Forest Value Chain Optimization and Sustainability

Sophie D’Amours, Mustapha Ouhimmou, Jean-François Audy, Yan Feng

Strategic Transformation of the Forest Industry Value Chain

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Cédric Diffo Téguia, Virginie Chambost, Shabnam Sanaei, Sophie D’Amours, and Paul Stuart

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3.1 PART I: KEY CONCEPTS AND TOOLS

3.1.1 INTRODUCTION

Over the past decade, the forest products industry in North America and Europe has been impacted by a decline in certain market segments, such as newsprint and printing and writing papers (Pöyry 2015; Schaefer 2015), while other segments, such as tissue and board, continue to experience stable growth. Although there has been some recovery in recent years, the North American housing market has been marked by a severe crisis between 2006 and 2010 that has caused a major reduction in demand for construction materials, leading to a difficult period for the entire forest industry (United Nations Economic Commission for Europe 2015). Coupled with low-cost competition from emerging countries in Asia and Latin America, these factors have been the driving forces that have led many forestry companies to consider revenue diversification and transforming of their business models.

Cost-cutting strategies have been employed to maintain the competitive position of forest-based products; however, over the longer term, a profound transformation of the business model is essential to guarantee a sustainable competitive position (Stuart 2006). Forest product companies should evolve from a commodity-centric culture that focuses on key performance indicators (KPI), to a margins-centric culture, as they diversify their traditional product portfolio to incorporate added-value products. This implies improving existing processes while new technologies are implemented, optimizing access to new biomass demands, and systematically developing new product supply chain strategies. In the manufacture of traditional pulp or paper products, for example, the fractionation of wood is accomplished by the kraft pulping process to recover cellulose. Residual streams including hemicellulose, lignin, and other chemicals remain underexploited and are typically burned in the recovery boiler for steam and power generation. The biorefinery concept aims to integrate conversion routes into and alongside existing processes for the production of fuels, bioenergy, and biochemicals from biomass (Axegård 2005). Today, opportunities to produce new bioproducts that compete economically with existing fossil-based products are being explored by forest product companies, examining the potential to create a competitive value proposal.

This chapter is divided into two parts that address the question of how forest products companies might consider strategic transformation and product diversification. Part I is a review of key concepts and tools for the assessment and evaluation of biorefinery business models. It highlights strategic planning concepts, specifics of market assessment, and decision-making from a multidisciplinary perspective. Part II proposes a systematic approach for the identification of promising transformative
business models and illustrates it through two case studies in the pulp and paper sector.

### 3.1.2 Strategic Aspects of Biorefinery Implementation

Rapid changes in the business and technology environments are affecting the competitiveness of forest product companies. Historically, companies used operational effectiveness to create operating cost advantage. Nevertheless, Porter (2008) demonstrated that in turbulent economic, social, and political environments, successful operational effectiveness strategy should be supported by efforts concerning the company’s strategic positioning. This approach includes synergies along the company value chain for creating unique competitive advantage.

Rather than targeting a first or second quartile position in market segments where they already compete, a better approach for forest product companies might be strategic (re)positioning, which implies enterprise transformation (ET). Two major ET approaches can be used: “inside-out” transformation and “outside-in” transformation (Chambost, McNutt, and Stuart 2009). The former relates to seeking bottom-line improvement by considering synergies in terms of work and process focusing on cost-competitiveness achievements across the value chain. In contrast, “outside-in” ET involves a core transformation of the vision and mission of a company—a makeover from the top down. For example, Georgia Pacific implemented an “inside-out” ET by focusing on improving its core business, while reworking how the company functions to deliver its product portfolio to the market. Another US-based forest products company, Potlatch, opted for an “outside-in” approach, transforming itself into a Real Estate Investment Trust or REIT to take advantage of favorable tax treatment and strengthen the company’s position in timberland ownership and management. One of the most successful examples of ET has been that of DuPont De Nemours, which combined both inside-out and outside-in approaches. DuPont has punctually reinvented itself by adapting its core business to market needs to ensure profitability and has grown its market share in profitable new businesses over the long term. The company recently again diversified its product portfolio and divided its business into five major areas to improve net sales consolidation. DuPont acquired bioproduction manufacturing competency through strategic mergers and acquisition, such as Danisco, in recent years. Dupont recently merged with Dow Chemical Company and has planned a 2017 spin-off into three companies that include the following: genetically modified seeds and pesticides, plastics and other commodity materials, and high-tech specialty products. Each of the three would be stitched together from Dow and DuPont. This undoubtedly is considered a high-risk transformation of Dupont.

If forest product companies are to remain competitive by implementing the biorefinery, then clear diversification targets and new product portfolio definitions must be set (“outside-in” ET), as well as unique operations and supply chain strategies (“inside-out” ET). Diversification of the product portfolio implies targeting new customers from commodity-driven to specialty-driven markets, including proactivity, efficiency, responsiveness, and flexibility in the business model.
3.1.2.1 Phased Implementation of the BioRefinery

Chambost, McNutt, and Stuart (2009) recommended a phased approach for the retrofit implementation of the biorefinery into and alongside existing mills for risk mitigation and incremental transformation of the business model taking into account short-, mid-, and long-term goals (summarized in Figure 3.1).

Phase I of biorefinery implementation focuses on reducing risks related to the implementation of new processes and products in the shorter term and sets the path for a longer-term vision defined by the corporation. It typically involves products that have lower market risk such as bioenergy and biofuels that are often used internally to displace fossil fuels and lower operating costs or sold in the market to generate early cash flow. The production of building block chemicals might be envisaged to create opportunity for early access to market for value-added derivatives in subsequent implementation phases. The latter typically includes products that have higher technology risk, as well as specific market penetration strategies. The preliminary phase must be supported by long-term access to a large volume of low-cost biomass.

Phase II (and its subphases) aims to create improved margins through the manufacture of added-value bioproducts as part of the expanded product portfolio. Once operational effectiveness is achieved, the forest product company should build competitive advantage through the strategic positioning of the product portfolio on the

![Figure 3.1 Phased implementation of the forest biorefinery. (Adapted from Chambost, V., J. McNutt and P.R. Stuart, Partnership for successful enterprise transformation of forest industry companies implementing the forest biorefinery. Pulp and Paper Canada, May/June 2009.)](image-url)
market. Definition of process/product combinations coupled with product delivery and market penetration strategies are key drivers for the new business model definition. Gradual development of the product portfolio is essential to reduce risk and accommodate market price volatility in a robust business model, which should involve collaborations and partnerships that are critical to minimize technical, commercial, and financial risks.

Phase III targets margins maximization and improvement of bottom line results through the reengineering of supply chains, advanced information systems, manufacturing systems that exploit production flexibility, and new delivery mechanisms. Phase III is the consolidation of the “outside-in” transformation. Creating a unique product portfolio and associated supply chain is essential to the long-term competitive position of the forest products company.

The phased implementation of the biorefinery implies having clear short- and long-term objectives along with an incremental technology implementation strategy to build a flexible and diversified product portfolio. Figure 3.2 summarizes some key drivers for implementing a biorefinery strategy at an existing pulp and paper mill. The box entitled “value chain planning” presents an overview of the biorefinery business strategy definition using a step-by-step approach. Both technology and business disruptions are implied with the definition and the implementation of the biorefinery strategy. The technology strategy at the facility level should be supported by the definition of the business strategy at the corporate level. For an effective “outside-in” transformation, it is critical that the mission and vision of the company are adapted to reflect transformational objectives.

![Figure 3.2](image-url) Transformation planning and implementation using a phased approach.
3.1.2.2 Strategic Interaction between Business and Technology Plans

3.1.2.2.1 Process- and Product-Centric Approaches for Biorefinery

Strategy Definition

Defining successful biorefinery strategies requires interaction between the product-market-business strategy and technology-process strategy, coupling process and product design methods.

Process design is a well-known field that defines technically and economically feasible processes for the manufacture of products, including the assessment of technological, environmental, and economic risks at different production scales. Product design for the biorefinery is critical and perhaps less recognized. Methods have been developed for identifying promising biorefinery product platforms using process-oriented approaches. For example, the National Renewable Energy Laboratory (Werpy and Peterson 2004) and Pacific Northwest National Laboratory (Holladay et al. 2007) have presented methodologies to identify promising bio-based and lignin-based products. The methodologies are driven by the review of preliminary economic and technical potential, a screening based on chemical functionality, the determination of technical barriers based on best practices, and the potential for each building block chemical to produce a range of derivatives. In contrast, Penner (2007) used a product-centric approach to develop a road map of the most promising value chains in Canada. This approach was mainly based on market drivers and product feasibility. It included national and regional analyses characterizing opportunities from product and market perspectives, supporting the potential to develop company-specific supply chain strategies.

