PARTNERSHIPS AND VALUE CHAINS FOR LIGNIN-BASED BIOREFINERIES - A CASE-STUDY APPROACH

by

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ABSTRACT

The Canadian forest products industry is exploring new opportunities to diversify their revenue sources and product portfolio, and accessing new markets by implementing a forest biorefinery. This research considered the overall approach for the implementation of a biorefinery at a Kraft pulp mill by creating partnerships within the value chains of the mill to mitigate risks and enhance the likelihood for success of a biorefinery. The key challenges with forming successful partnerships for a biorefinery revolve around finding and evaluating potential partners. This research attempted to mitigate the impact of these challenges by creating a systematic partner selection process and evaluation criteria. This was accomplished by creating partnership strategies which included a customized partner selection process, identification of types of partners needed, finding potential partners, and development of evaluation criteria using the analytical hierarchical method. These methods were applied to a case-study Kraft pulp mill in western Canada to demonstrate their applicability.

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LIST OF ACRONYMS AND TERMS

Adhesive: A chemical substance used to stick material together.

AHP: Analytical Hierarchical Process

BC: British Columbia, Canada

Biomass: Forest residues such as dead trees, branches and tree stumps, yard clippings, wood chips and even municipal solid waste.

Bioproducts: Are materials, fuels, chemicals, and energy derived from renewable organic resources.

BTX: Benzene Toluene Xylene

C$: Canadian Dollar, unless otherwise specified

CF: Carbon Fiber- Is a material consisting of fibers and composed mostly of carbon atoms

Dispersant: Any substance used to promote the formation and stabilization of dispersion

Eigenvector: A square matrix is successively squared to obtain eigenvalue

Ethanol fuel: A gasoline alternative that can be manufactured by converting feed stocks such as sugar cane, sugar beets, switch grass, corn, barley, wood, algae, municipal waste, and many other sources.

FPAC: Forest Products Association of Canada

GDP: Gross Domestic Product - A market value of all the final goods and services produced within a country in a given period of time.

Kraft process: A chemical process that uses sodium hydroxide and sodium sulfide to convert wood into wood pulp

Lignin: A complex chemical compound that binds wood fibre together.

LVL: Laminated Veneer Lumber

MDF: Medium Density Fiberboard

MTon: Metric Tonne

NBSK: Northern Bleach Softwood Kraft

NGO: Non-Governmental Organizations

NNFCC: National Non-Food Crops Centre – A United Kingdom based consultancy company specializing in bioenergy, biofuels and bio-based products.

OSB: Oriented Strand Board

OEMs: Original Equipment Manufacturers

Pair wise comparison: Refers to a statistical process of comparing entities in pairs to judge which of each entity is preferred over the other or which one is more important than the other.

R&D: Research and Development

$: United States Dollar, unless otherwise specified

Value added: The amount by which the value of a product is increased at each stage of its production.

VCA: Value Chain Analysis

Value chain: A chain of activities that are performed by a firm to design, produce, market, and deliver its products or services

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Chapter 1: Introduction

1.1 Overview

In recent years the Canadian forest products industry has been facing several challenges including rising energy and fibre costs, cyclical demand for traditional wood and paper product commodities such as newsprint, and increased competition from low-cost overseas producers. In response to these challenges the forest products industry has adopted strategies such as collaborations with other companies, new products development, and exploration of new markets (Douglas & Simula, 2010; FPAC, 2011; FPAC, 2010).

The focus of this research is on developing a business strategy to integrate a lignin-based forest biorefinery at an existing Kraft pulp mill. The strategy of combining lignin-based forest biorefinery within the existing Kraft pulp mill is less explored due to past economic and technological constraints. Lately, the concept of a lignin-based forest biorefinery has emerged as a frontrunner in the forest products industry in an effort to be more economically and environmentally sustainable, and to retain competitive advantage. The reasons for forest biorefineries recent popularity are, firstly, the high volatility in price of crude oil and the diminishing global oil resources (International Energy Agency, 2010; World Economic Forum, 2011). With numerous industries relying on petroleum-based products as inputs for production of final products, there is a growing interest in alternative inputs. Some of the petroleum-based products can be replaced with products from a forest biorefinery (International Institute for Environment and Development, 2011; Holladay et al., 2007). Secondly, there is a growing concern about energy security and geopolitical issues in many of the oil producing regions, compelling oil trading countries to resort to local alternatives and renewable resources (Benoit, 2008). Finally, increasing general awareness about environment degradation is propelling organizations to be more environmentally friendly (Food and Agriculture Organization, 2010), and products manufactured at a forest biorefinery are renewable and sustainable (Holladay et al., 2007). However, the uncertainty around fossil fuel resources is the most significant reason for strong interest in forest biorefinery (Fernando et al., 2006; World Economic Forum, 2010).

These developments have led to an exploration of renewable alternative sources of energy and chemicals, that can be used as a substitute for petroleum-based products. One type of forest biorefinery that is gaining significant attention is the lignin biorefinery due to the variety of energy and other bioproducts that can be manufactured with it and the availability of abundant renewable sources of lignin (Holladay et al., 2007). A lignin biorefinery is a facility that converts forest biomass through process and equipment into biofuels, bioenergy, and biochemicals (Pye, 2006). Lignin is the glue that binds wood fibre together and has to be separated through chemical or mechanical processes before making pulp at a Kraft pulp mill.

Traditionally, lignin has been burned and used as a source of energy at Kraft pulp mills. The growing demand for alternatives to petroleum-based inputs has motivated private and government organizations to devote more resources towards research and development of new value-added products that can be produced using lignin (Holladay et al., 2007; World Economic Forum, 2011). As a result, lignin has been used to produce several products such as dispersants, energy, fuels, binders, paints, pharmaceuticals, adhesives, ethanol, and other chemicals. The global market for such bioproducts is expected to reach an estimated $208 billion by 2020 (Smolarski, 2012). Table 1 presents estimated major markets for products that can be produced from lignin. Currently 80 percent of these products are produced from petroleum-based inputs. The current demand and expected growth in global market for the products that can be derived from lignin provides an opportunity for Canadian forest products industry to establish lignin-based biorefinery.

Table 1. Market for four major products that can be derived from lignin, 2010

Product	Estimated commercial date	Market volume in (Million Ton)	Market price (USD per tonne)	Market value (Billon$)	CAGR 2010-2020 (volume)
BTX	2020-2025	102	1,200	122	+4.4%
Phenol	2015	8	1,500	9.6	+3.9%
Vanillin	Commercial since 1933	0.016	600,000	0.1	+4%
Carbon fiber	2020-2025	0.046	34,800	1.6	+13%

Source: (Smolarski, 2012)

1.2 Research Goals

The purpose of this research is to identify key challenges a Kraft pulp mill faces when transforming into a lignin-based forest biorefinery and to develop effective partnership strategies to overcome these challenges. This research focuses on partnerships within the value chain of a Kraft pulp mill. The goal of the research is to address the following questions:

1) What is the process of partner selection?
2) What types of partners are needed to transform a Kraft pulp mill into a lignin-based forest biorefinery?
3) Where to find potential partners to implement a lignin biorefinery at a Kraft pulp mill?

4) How to select and evaluate potential partners for lignin-based biorefinery?

1.3 Methods

A case study approach had been followed in this research. An existing Kraft pulp mill is used to help illustrate the partner selection process developed in this research. The mill is a large, competitive softwood Kraft pulp mill owned by a large Canadian integrated forest products company. The case-study mill possesses several strengths and weaknesses similar to other Canadian Kraft mills that make it a good representative case of the challenges and opportunities faced when implementing a lignin-based biorefinery at a Kraft pulp mill in Canada. Due to confidentiality reasons the mill's specific location and name are protected. Throughout this thesis the case study mill will be referred to as the 'Case Mill'.

We collected information through primary and secondary sources. The primary sources included interviews and a questionnaire survey. The secondary data was collected from previous literature on the subject, annual reports, industry reports, government reports, and press releases.

Several tools were used to analyze the data and information collected. The customized partner selection process is based on case study analysis, and a review of relevant literature. This was followed by a SWOT (strengths, weaknesses, opportunities, and threats) analysis to assess what types of partners the Case Mill needs in order to implement a lignin-based forest biorefinery. We then used value chain analysis to find potential markets and industries for lignin-based products and partners for the Case Mill. Furthermore, we created partner evaluation criteria which are based on SWOT analysis of the Case Mill, case studies, and literature review. Finally, we surveyed experts using Analytical Hierarchy Process (AHP) to determine the relative importance of each evaluation criterion that is used to evaluate and rank competing potential partners as identified through the value chain analysis. The analysis of the AHP survey results and ranking of the potential partners was done through '***Expert Choice***' software specially designed for AHP methods. We provide details of the methods and tools used in Chapter 3. The partner evaluation criteria developed in this research are applied to select partners for the Case Mill.

1.4 Outline of the thesis

The thesis is arranged into seven chapters. The following chapter is a review of the literature around biorefineries, lignin biorefineries, partnerships, partner selection process, and partner evaluation criteria, value chains, and examples of partnerships for bioproducts manufacturing in the global forest products industry.

This is followed by an overview of the methods used in this research. Chapter 4 presents a SWOT analysis used to determine the types of partners needed to implement a lignin-based forest biorefinery at the Case Mill. Chapter 5 presents a value chain analysis of lignin-based products and identified prospective partners or customer for the Case Mill. Chapter 6 focuses on partner evaluation criteria for the Case Mill, MCDM AHP survey results, and includes an example to demonstrate applicability of the evaluation criteria established in this research. Finally, Chapter 7 presents conclusions, recommendations, limitations, and venues for future research.

Chapter 2: Literature review

2.1 Forest biorefinery

Governments and organizations around the world seek to achieve a balance between preservation and management of natural resources and economic development. This balance involves economic growth alongside conservation of natural resources so as to reduce the impact of industrial activity on the environment (Kamm et al., 2006). One of the ways to preserve environmental and economic growth is to reduce dependence on conventional natural resources such as fossil fuel that are not considered as sustainable and environment friendly (IPCC, 2012). This makes it imperative to reduce reliance on non-renewable fossil fuels such as petroleum, natural gas, and coal, which will propel a shift towards renewable resources such as forests and other biological resources.

One of the alternatives that have emerged as a strategy to shift from fossil fuels resources to more renewable resources is forest biorefineries. The key reason for the recent increase in interest of the forest biorefinery concept among industry leaders, academics, and industry researchers is the increased demand for alternative energy from renewable sources (Fernando et al., 2006; World Economic Forum, 2010; International Energy Agency, 2010). It is expected that biorefineries will eventually become more economically and environmentally viable than fossil fuel energy resources in the future (Holladay et al., 2007; World Economic Forum, 2011).

The concept of biorefinery can be understood from the definition given by the American National Renewable Energy Laboratory (NREL, 2012) "a facility that integrates biomass conversion process and equipment to produce fuels, power, and chemicals from biomass". A biorefinery can use different types of biomass including wood and agricultural crops, forest residues, organic residues, aquatic biomass (algae and sea weeds), and industrial wastes (International Energy Agency, 2010; Taylor, 2008; Demirbas, 2009).

In contrast to a conventional biorefinery, a forest biorefinery is a type of facility that uses wood based feedstock (such as residues, bark, and tree branches) to produce fuels, energy, and chemicals (Kamm & Kamm, 2004). The products that can be produced at a biorefinery could include bioenergy, biofuels, and bio-chemicals (Figure 1). The demand for such products from renewable resources is growing and expected to reach $200 billion by 2015 (FPAC, 2011).

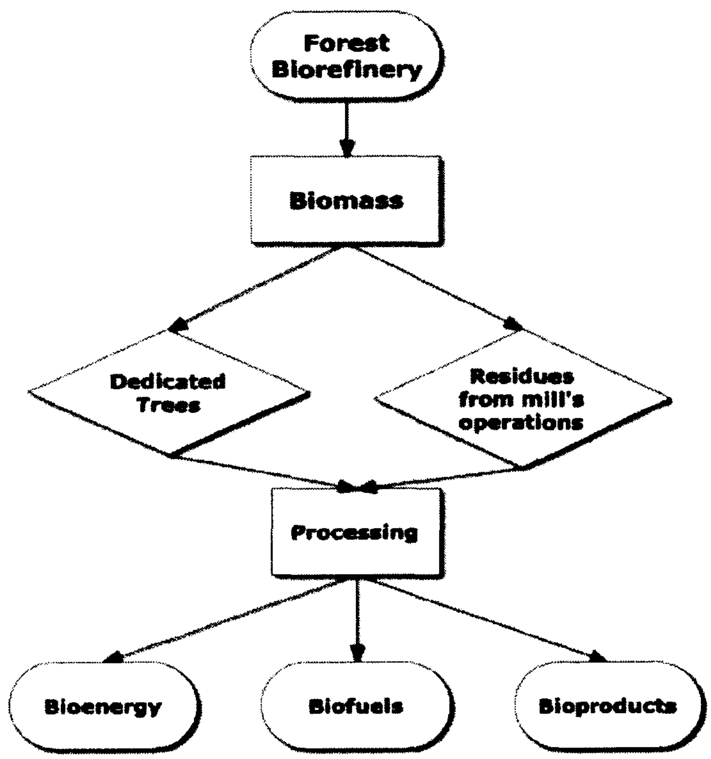


Figure 1. Forest biorefinery

Benefits of forest biorefinery

The potential benefits of a forest biorefinery can support the development of a more economically and environmentally sustainable Canadian forest products industry and consequently support many resource-based communities across Canada. The Canadian forest products industry can benefit from forest biorefineries in many ways, which include financial gains in the form of new revenue sources, environmental benefits by reducing dependence on non-renewable resources and increasing self-sufficiency for energy need, and societal gains by creating new jobs and sustainable environment for the community (Holladay et al., 2007; International Energy Agency, 2009; International Energy Agency, 2010; Mabee et al., 2010; World Economic Forum, 2011; Kamm et al., 2006; Benoit, 2008).

Other benefits that are not covered in the literature include creating new opportunities for partnerships, technology innovation and international trade. Forest biorefineries create opportunities for new partnerships within and outside the forest products industry. As an example Chevron, a petroleum company, partnered with Weyerhaeuser, a forestry company to produce biofuels (CatchLight Energy, 2012). Another example is British Petroleum (BP) created a joint venture with DuPont, one of the leading chemical companies to produce biofuels (Butamax, 2013). Forest biorefineries also contribute to innovate and create new technologies e.g. FPInnovations collaborated with forestry companies, universities, and institutions to research biorefining technologies (FPInnovations, 2013). Finally, Forest biorefineries help increase international trade in non-traditional forest based products as the global demand for renewable energy sources keeps growing exponentially (International Energy Agency, 2010). These non-traditional benefits accrue to industries, institutions, and communities, and also provide economic benefits to countries, encouraging more partnerships to be created.

Risks associated with forest biorefineries

While there are substantial benefits involved in pursuing forest biorefinery there are also risks associated with its implementation at a Kraft pulp mill. Firstly, investment risk as in any other project forest biorefinery also creates uncertainty about the capital invested in the project (Olsen, 1997). Companies have apprehension of losing capital due to the uncertainty around bioproducts demand (World Economic Forum, 2011), which depend on demand and pricing of petroleum-based products (International Energy Agency, 2010). This risk can be mitigated through partnerships by sharing the capital cost among partners.

