Guided tour: Implementing the forest biorefinery (FBR) at existing pulp and paper mills

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Abstract: The forest biorefinery (FBR) is being considered by many forest product companies as an option for improving their business models. FBR implementation presents significant challenges for mills, related to key technological, economical, financial, cultural, and operational risks – and most importantly, related to enterprise transformation (ET). Product platform definition needs to be systematically considered in order to develop sustainable biorefinery strategies, which in turn precipitates corporate transformation, while increasing overall profits. Foundation concepts with regards to ET and product design are presented in this paper. A hypothetical "guided tour" is given for the biorefinery implementation for the production of ethanol, in which a phased approach is proposed, and key issues that a given mill should consider for implementing the FBR are highlighted.

Mature commodity industries such as pulp and paper are characterized by low R&D intensity, and as demand growth for products has fallen, R&D activities have migrated from process and product innovation to enterprise efficiency research, e.g. supply chain optimization. There is little argument over whether the North American forest products industry is in deep distress. In response, the corporate strategy for many North American forestry companies in recent years has been to merge and acquire (M&A), plus to establish programs for continuous belt tightening and selling 'non-core' assets – seeking to be the lowest cost producer. M&A activity has undoubtedly been critical. Combined with several mill closures in recent years, this has led to price optimism for the near term. However, this may not be a long term sustainable situation for the cyclical industry sector.

With a multitude of biorefinery innovation providers and chemical and petrochemical companies hungry for biomass sources and engaging in partnership discussions, forestry companies must act quickly to secure their opportunities, as the biorefinery world is evolving at a fast pace. Accordingly, the forest biorefinery (FBR) is being seriously considered by some forestry companies (and likely more as time moves on) as a strategy for diversifying their basic business model [1]. However, the implications of this strategy go beyond a requirement for significant capital spending by a cash-limited industry. In our view, diversification to a new business model is essential in order to successfully transform into a sustainable FBR, while at the same time, optimizing the value of existing assets and pursuing new product development. The strategy to achieve these objectives while mitigating risk is far from obvious.

The "titans" of the natural resource industries, as the President of Domtar calls DuPont and other leading manufacturing companies, typically achieve good returns over the long term through product development. On a continuous basis, these companies typically seek to replace existing revenues through new products, and even divest products that have become commodities and provide minimum margins.

One of the most important challenges that forestry companies considering the biorefinery must face concerns which biorefinery products to manufacture, and those in particular that are likely to have a promising market potential over the long-term. Incorporating new products in addition to the existing pulp and paper product portfolio is a complex problem – and perhaps the key to a company's success in diversification. Those who will eventually succeed with implementing the biorefinery will define their product portfolios considering the optimization of profit margins via advanced supply chain strategies. There are critical related questions that must be addressed by companies establishing biorefinery strategies. What is the optimal product portfolio, and the best business partners and business model for implementing this? What emerging production processes (biochemical, thermochemical or chemical) enable this product diversification, while providing the targeted return on investment? What would be the most successful product/process scenario for a given mill, and then for several mills within a forestry company? What would be the

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best business model for outsourcing some of the key market delivery functions? The answers to these questions are far more important than which technology are we going to use.

Far from obvious is how the forest industry might transform from a manufacturing-centric culture to a product and customer-centric culture [2]. To be successful, a company's biorefinery development must account for this. Such a change will impact the day-to-day pulp and paper operations and the overall business model. This impact should be characterized and anticipated during the design of a sustainable FBR operation.

A methodology for product portfolio definition that links customer needs is considered to be the preliminary step in biorefinery decision making [3]. The definition and evolution towards a new product portfolio should be carefully evaluated using product- and process-driven approaches, while considering production flexibility to mitigate the impact of price volatility. A phased approach is presented in this paper that compiles many of the key dimensions that must be considered in order to incrementally implement the FBR at a pulp and paper company. The types of transformation implied through the implementation of this phased approach are outlined.

OBJECTIVE

This paper seeks to describe the implied corporate transformation for companies implementing the FBR, and related to this, the importance of product portfolio definition and management. A phased approach is presented that companies could use for biorefinery implementation, accounting for product design and recognizing ET.

BIOREFINERY CONTEXT

The FBR has been defined as the "full integration of the incoming biomass and other raw materials, including energy, for simultaneous production of fibers for paper products, chemicals and energy" [4]. By integrating FBR activities at an existing plant, pulp and paper mills have the opportunity to generate significant amounts of bio-energy and bio-products and to drastically increase their revenues while continuing to produce wood, pulp and paper products. A new generation of technologies based on thermochemical, biochemical and chemical pathways is likely to enable the development of the FBR. Manufacturing new value-added by-products (e.g. biofuels, bulk and specialty chemicals, pharmaceuticals, etc.) from biomass represents for some forestry companies an unprecedented opportunity for revenue diversification. Nevertheless, implementing the *right* FBR is not an easy process and will be very company-specific, depending upon a host of factors unique to each company. The FBR should not only be considered as a project, but also as one industry solution that induces critical innovation and a makeover of the current corporate culture.