More recently Forest Products Association of Canada, in collaboration with Canada’s national forestry research center FPInnovations, led a project (entitled The Bio-Pathways Project) to investigate opportunities for producing a range of bioproducts from wood fiber (Forest Products Association of Canada 2010). The methodology involved the following: (1) examining the potential economic, social, and environmental benefits of a set of technologies; (2) defining a set of promising biopaths considering their potential to create employment and enhance sector competitiveness; and (3) considering the global market potential of emerging bioenergy, biochemical, and bioproduct companies. Key drivers for establishing market value, fostering innovation, and deploying technology were examined.

Forest product companies that are considering biorefinery implementation should employ both market-driven and process-driven approaches within the strategy-building framework (Chambost and Stuart 2007). Specific characteristics such as the potential to penetrate markets, potential to create synergies in existing supply chains, the selection of partners for market risk minimization, and the definition of a value proposal are equally as important as technology identification, process design, and implementation when it comes to shaping business models at the corporate level (Chambost, McNutt, and Stuart 2009).
3.1.2.2 Product Portfolio Definition

Figure 3.3 illustrates the complexity of defining a product architecture based on the interaction among product functionalities (what the market expects), technology constraints (capacity limitations, yield, etc.), and product strategies (single product versus multiple product strategies) (Batsy et al. 2012). The challenges are associated with the definition of a multiproduct strategy that ensures profit maximization considering product and process design limitations, for example, by technology pathways (Sanderson and Uzumeri 1995).

When commodity products such as biofuels are targeted, limitations in production volume, price volatility, and uncertain energy policy may endanger the viability of the business model. A driver for the success of the biorefinery implementation is the development and management of a robust product platform (Chambost, McNutt, and Stuart 2009). Inspired from the experience of conventional refineries that yield a good deal of their margin through the sale of a relatively small amount of product, the biorefinery product family includes the production of building block chemicals as well as the production of added-value derivatives (Figure 3.4). The systematic development of the biorefinery product portfolio enables margin maximization, margin stabilization through production flexibility, and risk mitigation considering the phased implementation of the biorefinery.

![Typical product portfolio structure](image)

3.1.2.2.3 Some Critical Elements of Transformational Biorefinery Business Models

Business models for successful biorefinery implementation should consider external factors for attracting potential investors:

- Transformational strategies that imply minimum technology risk, mitigated through the systematic appraisal of technology and process maturity.
- A technology plan that explicitly serves a strong business plan, which is implemented in a phased manner through the development of the product portfolio.
- Transformational strategies that rely on a secure and long-term plan for fiber supply agreements based on volume and price.
- Market strategies that support the gradual development of product portfolio profitability, including long-term off-take agreements for the products or partnership definition for value chain penetration.
- The financial situation of the proponent company needs to be robust, relative to the risk implied by the strategy.

Internal success factors should be defined to minimize the likelihood that the new business model becomes obsolete over the longer term. Even if technology selection may lead to short-term competitive advantage in terms of first-of-kind implementation and production costs, over the longer term, competitive advantages will be driven by the market and supply chain synergies that enable value chain penetration for each product of the biorefinery portfolio.
For building robust transformative business models that take into account external and internal success factors, an interaction between technology and business plan development is essential (Figure 3.5).

### 3.1.3 Market and Competitive Assessment of Transformative Biorefinery Strategies

#### 3.1.3.1 Market Value Potential

The primary objective of a market assessment is to identify product/market combinations that will potentially lead to value creation over the longer term. The success of new product development relies on the fine-tuning of the market assessment accomplished through an iterative process. It involves reevaluation of the strategy as the product is developed over time to ensure (1) functionality and fit on the market, (2) optimum pricing and distribution strategy, and (3) the ongoing recognition and mitigation of market risks and uncertainties.

#### 3.1.3.1.1 Strategic Corporate Planning as a Driver

Strategic planning is essentially driven by the objective of targeting a corporate vision and mission, setting specific benchmarks for success in specific time frames. Ranging from low-risk objectives to higher-risk diversification targets, product/market strategies associated with long-term business growth are presented in the Ansoff Matrix (Ansoff 1980) (Figure 3.6). This matrix is used as a marketing tool and characterizes four ways of business growth while considering the level of risk associated with each strategy—low-risk strategies are associated with business-as-usual while higher-risk strategies involve market expansion and/or new product development.

In the case of forest company transformation through biorefinery implementation, corporate drivers can be difficult to define. The culture in place in the forest products industry must emphasize short-term objectives that have a positive impact on the

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**FIGURE 3.5** Concept of integrated business and technology plan development for innovative transformative business models.
core business, and it is difficult to justify riskier transformational strategies seeking revenue increase and improved returns over the longer term. Since transformation to the biorefinery is not yet considered as an essential strategy for many forest companies, biorefinery projects are in competition with core business improvement projects involving less risk and having competitive returns.

As introduced in Figure 3.2, the business model for the biorefinery should be supported by a robust market strategy. Identifying and developing the market strategy relies on two major activities: (1) value creation through the assessment of market potential over the short and long term and (2) value retention through the definition and maximization of competitive advantages associated with the product and/or process strategy (Figure 3.7) (Forest Products Association of Canada 2011).

3.1.3.1.2 Types of Bioproducts and Associated Market Strategies
As part of the business model, the marketing plan includes the expression of the market strategy over short, mid, and long terms and identifies risks and mitigation strategies. The methodology for the development of a marketing plan includes (1) characterizing potentially promising market segments, (2) identifying the potential for creating value on those segments, (3) determining the competitive position and associated competitive advantages that may enhance market positioning, (4) defining and selecting the best approach to penetrate identified market segments considering long-term viability and market uncertainty, and (5) expressing the chosen market strategy in terms of value proposal, pricing, and distribution strategies.

In addition to pulp and paper products, nontraditional biorefinery products comprising the new product portfolio will have different market potential and market strategies. Products can be characterized as commodity, specialty, or niche products in regards to the type of markets that are targeted, mainly in terms of differentiation potential and market volume (Figure 3.8). Competitive advantages that a company may build are typically the result of the following factors: (1) existing value chain

![Ansoff Matrix for product/market strategies for targeted corporate growth objectives.](image-url)
drivers that affect the value proposition for each product and determine the potential of targeting commodity versus specialty markets, (2) the potential to create barriers-to-entry for prospective competitors in specialty markets considering that their presence would ultimately turn today’s specialties into commodities in the future, and (3) “cost leadership” for commodities and “unique differentiation” for specialties and niches, enhancing the influence on the market (Chambost, McNutt, and Stuart 2009).

Biorefinery products are also be characterized as being replacement, substitution, or breakthrough products in regards to what they replace on targeted markets. Replacement products have identical chemical composition and target existing mature supply chains, such as biopolyethylene. Products are considered substitution products if they have similar or enhanced functionality/performance compared with products currently in the market, while having a different chemical composition,
such as polylactic acid as a substitution for polyethylene terephthalate. Breakthrough products target enhanced performance or new functionality compared to existing products, such as the case for biocomposites compared to existing composite materials. Regardless of the type of new products, existing value chains must be assessed to evaluate new product positioning in the market, possible point-of-entry in the value chain, and the potential for competitive advantage.

### 3.1.3.1.3 Product Portfolio Considerations during Market Assessments

Using a market-centric approach, Chambost and Stuart (2009) defined a step-by-step methodology for the systematic assessment of potentially promising biorefinery product portfolios (Figure 3.9). It consisted of four main activities: (1) assessment and characterization of markets for individual products comprising the product portfolio, (2) assessment of potential value creation through the development of a “product family” of bioproducts, (3) definition of a company-specific supply chain for the sale of the product portfolio including the core business product portfolio, and (4) identification of possible partnerships that mitigate market risk and facilitate product positioning.

Classical indicators needed to assess the market potential associated with a product include the following: (1) market volume, value, and potential growth; (2) price volatility associated with the substituted product on the market; (3) market penetration options including potential for partnership; (4) “green” market potential and associated penetration potential in terms of market share and revenues; and (5) market risks.

The identification of potential competitive advantage is a prerequisite for the adequate definition of market strategies for new bioproducts. This can be achieved through the assessment of different points-of-entry in existing value chains, along with an understanding of competitive positioning.

![Figure 3.9](image_url) Systematic methodology for biorefinery product portfolio assessment.
Assessing the life cycle of a product from a market perspective helps to better understand market segments, potential market value, and the arena of competitors. This consists of identifying the stage of development achieved by the product on a given market segment—introduction, growth, maturity, or decline. Stages are characterized by different levels of competition and risk due to market volume, barriers-to-entry for new competitors, and price rivalry, implying different strategies depending on the maturity of the value chain.