Secondly, the technological risk relates to availability and integration of technologies into the existing Kraft pulping process for bioproducts manufacturing. There is a substantial technological risk due to the availability of a limited number of technologies for bioproducts manufacturing. Also the available technologies are not fully developed and need further R&D (World Economic Forum, 2011). Technology is one of the key components for successful implementation of lignin biorefinery at a Kraft pulp mill and requires substantial investment (Chambost et al., 2008; World Economic Forum, 2010; Demirbas, 2009). The selection of appropriate technology is important since different technologies produce different products or the same products but with different quality. Also the choice of technology depends on the impact on the operations of a mill, since the mill has to balance pulp and bioproducts production. The technological risk creates avenues for companies to work together to enhance available technologies and create new technologies that will minimize the impact on mill's operation.

Finally, commercialization risk which is associated with marketing and distribution of bioproducts and creating markets for bioproducts (Janssen et al., 2008; World Economic Forum, 2010). Most of the companies interested in bioproducts do not possess sufficient infrastructure to support commercialization of bioproducts (International Energy Agency, 2010). Also most of the bioproducts are competing with petroleum-based products. The latter have strong supply chain networks that make it difficult for bioproducts companies to create a new supply chain strategy. The supply chain strategy to promote bioproducts can effectively be established through collaborations with other companies as highlighted previously in Chevron and Weyerhaeuser, and BP and DuPont joint ventures.

The gravity of these risks depends on the type of biorefinery that an organization is considering to implement. For instance, these risks depend on the type of feedstock, products manufactured, and process and technology adopted for the production of bioproducts. Due to such risks, forest biorefineries have failed to fully develop in the last decade (Kamm et al., 2006; Chambost et al., 2008; Mabee et al., 2010; World Economic Forum, 2010). However, such risks can be mitigated by sharing them with other companies, and choosing the right type of biorefinery with the appropriate technology.

Types of biorefinery

Biorefineries are classified as first, second, or third generation based on the technology and raw materials they use (Fernando et al., 2006). A first generation biorefinery has a fixed processing capability and uses grain as raw material. An example of a first generation biorefinery is a dry-milling ethanol plant, which uses grain to produce a fixed amount of ethanol, other by-products, and carbon dioxide (Kamm et al., 2006). A second generation biorefinery also uses grain as feedstock and has flexibility in producing various end-products based on the product demand. An example of such a biorefinery would be a plant producing plastic, sugar, and ethanol using grain feedstock. In contrast to first and second generation biorefineries, a third generation biorefinery is capable of using a variety of feedstock and processing methods to produce variety of products (Kamm & Kamm, 2004; Kamm et al., 2006; World Economic Forum, 2010). Lignin-based biorefineries classify as third generation as they use different types of wood-based feedstock to produce a variety of bioproducts. The third generation biorefinery is still under research and development stages and several companies and institutions are developing technologies around such processes.

Lignin-based forest biorefinery

Lignin is a complex chemical compound that is found in every woody substance. Wood is composed of cellulose, hemicellulose, lignin, and extractives as shown in Figure 2. Lignin is conventionally burned to generate power for a Kraft pulp mill. Lignin is used to produce several products which include dispersant, binder, adhesive, ethanol, and other chemicals. This provides an opportunity for Kraft pulp mills to enhance their operation and to generate new revenue source and products, and to be more environmentally sustainable by integrating lignin-based forest biorefinery (International Energy Agency, 2009). There are numerous companies such as Domtar, Tembec, Borregaard, Domsjo, MeadWestvaco, Virent, Gevo, Metso, and Lignol producing lignin based products and many other companies are venturing into lignin biorefinery.

The key markets for lignin-based products are in the construction, mining, and agriculture industries. There are some other small and medium markets such as resins, oil well mud additive, rubber additive, water treatment, pesticides, and carbon black markets. The main uses of lignin-based bioproducts are as dispersants in concrete admixtures,

admixtures, oil drilling additives, road dust control, animal feed additive, additive to automotive lubricant, and dyestuff for textiles (Holladay et al., 2007; Pye, 2006). The other significant uses include wood adhesive and binder which accounts for 32.5 per cent of 1.1 million tonnes global capacity (NNFCC, 2011). Recently, new promising uses of lignin are carbon fibers, energy and fuels, pharmaceuticals, and value added chemicals (Holladay et al., 2007; World Economic Forum, 2011).

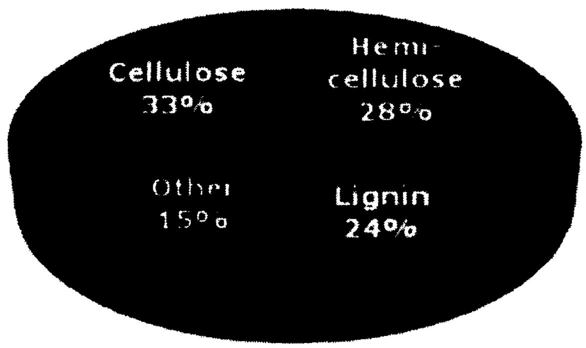


Figure 2– Wood composition
Adapted: (Created from International Lignin Institute, 2012)

The Canadian pulp and paper industry is facing challenges such as the decrease in demand for traditional products, high energy cost, and competition from overseas producers. The impact of these challenges can be mitigated by implementing a lignin-based forest biorefinery at existing Kraft pulp mills (Chambost et al., 2008). Currently, Canadian companies like Tembec and Domtar are producing and selling lignin in domestic and international markets. Some companies like Lignol, Ensyn, and Iogen Corporation, are researching and experimenting, new products and technologies to create new value added products from lignin. Other non-governmental organizations such as FPInnovations are also supporting and participating in research and development of new technologies to use lignin for high value-added products. In fact, FPInnovations in partnership with Centre for Research and Innovation in the Bio-Economy (CRIBE), Natural Resources Canada (NRCAN), and Resolute Forest Products have established a pilot-plant for production of lignin for experimentation and further research (FPinnovations, 2011). These organizations are collaborating to research and test lignin products that can be produced at a Kraft pulp mill.

Several global companies, including MeadWestvaco, Domtar, Domsjo, and Borregaard, have constructed commercial facilities with large capacity to manufacture products from lignin. The products manufactured at these facilities range from raw lignin, dispersants, concrete admixtures, industrial binder, fertilizers, micronutrient, and many other niche uses. Recently companies are exploring new value-added products such as PF resins, carbon fibers, and carbon black. To create new value-added products these companies relied heavily on partnerships with technology, energy, and chemical companies to pursue lignin-based forest biorefinery. Therefore, some scholars believe that partnerships are essential for the successful implementation of forest biorefinery at a Kraft pulp mill and to create value-added lignin-based products (Holladay et al., 2007; Chambost et al., 2008; World Economic Forum, 2011; Demirbas, 2009; International Energy Agency, 2009).

2.2 Partnerships

Partnerships are effectively used by the organizations interested in pursuing forest biorefineries. Therefore, it is essential to understand the concept of partnerships. Partnerships have been described in several other terms in the literature such as alliances, cooperative arrangements, collaborations, strategic alliances, and coalitions (Roberts, 2004; Austin, 2000; Contractor & Lorange, 2004; Brouthers et al., 1995; Doz & Hamel, 1998; Ohmae, 1989; Roberts, 2004). The usage of different terms for the concept of partnership is due to partners having different perceptions about its purpose, operation, and governance structures; hence, partnership is considered a varied and ambiguous concept (McQuaid & Christy, 1999).

Roberts (2004, p.27) defines a partnership simply as "a relationship in which we are jointly committed to the success of whatever process we are in." In contrast, Mohr and Spekman (1994) followed a holistic approach to define partnership. They characterize partnership as having at least two independent organizations that share compatible goals, are looking for mutual benefits, and have a high level of mutual interdependence. Mutual interdependence is necessary for creating a successful partnership strategy that will complete a supply chain network needed for a lignin-based biorefinery, since many companies' posses a part of infrastructure needed

In the past few decades, there has been an unprecedented increase in the number of partnerships through international joint ventures, licensing agreements, co-production agreements, joint research initiatives, and other strategic relationships among two or more firms (Contractor & Lorange, 2004; Hagedoorn, 1993). This increase in partnerships can be attributed to liberalization of global markets, change in demand, and faster diffusion of technology that intensified competition from local and overseas producers. Due to such development and growth, partnerships have emerged as a cornerstone for reinstating competitive advantage, creating new products, and entering new markets (Contractor & Lorange, 2004; Harrigan, 1988; Mohr & Spekman, 1994).

Benefits and drawbacks of partnerships for lignin biorefinery

In the literature there is no consensus over the basic reasons for partnerships. However, the main reason for partnerships that is highlighted in the literature is to gain or sustain competitive advantage in areas such as reduction in production and operation cost, access to raw materials, research and development for new products or processes, and access to marketing, and distribution resources (Austin, 2000; Contractor & Lorange, 2004; Davies, 2000; Doz & Hamel, 1998; Gibbs & Andrew, 2009; Hagedoorn, 1993; Kogut, 2004; Roberts, 2004). More recently, the emerging reasons for partnerships have moved towards access to new knowledge (Kogut, 1988), acquiring new expertise and skills (Inkpen, 2008; Hamel et al., 1989), access to new markets and new products (Culpan, 1993; Roberts, 2004; Ohmae, 1989), creating new technologies (Doz & Hamel, 1998), financial gains (Contractor & Lorange, 2004; Ohmae, 1989), and risk mitigation (Steward, 1999).

The benefits of partnerships to a Kraft pulp mill that is interested in integrating a lignin-based biorefinery are multifold. Firstly, access to technology; some of the Kraft pulp mills do not possess technology to produce lignin at the mill (Chambost et al., 2008), so a partner with lignin technology will save initial investment in its development and further innovation. Secondly, co-development of supply chain infrastructure; a Kraft pulp mill may not possess sufficient infrastructure to develop markets for lignin-based bioproducts. Therefore, a partner with an existing supply chain infrastructure with marketing and distribution capabilities will benefit lignin-based biorefinery. Finally, capital investment; it is estimated that the capital and operating cost of a lignin biorefinery with 50 tonne/d capacity to be between $16-20 million (Paleologou et al., 2011). This will increase or decrease depending on product manufactured and production capacity. Therefore, a partner that can share this initial investment and operating cost will reduce the capital risk for a Kraft pulp mill.

Despite several benefits partnerships can offer to a Kraft pulp mill interested in integrating a lignin-based biorefinery at the mill, it can also have some potential drawbacks. Firstly, partnerships are often considered as 'complicated and risky' since they involve two or more organizations with different interests, goals, corporate structure, culture, and vision, which often leads to delay in strategic decisions due to conflict of interest (Culpan, 1993; McQuaid, 2000). The delay in decision making could have detrimental effect on long-term sustainability of a lignin biorefinery as the bioproducts markets are very dynamic and requirement swift decision making. The complex nature of partnerships and the fear of losing autonomy make partnership an unfavorable strategy and it is often used as the last resort (Austin, 2000).

Secondly, in a partnership there is always a possibility of 'unequal financial and non-financial gains' accrued to partners that may lead to uncertainty about the long-term sustainability of the partnership (Culpan, 1993; Mohr & Spekman, 1994; Austin, 2000). This is a crucial element for a Kraft pulp mill since different organizations have different financial expectation from a project, and financial equity should therefore be addressed in the early stages of establishing a biorefinery project.

Finally, every organization is unique in its culture and corporate structure and that may serve as an impediment for any cooperative arrangement (Austin, 2000; Culpan, 1993; Roberts, 2004; Geringer, 1991). This will pose some challenges for a Kraft pulp mill when they want to partner with a particular company where there is a mismatch of corporate structure and lack of collaborative culture (Chung et al., 2000).

These drawbacks of partnerships need to be addressed to successfully implement a lignin biorefinery at a Kraft pulp mill. To mitigate the impact of these disadvantages several scholars have proposed that a firm needs to: 1) structure its partner selection process and clearly define its evaluation criteria, 2) to clearly understand the objectives of the partnership, and 3) to clearly define the roles and responsibility of the firm and partner (Austin, 2000; Deakin et al., 2001; Culpan, 1993). The next section provides an overview of the partner selection process and evaluation criteria available in the literature.

Partner selection process and evaluation criteria

There has been an increase in the number of partnerships in the last two decades. According to Dyer (2001) the top 500 global businesses have nearly 60 major collaborations each. Despite the growth in collaborations, the success rate has remained fairly low. The failure rate is estimated to be between 50 and 60 percent (Duisters et al., 2008). However, the high rate of partnerships failure has encouraged scholars to study and identify some the reasons behind it such as a mismatch of partners objectives and goals (Brouthers et al., 1995; Varis et al., 2005); cultural incompatibility (Douma et al., 2000; Duisters-Twardy, 2008); poor management, execution, and implementation (Duisters et al., 2008); incomplementary resources (Brouthers et al., 1995; Gibbs & Andrew, 2009); and, poor partner selection process and evaluation criteria (Doz, 1988; Mohr & Spekman, 1994; Holmberg & Cummings, 2009; Wu et al., 2009; Brouthers et al., 1995). Among all the reasons, a study of 810 global alliances conducted by Duister et al. (2008) found that 80 percent of partnership failure is mainly related to the partner selection process and evaluation criteria.

In the literature, partner selection has been considered as a fundamental element in building a successful partnership (Dyer et al., 2001; Holmberg & Cummings, 2009; Doz & Hamel, 1998; Wu et al., 2009). But only a few articles have studied the partner selection process and evaluation criteria. Among those who tried to define the essential elements of a partner selection process, Holmberg and Cummings (2009) concluded that a partner selection process should start with the determination of partnership motivation and goals. Duisters, et al. (2008), on the other hand, suggested that it should start with identification of types of partners a company may need and that the organization should analyze its own culture, financial capabilities, needs and goals, technology, and marketing and distribution infrastructure.

Duister-Twardy (2008) offered the most comprehensive partner selection process consisting of 16 steps, which we described in Figure 3. This research also highlighted that not all companies need to follow all these steps but should customize the process according to their needs.

Apart from the process of partner selection several studies also suggested that using an analytical or systematic method to determine partner evaluation criteria will enhance the success rate of partnerships (Holmberg & Cummings, 2009; Wu et al., 2009). However, developing comprehensive evaluation criteria is a difficult task and represents an extremely critical step (Doz & Hamel, 1998; Douma et al., 2000; Duisters-Twardy, 2008; Geringer, 1991; Mohr & Spekman, 1994; Holmberg & Cummings, 2009; Wu et al., 2009). The literature only highlighted essential components of partner evaluation criteria and provided general criteria for partner selection, such as: cultural compatibility, resource and skills complementarity, goals and objectives compatibility, and financial and marketing capabilities.