Several general biorefinery configurations are being considered by pulp and paper companies, for example:

- In the simplest case, biorefinery configurations that seek to transform biomass into biofuels replacing bunker C or natural gas currently consumed in the pulp and paper manufacturing processes, and potentially benefitting from an improved carbon footprint and carbon credits,
- Greenfield stand-alone biorefineries, versus those implemented in retrofit to operating pulp and paper mills, versus brownfield or "repurposed" biorefineries that are developed around pulp and paper mill closures, and
- Biorefineries that seek to capitalize from the emerging huge biofuels market via ethanol or diesel production, versus biorefineries seeking to focus more on smaller volume bioproducts potentially having a higher added-value.
- And in the most complex, and potentially most value-generating one for the forest products industry, is to seek to establish a fully integrated FBR along with the proven and needed pulp, paper and paperboard manufacturing operations. In this highly evolved platform mode, the aggregate benefits of operating and management synergies will emerge across time.

Which FBR to implement is far from obvious. There are many investigators assessing biorefinery technologies and pathways; however these analyses are typically limited to techno-economics and lack analyses regarding product design and new customer linkages. FBR design must consider a multidimensional and multidisciplinary approach, including customer/product and process concepts in order to make the biorefinery not only a capital project, but an initiative that results in a successful business transformation. A systematic methodology for helping industry executives decide which technologies to implement and which biorefinery products to manufacture is needed.

ENTERPRISE TRANSFORMATION (ET)

Turbulent conditions (economic, social and political, environmental, and industrial) have reduced the effectiveness of once-powerful operations improvement programs whereby companies seek to become the low-cost producer in their market segment. ET is rapidly replacing past approaches in several industries that once also focused on incremental change. What is evolving are aggressive corporate-wide initiatives designed to impact the strategies, structures, and human systems of the corporation – as well as to create more sustainable and profitable organizations. If the forestry industry is to survive by implementing the biorefinery, it must recognize and embrace concepts of ET.

ET can be considered to be a continuum of opportunities which transform the enterprise in two broad ways, referenced here as "inside-out" and "outside-in". *Inside-out* ET relates to seeking improved bottom-line results via transforming the enterprise in terms of work and process steps within the existing organization. On the other hand, *outside-in* ET involves transforming the enterprise by changing the core mission, vision, as well as goods and services that are delivered to the marketplace. With outside-in ET, the core definitions of markets and customers served (including products and services provided) are altered, which in turn drives a top-down organizational make-over. This can create an organization that is sustainable, with vastly improved bottom-line results. A few examples of recent ET initiatives within and outside the paper industry will help illustrate these two distinct types of ET.

An example of an inside-out ET is that of Georgia Pacific (GP). Under the ownership of Koch industries, GP is essentially pursuing its past focus. Similar or identical products and services are delivered to essentially the same marketplace and customer base. Yet GP is reworking how the company functions to deliver this same

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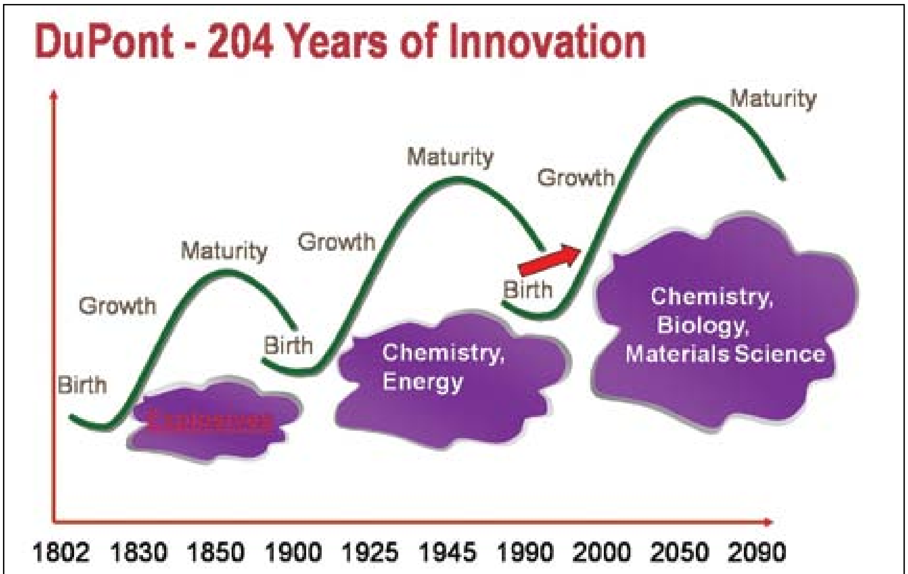

FIG. 1. DuPont's ETs.

basket of goods and services.

Alternatively, a firm outside the paper industry, UPS – now "Big Brown" – began a major outside-in ET a few years ago, wherein UPS adopted a new corporate vision and mission. To assure a sustainable and profitable long term existence, UPS, the leading long distance package shipping and handling company in the world, morphed itself into a supply chain services organization wherein their basic reason for existence was altered.