Given that product families resulting from biorefinery processes are comprised of combinations of commodity and specialty products, approaches for mitigating market price volatility risks are different from one product to the other. Commodity markets are characterized by high volume and low margins, and prices tend to rise or fall with business cycles due to fluctuations of raw material prices in a highly competitive environment (Regnier 2007). Specialty products, however, are subject to less volatility and lead to a more stable and higher margins (Price Waterhouse Coopers 2009).

Developing a biorefinery product portfolio that combines commodity and specialty products should be seen as an opportunity for developing certain transformation strategies that mitigate market price volatility risk and stabilize margins.

• Manufacturing flexibility allows for change from one manufacturing regime to another, adapting the product portfolio yields with market volatility. This strategy requires higher capital and operating costs; however, it leads to substantially higher margins under all market price volatility scenarios (Mansoornejad, Chambost, and Stuart 2010).

• Combining contract and spot sales strategies enables enhanced price control and margin generation. Supply chain operating strategy taking into account spot/contract sales strategy and manufacturing flexibility is part of the value proposal representing the potential for competitiveness improvement (Dansereau, El-Halwagi, and Stuart 2009).

Besides optimizing operational effectiveness and flexibility, the supply chain strategy, in many cases, involves the creation of quality partnerships that help to retain value, mitigate supply and distribution risks, facilitate value chain penetration, and create competitive advantages.

Important drivers to be considered for creating viable and sustainable partnerships include the following: (1) the strategic compatibility of business models and visions between the two partner companies, as it is not obvious to identify a balanced business model serving both interests, each company having a different level of risk acceptance, financial capacity, and objectives over the short, mid, and long term; (2) access to the long-term capital resources required for developing and sustaining the biorefinery strategy; and (3) manufacturing flexibility needed to respond to or anticipate market and/or technology disruption, allowing the product portfolio to evolve with time and achieve higher competitive advantages (Chambost and Stuart 2007).
3.1.3.2 Competitive Analysis

As it is essential to identify the value that a product can bring and how the combination of several products within a portfolio can generate more value, it is also crucial to define the potential of a company to retain this value through its unique competitive position. Performing a competitive analysis requires that the company characterizes the drivers for profitability within the targeted value chain and provides a framework for securing its profitability over time relative to the market place (Porter 2008). To characterize potential competitive advantages, it is necessary to understand such factors as (1) the competitive environment associated with the targeted value chains, (2) the drivers that impact the value chains and product price, and (3) the risks and mitigation strategies associated with penetrating the value chains.

An approach commonly used for analyzing the competition is the one defined by Porter (2008) based on the identification of Five Forces that shape the competitive landscape: (1) direct competitors, (2) new entrants, (3) power of suppliers, (4) power of buyers, and (5) substitute products.

An analysis of the direct competitors provides an understanding of the market share potential, which is also an indicator of the value achievable by targeting a specific market segment. The intensity of the competition is assessed considering the number, relative size of competitors, market growth, and the presence of high barriers to enter. The type of product also plays a major role in identifying the drivers of the competition—generally being cost driven for commodity products and performance/quality driven for specialty products.

The threat of new entrants comes from competition drivers such as market price relative to production costs and investment rate. The level of threat depends on barriers-to-entry created by existing players on the market including unique supply chain access, production economies of scale, capital requirements, or regulations. Besides barriers-to-entry, cost reduction strategies are a deterrent to potential new entrants to the market. The ability to moderate production levels, or even cease production, when market conditions are not favorable has to be considered as a competitive advantage (Oster 1999). This latter factor will be especially critical for substitution and breakthrough bioproducts.

The bargaining powers of suppliers and buyers have a similar impact on the potential competitive position of a company in a new market, especially if companies are vertically integrated. For example, forestry companies who have retained their cutting rights and who manufacture wood-based as well as pulp and paper products have a considerable competitive advantage when transforming to the bioeconomy. Further along the value chain, the concentration of suppliers to a targeted market segment, as well as the switching costs to change suppliers for market intermediates, enables the definition of value chain dynamics and associated competitive factors. From a buyer perspective, concentration as well as the potential to switch from one supplier to another due to standardization of the product may lead to a strong pricing negotiation position. Since any player on a value chain is successively a buyer or a supplier depending on its position on the value chain, the supplier matrix (Figure 3.10) can be developed to assess the company’s competitive position relative...
to other actors upstream and downstream, where a monopsony is essentially where the buyer drives a monopoly.

The last competitive force is associated with substitute products, that is, the threat of a larger offering fulfilling partially or completely the same needs on the market. The threat is high if a substitute product offers an attractive price-performance trade-off, coupled with low switching costs for the buyers (Porter 2008). An example of this may be that of biodiesels made from different second generation biomass feedstocks such as algae having different performance. Whether buyers actually switch to substitute products or not, the presence of many substitutes reduces profitability by implicitly imposing a ceiling on prices. A parameter that represents this limitation is the cross-elasticity of demand, represented by the ratio of the percentage change in demand for one product, in response to an increase of one percent of another product’s price. Cross-elasticity generally has positive values for substitute products implying a competitive environment (Oster 1999), leading to lower profitability.

Based on the competitive assessment using the Five Forces framework, a set of key variables should be defined and used to evaluate the value proposal against the competition, and to position the biorefinery product portfolio over the long term. Using this analysis, forestry companies assess barriers-to-entry via production cost advantages, unique product attributes/quality, unique value chain potential, and so on. Different price scenarios considering the competitive landscape should be defined. Most importantly the competitive assessment leads to the identification of certain market and business risks associated with the biorefinery implementation.

Market potential analysis combined with competitiveness analysis leads to the determination of adapted strategies for the penetration of value chains. For each potential biorefinery option that a forestry company may be considering, a systematic evaluation of the Strengths and Weaknesses along with potential Opportunities

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and Threats from the external environment—widely known as SWOT analysis—is an important complementary tool to understand the competitive position of the company and shape a strategy from there. Through the creation of additional advantages that balance identified weaknesses, the SWOT analysis leads to the definition of a more robust transformative strategy.

3.1.4 Practical Approach for the Evaluation of Biorefinery Strategies

Evaluating the gamut of potential biorefinery strategies available to forest product companies to determine which of these offer the greatest competitive advantage is a daunting task. Product design involves the screening of less viable ideas among the set of possible alternatives, with the aim of identifying the few that can potentially be converted into successful products (Cussler and Moggridge 2011). It is critical that forestry companies use product design in a structured manner to evaluate the set of promising transformation strategies in conjunction with opportunistically testing technologies and their business and economic advantages one-at-a-time.

Three main product evaluation approaches are identified from the literature (Killen, Hunt, and Kleinschmidt 2007; Cooper 2001b) namely, (1) benefit measurement techniques, (2) economic models, and (3) project portfolio optimization methods.

The first approach recognizes the lack of accurate data at the early stage of the design process and is often based on the usage of subjective criteria such as the alignment of the project with the corporate global strategy, the order-of-magnitude capital cost associated with the project, the attractiveness of potential markets, or the potential competitive advantages the project could provide to the corporation. This approach typically includes methods such as checklists and scoring models, which allow a preliminary and quick screening of possible options.

Economic models consider each project as an investment for which economic targets can be estimated. The decision is based on indicators such as net present value, discounted cash flow analysis, or internal rate of return (IRR). The availability of uncertain data at the early design stage is the main limitation of these methods, and statistical methods such as Monte Carlo analysis can be coupled with economic models to support economic estimations under uncertainty.

The third class considers that projects are not evaluated individually but rather as part of an overall project portfolio of the company. Constraints such as budget are applied, thus turning the decision-making problem into a mathematical problem, where a parameter (IRR for example) is optimized using a set of constraints. The complexity of these methods has limited their applicability in practice (Enea and Piazza 2004; Kornfeld and Kara 2011). The main advantages and disadvantages of some commonly used methods are summarized in Figure 3.11.