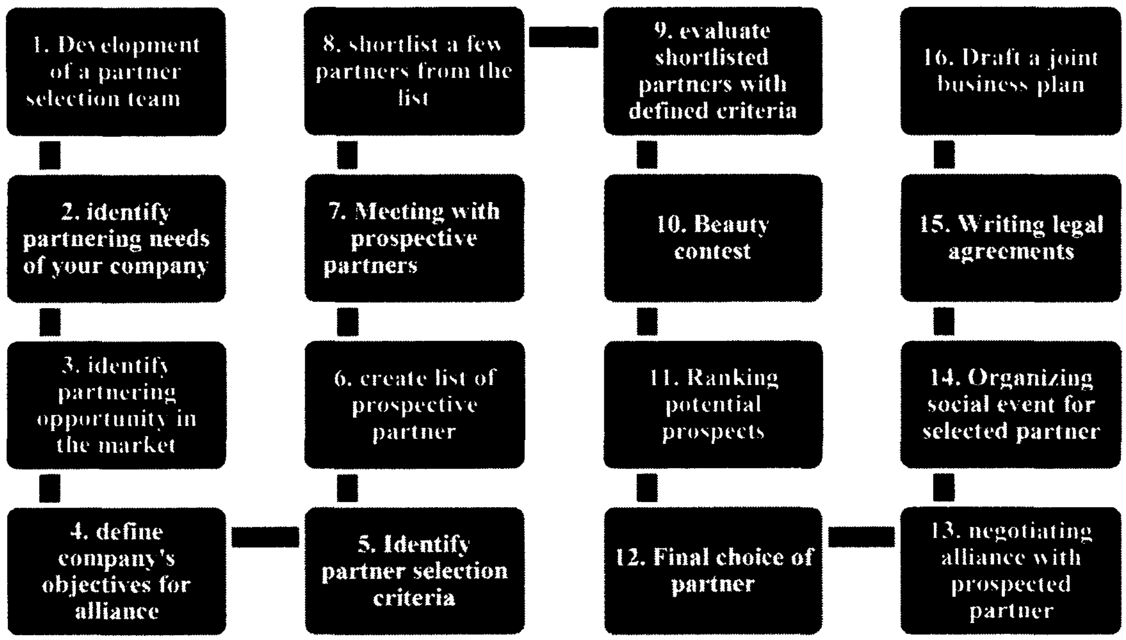


Figure 3. Process of partner selection
Source: (Duisters-Twardy, 2008, p.5)

The research on partner evaluation criteria revolves around Geringer's typologies. Geringer (1991) divided the evaluation criteria into two general types: task-related and partner-related. The task-related criteria pertain to operational skills and resources required to achieve competitive success of collaboration. This includes financial resources, technical know-how, and marketing and distribution resources and infrastructure. The partner-related issues address the efficiency and effectiveness of the partnership, which also include hard to define attributes such as corporate culture, partnership history, and trustworthiness. Geringer's criteria have been used in several studies to further develop partner evaluation criteria (Hoffmann & Schlosser, 2001; Cavusgil & Evirgen, 1997; Tatoglu, 2000).

Partnership for forest biorefinery

Companies within the global forest products industry have been building partnerships within and outside the industry. These partnerships within value chains are considered as the way forward to find potential partners for successfully pursuing forest biorefinery strategy (Demirbas, 2009). A value chain partnership can be defined as "companies in different industries with different but complementary skills which link their capabilities to create value for ultimate users" (Chambost et al., 2008). This can further be understood from the value chain concept.

The value chain concept was first introduced in the 1960s and 1970s to understand markets and competition in the exporting countries (Kaplinsky & Morris, 2001). Later, it was popularized by Michael Porter in 1980s and 1990s through his seminal book "*Competitive Advantage: Creating and Sustaining Superior Performance*". According to Porter (1985), every firm is a collection of activities (Figure 4) that are performed to design, produce, market, and deliver its products or services. In his framework Porter described two categories of business activities that firms perform in order to produce goods or services. The first category is primary activities and involves the transformation of inputs into outputs. These activities are summarized as in Table 2. The second category is support activities which provide support to primary activities. These activities are summarized in Table 3.

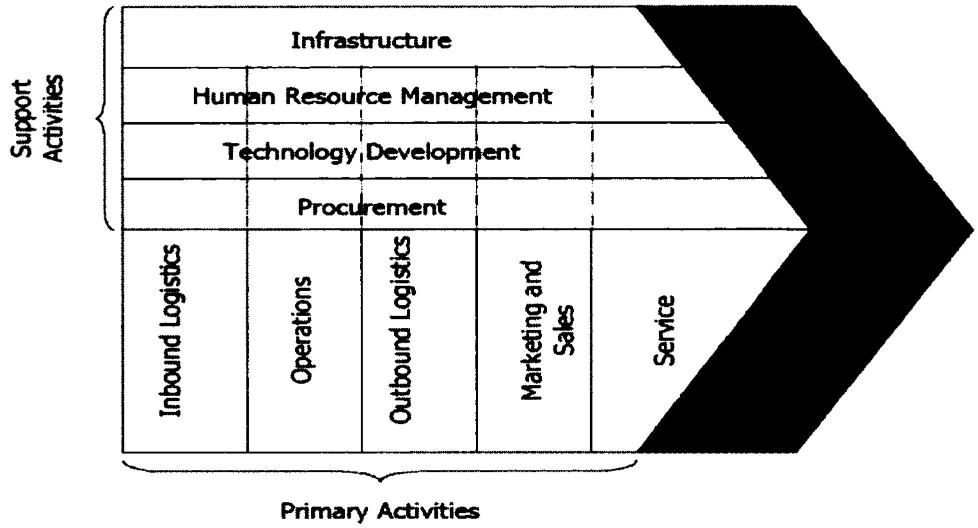


Figure 4. Porter Value chain
Source: (Porter, 1985, p.58)

Table 2. Primary activities in a value chain

Primary Activities	
Inbound logistics	Sourcing of raw-materials and storage
Operations	Process, technology, equipment, and manufacturing facility
Outbound logistics	Distribution of outputs
Marketing and sales	Communication, pricing, promotion, and brand management
Customer service	Technical assistance, repairs, installation, and maintenance

Source: (Porter, 1985, p.62)

Although Porter's value chain framework is widely accepted and used, Fabe et al. (2009) argued that Porter's value chain approach ignored the activities outside the firm and focused on activities performed within the firm. Keeping in mind this criticism, some authors have described the value chain concept in a broader fashion. Shank and Govindrajan (1993, p.56) stated that "the value chain for any firm is the value creating activities all the way from component supplier through to the ultimate end-use produced delivered into the final consumer hands". They view a firm as an integral part of the overall value creating processes, and other organizations as also part of this broader value chain.

Therefore, the role of outside organizations such as suppliers, retailers, dealers, customers, and governments is important and should be included in the value chain of a firm. To understand the role of outside organizations there is a need to study the structure of partnerships created in the global forest products industry. The next section provides a few examples from the global forest products industry of partnerships created with organizations other than forest products industry. The examples illustrate the effective use of value chain analysis to find partners.

Table 3. Support activities in the value chain

Support Activities	
Procurement	Purchasing of raw material, consumables, and equipments and machinery
Technology development	Technological inputs and research and development activities
Human resource management	Hiring, promotion, promotion, and training and development
Firm infrastructure	General management, accounting, finance, legal, and government affairs

Source: (Porter, 1985, p.64)

Partnership within the value chain - Empirical evidences from global forest products industry

The examples in this section represent companies with complementary resources that provide mutual benefits to the partners. These examples include organizations from forestry, automobile, energy, textile, research institutions, and universities that have effectively used partnerships to overcome their weaknesses and mitigate risks involved with a forest biorefinery. They pooled needed resources such as technology, raw materials, capital, and marketing and distribution to complete the value chain of bioproducts manufacturing.

The Aditya Birla Domsjo example

Aditya Birla Domsjo is an illustrative example of how a company can effectively use partnerships to pursue a forest biorefinery. Initially Domsjo started as a bleaching company and over time transformed into a full-fledge biorefinery by creating partnerships throughout its value chain. The primary bioproducts it produces at the biorefinery are: specialty cellulose, lignin, and bio-ethanol (Aditya Birla Domsjo, 2012). Aditya Birla Domsjo transformation has been accomplished through successful partnerships. The partnerships created by Domsjo within its value chain are illustrated in Figure 5.

Domsjo has research collaborations with MORE Research, an independent research and development company in Sweden, UMEA University, a Swedish university with strength in forestry research, and Processum a Sweden based biotechnology research company, for its research and development activities. Similarly, the company has developed a partnership with Ekmans, a marketing and sales service provider specializing in forest products.

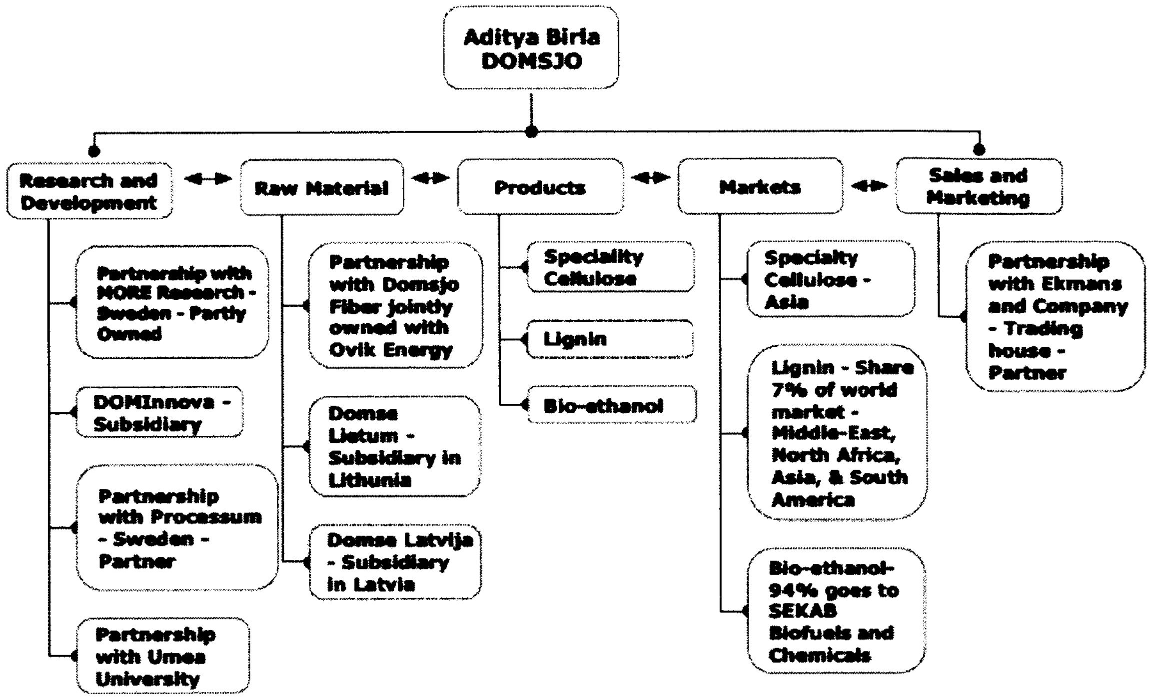


Figure 5. Aditya Birla Domsjo partnerships within the Value chains

The Catchlight Energy example

Catchlight Energy is a joint venture between Chevron and Weyerhaeuser. The focus of the venture is to accelerate the commercialization and economic development of cellulosic biofuels to meet the current and future energy need (CatchLight Energy, 2012). On one side, Weyerhaeuser is a forestry company and an expert in innovative practices in land management, resource pooling and management, and capacity to provide cellulose-based feedstock needed for the production of biofuel (Weyerhaeuser, 2013b). On the other side, Chevron is a petroleum company and an expert in conversion technology, product engineering, advanced fuel manufacturing and fuels distribution. The pooled resources are complementary to each other and are required to successfully build a forest biorefinery.

Catchlight Energy highlights the parent companies' common vision about the future of transportation fuels, which will diversify the energy sources along with addressing the issue of global climate change by providing low-carbon transportation fuel. This is an example of how one company can utilize another company's competitive advantage to overcome weaknesses within their organization. This partnership combines feedstock technology, capital, distribution and marketing, and employees to create a new product for the existing and future markets.

The UPM, VTT, and Volkswagen (VW) – Wood based diesel example

UPM initiative to create wood-based diesel is an example of product portfolio diversification and accessing new market to mitigate the impact of decrease in demand for forestry products. UPM is one of the largest forestry companies in the world and has stated that it intends to become a major player in Europe in the production of high quality renewable biofuels (UPM Kymmene, 2013a). However, UPM does not possess technology for production of wood based diesel, but rather has access to raw material, capital, and distribution infrastructure. The company has adopted partnerships along the biofuels value chain as one of the strategies to achieve its goals. UPM is promoting biodiesel produced through technology developed with VVT- Technical Research Centre which is a leading applied technical research organization in Northern Europe. The UPM BioVerno Diesel is produced from renewable materials and testing is done on cars provided by VW auto group. The raw materials used in the production of biodiesel comprises logging residues, wood chips, stumps, bark, and additional raw material derived from industrial residues such as tall oil from sulphate pulp process (UPM Kymmene , 2013).

These three above described examples of partnerships highlight the value for potential partnerships and show how companies are using collaborations within the forest products industry to create new products, develop new technology, enhance environmental performance, reduce operating cost, and access new markets. However, in order to implement a partnership strategy, several challenges need to be addressed such as choosing partner selection process, and identifying and evaluating potential partners. The next section provides an overview of the literature on partner selection process and evaluation criteria.

2.3 Conclusion and Analysis

The forest products industry is facing numerous challenges such as a decrease in demand for traditional wood and wood-based products, high fiber and energy cost, and competition from low-cost overseas producers. Forest biorefinery has emerged as a key strategy to mitigate the impact of these challenges by diversifying product portfolio, generating new sources of revenues, and accessing new markets. This is also due to increase in demand for renewable sources of energy, economics of fossil fuels, uncertainty about availability of fossil fuels due to geopolitical crisis, and concerns about climate change and environmental risks. The implementation of a lignin forest biorefinery at a Kraft pulp mill can be helpful in overcoming some of the challenges that forest products industry is facing. However, lignin forest biorefinery is a fairly new concept to forest products industry and there are four major challenges. First, technology is important aspects of lignin biorefinery implementation at a Kraft pulp mill. Kraft pulp mills do not possess technology to convert lignin into value-added products. Hence, there is a need for investment in research and development and procurement of technology. There are several technologies such as lignin precipitation and solvent pulping available to produce lignin-based bioproducts, but each technology creates a unique technological challenge for a Kraft pulp mill. The choice of the right technology is critically important for the successful implementation of a lignin biorefinery at a Kraft pulp mill.

Second, the introduction of new technology and process will affect a Kraft pulp mill's production operations. The lignin-based bioproducts need new processes and handling techniques. There is also a need to train the existing workforce to handle new processes, equipment, and machinery. The integration of the lignin biorefinery into the existing plant needs to be done carefully to minimize any detrimental impacts on current operations.

Third, there is a substantial amount of investment needed for the implementation of lignin-based forest biorefinery at a Kraft pulp mill. The investment pertains to procurement of technology, machinery and equipment, training employees, and building supply chain infrastructure.

Fourth, the market demand for lignin-based bioproducts is uncertain and all bioproducts produced from lignin are competing with petroleum-based products (World Economic Forum, 2010; Holladay et al., 2007). A Kraft pulp mill needs continuous R&D activities to create new products, and establish marketing and distribution infrastructure such as packaging, shipping and handling, and dealer and retailer networks to commercialize lignin-based products.

These challenges need to be addressed in order to successfully implement a lignin-based biorefinery at a Kraft pulp mill. One strategy that has been highlighted in the literature to mitigate risks involved in the implementation of a forest biorefinery is to create partnerships with other organizations. However, there is no research that provides details about the types of partners needed to implement a lignin-based forest biorefinery at a Kraft pulp mill. Also forming partnerships can be challenging due to high rate of partnerships failure.