Another firm that has followed an outside-in ET, within the forest products sector, is Potlatch. Once a vertically and horizontally integrated producer driven by a mix of paper and solid wood products delivered to a defined marketplace and customer base, Potlatch transformed itself into a Real Estate Investment Trust (or a "REIT") to take advantage of the favorable tax treatment for REITs, as well as some unique strengths the firm has in timberland ownership and management. Changing the firm to a REIT led to a NYSE delisting, and an entirely new way of running the firm driven by a totally new mission and vision. This has in turn resulted in a major make-over of the way in which Potlatch operates, from the inside out.

The chemical industry has an outstanding example of how to manage both inside-out and outside-in transformation by defining a new product portfolio.

After a 'golden age' based on commodity consumption growth in the early 80s, the chemical industry had to consolidate its businesses and deliver products differently in order to remain profitable while optimizing production [5]. More recently, three strategies were offered to the chemical industry: (1) exit the chemical business before bankruptcy, (2) continue to focus on commodities, while tightening the belt and concentrate on in-house efficiencies; or (3) specialize in product niches. There are clear similarities here with the forestry industry. The last option was the most profitable solution to build on the core competency in the chemicals business while targeting higher profits. Developing the specialty chemicals business implied an important change in corporate culture affecting the product portfolio and related strategies [4].

One of the most successful examples in this context is the business transformation carried out by DuPont. Adapting its core business to market needs, Fig. 1 [7], DuPont has ensured profitability and maintained a growing market share by employing 'Rapid Market Analysis'. DuPont is strategically developing interests regarding biotechnology, genetics and bio-intermediaries – for example, development of the DuPont™ Sorona® polymer, i.e. corn-based 1,3-propanediol, for which production has reached 100 million liters/year in Tennessee [6]. To remain competitive while diversifying its core business for the third time, Fig 1, DuPont has organized its product platform and divided its business into 5 areas that helped to improve consolidated net sales by 4.6% between 2004 and 2005.

The adaptation to change and a shift between core businesses by companies implies (a) a definition of new objectives driven by market opportunities as well as technical innovation, (b) a concentration on product development, and (c) a systematic analysis of the manner the new product portfolio is delivered to customers. Proactivity and efficiency are essential for successfully addressing transformative needs and reaching new profitability goals, for example, chemical companies such as DuPont have evolved strategically and rapidly from manufacturing commodity, or low value products to specialty, or high value chemicals

These concepts of transformation are intimately linked to the FBR. In an initial sense, biorefinery implementation results in the manufacture of new products that optimize the value of raw materials extracted from the forest: outside-in transformation. Just as importantly, if forestry companies are to succeed with the biorefinery, they must establish new ways to deliver the slate of products in the altered product portfolio that are effective and responsive: inside-out transformation. Through these changes, it will be imperative for the company to recognize the change in its essential vision, mission and reason for existence.

Interestingly, biorefinery products manufactured by different forest product companies will likely be different, and these firms must therefore implement unique company transformations.

From a revenue diversification perspective, the FBR platform can serve as an enabler for industry-wide transformation in the following ways:

- By generating a general industry-wide "inside-out" ET, while driving the industry to a more diverse mix of core products with, in the cases of success, vastly improved results and associated operating environment; or
- In a more aggregate sense, by leading the industry to a major industry-wide makeover to deliver renewable energy/chemicals products. Such a top down transformation via biorefinery initiatives would result in an "outside-in" transformed industry, with a diverse product mix.

PRODUCT SELECTION AND PRODUCT PORTFOLIO

Examples of industry transformation, inside-out and outside-in, are driven by product portfolio management changes and

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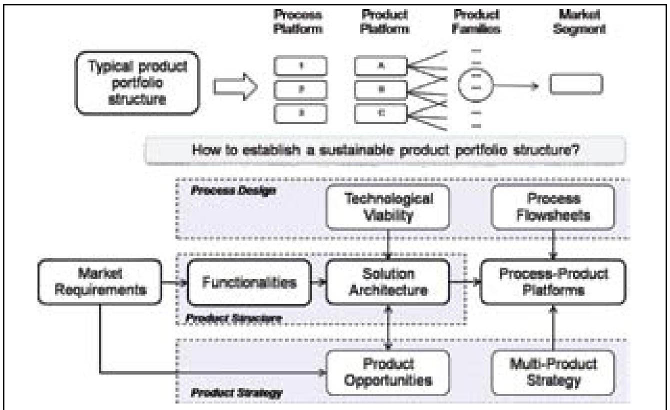

FIG. 2. Sustainable product portfolio definition.