3.1.4.1 Multicriteria Decision-Making

Transformational projects are distinct to investments in the core business. They represent a higher-risk investment, sacrifice capital that could otherwise be available for strengthening the core business, and a dilution of focus. In contrast, transformation is essential for every company in the longer term, especially when disruption occurs in the marketplace, such as is the case in the forest products industry today.
For transformation decision-making, a multidisciplinary approach is needed considering a wide range of market, technology, environment, and other factors. There exists risk in each of these decision-making elements due to scarcity and uncertainty of data. Multicriteria decision-making (MCDM) is an increasingly used, appropriate tool to assist in making well-informed and balanced decisions considering this environment. The MCDM approach requires that a series of multidisciplinary analyses be conducted on each transformational product/process option, which includes the following: (1) competitive assessment of each product portfolio, (2) techno-economic assessment, and (3) environmental analysis, that

<table>
<thead>
<tr>
<th>Type of Method</th>
<th>Subtypes Presented Here</th>
<th>Basic Purpose</th>
<th>Major Advantage</th>
<th>Major Disadvantage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Numerical ranking methods</td>
<td>Scoring models</td>
<td>Rank candidate projects in order of desirability. Manage fund projects in order until resources are exhausted.</td>
<td>Completely transparent, easy to use, readily understandable.</td>
<td>May give impression of false precision. Requires significant input from higher management.</td>
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<tr>
<td>Analytic hierarchy process</td>
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<td>Allows criteria to be disaggregated into several levels.</td>
<td>Requires extensive input from functional and higher management.</td>
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<tr>
<td>Numerical, economic methods</td>
<td>Payback period</td>
<td>Evaluate economic payoff.</td>
<td>Simple to use and understand; very robust against uncertainties. Direct comparison with capital budgeting.</td>
<td>Does not account for time value of money. Required data may not be available for some projects such as basic research.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Evaluate economic payoff, including time value of money.</td>
<td>Easy to calculate using spreadsheet; direct comparison with capital budgeting.</td>
<td>Required data may not be available for some projects such as basic research.</td>
</tr>
<tr>
<td>Numerical, optimization methods</td>
<td>Portfolio selection</td>
<td>Choose portfolio of projects that maximizes some measure of payoff.</td>
<td>Allow use of multiple criteria for selecting an entire portfolio of projects.</td>
<td>Extensive computations required for large project portfolios.</td>
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<td></td>
<td>Projects as options</td>
<td>Reduce risk by selecting best combination of alternatives.</td>
<td>Reduces both downside and upside risk associated with projects.</td>
<td>Requires extensive data and analysis.</td>
</tr>
</tbody>
</table>

is, life cycle assessment. MCDM consists of two phases as illustrated in Figure 3.12: (1) the prepanel activity and (2) the panel activity. Prepanel activities include definition of decision-making objectives, presentation of candidate biorefinery strategies, and introduction of the set of decision criteria. The MCDM panel session is a one-day activity during which the meaning and significance of each criterion is discussed leading to the elicitation of panel member preferences and the determination of a weighting factor for each criterion. The process of gathering panel member preferences and the mathematical method to calculate weighting factors differ with the type of criteria that might be used. Common MCDM methods include the “multiattribute utility theory” and the “analytical hierarchy process” (Wang et al. 2009).

The MCDM panel session is conducted with a multidisciplinary group of ideally six to eight participants (decision-makers) who have a wide range of company perspectives (business, technology, financial, environmental). The outcome of the MCDM activity is to allocate a score to each biorefinery strategy. The score is calculated based on two parameters: (1) utility value (the normalized value of each criterion) and (2) weighting factor (a value between 0 and 1 that represents the preference of decision makers). Utility values are calculated using the results of techno-economic, market, and environmental analyses, while weighting factors are estimated through values expressed and justified by MCDM panel

**FIGURE 3.12** Overview of multicriteria decision-making (MCDM) methodology. (From Janssen, M. et al., MCDM methodology for the selection of forest biorefinery products and product families, International Biorefinery Conference, 2009.)
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members. Figure 3.13 summarizes how criteria are organized for different biorefinery alternatives.

Sanaei (2014) presents a review of cases in which the MCDM tool has been employed for decision-making in the biorefinery context. In occurrence, Cohen et al. (2010) and Quintero-Bermudez et al. (2012) used it for analyzing emerging ethanol production technologies. As well, Sanaei, Chambost, and Stuart (2014) used it for assessing alternatives for the development of greenfield triticale biorefinery.

Financial and capital performance metrics are typically used for capital spending decisions but have limitations when considering the unique strategic biorefinery investment. Competitive and environmental metrics need to be considered to ensure the sustainability of the decision-making (Batsy et al. 2012). A social aspect could also be incorporated in the definition of decision criteria in some cases; however, this perspective has not yet been widely covered in the literature and remains an area for future development.

3.1.4.2 Techno-Economic Criteria

Besides financial and capital performance metrics such as return on investment or internal rate of return (IRR), Hytönen et al. emphasized the importance of a better analysis of the process and economic risk associated with a specific technology along with the business transformation potential that the project may imply. More than one profitability metric is typically considered to accurately express the underlying risks and uncertainties of different capital spending scenarios.

In this regard, Sanaei and Stuart (2014) suggested dividing techno-economic indicators into two categories, where profit-oriented and strategy-oriented criteria are distinguished (Figure 3.14). A subset of these six criteria is typically used to reflect downside return or whether the strategy can be substantive enough to reach revenue diversification objectives.

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**FIGURE 3.13** Summary of MCDM criteria organization.
### 3.1.4.3 Market and Competitiveness Criteria

Besides economic risks that are inherent to every transformation and investment project, issues related to transforming the company business model over the longer term in terms of impact on the core business, portfolio diversification, market penetration, and partnership options are considered as part of the decision-making framework. For example, from a financial point-of-view, access to capital can represent a major limitation for a project appropriation. Several indicators can be defined to illustrate this, such as (1) the amount of capital required for the investment, (2) the potential to attract investors or to involve stakeholders in the project, (3) the potential to secure financial support from the government in the form of a subsidy or grant to lower the investment risk, or (4) the possibility to divide the project into phases of lower investment and risk.

Important issues considered on the market side concern mainly the interaction with actors upstream and downstream on the value chain and the potential to capture or enhance competitive advantages. Both types of issues need to be addressed regarding the chances of success in the implementation of the project and the potential to retain value over the long term. Performing a competitive analysis helps to identify issues specific to the targeted market and to determine drivers for competitive advantage. An example of market-oriented decision metrics was presented by Diffo and Stuart (2012) for assessing triticale biorefinery alternatives (Table 3.1), including short- and long-term interpretations of each criterion.

### 3.1.4.4 Environmental Metrics

Reasons to consider environmental decision criteria are numerous; however, these are not always central in the decision-making process. The rise of environmental concerns in response to global warming issues and the predicted shortage of fossil
resources resulted in (1) higher expectations in terms of green standards from customers and (2) development of governmental policies. It is unlikely that a project having relatively poor environmental performance would be selected against other alternatives.

Environmental impacts of a product or a project are commonly evaluated using life-cycle assessment (LCA) (Mu et al. 2010). LCA considers the inputs and outputs implied across the life cycle of the product from raw material extraction to end-of-life and evaluates their potential impact (International Standard Organization 2006). LCA provides an understandable vision of the environmental trade-offs occurring at different steps of the product life cycle and is suitable to generate decision metrics to differentiate between prospective transformation strategies. Gaudreault, Samson, and Stuart (2009) developed a set of criteria adapted to the biorefinery context using end-point impacts of the IMPACT 2002+ software (namely, human

### TABLE 3.1

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Competitiveness Issue</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Competitive access to biomass</td>
<td>Is there a long-term biomass strategy in place?</td>
<td>Potential (1) to provide a competitive value proposal to suppliers and (2) to secure economically viable and long-term access to the feedstock</td>
</tr>
<tr>
<td>Product portfolio positioning</td>
<td>Is there good potential to secure a competitive position on the market and keep it over the long term?</td>
<td>Potential (1) to capture market share on existing markets and (2) to implement first-to-market strategy on growing future markets</td>
</tr>
<tr>
<td>Competitiveness on production costs</td>
<td>Do production costs provide competitive advantages?</td>
<td>Potential (1) to compete on a market-price basis and (2) to create margins for mitigating price volatility</td>
</tr>
<tr>
<td>Margins under price volatility</td>
<td>Is there potential to remain competitive under price volatility?</td>
<td>Potential (1) to survive under unfavorable conditions and (2) to generate high margins under favorable conditions</td>
</tr>
<tr>
<td>Technology strategy related to market competitiveness</td>
<td>Is there potential for a clear and incremental technology strategy that serves the business strategy?</td>
<td>Potential (1) to face short-term capital investment constraints and (2) to easily adapt the strategy when required</td>
</tr>
</tbody>
</table>

health, ecosystem quality, climate change, and resources) as described by Jolliet et al. (2003), and additional indicators including aquatic acidification, fresh-water input, and cropland occupation.