The limitation of evaluation criteria in the literature is that each evaluation criterion was assigned equal importance in the decision. However, they should be assigned relative importance according to their significance in the decision because some criterion can make a partnership a success or failure. The literature also provides some insight into partnerships within the value chain of a company, but there is a need for a targeted approach catering to the issues a Kraft pulp mill may face while pursuing forest biorefinery strategy. Henceforth, a case study approach is followed to complete this research, where a Kraft pulp mill in western Canada is used as a case-study.

Chapter 3: Methodology

3.1 Steps to find partners for integrating a lignin-based biorefinery at the Case Mill

This chapter explains the methodology we use to investigate how a Kraft pulp mill might pursue a partnerships strategy to implement a lignin-based forest biorefinery. The geographic scope of the research is western Canada. Focusing on a case study of a western Canadian Kraft pulp mill permitted face-to-face meetings with mill representatives to fully understand the challenges in implementing a lignin-based forest biorefinery at an actual mill.

For the purpose of this research we collect information from primary and secondary sources. The primary sources included interviews and a questionnaire survey. The secondary data originated from previous research, annual reports, industry reports, government reports, and press releases.

As highlighted in Chapter 2, a formalized and systematic method of identifying and evaluating prospective partners may increase the chances of a successful partnership. The overall process developed for the Case Mill is a partner selection process with eight steps (Figure 6) customized based on insights from existing literature and relevant forestry case studies. All these steps can be followed by any Kraft pulp mill setting up a biorefinery at the mill to select new partners. We on the other hand accomplished our research by following step 3 to step 7. That included identification of types of partners needed for the Case Mill using SWOT analysis, identification of potential partners using value chain analysis, and creation of partner evaluation criteria using literature on the subject and AHP methodology. The complete process of partner selection is discussed in the next few paragraphs.

The first step involves forming an internal partner selection team (Duisters-Twardy, 2008). It is important for this team to include professionals from different areas with different sets of knowledge, skills, and competences to ensure the success of this process (Roberts, 2004). Therefore, an ideal team for the Case Mill would include professionals from finance, human resources, marketing, procurement, operations, and research and development divisions, as well as a team leader with a background in management or administration.

The second step involves identification of partnership's needs, motivation and objectives. One of the causes of partnerships failure is the inability to mobilize internal resources to support it (Dyer et al., 2001). Many studies have supported that this is due to miscommunication of the partnership's needs and objectives (Austin, 2000; Mohr & Spekman, 1994).

The third step includes a SWOT analysis which will allow the Case Mill to analyze all its activities starting from procurement to customer services. This is one of the key steps in partner selection process as it helps the Case Mill to identify the types of partners needed to implement a lignin-based forest biorefinery.

The fourth step involves creation of partner evaluation criteria for the Case Mill. The criteria are based on previous literature and case studies. Chapter 6 provides details about the evaluation criteria used in this research.

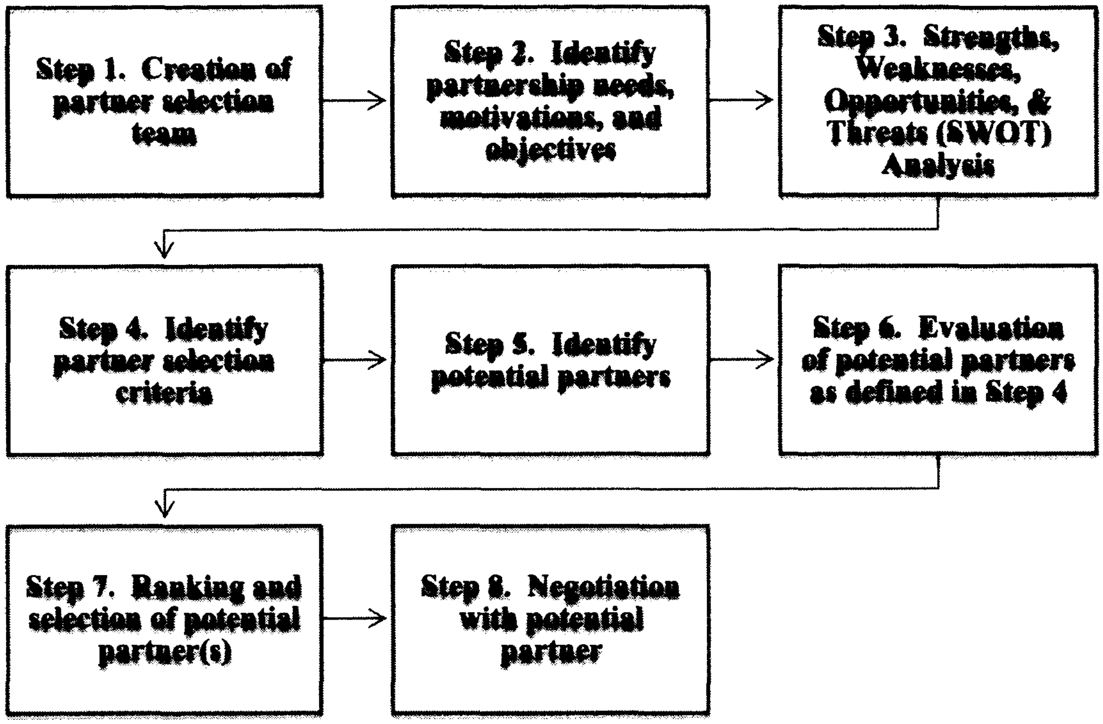


Figure 6. A stylized step-by-step partner selection process for the Case Mill
Adapted from: (Duisters-Twardy, 2008)

The fifth step in the partner selection process is to reflect on the results of the company's SWOT analysis in order to identify what types of partners are needed. Partners within the value chain of the potential products were considered as the best possible options. More details about identification of potential partners are discussed in Chapter 5.

In the sixth step potential partners are evaluated using the evaluation criteria established in step four. The information for evaluation is collected through secondary sources such as company reports, financial statements, and press releases. Chapter 6 provides an example of partner evaluation for the Case Mill.

The seventh step involves ranking of the criteria and potential partners. Ranking is a significant challenge due to the numerous qualitative and quantitative criteria used to evaluate partners. One of the ways to overcome this challenge is to use a questionnaire survey based on the AHP. AHP is a multiple criteria decision-making tool that is widely used to choose among several alternatives (Saaty, 1990). Chapter 6 covers the application of AHP method to rank evaluation criteria and potential partners for the Case Mill.

Though not done in this research, a final step in the partner selection process is to enter into discussion with prospective partners to negotiate terms of a partnership. A team of negotiators meets with the potential partners to discuss the terms, conditions, and benefits of the proposed partnership.

The methods we applied at different stages of the partner selection process are case-study approach, SWOT analysis, value chain analysis, and MCDM AHP.

3.2 SWOT (Strength, weaknesses, opportunities, and threats) analysis.

There are several tools such as PEST (Political, Economic, Social and Technological analysis), PESTLE (Political, Economic, Social, Technological, Legal, and Environmental analysis), and MOST (Mission, Objectives, Strategies, and Tactics analysis) to understand and analyze business environment. But we use SWOT analysis since it serves the purpose of this research which is to analyze the internal environment of the organizations to identify what type of partners are needed at the Case Mill to implement a lignin biorefinery. SWOT analysis helps focusing on the Case Mill and some of the external factors that will effect implementation of a lignin-based forest biorefinery. Chapter 4 is dedicated to the application of this analysis and results for the Case Mill.

We use SWOT analysis to identify the types of partners the Case Mill will likely need to implement a lignin biorefinery at the mill. The origins of SWOT analysis can be traced back to the 1960s and its development is often credited to Harvard Business School and other American business schools (Hill & Westbrook, 1997). Strength for an organization is a resource or capacity that can be used effectively to achieve defined objectives. A weakness is a limitation or defect that will restrict an organization to achieve its objectives. An opportunity is a favorable situation in the organization's environment. A threat is an unfavorable situation that is potentially damaging to an organization's strategy (Harvard Business School, 2005).

SWOT analysis has been commended for its simple and targeted approach on key issues that may affect a company's development and growth (Pickton & Wright, 1998). It has also been widely used by organizations for its simplicity, but at the same time an adoption of SWOT analysis that is too simplistic may lead to serious consequences, such as neglecting important strengths or weaknesses, and perceiving threats or opportunities without supporting information (Pickton & Wright, 1998). Some of the limitations of SWOT analysis can be found in Table 4.

Table 4. Limitations of SWOT analysis

Inadequate definition of factors	**Lack of prioritization of factors**	**Over-subjectivity in the generation of factors: compiler bias**
• Factors which appear to fit into more than one category • Factors which do not appear to fit well into any category • Factors described broadly: lack of specificity • Lack of information to specify factors accurately	• Factors which are given too much emphasis • Factors which are given too little emphasis • Factors which are given equal importance	• Factors missed out: lack of comprehensiveness • Serendipity in the generation of factors • Disagreement over factors and to which category they belong • Factors represent opinions not fact

Adapted from: (Pickton & Wright, 1998, p.104)

For this research SWOT analysis is used to ascertain the Case Mill's needs and requirements to implement a lignin-based forest biorefinery.

The result of the analysis provides insight into the mill's specific strengths and weaknesses while also provide information about opportunities and threats prevalent in western Canada to setup a forest biorefinery. Furthermore, the analysis provides a basis to determine the types of partners needed to implement a lignin-based forest biorefinery at the Case Mill.

3.3 Value chain analysis (VCA)

VCA is useful to understand the relationship within each activity as explained in Chapter 2, sub-section 2.2. In this research we used VCA to understand the markets for lignin-based products and to find partners to implement a lignin-based forest biorefinery at the Case Mill. There are several products that can be produced from lignin and in order to focus this research to a few products we have identified only two products: PF resins and carbon fibers based on their current and future market projections and technology availability. Table 1 in Chapter 1 provides an overview of commercial market for these products.

In order to identify value chains for these two products, we analyzed the markets for carbon fibers and PF resins in Alberta and British Columbia. We used industry reports, government reports, and reports from other organizations in the region. We identified prospective partners within the value chains of PF-resins and carbon fibers. More details about the value chains can be found in Chapter 5 on VCA.

3.4 Multi-criteria decision making (MCDM) analytical hierarchical process (AHP)

MCDM AHP is a tool used to assign relative weights to each partner evaluation criterion and rank potential partners.

There are generic evaluation criteria available in the literature as discussed in Chapter 2, but each criterion is weighted equally. For example, culture compatibility is equally important as financial compatibility. However, each criterion should be weighted based on its relative importance in decision making. Consider a scenario where a company is looking for a location for a new lumber production plant. The price of the land will be less important than the geographic location since the company wants the plant closer to the markets and raw-material sources. Therefore, the location of the land is more important than any other criteria, in such a situation company will trade-off between two or more criteria. Hence there is a need to assign relative importance to each criterion as to their importance in achieving the goal. In order to assign weight to each criterion we conduct a survey with a select group of experts in various fields. A survey design was adopted from Saaty (1990) methodology to conform to the requirements of the AHP, a MCDM tool. Under AHP methodology, there is a need to develop a set of criteria that will be used to judge the potential partners in this research. Where eight fundamental steps were followed to implement the AHP method to the partner selection problem.

The first step in an AHP process is to set a goal for the research. Our goal in this research is to select partners using defined evaluation criteria. In step two, we defined the criteria used in this research. We expanded more on the partner evaluation criteria in Chapter 6. Based on the criteria, we design in step three an electronic questionnaire for the survey. A copy of the questionnaire can be found in Appendix 1.

Further in step four we selected participants for the survey. We included 17 experts from different fields within the biorefinery industry. The experts are from engineering, finance, marketing, distribution, resources, environment, human resource, academia, and government. More details about the sampling can be found in the next section on data collection. In step five we use pairwise comparison to ascertain the relative importance of each criterion (Triantaphyllou & Mann, 1995) by comparing them in pairs to judge which criterion is preferred over the other. For the pairwise comparison AHP uses a 1 to 9 scale to rank the different criteria. An overview of the scale used in the survey is presented in Table 5.

Step six involves assigning weights based on the responses from the participants, we use AHP software *'**Expert Choice**'*, which is specially developed to help decision makers for computation. This software permits straightforward analysis of the pairwise survey results and computation of weights for each criterion and alternatives. A more detailed explanation of AHP calculations is provided in an example in appendix 2.

Table 5. AHP Scale

Intensity of Importance	Definition	Explanation
1	Equal Importance	Two activities contribute equally to the objective
3	Weak importance of one over other	Experience and judgment slightly favor one activity over other
5	Essential or strong importance	Experience and judgment strongly favor one activity over another
7	Demonstrated importance	An activity is strongly favored and its dominance demonstrated in practice
9	Absolute importance	The evidence favoring one activity over other is of the highest possible order of affirmation
2,4,6,8	Intermediate values	When compromise is needed

Adapted from: (Triantaphyllou & Mann, 1995, p.3)

For step seven, the potential partners are identified with the help of value chain analysis and pairwise comparison is done based on supporting information such as financial statements, distribution channels, type of products manufactured, and R&D activities about each potential partner. This information is collected through secondary sources which include company reports, press releases, and other documents. More details about collected information is provided in Chapter 6. Finally, based on the information collected through previous steps, potential partners were ranked in step 8 according to the criteria using *'Expert Choice'* software.

3.5 Data and information collection

Data and information collection is crucial in a research, as the data will be used to answers research questions. In this study, data was collected by direct observation, personal interviews, participation at the meetings, forums and field school, questionnaire survey, publically available reports and documents, and available literature on the subject.

This research relies on knowledge and expertise of people involved in forest biorefinery industry. For this purpose we used purposive sampling to select participants in the survey. A purposive sampling is a type of non-probability technique that is used when one needs to study certain aspects of a domain with the help of knowledgeable experts from the field of study (Bernard et al., 1986). In this type of sampling researcher decides what type of information is needed and finds experts who are willing to provide that information (Bernard, 2002).

However, there are possible limitations of purposive sampling that the researcher must rely on his or her judgment about the reliability and competency of the participants (Campbell, 1955). The responses of the participants are also subject to the personal biases.

To avoid these pitfalls, we included experts with knowledge in at least one aspect of biorefinery industry.

Personal interviews of the Case Mill's officials were carried out to understand the operations of the mill. The unstructured interview approach was adopted for conducting interviews. Interviewees were chosen because of their expertise and position at the Kraft pulp mill. All of the interviews took place at the Case Mill. The information collected from these interviews was used to complete SWOT analysis of the Case Mill and to understand what types of partners the mill could need.

The key documents referenced in the study include the Case Mill annual reports, news releases, and other reports pertaining to the mill. The information from these documents feeds into the SWOT analysis of the mill. Other documents consulted include industry and government reports, news releases, and previous research on the subject matter.

Chapter 4: SWOT Analysis of the Case Mill

4.1 Introduction

One of the key tasks in the partner selection process is to determine the types of partners needed to implement a lignin-based forest biorefinery at the Case Mill. As explained in the methodology Chapter 3, SWOT analysis is the tool we used for this purpose.

4.2 The purpose of SWOT Analysis of the mill

The SWOT analysis of the Case Mill provided the necessary details and information about its capabilities and deficiencies for implementing a biorefinery. The activities analyzed under this analysis include research and development, raw materials and sourcing, operations and processes, distribution infrastructure, and marketing and sales.