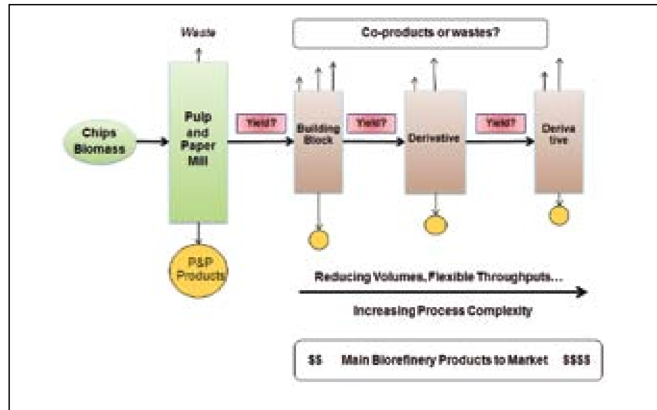

FIG. 3. Biorefinery platform definition.

product diversification. The product portfolio of a forest products company implementing the biorefinery would include a complex mixture of wood products, pulp and paper products, energy products – all currently manufactured – plus new products, depending on the biorefinery strategy identified. Product portfolio changes should be carefully designed as a company profit enabler, but also to meet other goals, such as addressing customer expectations relative to existing and new products, and as a tangible expression of the company vision.

New Product Development (NPD) for the biorefinery will define the necessary ET.

Innovative NPD and management of new product portfolios are essential in order to ensure the development of robust, sustainable and profitable product families [8]. The biorefinery product diversification process should target productivity objectives while meeting customer expectations in terms of technical performance, function and time of delivery.

Product organization is driven by four main criteria:

a) **Product Function** – i.e. "What the product does as opposed to what the physical characteristics of the product are" [4], is a key driver for determining generic similarities and commonalities among products.

b) **Product Architecture** – A fundamental part of the product organization, and implying the definition of platforms and families. Product variety, product and process performance, product quality and functionality, as well as other requirements are part of the definition of a sustainable product architecture.

c) **Product Platforms** – Defined as "a set of subsystems and interfaces intentionally planned and developed to form a common structure from which a stream of derivative products can be efficiently developed, produced and delivered to the customer base/market" [9]. By exploiting commonalities among the product offering, the platform approach is a driver for ensuring product performance. Commonalities in both product and process design are sought in order to develop an efficient and sustainable product platform while considering the product's technological features, physical structure as well as market expectations, supply chain requirements, and distribution channels [10].

d) **Product Families** – Defined by Meyer [8] as a set of products that share a common platform, but have specific features and functionalities required by different sets of customers. From a marketing perspective, a product family is the expression of a product line that typically addresses a market segment, while product variants within the family target niches in that segment. From an engineering perspective, all product variants share common structures and production technologies [11].

Working with product platforms and product families using these criteria potentially brings economic and technical advantages: cost efficiency, technological leverage, and strategic market penetration. Nevertheless, the overall challenge in designing the FBR resides in defining an optimal number of successful product platforms and families based on cost and manufacturing flexibility associated with the product mix [8].

The schematic presented in Fig. 2 describes two important concepts (a) a market-centric approach for defining new products, and that (b) this must be supported by product and process design. The choices regarding product architecture (defined by product platforms and families) are influenced not only by product functionalities but also by technological constraints and product strategies [8]. The challenge resides in defining a multi-product strategy that ensures product family profit maximization [9]. From a process perspective, the challenge is to develop technical pathways for the production of multiple products by carrying out rapid changeovers and incorporating process flexibility. Sanderson and Uzumeri [12] emphasize the benefits of flexibility, small-lot production and ease of change.

Implications of product portfolio definition for the FBR

The challenge for the implementation of the FBR is to identify the most interesting markets for commodity and/or specialty chemicals [13] and then to define promising product and process technology scenarios in the right sequence that together can ensure profit creation and maximization, with the minimization of processing costs. This brings to bear several issues: which products offer the best economic opportunity while mitigating technology risks? What would be the best technology pathway for production of the targeted product family? Which partners and supply chain strategies should be used in order to mitigate technical and commercial risks? What is the appropriate timing for delivering new biorefinery products?

Critical to the economic and commercial success of the FBR is the identification and management of a "biorefinery product platform", Fig. 3. The FBR platform definition involves the determination of *building blocks* and value-added *derivatives*. This platform-based approach is typical

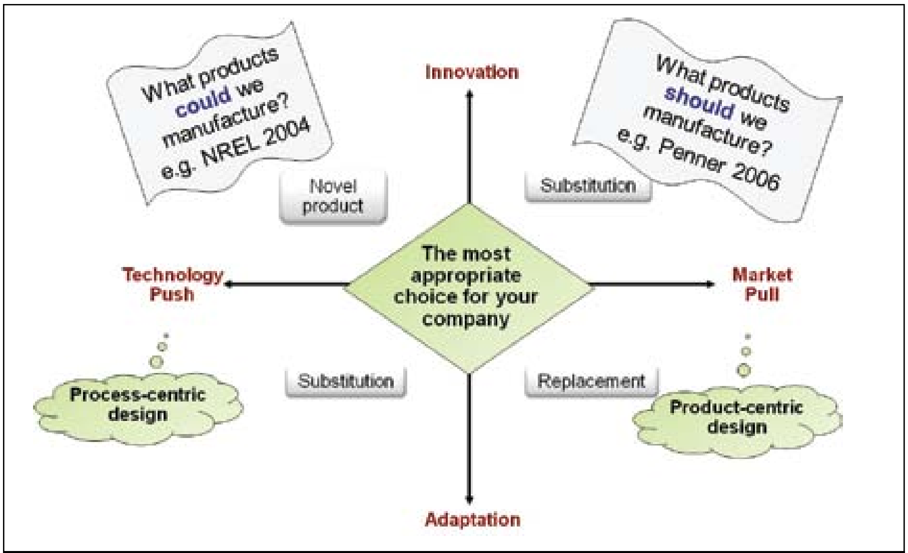

FIG. 4. Analytical approaches for examining forest biorefinery product portfolios.

for the petrochemical industry, i.e. building blocks are produced from crude oil and natural gas, e.g. naphtha, and then transformed into primary and then secondary chemicals.