However, environmental indicators present the challenge of being complex and, in the case of MCDM panels, not easy to interpret for decision-makers who are not familiar with LCA. Liard et al. (2011) highlighted the importance of normalization and the definition of normalization factors specific to the context to have a better perspective of spatial scales of the impact categories in MCDM, as summarized in Table 3.2.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Description</th>
<th>Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Human health</td>
<td>Damage to human health that any substance can cause due to its toxic and respiratory effects, as well as ionizing radiation and ozone layer depletion it creates.</td>
<td>Local</td>
</tr>
<tr>
<td>Ecosystem quality</td>
<td>Degradation of ecosystems relative to ecotoxicity, acidification and nutrification of terrestrial systems, land occupation, ecotoxicity, acidification and eutrophication of aquatic systems, ozone layer depletion, photochemical oxidation, and land occupation.</td>
<td>Regional</td>
</tr>
<tr>
<td>Greenhouse gas emissions</td>
<td>Amount of greenhouse gases emitted at each step of the life cycle accounted in the analysis for a given product, in CO$_2$ equivalent.</td>
<td>Global</td>
</tr>
<tr>
<td>Nonrenewable resources</td>
<td>Energy used at each step of the life cycle accounted in the analysis for a given product and generated by primary nonrenewable resources and minerals.</td>
<td>Global</td>
</tr>
<tr>
<td>Aquatic acidification</td>
<td>Amount of acidifying substances emitted in aquatic systems at each step of the life cycle accounted in the analysis for a given product, in SO$_2$ equivalent.</td>
<td>Regional</td>
</tr>
<tr>
<td>Fresh water input</td>
<td>Amount of fresh water used at each step of the life cycle accounted in the analysis for a given product. It excludes water that is used and recycled within process loops.</td>
<td>Regional</td>
</tr>
<tr>
<td>Cropland occupation</td>
<td>Area used by the biorefinery activities that would normally be used for crops culture, or advantages associated to growing biorefinery feedstock on marginal lands.</td>
<td>Regional</td>
</tr>
</tbody>
</table>

3.1.5 CONCLUSIONS

Many forest product companies seek to define long-term strategies for improving their competitive position, while considering diversification and new business model definitions including outside-in transformation models. There have been many lessons learned, even as the forest sector begins to transform. Biorefinery strategies are identified, defined, and assessed considering a phased approach to identify and mitigate risks inherent to the transformation. The phases accomplish the short- and long-term corporate goals for the transformative strategy and imply both technology and business disruptions that have good potential to capture, create, and retain value.

The success of a biorefinery strategy is highly dependent on the targeted product portfolio strategy and its development over the short and long term. The definition and selection of the product portfolio involves both product and process design tools and requires systematic market and process evaluations. The market-driven analysis evaluates the strategic positioning of the new product portfolio considering market potential and uncertainties, while process design tools support product portfolio development and optimization through scale-up phases and incorporating manufacturing flexibility. Decision-making strategy to identify the most preferred biorefinery strategies based on preliminary technology and business plans uses a set of sustainable criteria considering economic, competitive, and environmental criteria.

Part II of this chapter presents biorefinery case studies, considering the fundamental concepts presented here.

3.2 PART II: TRANSFORMATION METHODOLOGY AND CASE STUDIES

3.2.1 INTRODUCTION

Since the early 2000s, first-generation biorefineries (based on sugar, starch, and oil feedstocks) have been implemented. Second generation biorefineries (based on lignocellulosic feedstocks) are more recent (Demirbas 2010). As a result, the interest in transformation via the manufacture of bioproducts from wood has increased significantly in recent years on the part of forest product companies. Success is not obvious. Recent examples of failed ethanol projects highlight the difficulties that will be encountered to overcome technology challenges and to penetrate commodity-driven markets while relying on capital subsidies.

However, the biorefinery offers a plethora of technology pathways and product-process combinations, implying different risk levels (Agbor et al. 2011; Maity 2015a, b). These are expressed in terms of a range of characteristics such as maturity of the selected process pathways, product portfolio options over the short and long term, market positioning, and competitiveness of the product portfolio. From the investor perspective, it is essential that the risks and uncertainties associated with the biorefinery be identified and mitigated as part of the development of transformational strategies. There is surprisingly little information in the literature offering a clear pathway for the definition of such strategies in the context of the biorefinery.
Part I of this chapter introduced a set of fundamental concepts critical for the evaluation of transformative strategies. For example, forest product companies need to implement transformative business models considering a phased approach to mitigate risks (Chambost, McNutt, and Stuart 2009). Product design tools are used, which consider a market-driven approach to build a successful business plan through market analysis, product life cycle assessment, value chain assessment, and competitive analysis (Ansoff 1980; Chambost and Stuart 2007; Porter 2008). The Ansoff Matrix, SWOT analysis, and Porter’s Five Forces model are among some of the recommended tools critical to gathering and critically analyzing market and business-driven information. The outcome of this assessment is a clearer understanding of the value proposal of products within the biorefinery portfolio, with the objective of defining a robust product portfolio. Product design tools are supported by process design tools for the definition of a technology plan.

MCDM is increasingly employed to guide decision-makers in selecting promising strategies (Janssen, Chambost, and Stuart 2009). MCDM implicates a range of stakeholders relative to the decision and is supported by (1) a systematic decision-making procedure and (2) the use of a multidisciplinary set of criteria. Evaluation metrics are calculated for each transformation option in order (1) to obtain a contextualized weighting of the criteria and (2) to calculate overall scores for each of the options. These scores are used to rank the strategies and to identify the most promising ones for further investigation. Part I of this chapter also provided examples of environmental, techno-economic, and market and competitiveness criteria that could be used in an MCDM.

Part II of this chapter aims to introduce a systematic methodology for defining a forest product company’s business model for the implementation of the biorefinery, considering both technology and market drivers. Many different approaches can be and indeed are being used by forest product companies to determine preferred transformation options. This chapter presents a systematic methodology based on extensive work in this domain that is proving successful with forest product companies.

The methodology considers the entire design process starting with the identification of possible product–process combinations through to the implementation of the business model. It integrates a phased-implementation approach, the interaction between business and technology plans, the product design and process design assessment tools, as well as the MCDM tool. First, a stage-and-gate model is introduced to capture the vision that brings these elements together into a single methodology. Two case studies treating (1) the early stage evaluation and decision-making of lignin-based biorefinery options and (2) the value proposal definition for torrefied pellets production are used to illustrate certain critical steps of the methodology in the context of biorefinery implementation in retrofit to forestry companies. We have not elaborated on critical elements of market assessment in this chapter including, for example, the Ansoff Matrix, SWOT analysis, and Porter’s Five Forces.

### 3.2.2 Framework for New Product Development

In the context of an outside-in enterprise transformation, product diversification implies novelty and risk at several levels of the corporation. The introduction of biorefinery products into the existing company product portfolio requires (1) new technologies and processes to be implemented, (2) penetration/creation of value chains new to the
company, and probably (3) new partnerships required to penetrate nontraditional market segments with the new products. Cussler and Moggridge (2011) developed a methodology involving the interaction between market-driven and process-driven factors for new product development. An important distinction was made between industrial and chemical product designs, considering different approaches to product development and structure of the value chain. Industrial product design focuses on assembled products, which consist of a combination of solid-state components such as razors, bicycles, and computers (Favre, Marchal-Heusler, and Kind 2002), whereas chemical product design focuses on formulated products, which can be represented by a single chemical or a mixture of chemicals resulting in a set formulation or a microstructure (Hill 2009).

Considering the context of the biorefinery, a focus is made on chemical product design. Several approaches have been presented in the literature to discuss the chemical product design process through a logical sequence of key steps (Costa, Moggridge, and Saraiva 2006; Cussler and Moggridge 2011) generally including (1) the identification of new customer needs, (2) the generation of ideas to fill these needs, (3) the selection of the most promising ideas, and (4) the development of the product and the associated manufacturing process. Most of these approaches do not systematically consider the simultaneous development of the product from a technology and a business perspective. In this regard, Seider et al. (2009) proposed a stage-and-gate approach incorporating the conventional chemical product design approach with the Stage-Gate® Product Development Process developed by Cooper (2001a) summarized in Figure 3.15.

The Stage-Gate® process consists of a combination of blocks of activities—called *stages*—separated by decision points where the evaluation and approval on whether to pursue a given project is made—called *gates*. It is traditionally constituted of five stages and five gates, as illustrated on the top-arrow in Figure 3.15. Projects are run by multidisciplinary teams within the organization including product and technology development, manufacturing, and marketing divisions. Activities within stages (see more detail below) lead to specific deliverables used to support decision-making regarding the continuation of the project. The evaluation of deliverables through a specific set of criteria is performed at each gate, and the decision is either made to (1) continue the project development, (2) kill/abandon/reject the project, or (3) put the project “on the shelf” until gate criteria are satisfied. This decision is usually based on showstopper criteria, while flexible or preference criteria are used to prioritize projects. Several evolutions to the traditional process have emerged with time to make it more flexible to the type and risk-level of the development projects, and to accelerate its time-to-market by overlapping stages and activities (Cooper 2014).