The purpose of the SWOT analysis is as follows:

1) To ascertain areas of weaknesses and strengths of the Case Mill.
2) To identify opportunities and threats in pursuing lignin biorefinery integration at the Case Mill.
3) To identify the types of partners needed to implement a lignin-based biorefinery at the Case Mill.

4.3 About the Case Mill

The Case Mill produces Northern Bleach Softwood Kraft (NBSK) pulp and produced 370,000 tonnes of pulp in 2012. The mill was completely renovated in the 1990s and is considered a modern Kraft pulp mill. The mill uses a Kraft pulping process, which is one of the most widely used chemical processes for making pulp from wood. Lignin is one of the by-products that is produced at the mill; currently it is burned to generate power to run the mill's production process.

4.4 Results of SWOT analysis of the Case Mill

The analysis is divided into five sections representing each important production activity performed at the pulp mill.

4.4.1 Research and Development (R&D)

Given that the technology for producing bioproducts from lignin are in the nascent stage (Ackom, 2013), the focus of the implementation of a lignin-based forest biorefinery is on technology and R&D. Indeed, R&D activities that continuously improve technology and processes are essential for long-term sustainability of a forest biorefinery.

The management at the Case Mill claims to be committed to R&D activities that create new wood and wood-based products. However, the mill's R&D needs are supported by subsidiary organizations in the region and outside research organizations. The relationship with subsidiaries and outside organizations could be helpful for the mill to continuously create innovative lignin-based bioproducts. The R&D activities are also supported by the provincial government through funding for various environment friendly projects.

Besides research initiatives and government funding, the geographic location of the mill is of strategic importance, since the western Canadian region has well established forestry, petrochemicals, automotive, pharmaceuticals, construction, mining, and agribusiness industries. These industries may contain companies that could be potential collaborators for R&D activities.

Within the Alberta and British Columbia region, many companies and institutions are involved in R&D of bioproducts, which can serve as an opportunity for the mill to collaborate with these organizations. For example, FPInnovations is a Canadian organization that is among the world's largest private not-for-profit forest research institutes (FPInnovations, 2013) involved in lignin bioproducts R&D. Another example of an institution involved in biotechnology R&D activities is Alberta Innovates-Technology Futures. The latter provides research and development, testing and pre-commercialization support to companies in the region (Alberta Innovates-Technology Futures, 2013).

Although there are opportunities for the Case Mill to collaborate with outside organizations and gather funds from other sources for R&D activities, there is a lack of funding for such activities at the mill level. The focus of the mill's research program is on process improvement, new equipment, energy efficiency, and sustainable practices. In addition, the Case Mill does not have an in-house R&D facility (Interviewee A, 2012), which can be an impediment for the long-term sustainability of biorefinery at the mill.

4.4.2 Raw material and sourcing

One of the most essential parts of a manufacturing process for lignin-based forest biorefinery is raw materials. For a biorefinery, securing a low-cost feedstock is essential for production of bioproducts from lignin. The availability and type of feedstock will determine the process and technology required to integrate a biorefinery at the mill (Chambost et al., 2008).

The geographic location of the Case Mill provides access to high quality wood fibre that facilitate the production of pulp and possible lignin products. The mill has long term harvesting contracts with the provincial governments, which secures a consistent supply of raw materials. The raw materials in the form of wood chips are procured locally through subsidiary and other sawmills. This reduces exposure to price and quality fluctuations. The mill's proximity to sawmills and harvesting lands reduces transportation cost which is a substantial cost component. The recent acquisition of a sawmill by the company will also secure the future supplies of wood chips for pulp production. The presence of a large number of sawmills in the region can fulfill any additional raw materials needs for a lignin biorefinery operation (Interviewee A, 2012). These advantages make the mill a feasible location to produce lignin-based bioproducts.

However, there are some inherent risks to feedstock supply for the mill. These risks include harvesting contracts connected to government policies. Any change in the policies will affect the cost of fibre for pulp and possible lignin products. Another challenge is the mountain pine beetle epidemic, which is spreading within the region and making the future level of harvesting in the region uncertain. About 50 percent of the total volume of lodgepole pine was killed in BC (Canadian Forest Services , 2012c) and nearly six million hectares of pine forest in Alberta is expected to be affected by mountain pine beetle, that is about 15 percent of the total forest area of Alberta (Alberta Government, 2013). There is even a threat that the outbreak will continue eastward through the boreal forests of Canada (Natural Resources Canada, 2013).

These challenges will create imbalance in demand and supply of raw materials that are needed to produce lignin-based bioproducts. Furthermore, this will affect pricing of the lignin bioproducts due to higher procurement and transportation cost of inputs The transportation cost for up to 50 percent of fibre supply costs at Canadian mills, and 25-40 percent of products delivered by the industry (Lehou et al., 2012), therefore, it has to be managed effectively. Any movement away from current harvesting land due to either mountain pine beetle or a change in harvesting contracts will increase the cost of the final product such as Kraft pulp and lignin products.

4.4.3 Operations and Processes

The role of operations, processes, and equipment for the transformation of a Kraft pulp mill into a biorefinery are very crucial. There are several processes available for production of lignin, but the selection is largely dependent on the type of feedstock available and type of products the mill wants to manufacture (Interviewee B, 2012; Chambost et al., 2008).

The Case Mill is self-sufficient for its energy needs, and recently installed energy efficient technology (Interviewee A, 2012). There are processes that can be integrated into the existing Kraft pulping process to produce lignin-based bioproducts (Holladay et al., 2007). Also there are several companies, research organizations, and institutions in the region that are working on the development of various bioproducts from lignin (Holladay et al., 2007). The mill can collaborate with these organizations to use their technology and processes for manufacturing lignin bioproducts. Within such arrangement the mill can be used as a pilot plant for the production of lignin products due to available infrastructure and manpower at the mill.

However, there are also a few challenges the Case Mill will face. First, lignin is an important fuel for a Kraft pulp mill since it contributes to the mill's energy self sufficiency by running its recovery boilers and generating power (Holladay et al., 2007). The amount of lignin that can be recovered from the process will be limited due to its importance in energy self-sufficiency. The availability of lignin extraction depends on the cost of energy procured from the other sources such as natural gas. Second, the mill has no experience managing processes for producing bioproducts. Third, the mill does not have an in-house process to produce lignin-based bioproducts (Interviewee A, 2012). Therefore, the mill has to rely on outside organizations for technology and also for the maintenance and technical problems. Finally, the integration of lignin manufacturing process within the existing Kraft pulp production process will disturb the existing operations at the mill. Given their seriousness, all of the above issues need to be addressed while implementing a lignin biorefinery at the mill.

4.4.4 Distribution Network

A distribution network is an arrangement of people, storage facilities, and transportation that move goods and services from producers to consumers (Hiam & Rastelli, 2007). Distribution infrastructure is considered as one of the most important sources of competitive advantage (Stalk, 1989). The lignin-based products are competing with petroleum-based products such as oil based PF resin and carbon fiber that have well-developed distribution infrastructure. Lignin-based products require a strong distribution infrastructure support to make them available in the prospective markets and competitive with other products.

The geographic location of the Case Mill provides a strategic advantage over the other pulp mills in the region. Apart from its location, there are several established industries in western Canada such as forestry, petrochemicals, pharmaceuticals, aerospace, automobile manufacturing, construction, mining, and agribusiness that could benefit from the biorefinery. A lignin-based biorefinery can manufacture products that can be used in all or some of these industries. Lignin-based products are derived from renewable sources while some of the inputs used in these industries are derived from non-renewable sources such as petroleum. The addition of lignin-based input will provide environmental benefits in the form of renewable inputs in the production operations of these industries. Furthermore, currently the Case Mill exports NBSK to Asia, North America, South America, and Africa (Interviewee C, 2012). These are the potential overseas markets for lignin products (NNFCC, 2011). The mill also has access to a wide distribution network across the globe and also has established long-term relationship with shipping companies. This distribution network can be used to reach domestic and overseas markets for lignin bioproducts.

In the region there is availability of strong infrastructure around utilization of natural resources, which can be used by the mill to its advantage (Government of Alberta, 2013; Government of British Columbia, 2013). Apart from local infrastructure, organizations in the region are also investing in expanding to create new products from renewable sources. This provides the mill with an opportunity to collaborate with these industries by introducing lignin-based bioproducts in their operations. Governments of Alberta and British Columbia are also building infrastructure to support the development of biorefining capabilities in the region (Government of Alberta, 2013; Government of British Columbia, 2013).

Although there is support from the government and an availability of well-developed infrastructure, there are a few challenges that still need to be addressed. Firstly, a lignin-based biorefinery needs special delivery infrastructure due to its chemical composition and nature (Holladay et al., 2007). Secondly, the mill does not have knowledge about existing bioproducts distribution channels which may be very different from forest products distribution channels. Finally, it would be challenging for the mill to adjust its current distribution channel to introduce new products. These challenges can be addressed through a collaborative strategy where Case Mill can provide the necessary support alongside partners with strong distribution channels.

4.4.5 Marketing and sales

Key components of marketing and sales are to know you consumer and to deliver products that are appealing to them (Hiam & Rastelli, 2007). Traditionally, marketing in the forestry industry had no significance due to the large market demand in relation to the number of producers (Stuart, 1970). More recently, the marketing and sales function in the forestry industry is significant due to intense competition (Canadian Forest Service, 2011).

The successful implementation of a biorefinery also involves marketing and sales strategies and infrastructure for promoting lignin-based bioproducts since many companies find it challenging to develop a market for bioproducts (World Economic Forum, 2011; Ackom, 2013; International Energy Agency, 2009). A key to develop a strategy for the marketing of lignin bioproducts is choosing the right product (Holladay et al., 2007).

The Case Mill studied in this research has marketing and sales office on West Coast of Canada (Interviewee C, 2012). The sales and marketing is also supported by the mill's parent company's sales office in Asia, especially China and Japan. The local and overseas sales offices could be beneficial for lignin bioproducts sales. The Case Mill brand recognition in North America and Asian markets can be used to promote lignin bioproducts using the same brand name.

One of the challenges the mill will face at this level is to balance its marketing efforts for pulp products and lignin bioproducts. Another challenge is competition from other companies producing or considering production of bioproducts. This could create a very competitive marketing environment for the Case Mill, which could lead to higher marketing and sales expenses. Several companies have adopted collaborative strategies to address this challenge. For example, DuPont and BP entered into a joint venture to manufacture biobutanol, where DuPont used BP's distribution network and marketing capabilities to enter new markets and its technological capabilities to create unique products (Butamax, 2013). The mill can collaborate with companies from either the petrochemical or agribusiness industries to expand its distribution infrastructure.

4.5 Conclusion

On the basis of the SWOT analysis, we find that the Case Mill has geographic and strategic advantages as far as the feedstock is concerned which the mill procure from subsidiary sawmills and other sawmills in the region. The mill has long term harvesting contracts in BC and Alberta regions, which provides sawmills access to lumber, and wood chips and residuals to mill for pulp production.

The SWOT analysis of the mill also highlighted that the company does not have sufficient R&D infrastructure to support a biorefinery technology. Apart from technology, the mill does not have the necessary infrastructure required to market and distribute lignin-based products.

The types of partners the Case Mill need might include: a) a technology partner that will provide access to lignin technology for the mill, and b) a partner with capital and marketing and distribution infrastructure to support market development of lignin products. In this scenario, the possible strategy for the Case mill is to create a multi-company joint venture where the mill can be used as a pilot plant and provide feedstock material, skilled workforce, and part of the capital investment. The other companies in the joint venture, could include a technology provider for process and technical assistance and a company to provide capital in addition to marketing and distribution infrastructure. The multi-company joint venture will then bring together three separate firms with different sets of expertise and shared vision and goals. The proposed partnerships will then address the issues uncovered in the SWOT analysis and provide a strategy in support of a successful transformation of the Case Mill into a lignin-based biorefinery.

Chapter 5: Value chains for lignin-based products and list of potential partners or customers

5.1 Introduction

This chapter seeks to establish value chains for lignin-based products in western Canada. We identified various players within these value chains that can help the Case Mill to implement a lignin biorefinery. The products that our analysis focusses on are PF resin and carbon fibers. These two products are chosen due to their potential markets and the availability of technology to produce these products from lignin. The potential market value for these two products is estimated to be \$9.6 billion for PF resin and \$1.6 billion for carbon fibers (Smolarski, 2012). Furthermore, there are technologies available that can be integrated within the existing Kraft pulping process to make these products (Holladay et al., 2007). All this makes these products a good alternative for the Case Mill.

The methodology we adopted to do a value chain analysis is based on the primary and secondary research consisting of interviews, case studies, and industry and government reports. We identified a number of industries in western Canada related to these products. Further, we identified companies within these industries that use carbon fibers and PF resins. These two products are selected due to their current and future market demand as highlighted in Chapter 1.

5.2 Value chain identification

The Case Mill's current value chain starts with the procurement of harvesting contracts from the provincial government. Then the harvesting contractors are hired to provide wood chips to the mill for the production of Kraft pulp. Apart from the wood chips, the mill also needs several chemicals such as sodium hydroxide and sodium sulfide, which are procured locally (Interviewee A, 2012). The wood chips are then processed with chemicals to produce Kraft pulp. The extracted pulp is then sent to packaging and storing facility. Finally, orders are received by the marketing and sales office and the packages are sent via rail and trucks to the customers in North America and to the nearest port for shipping to China and other international markets (Interviewee C, 2012). Figure 7 presents the value chain of the Case Mill.

It can be seen from the value chain of the Case Mill that the lignin is currently burnt in the process to produce energy for the mill. As highlighted in the previous chapter on SWOT analysis, there is a need to introduce technology, equipment, and market and distribution infrastructure at the Case Mill. The Case Mill could follow a collaborative value chain approach since it does not possess all the resources needed to implement a lignin-based biorefinery as highlighted in the SWOT analysis.

The collaborative strategy can be implemented by identifying the potential partners. In order to find potential partner the first step is to find applications of carbon fibers and PF resins in various industries, as this will help the Case Mill to focus on industries that are already either using or producing these products. Table 6. provide a list of industries that use these products.