The methodology for establishing candidate biorefinery product platforms should consider increased profits, but also other factors such as implied changes to existing manufacturing processes, process risks associated with innovative processes, increased process complexity with derivatives manufacturing, yields and overall mass/energy balances, process constraints related to supply chain flexibility, and co-product opportunities. How will processes for manufacturing the building block and derivative products be implemented in a stage-wise manner so that the supply chain remains effective throughout? Two major issues must be addressed:

(a) **The existing chemical market must be evaluated to assess the new product position on the market.** Some biorefinery products will be replacement products (which are identical in chemical composition to existing products, but green – e.g. biodiesel), while other products will be *substitution* products (having different chemical composition to existing products, but having a similar functionality – e.g. polylactic acid (PLA) is a substitute for polyethylene terephtalate (PET)), while yet others will be positioned as novel products (e.g. biomaterials having enhanced functionality to existing products). The competitive advantage achieved by developing replacement and substitute products will be the result of 4 main factors: (1) the potential of securing the existing biomass market at an affordable and sustainable supply and price that will affect the product strategy and may redirect the competitive advantage to producing specialty chemicals and developing greater barriers to potential entrants, (2) market drivers, (3) "cost leadership", as well as (4) the existing value and supply chain potential.

(b) **Identifying future value that may result from additional processing to added-value products, implemented in a stage-wise manner.** If further product conversions are sought, this should be driven by value chain considerations. Described by Porter [14], the value chain is the expression of a chain of activities that brings competitive value to the product family. Capturing the value generated along this chain is ensured by considering process options and their operating costs, and identifying potential profit margins versus existing products on the market.

The systematic development of a biorefinery product portfolio may lead to the following benefits:

(a) Process flexibility results in the capability of the production system to react to market price fluctuations. Supply to the market can be adjusted which mitigates market risk. However, this can be costly to incorporate into process design, and then to manage. Process systems analysis tools, including supply chain analysis, help to identify strategies that mitigate such risks and their underlying uncertainties.

(b) Developing a product platform will help to stabilize biorefinery margins and secure return on investment for the long term. Success from the development of a single biorefinery product is not obvious. For example, even with the production of cellulosic ethanol, commercial risk can be expected based on the experience of the market response to corn ethanol and its real and perceived impact on inflation, price volatility of ethanol, changes in legislation, and other factors.

(c) Product sales along the value chain require strategic analysis in order to create a unique supply chain, incorporating pulp and paper products in addition to the new bio-based products. Support of the value chain is also critical, i.e. the definition of the best partner/product/process combination for the supply chain. Proactively building and consolidating changes in the biorefinery supply chain will be critical to achieving profitability requirements, lowering the commercial risk of entering an existing chemical value chain, and establishing long-term, sustainable FBR success.

(d) Additional value from energy integration is critical for the biorefinery – energy being part of the product portfolio. The energy profile of an existing mill should be aligned with the biorefinery process configuration in order to maximize this benefit.

PRODUCT PORTFOLIO DEFINITION FOR THE FBR

Product design for the FBR implementation is still in its early stages. Various methods are emerging for identifying promising biorefinery product platforms using a process-centric approach for product selection [11]. A process-driven methodology was developed by NREL [15] (National Renewable Energy Laboratory) for bio-based product analysis and was adapted recently by PNNL [16] (Pacific Northwest National Laboratory) for identifying lignin by-products potential. Based on the definition of a carbohydrate platform compiling more than 300 chemicals, the NREL analysis targeted a group of promising value-added chemicals taking into account:

(1) Preliminary economic and technical criteria,

(2) Chemical functionality and technical screening,

(3) Technical barriers based on the best available technical pathways, and

(4) Potential for each building block

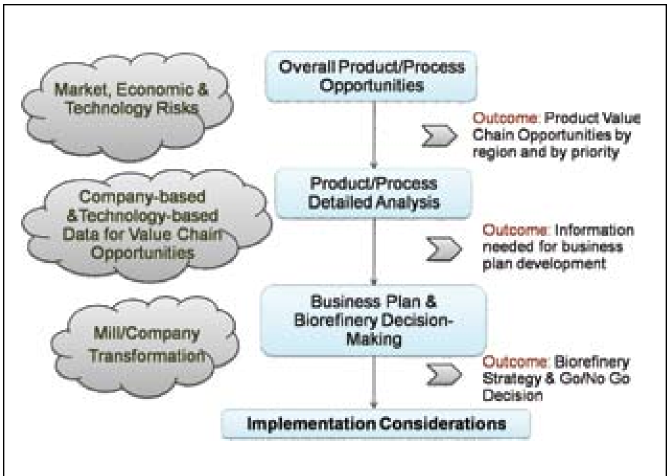

FIG. 5. Overview of product design methodology.

