitive analysis for ethanol production**

Procter [18] describes the potential for ethanol production at mills from “business opportunity” to “dashed hopes”, depending on the biofuel business scenario. Pervaiz [19] characterizes some of the critical criteria for the competitive development of bio-based products, such as price, political incentives and feedstock availability. Society is not prepared to pay a premium for the environmental benefits from E10 or E85. Various factors will impact bioethanol “price”, such as the price of gasoline, feedstock costs and logistics, capital equipment requirements, conversion efficiencies, manufacturing size, and market influence [20].

In order to assess Canadian competitiveness for the production of ethanol, government action is needed at the country level, Fig. 10.

At the sector level, Fig. 11, the criteria are influenced by the country competitiveness. Political incentives play an important role in commercial support for ethanol development, encouraging clusters between sectors, and lower corporate taxes, for example. Proven ethanol processes or those under development, as well as biomass availability, will influence ethanol production.

Based on basic assumptions, consider the co-production scenario for the company/mill level competitive analysis. Van Heiningen [21] proposed an order-of-magnitude economic analysis methodology using added-value estimates for different product scenarios, feedstock/by-product prices, and conversion yields. Comparing the present added value of hardwood kraft pulp mills (180 US$/t) with the added value of a stand-alone ethanol production (154 US$/t), there would be no benefit by producing ethanol alone. Looking at the co-production of ethanol and pulp, the value-added was 286 US$/t. This analysis could further take into account feedstock diversification scenarios in order to investigate additional volumes and their impact on co-production added-value.

While producing ethanol appears to
be an interesting possibility, before concluding that ethanol is an attractive product option for a company/mill to implement, several critical questions need to be first addressed.

**CONCLUSIONS**

The forest biorefinery presents a promising opportunity for enterprise transformation of the pulp and paper industry, as well as an important environmental opportunity related to reduced emissions of greenhouse gases. Its successful implementation is not obvious, and requires a serious and systematic analysis on the part of companies for which the product and process design tools are available. As a promising plan, the forest biorefinery needs to be investigated systematically by using existing tools. Product design is an essential step in the forest biorefinery analysis, and is recommended as a predecessor to process design in the methodology proposed here. Product design can be conducted at a generic (industry) level and a specific (company/mill) level, leading to the systematic identification of a set of economically-viable biorefinery products.

Undoubtedly, the race is on. Technological improvements are already leading to biorefinery deployments, pilot plant projects supported by the US and EU governments are underway, and many biorefinery products already have a strong market demand. It is now time for government and pulp and paper companies to be proactive. In order to define and mitigate uncertainties and risks, a product-centric approach is required: there is no single solution for the industry, and the pulp and paper sector transformation to the biorefinery is too critical to be conducted without setting up a sustainable business model.

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**LITERATURE**


**Résumé:** Le bioraffinage forestier offre à l’industrie des pâtes et papiers l’occasion d’améliorer sa performance en affaires, mais pour mettre en œuvre des stratégies gagnantes en matière de bioraffinage forestier, il faut bien comprendre les enjeux commerciaux dès le début de la planifica-


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