Specific activities performed in the stages generally include the following:

- **Scoping:** The objective of this first step is to determine the value of the project from both a technology and business perspective. It consists mainly of rapid analysis and gathering of key data relative to market and technical feasibility such as market size and forecast, likely acceptance of the product by targeted customers, possible technology pathways, as well as market and technology risk.

- **Building the Business Case:** This point in the process is critical for the identification of a product concept and the definition of a business plan to
support it. Besides verifying the attractiveness of the project, it is critical at this stage to gather the “voice-of-customer”—market needs, desires, and preferences—and to convert this into product specifications in order (1) to freeze benefits that will be specific to the new product and (2) to define the value proposal and the product positioning strategy. This work, coupled with a detailed business and financial analysis, leads to the definition of the business case. At the end of this step, a clear definition of the product concept as well as a road map for subsequent development activities should be achieved.

- **Development**: Once product specifications are determined, further activities include the technical work necessary to convert the concept idea into a product that achieves expected performance and to perform preliminary testing for securing a competitive value proposal. The development stage is considered completed when there is assurance that the product can meet technical and market requirements under controlled conditions.

- **Testing**: Besides product testing, the production process must be designed and the associated economics refined to a greater degree of accuracy. A negative or marginal outcome at this stage is considered a showstopper, and implies a refinement of the project at the development stage. Typical activities might include (1) extended “in-house” tests to validate product quality, (2) testing of the product under functional use conditions to validate performance, (3) operation of the manufacturing process at the demonstration scale to identify and correct potential limitations, and estimate production costs more accurately.

**FIGURE 3.15** Traditional Stage-Gate® Product Development Process and variants. (From Cooper, R.G., *Research-Technology Management* 157, 2014.)
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precisely, (4) validation of market penetration strategy, and (5) refinement of business and financial analysis to determine the project’s economic viability.

- **Launch:** The marketing and production plans are implemented at the desired industrial scale during this stage. Efforts regarding market penetration should be supported by a supply chain strategy to enable manufacturing flexibility.

The Stage-Gate® process proposes a systematic approach for new product development; however, it is not obvious how it should be applied for the bioproducts portfolio, in the case of a forest products company implementing biorefinery processes. For instance, time-to-market and supply chain considerations are critical to capture early market share and achieve a competitive position for specialty products—but this is not the case for commodity products. Considering as well (1) the risks related to market penetration, (2) the relative lack of investment in new products research and development by forest products companies, and (3) the limited access to capital, a partnership strategy may be critical in the modified stage-and-gate process.

### 3.2.3 Systematic Methodology for Transformation through Biorefinery Implementation

The methodology proposed here follows a stage-and-gate approach and targets the development of innovative business models for the transformation of forest industry companies: (1) an iterative approach combining product and process designs is used for identifying, selecting, and designing robust product portfolios; (2) the technology plan supports the business plan to mitigate risk, to enhance margin creation, and to create long-term competitive advantages; and (3) the product portfolio market positioning should be defined through a systematic assessment of the existing value chains, market potential, and competitive position.

Three main steps are considered in the methodology as summarized in Figure 3.16, where P–P–P refers to product–process–partner combinations.

#### 3.2.3.1 Step 1: Identification of Product–Process–Partner Combinations

A set of promising biorefinery product–process options needs to be identified, defined, and evaluated by the forest products company considering the following activities:

- Definition of the company prerequisites for implementing biorefinery options in terms of risk acceptance, existing assets and core business, and business diversification targets
- Identification of a set of biorefinery technologies that meet the company’s prerequisites
- Identification of value chains in the vicinity of the mill(s) considered for the biorefinery strategy that can support the development of product portfolios

A set of “showstoppers” need to be defined based on process and market perspectives, to narrow the number of options and focus on company-adapted strategies that meet corporate needs over the short and long term. For the first screening of biorefinery options, typical showstoppers include the level of technology maturity, the order-of-magnitude of capital investment required, the volume of biomass feedstock
FIGURE 3.16 Systematic methodology for the definition of biorefinery business models.
required to have attractive economies-of-scale, the magnitude of expected growth for targeted market segments, the order-of-magnitude of the return on investment, and the existence of potential partners to create synergies.

3.2.3.2 Step 2: Evaluation and Selection of Promising Combinations

Preliminary business and technology plans are developed during this step to characterize the economic viability of each product–process–partner combination while identifying preliminary business strategies. The identification of market and technology uncertainties and risks, along with the characterization of the competitive environment, are critical activities.

At such an early stage of the design process, there remains significant uncertainty in cost estimates. A “large block analysis” cost estimating method can be employed, that is, a base case product–process combination is agreed on for which costs are developed, and alternatives are compared to the greatest extent possible to obtain relative cost estimate for the different options. By using this approach, the costs between processes are rendered comparable for decision-making.

A rapid market analysis is performed for the products defined within the portfolio, considering especially the local and regional value chains potential. Market parameters are estimated, including uncertainties in terms of future pricing, future supply, and demand for each product. Sensitivity analyses are performed for technology and market uncertain parameters, and the potential impact on profitability. Multiple criteria can be calculated to express the techno-economic, technology, market, and environmental risks, issues, and challenges identified along the phased implementation process, considering short- and long-term perspectives.

An MCDM panel with project stakeholders can then be organized in order (1) to fix a set of criteria that would be considered practical and complete enough in the context of the decision to be made, (2) to appreciate biorefinery options in regard to the set of criteria defined, (3) to weight criteria based on their relative importance in the context, and (4) to compare biorefinery option scoring and relative ranking, and elaborate on the most promising ones.

3.3.2.3 Step 3: Stepwise Development of the Business Model

A limited number of biorefinery options—typically not more than three—are retained at the outcome of the MCDM panel. A systematic process includes business and technical milestones such as (1) the negotiation of a letter of intent (LOI) for the off-take of bioproduct(s), (2) initiation of potential partnership discussions, if appropriate, (3) feasibility engineering for capital and operating costs, and (4) pilot and demonstration trials, if needed.

The business model is the formal statement of the business goals associated with the biorefinery strategy, along with the plan to implement the project considering the associated risks. The business model for the biorefinery transformation takes into account the following elements:

- **Executive summary**: key business plan elements and summary of risks and key project economics.
- **Business overview**: critical analysis of the current situation and unique value proposal of the project.
• **Market analysis**: market potential and future product positioning in the market as well as competitive analysis.

• **Sales and marketing plan**: market strategy for penetrating value chains while focusing on the off-take agreement/partnership, pricing strategy, and distribution strategy, that is, supply chain policy.

• **Operational plan**: operating strategy focusing on a review of the technology and the associated risk.

• **Project management plan**: project team and organizational structure.

• **Action plan**: project development schedule through to completion of the project highlighting key milestones.

• **Financial plan**: historic and projected financial performance through balance sheet and bottom line analysis, cash flow projection, and scenario and sensitivity analyses including identification of potential funding sources.

An emphasis should be put on the definition of a value proposal supporting the creation of competitive advantages over the long term. This value proposal should result in the negotiation of a memorandum of understanding and/or a letter of intent with potential off-takers and/or partners, establishing the basis for future terms and conditions for the sale of the biorefinery product(s). It is also critical to consider that the financial plan of the project be well-defined involving (or not) governmental subsidies, bank loans, or private investment.

The following case studies underline the (1) assessment and decision-making and (2) value proposal definition steps of the methodology. These two steps are of particular importance for the definition of successful biorefinery business models. Biorefinery project selection is sometimes done opportunistically or on an *ad hoc* basis by forest product companies, evaluating one transformation possibility at a time, without a consistent process to systematically identify the set of possible options and to aggregate results of their assessments from different perspectives. Another emphasis in the case studies concerns the value proposal definition step to highlight its importance on the creation of competitive advantages and the generation of possible partnerships.

### 3.2.4 Case Studies

#### 3.2.4.1 Case Study 1: Evaluation and Decision-Making of Lignin Biorefinery Options

The context of this case study is a pulp manufacturing facility, manufacturing softwood kraft pulp. The objectives of the case study were (1) to identify opportunities suitable for product diversification in the context of the company considering its current assets (process and unused feedstock), (2) to identify potential partners for implementing the technology and business strategies, and (3) to determine under which conditions each biorefinery alternative would be economically preferred. For this purpose, the company identified promising product–process–partner combinations internally, and then assessed the value proposal associated with each strategy.

#### 3.2.4.1.1 Identification of Biorefinery Process Alternatives

The preliminary analysis consisted of (1) identifying process streams within the existing facility from which value from lignin products could potentially be created

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without negatively impacting the quality and quantity of pulp and (2) determining the quality and quantity of biomass potentially available for the transformed site. Process considerations are not the central point of this chapter and are presented only in a general context.