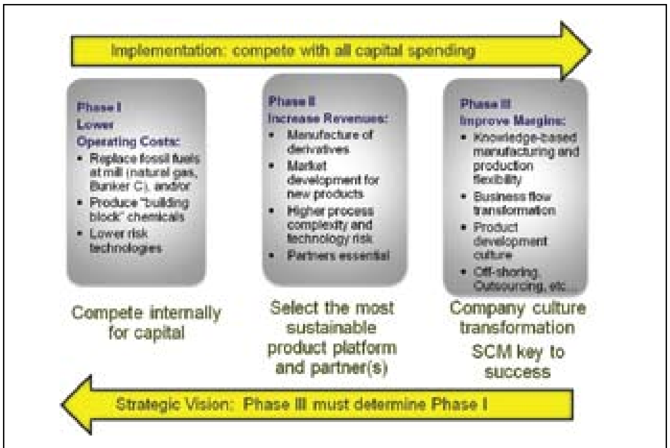

FIG. 6. Strategic implementation of the biorefinery by a forestry company.

chemical to produce a range of derivatives.

The NREL approach has been considered and supported by other reports [17] in order to select promising building blocks for the biorefinery.

A roadmap of the most promising value chains in Canada has been developed by Penner using a product-centric approach based mainly on market drivers and product technical feasibility [18]. This approach considers national, regional and local analyses which characterize specific opportunities related to company geography. The understanding of an existing supply chain provides important knowledge for defining a specific company-based supply chain opportunity.

However, no comprehensive methodology has been presented for the biorefinery that systematically couples process-centric and product-centric design, Fig 4, and for strategically penetrating new markets considering essential factors such as potential integration into the existing supply chain, phased implementation strategy, as well as selection of partners and potential market dominance. It is critical that forestry companies considering the biorefinery assemble both market-driven and process-driven approaches in the decision-making framework [19].

The general methodology presented in Fig. 5 helps to characterize a stage-wise approach for biorefinery design. The initial step of this approach results in the following:

(a) An understanding of the chemical market in order to identify promising value chains while considering product functionalities, volume, market size and growth, market saturation, basic margins, existing supply chains, and

(b) An economic and technology risk assessment of possible biorefinery product platforms in order to select the most viable and profitable ones while considering, for example, technology availability and maturity as important criteria for risk assessment.

The second step is a more detailed enterprise-based analysis of each promising value chain identified in the initial step, based on the following:

(a) A competitive analysis that includes consideration of technology providers and their ability to provide a competitive advantage, and

(b) A systematic analysis using systems analysis tools such as large-block techno-economic analysis, supply chain management and life cycle assessment, which together provide essential quantitative data for business plan development.

The third and last step compiles information from the first two steps into a business plan which can be reviewed by company executives to address biorefinery strategies, i.e. a go/no-go decision regarding the proposed value chain scenarios.

For supporting biorefinery business models and enabling value maximization, enterprise transforming supply chain management decisions can be developed regarding outsourcing and off-shoring strategies.

UPM-Kymmene is a leading company in this area, has developed strategic partnerships with technology providers, and seeks to build a profitable and flexible value chain as an extension of their product portfolio [20].

PHASED IMPLEMENTATION OF THE BIOREFINERY

These concepts of ET and product design have been assembled into a phased approach that forestry companies can consider to establish promising biorefinery strategy, Fig. 6.

Phase I of the strategy would be the implemention of biorefinery projects whose objective is to reduce manufacturing costs by the production of substitute fuel products for fossil fuels such as bunker C (e.g. through fast pyrolysis of biomass) or natural gas (e.g. through biomass gasification). Phase I implies new biomass harvesting techniques, bioenergy technologies which are still under development but currently more advanced than others, and the potential for realizing significant carbon credits. Phase I draws on the competitive strengths of forest product companies: their know-how regarding responsible and effective harvesting, and their existing infrastructure of sawmills and pulp and paper mills. There is no market risk in Phase I, since the forestry company will consume the biorefinery product. Bioethanol and/or biodiesel might also be considered as Phase I biorefinery products, since they are generally characterized as substitute fuel products, however can be sold on the market into blend tanks. Phase I projects would compete for capital in the company's limited capital spending budget, and as such, opportunities to mitigate risk and enhance project potential through cost reduction, carbon credits and technology development support are critical. Phase I also implies no change to the core business of the forest products company, which however may well at this point consider

strategic planning T187

TABLE I. Analysis of the ethylene value chain in Canada

Ethylene value chain	Economic drivers	Technical drivers
Competitive advantages	- Healthy value chain for polyethylene - Large market volume - Interesting price point ($1,06/kg) - Polyethylene market offers valuable perspectives (LLDPE, LDPE, HDPE) catalytic dehydratationi	- Ethanol to ethylene: catalytic dehydratationi - Ethylene to polyethylene: well-known technology used in petrochemical industry
Challenges	- Imbalances in production by region across Canada - 85% of polyethylene production cost = ethylene cost - Need for securing feedstock supply for economies of scale in production - Less liquid cracking capacities in some regions	- Ethylene = simple molecule from petrochemical platform - Ethanol to ethylene technical pathway is not obvious

new alternative feedstocks in addition to woody biomass, such as agricultural wastes or local industry waste streams.