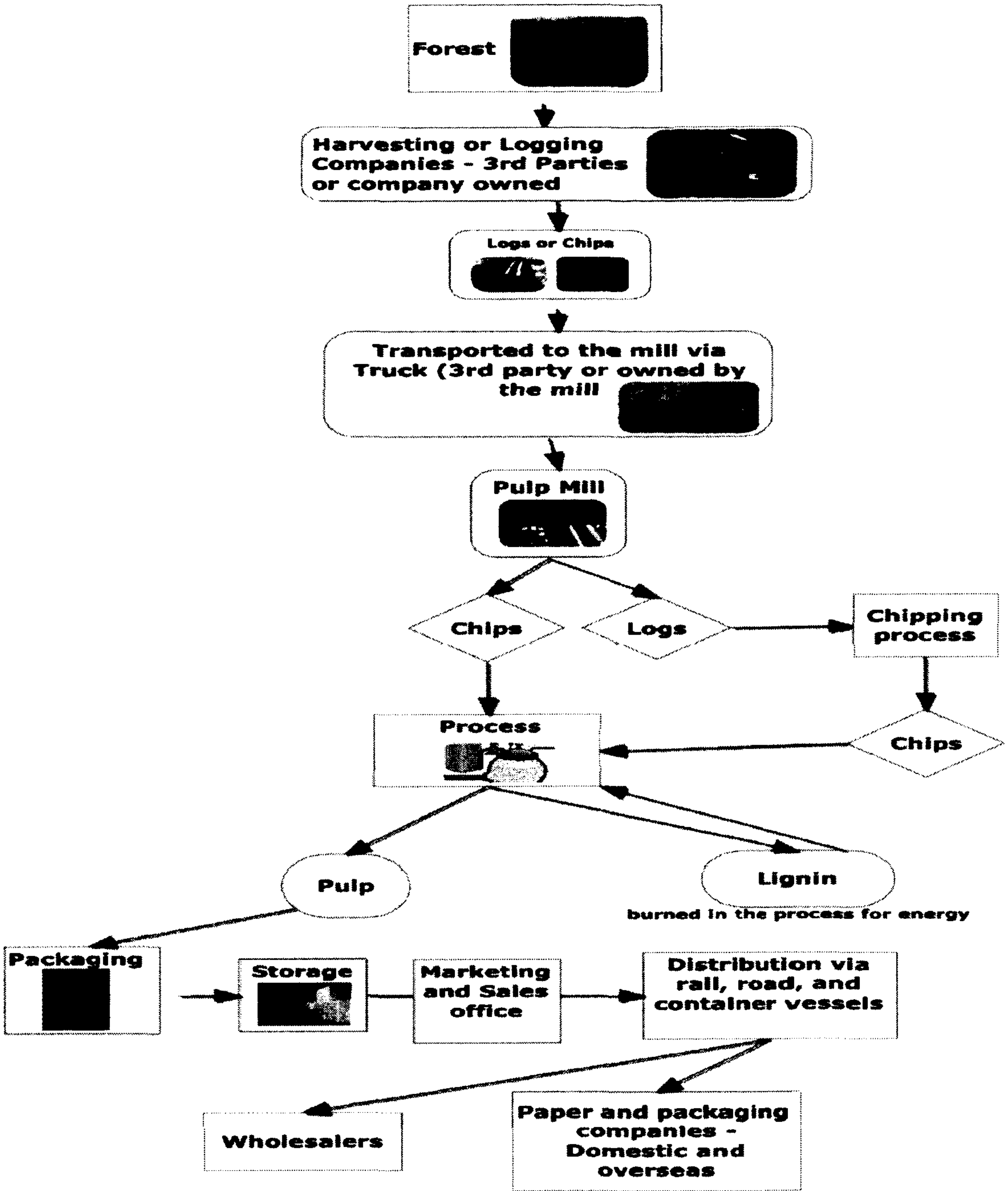


Figure 7. Value chain of the Case Mill

Table 6. List of industries for carbon fiber and PF resins

Carbon Fibers industrial applications	PF Resins industrial applications
Aerospace and Aircraft	Forest products – Plywood, LVL, MDF, and OSB
Military and Defense	Coating and Adhesive
Sporting Equipment	Food additives
Home Furnishings	Automobile
Medical Instruments	Aerospace
Automobile	Healthcare

5.2.1 Value chain of Kraft lignin-based carbon fiber

Kraft lignin originates from both hardwood and softwood and is isolated with various chemical processes. Kraft lignin can be converted into carbon fiber (Holladay et al., 2007). Currently, over 90 percent of the carbon fiber originates from oil-based raw-material (Norberg, 2012). This is an opportunity for the forest product industry to replace a part of carbon fiber produced from petroleum with Kraft lignin-based carbon fiber. A simple value chain for the Case Mill to produce Kraft lignin-based carbon fiber is shown in Figure 8. As highlighted in the SWOT analysis in the previous chapter the Case Mill does not have the technology and strong market development infrastructure. The value chain for Kraft lignin based carbon fiber can be completed with the help of a technology organization and a company with a strong marketing and distribution infrastructure and capital needed to procure equipment.

The value chains of the carbon fiber depend on the type of the carbon fiber products that companies are manufacturing. A good example to explain the value chain of carbon fiber is the automobile industry. The automobile industry uses carbon fiber in some car parts to make them lighter and stronger. The companies will procure the required carbon fiber from a forest biorefinery, a renewable source, and provide consistent supply of carbon fiber sources compared to petroleum-based carbon fiber which rely on crude oil resources and prices (Holladay et al., 2007).

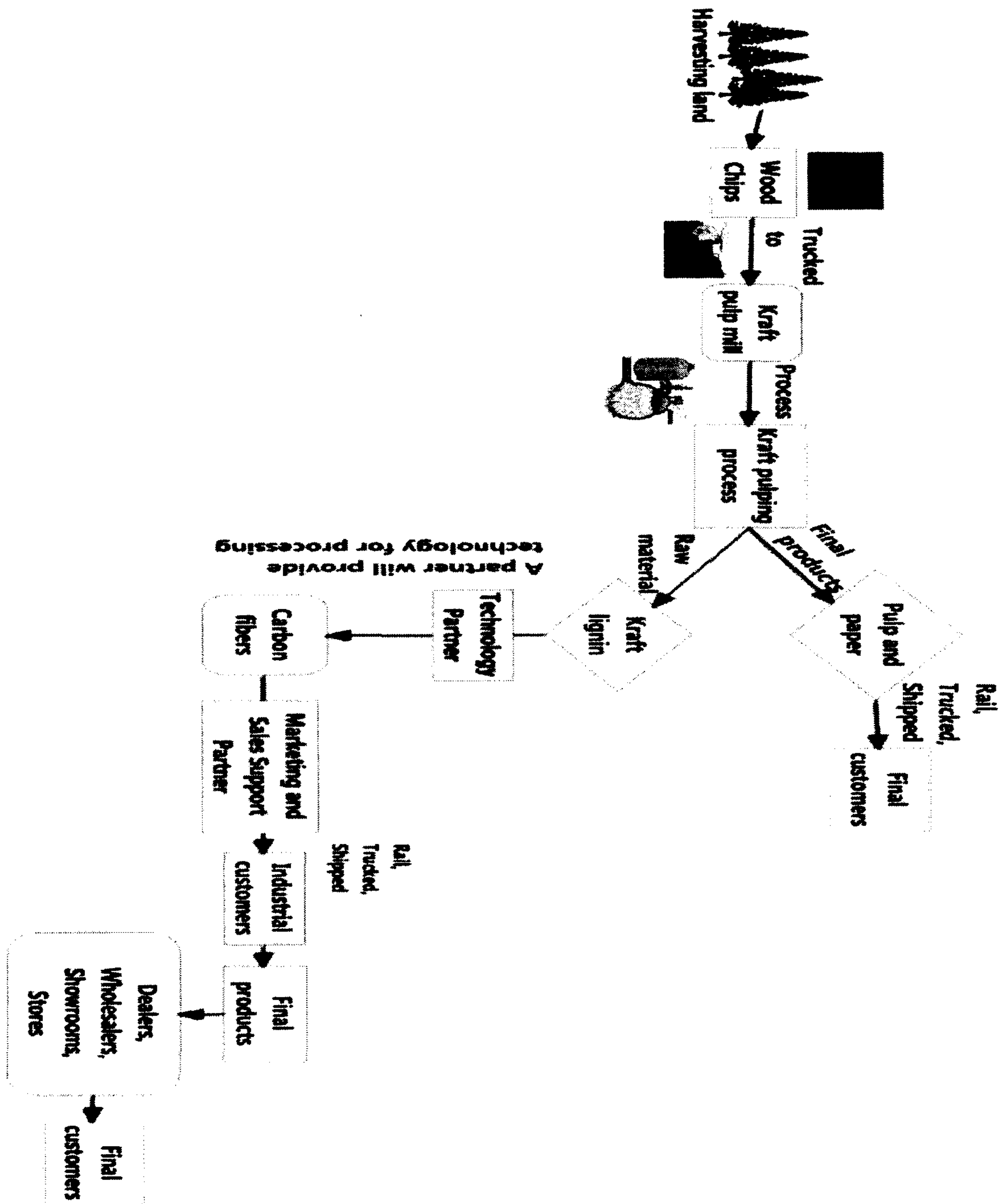


Figure 8: A simple value chain of a Kraft lignin-based carbon fiber

The value chain of carbon fiber in western Canada includes industries within the region that can use carbon fibers in their production process. The industries in western Canada that are already using carbon fibers include:

1) **Aerospace**: There is a strong presence of the aerospace industry in western Canada, especially in the province of Alberta. Carbon fiber has a high demand in this industry due to its lightweight and high thermal conductivity properties (Traceski, 1999). The sector is involved in the manufacturing and R&D of equipment and components from carbon fibers.

2) Aircraft: Carbon fiber's light weight and strength properties are ideal for replacing aluminum alloy components. There are several original equipment manufacturers (OEMs) in western Canada that can use carbon fiber in manufacturing components. Several aircraft manufacturers are already using carbon fiber in aircraft manufacturing. The use of carbon fibers for component manufacturing increases fuel efficiency and decreases emissions.

3) **Automobile**: This industry use carbon fiber reinforced plastics to make automotive structure to reduce weight and improve fuel efficiency (Traceski, 1999). There are several automobile parts manufacturers in the province of Alberta who can use a part of carbon fiber produced at the Case Mill.

4) **Petrochemicals**: Western Canada is a leading petrochemicals manufacturer in Canada. The sector produces chemicals and biochemicals. The Case Mill can create partnerships with petrochemical companies to make carbon fiber from lignin instead of using petroleum as an input for carbon fiber manufacturing.

5) **Defense**: Carbon fiber has been extensively used in defense sector due to its light weight and high strength. The defense sector in western Canada is expanding into new markets and industries. This provides opportunities for the Case Mill to collaborate and manufacture carbon fiber with this industry. Western Canada provides significant opportunities as a market and to find potential partners to manufacture carbon fiber at the Case Mill.

5.2.2 Value chain of Kraft lignin-based PF resins

PF resins have a wide range of industrial applications due to their physical strength, hardness, glossy finish, electrical properties, heat resistance, and chemical stability (Pye, 2006). The global demand for PF resins is rising due to the general increase in world economic activity. The largest market for PF resins is plywood and other related wood products (IHS , 2011).

The market for PF resins in western Canada is dominated by the wood adhesives industry especially in production of plywood, LVL, MDF, and OSB. The other industries that use PF resins in their production processes include construction, specialty chemicals, automotive, and aerospace. A simple value chain of the Case Mill producing Kraft lignin-based PF resins is shown in Figure 9. Again, the mill does not possess the technology, marketing and distribution infrastructure, and required investment, this can be provided by the partners within the value chain.

The industries within the value chain of PF resins, which could be the potential partners or customers for the Case Mill include:

1) **Panel board**: PF resins based binders for panel board manufacturing is the largest market representing nearly half of the PF resins used (IHS , 2011). The market is segregated between plywood, OSB, MDF, LVL, and other engineered panel boards. There is a large market for PF resins as binder in western Canada due to the large number of panel board manufacturers in the region. These companies could be potential partners or customers. There are also a large number of chemical companies involved in manufacturing of PF resins in BC and Alberta. The Case Mill can collaborate with these companies for R&D activities.

2) **Construction**: PF resins have been used in construction industry as adhesives and concrete admixtures (Pye, 2006). The construction sector in Alberta accounted for 7.8 percent of its GDP in 2011 (Goverment of Alberta , 2013), similarly the sector in British Columbia accounted for 7.0 percent of its GDP in 2011 (Wilson, 2012). There are opportunities for the Case Mill to produce PF resins for this industry.

3) **Specialty chemicals:** PF resins have been used as antioxidants in lubricants, animal feed supplements, specialized adhesives, and in the rubber industry. They are used as dye dispersants, dispersants for herbicides, pesticide, and fungicides, and in the manufacturing of circuit boards. Western Canada has a presence of national and international chemical and agri-business companies that are involved in R&D activities around PF resins. The Case Mill can collaborate with these companies and provide them with PF resins they require.

4) **Aircraft, Aerospace and Automobile**: PF resins have high thermal stability and fire resistant properties which are utilized in a wide range of manufactured components. These applications include gas valves, automotive brake pistons, pulleys, and hydraulic and

water pump seals. The applications of phenol resins in the aircraft and aerospace manufacturing, due to its resistance to chemical and corrosiveness, include electrical commutators, switches, and wiring devices. There are several automobile original equipment manufacturers (OEMs) in the province of Alberta, they can use PF resins produced at the Case Mill.

To conclude, PF resins from a forest biorefinery could add environmental value to these industries in the region since the majority of PF resins is currently manufactured using petroleum-based raw materials.

5.3 Prospective partners or customers

The prospective partners or customers are selected based on their current product portfolio, geographic location, and potential use of identified products. As highlighted in the SWOT analysis, the western Canadian region has a presence of a large number of forestry and chemical companies with strong infrastructure for biorefinery development. The illustrative list is prepared from a complete list of forestry, petrochemicals, and technology companies in the region.

The criteria we use to create an illustrative list of companies are: first, whether the company has a production facility in the western Canada and use or manufacture either carbon fiber or PF resins, second, whether the company has a technology to produce either carbon fiber or PF resins, and finally, involvement in future and current projects around biorefinery. We selected a company if it satisfies at least one of the criteria.

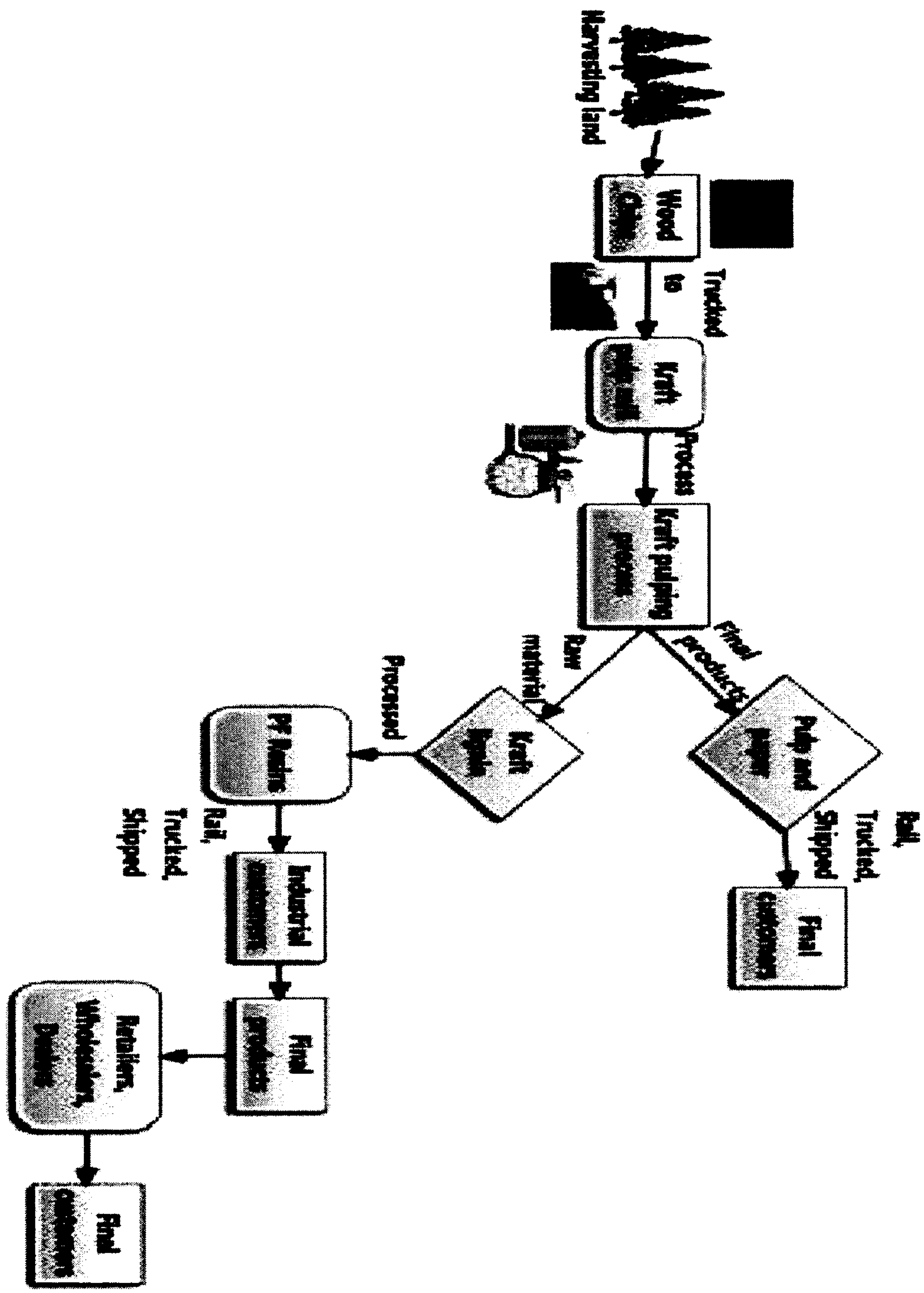


Figure 9: A simple value chain of Kraft lignin-based PF resins

The list of prospective partners or customers includes partners or customers from three different industries which include forestry, chemicals, and biotechnology. The list of such partners or customers is summarized in Table 7. These companies are part of the value chain identified in the previous section. All of these companies are either part of the value chain or provide raw-materials to the industries identified in the value chain. Some of the companies in the list are already manufacturing both PF resin and carbon fibers sourced from petroleum based raw materials.