Possible feedstock–process transformation combinations were triaged based on two drivers:

- The biorefinery project must not impact the quality or the quantity of market pulp produced.
- The technology risk related to the project should be mitigated via a strategic alliance with the technology provider.

Potential biorefinery feedstocks included hardwood chips, and the black liquor stream produced and recovered by the kraft pulping process. Several pretreatment processes exist to extract hemicellulose and/or lignin from chips prior to pulping; however, the pretreatment processes generally degrade wood components including cellulose to a certain extent depending on operating conditions and were considered likely to impact pulp quality. Extracting lignin in black liquor on the other hand has less direct impact on pulp quality, since it affects primarily energy requirements at the mill and amounts of make-up chemicals needed for cooking in the kraft process digester. Lignin precipitation technologies can be used to extract lignin from black liquor to target potentially interesting bioproducts. It was estimated that up to 2000 tons per day of hardwood was potentially available. To exploit this, a biomass fractionation plant could be built in parallel to the existing pulping process based on this feedstock supply, from which lignin could be isolated and hemicellulose- and cellulose-based bioproducts sold.

Two commercial lignin precipitation processes were retained for further analysis: (1) black liquor acidification using carbon dioxide to precipitate lignin, which is separated from the remaining liquid by filtration and washing; and (2) black liquor oxidation prior to acidification, to facilitate the filtration and washing steps. Principles of operation of the oxidation and acidification process and its integration with the existing pulp producing process are presented in Figure 3.17. The delignified black liquor and the washing liquor used to purify lignin are recycled in the chemical recovery unit in the kraft process.

Among other potential technology pathways, a solvent fractionation process was considered that separates wood components into a cellulose-rich stream, and a mixed stream containing lignin and hemicelluloses solubilized in an organic solvent. From these streams, modules of the process include (1) an ethanol production line from the cellulose-rich stream, (2) a solvent recovery unit, and (3) a separation/purification unit that isolates a hemicellulose-rich syrup and extracts lignin of distinctive grades (Figure 3.18).

3.2.4.1.2 Definition of Product Portfolios

A gamut of bioproducts ranging from commodities to added-value products can be manufactured from wood-based feedstocks, such as cellulose, hemicellulose, or lignin. Product–process combinations are defined using a phased-implementation strategy: Phase II portfolios including added-value products are initially targeted, then
Phase I intermediates are identified to mitigate short-term technology and economic risks.

In the case of the solvent pulping process, ethanol is considered the cellulose derivative for Phases I and II, while for the hemicellulose stream, a pentose-rich product sold as animal feed was considered during Phase I, prior to being converted into furfurals during Phase II. Formic and acetic acids are obtained as coproducts of sugar conversion into furfurals (Xing, Qi, and Huber 2011). Lignin was to be sold as a polyacrylonitrile replacement in carbon fiber or as a phenol replacement in resin production during Phase I. In Phase II, lignin was to be converted into carbon fibers or phenolic resins on site. Figure 3.19 summarizes the biorefinery options considered.

Certain technical differences characterize the conversion of lignin into added-value products from (1) kraft softwood lignin and from (2) solvent pulping of hardwood. In the case of phenolic resins production, the reactivity of depolymerized lignin is critical and determines the degree of substitution of phenol that can be attained by lignin (Wang, Leitch, and Xu 2009). Although solvent pulping lignin is relatively more reactive than precipitated lignin, the lignin extracted from both the precipitation and solvent pulping processes would be chemically modified to increase its reactivity before being used in resin formulations. Among possible pretreatment techniques, phenoylation was selected to meet required resin specifications related to processing (e.g., curing time and strength of resulting particleboards) while maintaining a low amount of free phenol and free formaldehyde (Çetin and Özmen 2002). The resin precursor to be commercialized in Phase I was thus phenoylated lignin.
Regarding carbon fiber production, the process considered includes (1) spinning for turning lignin into lignin fibers, (2) stabilization to give thermoset properties to the fibers and prevent fusing at high temperatures, (3) carbonization to form tightly bonded carbon crystals that are aligned more or less parallel to the long axis of the fiber, and optionally (4) graphitization to improve fiber properties depending on the targeted application (Figure 3.20). Due to its highly branched structure, softwood lignin is difficult to spin, and usually chars instead of spinning (Kadla et al. 2002) unless it is acetylated (Eckert and Abdullah 2008). In contrast, hardwood lignin is less reactive and therefore has a much longer stabilization step than softwood lignin (Nordström et al. 2013). Whether lignin is extracted from black liquor precipitation or biomass solvent pulping, it is essential to add a plasticizer to obtain final properties closer to existing carbon fibers. Pellets of lignin mixed with plasticizer are commercialized in Phase I as a carbon fiber precursor.

**FIGURE 3.19** Summary of product–process options of the lignin biorefinery case study.

Regarding carbon fiber production, the process considered includes (1) spinning for turning lignin into lignin fibers, (2) stabilization to give thermoset properties to the fibers and prevent fusing at high temperatures, (3) carbonization to form tightly bonded carbon crystals that are aligned more or less parallel to the long axis of the fiber, and optionally (4) graphitization to improve fiber properties depending on the targeted application (Figure 3.20). Due to its highly branched structure, softwood lignin is difficult to spin, and usually chars instead of spinning (Kadla et al. 2002) unless it is acetylated (Eckert and Abdullah 2008). In contrast, hardwood lignin is less reactive and therefore has a much longer stabilization step than softwood lignin (Nordström et al. 2013). Whether lignin is extracted from black liquor precipitation or biomass solvent pulping, it is essential to add a plasticizer to obtain final properties closer to existing carbon fibers. Pellets of lignin mixed with plasticizer are commercialized in Phase I as a carbon fiber precursor.

**FIGURE 3.20** Carbon fiber manufacturing process. (From Axegård, P. et al., Road Map 2014 till 2025: Swedish Lignin-Based Carbon Fibre in Composite Materials of the Future. Sweden: Swerea SICOMP, 2014.)
3.2.4.1.3 Sustainability Assessment and Decision-Making

Using the perspective of conducting a sustainable assessment of biorefinery options, a multidisciplinary approach has been applied to this case study (Sanaei, Chambost, and Stuart 2014).

From an economic/competitiveness perspective, the following criteria were considered:

- **IRR** representing project profitability under expected market conditions.
- **Competitiveness on production costs (CPC)** measuring the potential to penetrate the existing market while facing price competition and to create margins when facing market volatility. This criterion is calculated based on the difference between the product portfolio market price, adding 10% discount on the minimum available market price, and the production cost of a given product family.
- **Phase I implementation capability (PIC)** representing the implementation capability of the technology at full-scale while considering (1) level of technology maturity, (2) process scalability, and (3) ability of implementing Phase I over a 2-year construction period.
- **Downside economic performance (DEP)** measuring the ability to sustain cash flow for a finite period of time under poor market conditions. This criterion is calculated as the operating earnings before interest and taxes (EBIT) considering minimum market price (Sanaei and Stuart 2014).
- **Return on capital employed (ROCE)** measuring the value of the business gains from its investment. This criterion is critical for evaluating economic risk associated with capital-intensive investments.

From an environmental perspective, the following three top-ranked criteria were considered:

- **Greenhouse gas emissions (GHG)** representing the carbon footprint of each biorefinery option measured as CO₂ equivalent compared to the competing processes to manufacture the functionally equivalent product portfolio.
- **Nonrenewable energy consumption** representing the level of dependency of the biorefinery option on fossil-based fuel/energy.
- **Respiratory organics** measuring the potential impact of contaminant emissions into the air affecting human health considering the relative amount of equivalent ethylene emitted into the air compared to the competing processes to manufacture the functionally equivalent product portfolio.

MCDM considering this set of criteria was conducted to evaluate the sustainability associated with each lignin-based biorefinery option. Based on the weighting factors obtained during the MCDM, IRR, GHG, PIC, and CPC were considered the most important criteria for decision-making. Applying the criteria utility values, a score was determined for each biorefinery option leading to the identification of the most promising options (Figure 3.21).
Lignin precipitation processes for the production of phenolic resins were the most preferred biorefinery options by the stakeholder group participating in the MCDM process. The MCDM result is similar for all solvent pulping options, regardless of the lignin derivatives. Based on the results, recommendations were made to consider several alternatives at the next level of the business model definition: (1) differentiation of lignin product specifications between lignin precipitation processes and solvent pulping, especially for carbon fiber and (2) risk assessment to examine ways to reduce capital and operating costs for the solvent pulping options.