In Phase II of the strategy, the biorefinery technology would be extended, Fig. 3, and derivative products would be manufactured and sold to market. It is critical that the forest products companies recognize that the biorefinery is not a single mill innovation concept, but one that would be implemented at several mills at large capacities to be cost-effective. The biorefinery should represent the potential for a significant revenue diversification for the company – it involves changing the core mission, vision, as well as the product mix delivered to the marketplace – and thus comprises an *outside-in transformation*. Which biorefinery platform to implement is critical, and requires a careful definition using product-centric and process-centric criteria as described previously in this paper. Acknowledging that Phase II of the strategy implies new capital, new technologies and new product delivery requirements, it is recognized by most forest products companies that partnership is essential at this point in order to be successful. To a greater or lesser extent (depending in good part whether replacement, substitute or novel biorefinery products are targeted), success during Phase II will depend on a resident strong product innovation and development culture. Again, selection of a strong biorefinery partner outside the forest products sector is critical here.

Phase III consists of optimizing margins by exploiting manufacturing flexibility through "knowledge-based manufacturing". This latter term is used to describe advanced supply chain techniques, where the scheduling of product manufacture is optimized considering:

- Existing orders,
- Future expected orders and tactical level supply chain optimization,
- Advanced cost accounting techniques reflecting key factors such as true running and marginal costs, product changeover costs, and overhead allocations,
- Manufacturing flexibility capability for existing (wood, pulp and paper, energy) and new biorefinery products.

In this manner, Phase III relates to seeking improved bottom-line results via transforming the enterprise in terms of work and process steps for the new product mix, and thus comprises an *inside-out transformation*. This analysis can include the consideration of the gradual implementation of innovative outsourcing to value chain suppliers, or even off-shoring parts of the value chain. Other key issues must be considered, such as the quality requirements of new biorefinery products and delivery requirements. For example, web-based or B2B strategies may be needed for ensuring the long-term competitive position of the transformed company.

Phase I projects lower operating costs, Phase II projects increase revenues, and Phase III projects optimize margins – these steps are accompanied with increasing financial benefits to the enterprise. Without achieving Phase III, companies implementing the biorefinery will not be able to realize the most significant improvements in free cash flow, will not mitigate against price volatility in existing and new products, and will not secure a competitive position for the longer term. In order to succeed, companies must design all three phases of the biorefinery before embarking on Phase I.

Where should forest products companies begin if they wish to implement this FBR strategy? The product-centric and process-centric approach, outlined in Fig. 4, is critical to defining the Phase II product mix – from here the company can identify quality biorefinery partners, and can explore the potential to define their unique supply chain for the transformed company. In accomplishing these initial tasks and the subsequent analyses suggested in Fig. 5, the company must plan for the outside-in and inside-out transformations that have been implied.

GUIDED TOUR: A PHASED APPROACH FOR IMPLEMENTING THE FBR

A guided tour of the phased approach and company transformation is presented here, based on the production of ethanol (used here only an illustrative example, as there are and will be a very wide array of potentially even more valuable FBR outputs over time). There is an emphasis on Phase II, since this is the starting point for biorefinery strategy design, i.e. product selection and product platform understanding. This tour considers generic market and technology issues in order to drive the product family selection.

Selecting the most promising building block

Implementing the FBR is based on selecting promising building blocks for sale directly to the market, and then manufacturing value-added chemicals based on this building block. A corporate strategy to capitalize on the expansion of cellulosic ethanol production is clearly supported by an established and growing market, and emerging technical pathways and process constraints. However, when considering market economics and the potential of reaching this market, cellulosic ethanol without considering derivatives implies significant risks to forest products companies seeking to improve their overall business model through implementing the biorefinery.

The 2007 US Energy Mandate stipulates a production of renewable fuels of 36 billion gallons per year by 2022, of which cellulosic fuels, i.e. including cellulosic ethanol, biobutanol, biodiesel..., would be expected to account for 16 billion gallons per year [21]. This represents a potential for cellulosic ethanol to be part of the solution for market requirements and to replace competing food resources such as corn feedstock.

Based on NREL assumptions [22] considering biochemical and thermochemical pathways, cellulosic ethanol production costs will decrease significantly over the next years to approximately $0.6/gal. In such a favorable technical context, production of cellulosic ethanol has great promise. However, the current volatility of ethanol prices on the market may deeply affect cellulosic ethanol competitiveness. Over 6 months at the end of 2007, ethanol prices dropped by more than 50%, from $3/gal in July to $1.25/gal in January of 2008 [23]. This was due to crude oil and natural gas price volatility, as well as supply/demand variations.

How can pulp and paper companies build a stable and profitable FBR business while overcoming this kind of price volatility? Forest product companies must then seek to secure their margins by diversifying risk, and develop much more rewarding value chains which consider ethanol (or other platform chemicals) as a building block for other derivatives [24].