Table 7. List of prospective partners or customers

Industry	Companies	Potential Partner or Customer	Current Products	Identified product
Forestry	West Fraser LVL	Customer	LVL	PF resin
	Weyerhaeuser	Partner	Lumber, OSB, Plywood, Engineered wood	PF resin
	Ainsworth Engineered	Both	Engineered wood	PF resin
	Richmond Plywood	Both	Wood panel	PF resin
	Canoe Forest Products	Both	Plywood	PF resin
	Tolko Industries	Both	Lumber, panels, specialty wood, Kraft paper	PF resin
Chemicals	Momentive	Both	Specialty chemicals and materials	PF resin or Carbon fiber
	BASF Chemicals	Partner	Chemicals and plastics	PF resin or Carbon fiber
	Dow Chemicals	Partner	specialty chemical, advanced materials, agro sciences and plastics	PF resin or Carbon fiber
	Chemtron	Partner	Adhesive and sealants	PF resin
	Sika Canada	Partner	Specialty chemicals and materials	PF resin or Carbon fiber
	Ashland Industries	Partner	Specialty chemicals	PF resin
Technology	Lignol	Partner	Biorefinery technology	PF resin or Carbon fiber
	FPInnovations	Partner	Research and development for Canadian forestry industry	PF resin or Carbon fiber

5.4 Conclusion

The value chains of PF resins and carbon fibers are very diverse due to their applications in several different industries. The majority of PF resins are used in wood adhesive sector for manufacturing plywood, MDF, LVL, and OSB. Similarly, carbon fiber has huge market potential in automobile, aerospace, and aircraft manufacturing industries.

Western Canada contains significant opportunities for the Case Mill. The presence of strong industries such as forest products, agribusiness, chemicals, automobile, petrochemicals, and aerospace provide impetus to setup a lignin-based biorefinery to fulfill current and future demand of these industries.

The next chapter uses the evaluation criteria and weights from the AHP survey results to evaluate some of the potential partners identified in this chapter. The results have been used to demonstrate how a Kraft pulp mill can use evaluation criteria to select potential partners.

Chapter 6: Partner evaluation criteria and MCDM-AHP to evaluate potential partners

One of the research objectives is to create partner evaluation criteria that can be used by the Case Mill to select appropriate partners. The overarching results of the literature review and case studies analysis highlighted two important aspects of partner evaluation criteria. First, there are no specific criteria that can be used by a Kraft pulp mill to evaluate potential partners. Secondly, each criterion is assigned equal importance than relative importance based on criterion importance in the decision making. To overcome these challenges Kraft mill specific partner evaluation criteria is created that can be used to evaluate and select potential partners and each criterion is assigned relative importance through a questionnaire survey.

This chapter seek to develop criteria that can be used to rank some of the potential partners identified in the previous chapter. We use previous literature and case studies to develop partner evaluation criteria for the Case Mill. Furthermore, AHP survey is used to assign relative importance weights to each criterion. This chapter also provides an illustrative example of application of the evaluation criteria by using some of the organizations identified in the previous chapter.

The evaluation criteria for the Case Mill are divided into strategic criteria and technical criteria. The technical criteria pertain to the operational skills and resources most needed as determined by the SWOT analysis of the Case Mill. These include financial resources, technology, and marketing and distribution resources and infrastructure. The strategic criteria address the efficiency and effectiveness of the partnership in the longer-run.

These criteria are to assure the long-term sustainability of the collaboration. This category includes hard to quantify attributes such as corporate culture, partnership history, complementary resources, and research commitment. These criteria are discussed in detail in the following sections of this chapter.

6.1 Technical Criteria

The first technical criterion is 'financial resources'. The study of 810 alliances by Duisters-Twardy (2008) showed that financial resources is the most important criterion for evaluating potential partners and companies that use this criterion are more successful. For a successful implementation and operation of a forest biorefinery need initial investment and regular funding for R&D and marketing activities (Chambost et al., 2008). Therefore, a sound financial structure of a potential partner is essential for the long-term financial sustainability of a biorefinery. The indicators that can be used to assess financial status of a company are presented in table 8.

Table 8. Indicators of financial status

Indicators	
Profit margins	• A measure of the amount of revenue remained after operating expenses, interest, and taxes
Average annual growth rate	• Measures the average increase in company's revenue over a period. It is a useful ratio to determine growth trends of a company
Return on assets	• An indicator of how effectively company is utilizing its assets and gives an idea about the revenue that can be generated from the capital
Current/Liquidity ratio	• A useful ratio to measure company's ability to fund its day-to-day operations over the next 12 months

The second technical criterion is 'technological compatibility'. The successful implementation of a forest biorefinery at a Kraft pulp mill relies greatly on adaptation of new technology and its integration into the existing operations (Chambost et al., 2008). The indicators that can be used to identify technological compatibility should be based on a Kraft pulp mill needs. The first indicator used to assess technological compatibility is the type of technology a potential partner possesses. There are several technologies available such as lignin precipitation and solvent pulping to implement lignin-based biorefinery at a Kraft pulp mill. The second indicator is the implementation challenge a Kraft pulp mill may face while integrating the technology within the existing process. Each technology for lignin-based forest biorefinery brings its own unique adaption challenges and this needs to be analyzed before deployment. The final indicator within the technological compatibility criterion is safety and security considerations, as there are several important safety concerns with each technology for producing lignin these needs to be understood before adaptation.

The third technical criterion is 'marketing and distribution resources'. A strong marketing and distribution infrastructure is crucial for the success of lignin-based biorefinery (World Economic Forum, 2011). Lignin-based bioproducts need to be marketed and distributed through different channels than traditional pulp and paper products. Therefore, there is a need to assess potential partners' marketing and distribution infrastructure. Appropriate indicators for marketing and distribution evaluation criterion should include: *brand image,* such as number of products manufactured and markets the potential partner have access; and, *distribution infrastructure* such as marketing channels, distributors, and retailers. The transformation of a Kraft pulp mill into a forest biorefinery is a challenging task that involves many technological and commercial risks. A Kraft pulp mill can mitigate these risks by collaborating with other businesses.

6.2. Strategic Criteria

The first strategic criterion is 'complementary capabilities'. Complementary resources significantly contributes to the project success (Brouthers et al., 1995; Chung et al., 2000). With the help of complementary resources a Kraft pulp mill may be able to overcome some of the technological and marketing challenges. The complementary resources a Kraft pulp mill may be able to provide include: production facility, feedstock, and workforce. In exchange the potential partner could provide technology, capital, and marketing and distribution infrastructure.

The second strategic criterion is 'cultural compatibility', which assesses whether companies will be able to work together or not. Several researchers concluded that cultural compatibility is the most significant and critical criteria in partners evaluation (Chung et al., 2000; Dacin et al., 1997; Dyer et al., 2001). However, indicators of cultural compatibility are somewhat vague and difficult to measure. One of the indicators to assess cultural compatibility is compatible goals, a collaboration is likely to fail if both organizations have dissimilar goals (Brouthers et al., 1995). It is therefore, of outmost importance to have compatible goals to mitigate the failure rate. Another indicator to test cultural compatibility is the way decisions are reached in an organization. In different organizations decisions are made differently. The decision making could be authoritative in which the organization's leader is the sole decision maker, an example of such business is a family-owned. A decision could be reached through facilitation by involving the organization's leader and subordinates. The other way to arrive at a decision is delegative where the organization's leader passes on the responsibility of decision making to subordinates. For long-term sustainability of forest biorefinery at a Kraft pulp mill, there is a need for a facilitative approach, otherwise there may be delays in strategic decisions such as investment in R&D, feedstock procurement, and establishing distribution infrastructure.

The third strategic criterion is 'research commitment'. For a Kraft pulp mill there are significant challenges around developing, adapting, and deploying new biorefinery technology. Therefore, there is a need for shared commitment to R&D. The indicators that can be used to evaluate research commitment of an organization should include: history of R&D and relationships with outside R&D organizations. The indicator to assess research commitment of a company may include financial commitment to R&D activities, and the number of collaborative research initiatives.

The fourth and final strategic criterion is 'history of partnerships'. Zollo et al. (2002) found that previous experience in partnerships positively enhances the performance of new collaborations. Prior experience helps companies to formalize the partnership establishment process and on-going partnership management process.

6.3 Results and analysis of the AHP survey

This section presents results of the survey conducted to assign relative weights to each criterion established in the previous section. As explained in the methodology chapter, relative weights assigned to each criterion are more practical than equal weights since each criterion has a unique role to fulfill in ranking and selection potential partners. One or more criterion could be more important than the others.

The survey was conducted to assign relative weights with the help of biorefinery industry experts. We asked experts to prioritize each criterion in order of importance. Table 9 provides the list of criteria developed in the previous section. The electronic questionnaire (see appendix I) was created based on AHP methodology to assign weights to each criterion. A total of 28 questionnaires were emailed to the experts. Returned questionnaires totaled 17 (9 from industry experts and 8 from academicians) for a response rate of 60.7 percent.

Through the questionnaire, participants were asked to use a pair-wise comparison scale to assign relative weights to each evaluation criterion based on their professional judgment. '*Expert Choice*' software was used to facilitate ease in computation of the survey data.

Table 9: Partner evaluation criteria and sub-criteria

Criteria	Sub-criteria (indicator)
Complementary resources	
Cultural compatibility:	*a) Compatible goals* *b) Decision making*
Research commitment:	*a) History of Research and development* *b) Relationship with outside organizations*
History of successful and failed partnership	
Financial resources:	*a) Profit margin,* *b) Average annual growth rate,* *c) Return on assets,* *d) Current ratio*
Technological compatibility:	*a) Type of technology,* *b) Implementation challenges,* *c) Safety, security, and environmental implications*
Marketing and distribution resources:	*a) Brand image,* *b) Distribution infrastructure*

6.3.1 Data analysis and result

Table 10 presents weights assigned by each participant to each criterion. The results show that 9 out of 17 experts believe that financial resources are the top priority when selecting partners for implementation of forest biorefinery at a Kraft pulp mill. These account for 52.9 percent of the total participation, which means that the majority of the participants consider financial resources to be the key criterion. The other top priorities are marketing and distribution (3 out of 17), research commitment (2 out of 17), history of successful or failed partnership (2 out of 17), and complementary resources (1 out of 17). Similarly, the least preferred criterion based on the number of responses is research commitment (6 out of 17), followed by cultural compatibility (5 out of 17), history of successful or failed partnership (4 out of 17), marketing and distribution infrastructure (1 out of 17), and financial resources (1 out of 17). The results show that technological compatibility is neither the least nor the most preferred criterion, which means experts have consensus about the importance of technology while selecting partners for a forest biorefinery.

The aggregate priorities can be seen in Figure 9. According to the survey results, the top three criteria for partner selection for setting up a biorefinery at a Kraft pulp mill are financial, complementary resources, and marketing and distribution resources. Figure 9 shows that among seven criteria, participants believe that financial resources should be the first priority with a weight of 0.211, followed by complementary resources (0.181). These are followed by marketing and distribution (0.172), technological compatibility (.153), research commitment (.100), history of failed or successful partnership (0.097), and finally cultural compatibility (0.086).

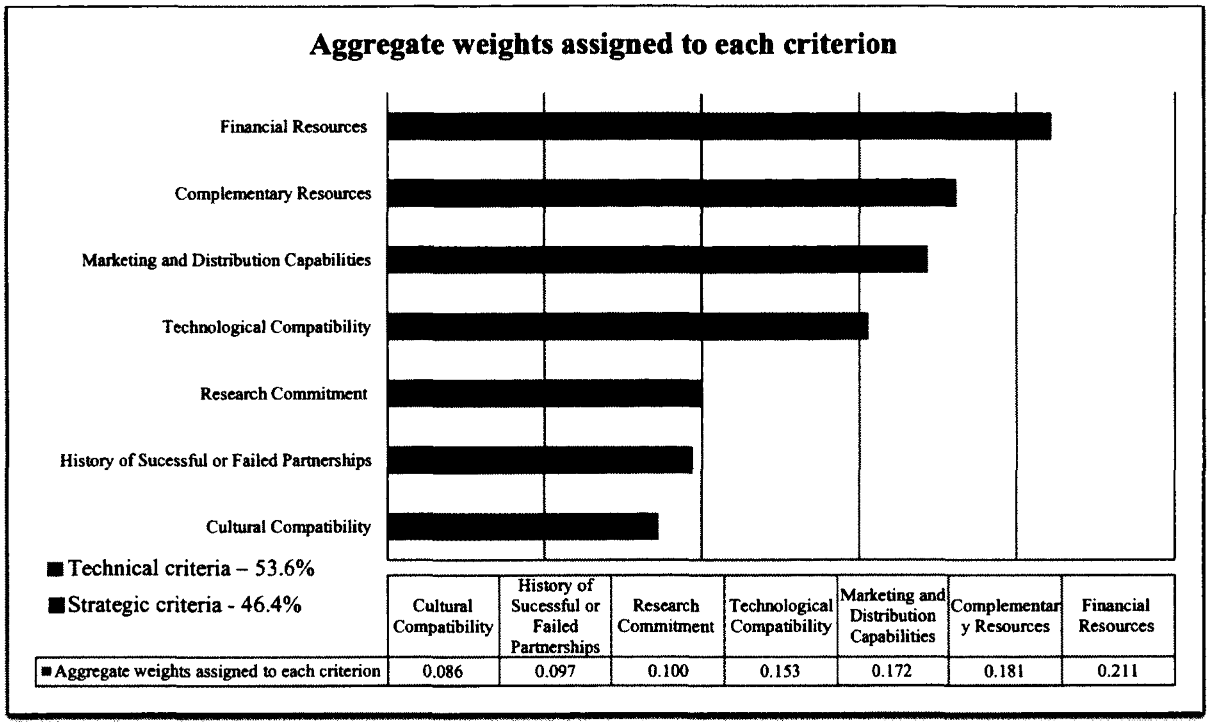
As indicated in Figure 10 the technical criteria together account for 53.6 percent and strategic criteria for 46.4 percent of the decision about the selection of a partner for establishing a forest biorefinery. Also, the majority of the experts surveyed strongly believe that financial resources (21.1 percent) have a greater role than other criteria in establishing a partnership for forest biorefinery.