This case study underlines (1) the importance of considering the set of possible conversion routes and product combinations that can be considered for the biorefinery objectives, (2) the importance of using restrictive showstoppers at the early stages in process design considering company/mill business requirements/constraints, (3) the role of decision-making criteria through the MCDM process to guide decision-makers regarding the selection of the most preferred options, and (4) the importance of the context in the MCDM results, since criteria weights and trade-off between options depend on the decision-making objective function.

### 3.2.4.2 Case Study 2: Value Proposal Definition for Torrefied Pellets

The case study considers the implementation of a torrefaction process in retrofit to an existing forest products company. As part of the definition of the most promising strategies considering short-, mid-, and long-term objectives, the forest products company identified several potential biorefinery pathways involving a range of emerging biorefinery technologies targeting commodity biofuels and bioenergy production. Based on economic, market, and technology-driven criteria, decision-making was conducted at the corporate level to identify the most preferred option, which was the production of torrefied pellets to be sold in Europe for electricity production. The criteria considered included (1) DEP reflecting how unfavorable market conditions may impact the financial situation of the company over the long term, (2) technology and project risks measuring the maturity of the technology, its scalability, and the ability to execute the
project over a short-term period, (3) IRR determining whether the project should go ahead considering the relative potential financial return, (4) total capital investment costs representing the capital spending required for the project, and (5) competitive access to biomass representing the margin gained for each ton of biomass.

Business and technology plans were developed for the production and sale of torrefied pellets in the European market. Key elements covered within the business plan are presented below, focusing on the definition of the value proposal and the determination of key drivers for the off-take agreement to build a viable business model.

3.2.4.2.1 Overview of Market Potential Assessment

Several market segments can be targeted for the sale of torrefied pellets on local and international value chains:

- Electricity and heat generation in Europe, considering cofiring torrefied pellets with coal in existing power facilities or dedicated biomass plants. Regulations in Europe are (currently) favorable for such projects and create the opportunity for competitive advantages against other sources of energy such as conventional wood pellets.
- Coal replacement for industrial thermal needs and as reducing agents in the metallurgical industry. However, challenges associated with quality issues and cost-competitiveness against coal made this segment less attractive.

The former market opportunity was targeted. The use of pellets as coal replacement in existing power facilities is increasing and demand is growing more rapidly than production. In 2010, Europe consumed 11.5 million tons of wood pellets (International Energy Agency 2011), representing 45% growth in 2 years. Growth in wood pellets demand is expected to remain strong (Figure 3.22) (RISI 2015). European markets are expected to benefit from the renewable energy directive (European Commission 2009) to reach 20% renewable energy by 2020, supporting renewable sources in the global European energy mix. Each member state is required to reach legally binding targets depending on their energy profile. The United Kingdom has set aggressive targets and has developed a system of renewable obligation certificates (Office of the Gas and Electricity Markets 2013) to reach 15% renewable energy by 2020 and up to 45% by 2030.

Torrefied pellets are new entrants to the wood pellet market. They could well be the next generation of wood pellets, offering better fuel characteristics and cost savings on transportation, storage, and handling. The production of torrefied pellets at a large scale has not yet been reached, with small volumes being tested at demonstration plants.

3.2.4.2.2 Overview of Competitiveness Assessment for Product Positioning

It was essential that the value proposal of torrefied pellets manufacture be built on competitive advantages against existing and substitute energy sources, considering (1) quality- and functionality–driven advantages and (2) cost-competitiveness. Table 3.3 illustrates the competitive positioning of torrefied pellets in terms of quality and functionality considering major drivers for energy production.
TABLE 3.3
Competitive Positioning of Torrefied Pellets Against Substitutes

<table>
<thead>
<tr>
<th>Main Fuel Properties</th>
<th>Wood</th>
<th>Wood Pellets</th>
<th>Torrefied Pellets</th>
<th>Coal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water content (% wt)</td>
<td>30–45</td>
<td>7–10</td>
<td>1–5</td>
<td>10–15</td>
</tr>
<tr>
<td>Calorific value (MJ/kg)</td>
<td>9–12</td>
<td>15–16</td>
<td>20–24</td>
<td>23–28</td>
</tr>
<tr>
<td>Bulk density (kg/L)</td>
<td>0.2–0.25</td>
<td>0.55–0.75</td>
<td>0.75–0.85</td>
<td>0.8–0.85</td>
</tr>
<tr>
<td>Energy density (GJ/m³)</td>
<td>2–3</td>
<td>8–11</td>
<td>18–20</td>
<td>18–24</td>
</tr>
<tr>
<td>Hydroscopic properties</td>
<td>Hydrophilic</td>
<td>Hydrophilic</td>
<td>Hydrophobic</td>
<td>Hydrophobic</td>
</tr>
<tr>
<td>Biological degradation</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Transport cost</td>
<td>High</td>
<td>Medium</td>
<td>Low</td>
<td>Low</td>
</tr>
</tbody>
</table>


Fuel characteristics associated with torrefied pellets led to a price premium relative to conventional wood pellets. Major savings can be achieved due to lower cost transportation and storage and handling on site since torrefied pellet handling does not require the same level of investment when used in existing coal-based power plants (Roberts 2012).

When considering the replacement of part of the existing coal supply to an existing power facility, limitations on cofiring rate should be considered. Tests made in Europe by leaders in the domain demonstrated that cofiring has reached 80% without requiring capital investment in new boilers, compared to a cofiring rate of 20% with conventional wood pellets.

### 3.2.4.2.3 Value Proposal Definition

The value proposal associated with torrefied pellets was built based on (1) existing market dynamics and the consideration of regulations in place, (2) intrinsic advantages of the torrefied pellets against other sources, and (3) cost–competitiveness.

Existing coal prices coupled with government incentives dictate the price of pellets. To build the proposal value and define a room for negotiation, the following elements were considered:

- Analysis of wood pellet and coal market prices and trends
- Identification of possible subsidies and financial incentives, including their sunset dates, resulting from policies for cost-competitiveness compared to coal
- Determination of potential cost savings on the part of the off-taker
- Evaluation of the production costs for torrefied pellets
- Definition of economic threshold for the company in terms of targeted IRR

At another level, the potential cost-competitiveness of torrefied pellets compared to traditional wood pellets was evaluated and is presented in Figure 3.23. The case of two plants located in the southeastern United States was taken into account, presenting

![Figure 3.23](image-url)

**FIGURE 3.23** Cost comparison between wood pellets and torrefied wood pellets. (Adapted from Roberts, D., The forest sector’s status and opportunities from the perspective of an investor (and what it takes to do more). Presentation at The Transformation of the Canadian Forest Sector and Swedish Experiences, Seminar, Stockholm, May 28, 2012.)
the same constraints in terms of production volumes for delivery to Rotterdam. The feedstock considerations included (1) the delivered chipped cost of whole logs for wood pellets and (2) whole logs and residues for torrefied pellets assuming 50% moisture content. Based on this analysis interesting savings can be achieved considering avoided cost at the utility site since torrefied pellets can be handled with the existing coal utilities. Additional savings can be achieved on landed costs associated with transportation due to the higher energy density of the torrefied pellets as well as, in this scenario, cheaper biomass cost due to the unprepared feedstock and access to residues. Thus, a room for negotiation of 3.7 $/GJ, that is, potential margin to be created, could be targeted during preliminary discussions with potential off-takers.

Some lessons learned from this case study included (1) a sound business plan to be served by the technology plan, (2) the value proposal to be identified early in the design of the biorefinery strategy, and (3) competitive advantages to be determined and maximized by robust market penetration strategies and partnership strategies.

3.2.5 Conclusions

This chapter has addressed the broad range of market- and technology-based assessments that need to be considered in a systematic manner by forest product companies to identify preferred transformation strategies.

To the extent possible, the many sources of risk must be identified and quantified. The magnitude of the impact of these risks on the economic, environmental, and competitive viability of the project requires a systematic methodology to guide decision-makers. The methodology presented in this chapter is founded on the combination of product design and process design tools and an effective interaction between business plan and technology plan development, considering a phased-implementation approach for transformation strategies. An approach inspired by the stage-and-gate model is employed to assemble these concepts. Stages are suitable to perform the analyses and assessments relevant to gather information on prospective biorefinery candidates prior to evaluating them. This is done during gate reviews incorporating proper milestones, such as MCDM activities.

The focus of this chapter was on value identification and capture in defining transformational business strategies. A practical approach based on value chain considerations has been developed. Whether it is via biomass procurement strategies, manufacturing flexibility, or optimization of the warehousing and product delivery network, supply chain management is crucial to take advantage of the uniqueness of biorefinery product portfolios and maintain a competitive position over the long term. These subjects are covered in greater detail in subsequent chapters of this book.

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Strategic Transformation of the Forest Industry Value Chain


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