Developing a product platform & selecting a family

Ethanol could be used as a solvent and raw material for the production of acetaldehyde, ester and ethylene-based chemicals. Penner's characterization of the Canadian chemical industry highlighted that the plastics market, e.g. products such as polypropylene, polystyrene and polyethylene, is a promising target for natural fiber composites [18]. Considering the Canadian resin market more closely (currently at 3.9MT per year production, and growing), an ethylene product family should be of interest for cellulose-based replacement products. Polyethylene benefits from several drivers on the market, but will face challenges in the near future due to cost competitiveness and feedstock supply, Table I.

A better strategy than producing ethanol only in a company's biorefinery strategy, might be to explore the production of ethylene from ethanol, and then derivatives from ethylene. The production of ethylene from ethanol, however, is not a common technology.

However, efforts regarding sugarcane-based ethanol for polyethylene production are ongoing in Brazil. Braskem expects to start the production of HDPE in 2009, reaching 120,000 to 200,000 t/y, and the joint-venture of Dow and Crystalvesone expects to start the production of LLDPE by 2011, reaching 350,000 t/y. Presumably, technical challenges and risks associated with this conversion can be greatly mitigated by companies willing to purchase this technology and implement after 2011. The production of different polyethylenes from ethylene is known technology and implies greatly reduced risk.

Several issues need to be considered for this process pathway at the outset:

(a) **Market-based value chain analysis:** The existing value chain for ethanol, ethylene, and polyethylene products must be evaluated, including the identification of existing producers. Basic criteria such as product volume, product growth and green product potential need to be evaluated – but also various competitive factors must be identified and addressed, e.g. domestic policy issues, potential for Brazilian ethanol import, etc.

(b) **Supply chain with the gradual implementation of the biorefinery:** Subtle yet important supply chain synergies are critical for a viable business model, and not obvious since the product mix for the biorefinery is likely to be unique. Ethanol should be considered as the final product while interesting and sustainable margins can be achieved. Ethanol to polyethylene conversion should be considered when conversion costs of ethanol to ethylene are lower than the current ethylene market price, and once a customer base has been developed. The supply chain at each of these two points in time must be competitive.

(c) **Process risk assessment:** The processes considered for the production of ethanol from biomass, and for the production of ethylene from ethanol are emerging technologies whose optimized performance will be better than current ones. What are the principles of operation, and how do these limit performance and process development? When should the processes be implemented? How should they be optimized?

(d) **Techno-economic risk assessment:** Evaluation of the biorefinery pathway must consider the cost of operating each implementation step versus current price on the market. The techno-economic risk assessment for the biorefinery needs to assess the range of risk issues, e.g. available biomass and its price, impact of the technical pathways used and estimated operating costs for relatively new processes, the impact of production yield and co-products, etc. The challenge is thus to convert biomass feedstock to sugar to ethanol to ethylene for a production cost lower than ethylene prices, i.e. $1.06/kg [26]. The answer to this question is not immediately obvious: cost accounting models that reflect an appropriate allocation of overheads and product changeover costs, and optimized production schedules across the biorefinery product lines are necessary to evaluate manufacturing costs.

Since manufacturing flexibility will be critical for the biorefinery, there may be added technology risk and costs associated with achieving the targeted level of production flexibility with the new processes, necessary to mitigate risk associated with price volatility. Ethanol can presumably be sold as biofuel into blend tanks to the extent necessary, permitting a good degree of flexibility as the biorefinery company builds a (green) polyethylene supply chain.

CONCLUSIONS AND IMPLICATIONS

While many forest products companies are considering the implementation of the FBR, there is little information available regarding the key overall issues implied by this, such as ET and product design in order to identify promising product portfolio extensions.

An implementation strategy is proposed whereby the FBR is implemented in 3 phases resulting in cost reductions with fossil fuel replacement, revenue increases with new product generation, and margins optimization through knowledge-based manufacturing. The second phase involves the manufacture of new products and evolving the product portfolio – changing the core mission, vision, as well as the product mix delivered to the marketplace, and comprises an *outside-in transformation*. Implementation of knowledge-based manufacturing in the third phase, which transforms the enterprise in terms of work and process steps for the new product mix, comprises an *inside-out transformation.*

All three phases of the biorefinery should be defined to some extent before embarking on the initial phase. This involves identifying promising product portfolios through employing a range of market-based assessments and analyzing various considerations. Product-centric and process-centric approaches should be coupled in order to identify candidate product mixes. Finally and critically, biorefinery partners should be identified early in the biorefinery development.

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Résumé: Resume F3

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Keywords: Reference/Keyword

Attached are the files for the completed tech paper. There are only 2 notes that I have:

1) As previously instructed, I have shortened the long places of work (Environmental Design Engineering Chair in Process Integration, Department of Chemical Engineering, École Polytechnique ˆ Montréal) to simply the university and the city/prov.

2) The author uses a mix of bullets, letters and numbers in his lists. I am not sure why he has done it that way - I left it as is.

please check literature #20