Some of the results such as financial resources are considered as the most of the important are consistent with the literature. Other findings like cultural compatibility being the least important criterion according to the survey participants is exactly the opposite to the findings of existing related literature.

Furthermore, to better understand the results of the survey we have segregated the weights assigned by academicians and industry experts. The results in Figures 11 and 12 show that the top priority for academicians is complementary resources (.219), which are closely followed by financial resources (.192). On the other hand, industry experts believe that financial resources are top priority with 0.226, followed by marketing and distribution infrastructure (.167). A close examination of the results revealed that marketing and distribution infrastructure play a significant role according to both industry and academicians since both assigned similar weight to the criterion. The least preferred criterion according to academicians is cultural compatibility, and for industry experts is the history of successful or failed partnerships. There is insignificant difference between weights assigned to technical and strategic criteria by academician and industry experts as shown in figure 11 and 12.

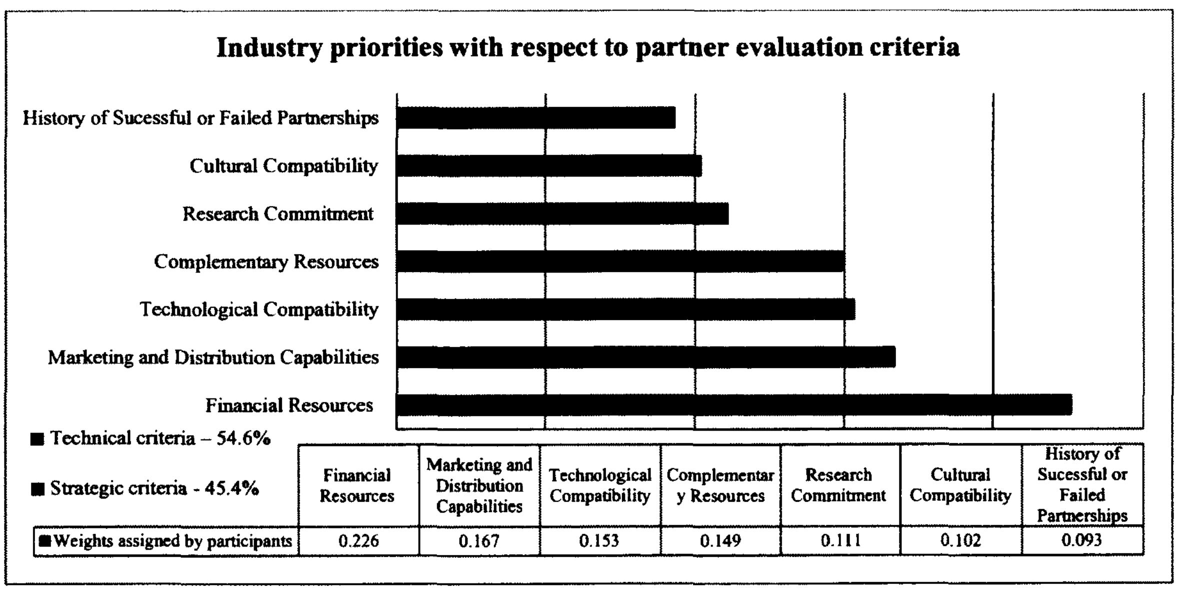
Table 10. Weights assigned by each participants

Participant no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Cultural Compatibility	0.066	0.037	0.222	0.119	0.222	0.039	0.159	0.045	0.043	0.129	0.093	0.035	0.093	0.034	0.232	0.085	0.060
Research Commitment	0.248	0.082	0.09	0.106	0.090	0.199	0.242	0.061	0.037	0.057	0.069	0.331	0.047	0.065	0.022	0.017	0.135
History of Successful or Failed Partnerships	0.043	0.236	0.043	0.020	0.043	0.023	0.084	0.179	0.096	0.060	0.118	0.060	0.129	0.418	0.026	0.084	0.070
Technological Compatibility	0.205	0.069	0.094	0.148	0.173	0.083	0.173	0.185	0.117	0.165	0.139	0.149	0.201	0.158	0.164	0.056	0.206
Marketing and Distribution Capabilities	0.063	0.157	0.067	0.172	0.188	0.166	0.063	0.168	0.189	0.063	0.204	0.076	0.243	0.095	0.302	0.310	0.100
Financial Resources	0.287	0.208	0.100	0.276	0.199	0.390	0.193	0.227	0.352	0.268	0.255	0.186	0.083	0.017	0.061	0.200	0.236
Complementary Resources	0.088	0.212	0.384	0.119	0.074	0.100	0.086	0.133	0.166	0.217	0.122	0.163	0.204	0.213	0.193	0.248	0.193



	Cultural Compatibility	History of Sucessful or Failed Partnerships	Research Commitment	Technological Compatibility	Marketing and Distribution Capabilities	Complementary Resources	Financial Resources
Aggregate weights assigned to each criterion	0.086	0.097	0.100	0.153	0.172	0.181	0.211

Figure 10: Overall priorities



	Financial Resources	Marketing and Distribution Capabilities	Technological Compatibility	Complementary Resources	Research Commitment	Cultural Compatibility	History of Sucessful or Failed Partnerships
Weights assigned by participants	0.226	0.167	0.153	0.149	0.111	0.102	0.093

Figure 11. Comparison of weights: Industry

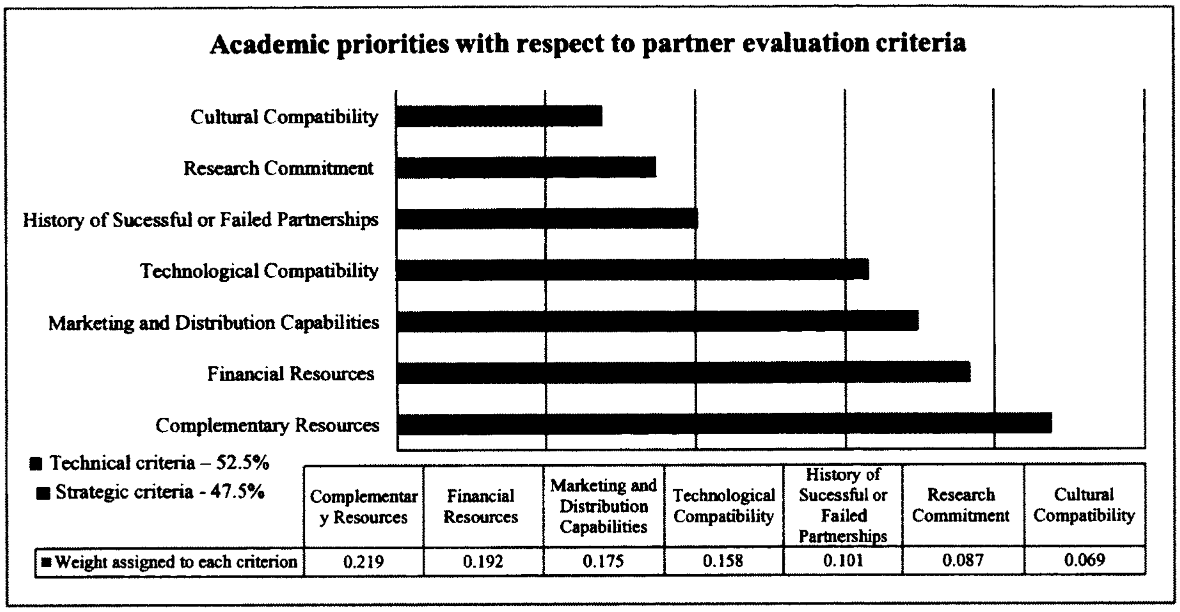


Figure 12. Comparison of weights: Academia

The comparison leads to the conclusion that both academics and industry experts strongly agree that financial resources are one of the key criteria in partner selection for forest biorefinery. They also accept that the technology compatibility and marketing and distribution infrastructure are very crucial for successful implementation of forest biorefinery at a Kraft pulp mill.

Furthermore, we consolidated the top five partner evaluation criteria (Table 11) based on AHP survey ranking to reduce the likelihood of partnerships failure. It is hoped that these criteria can serve as a reference for Kraft pulp mills interested in setting up a forest biorefinery with the help of partners.

Table 11: Top five evaluation criteria

Criteria	Sub-criteria (indicator)
Financial resources:	a) Profit margin, b) Average annual growth rate, c) Return on assets, d) Current ratio
Complementary resources	
Marketing and distribution resources:	a) Brand image, b) Distribution infrastructure
Technological compatibility:	a) Type of technology, b) Implementation challenges, c) Safety, security, and environmental implications
Research commitment:	a) History of Research and development b) Relationship with outside organizations

6.4 An example of MCDM AHP – ranking potential partners

The previous chapter identified value chains for lignin-based products in BC and Alberta and also identified a few of the potential partners or customers. This section seeks to demonstrate how to evaluate potential partners using top five evaluation criteria established in the previous section. For this purpose we evaluated a technology company, a petrochemical, and a forestry company from the list of potential partners' already identified. For this reason, we have arbitrarily chosen three organizations from the list of potential partners a) BASF Chemicals, b) Weyerhaeuser, and c) Lignol.

Figure 13 provide a schema of AHP methodology in which criteria are established to achieve specific goals and each alternative is evaluated based on each criterion. A more detailed computation on how to use AHP methodology can be found in Appendix 2. The information and data needed to evaluate potential partners was collected through publically available sources mainly comprising company annual reports, financial statements, and press releases. The required information is consistent with the top five criteria established by AHP survey in this chapter.

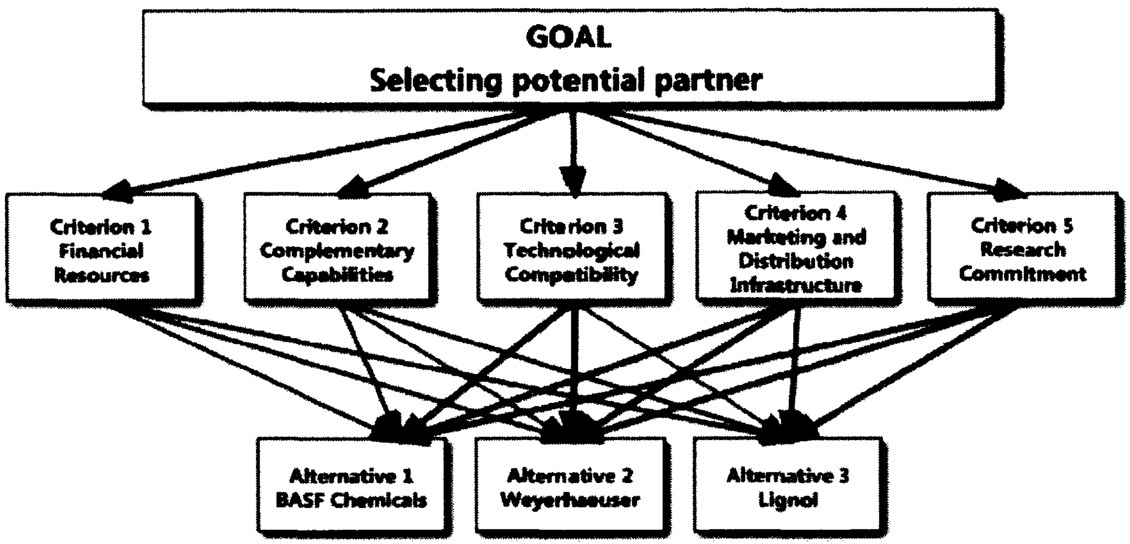


Figure 13. AHP hierarchy

'*Expert Choice*' software is used to evaluate and assign ranking to each organization. Rankings are assigned according to the company performance, for example companies were evaluated with respect to their published profit margins, average annual growth rate, and current ratios. Similarly, companies were compared based on their R&D expenditure and activities, and number of partners. Table 12 presents the types of data and information collected to assign ranking. This information is combined with the weights assigned to the criteria by AHP surveyed participants.

Table 12. Type of data and information needed to evaluate potential partners

Criteria	Data or Information type
Financial resources	Profit margin, average annual growth rate, current ratio, and return on assets
Complementary resources	Financial statements, technology related information, R&D activities, and marketing and distribution infrastructure.
Marketing and Distribution Infrastructure	Financial statements, marketing and sales market access, distribution channels, and products manufactured
Technological compatibility	Information about available technology, and projects related to biotechnology
Research commitment	Financial statements, number of partners in R&D, investment in R&D, and number of R&D projects

6.4.1 Company backgrounds

This section provide a brief overview of the companies that are arbitrarily chosen to provide an example of how AHP MCDM methodology can be applied to select potential partners for a Kraft pulp mill using criteria established in this research.

BASF Chemicals

BASF Chemicals is a world leading chemical manufacturing company. It owns 380 production facilities around the world (BASF, 2013). The portfolio of its products is vast and there are several products within its existing portfolio that can be replaced with renewable sources such as lignin-based bioproducts. It is also exploring new carbon-based materials. Its customers are from several industries such as chemicals, agribusiness, oil and gas, petrochemicals, construction, and nutrition and health. Some of these are potential industries to market products such as PF resins and carbon fibers. It has research centers for process, chemical engineering, advanced material research and has more than 600 partners (BASF , 2013).

Weyerhaeuser

Weyerhaeuser is one of the largest forestry manufacturers of wood and specialty cellulose fiber products (Weyerheauser, 2013). It owns production facilities in the US and Canada and has a strong presence in the provinces of BC, Alberta, Saskatchewan, and Ontario. It has strong R&D interest in bioproducts and established partnerships to build biorefining capabilities and share several R&D projects with other companies (Weyerhaeuser, 2013b). It sells products globally through its own sales organizations and distribution facilities (Weyerheauser, 2013).

Lignol

Lignol is a Canadian company involved in the development of biorefining technologies (Lignol, 2013). It provides R&D services to companies interested in biorefining (Lignol, 2013). It has developed technology for production of lignin-based products, and has pilot plant that uses lignocellulosic feedstock to produce biofuels and biochemicals. It is also involved in R&D activities for lignin-based bioproducts with other organizations.

Furthermore, the data collected for each of the above firms for comparison and evaluation is presented in Tables 13 and 14. This information is used to complete the pairwise comparison. A detailed pairwise comparison is provided in Appendix 3. As it can be seen from Table 13 that Weyerhaeuser and BASF Chemicals both have profit compared to Lignol. This is because Lignol is primarily involved in technology development and testing, while Weyerhaeuser and BASF Chemicals have well-developed sales portfolios. The R&D expenditure of Lignol is substantial compared to the other two companies. This makes this list of potential partners more reliable, since not every firm possess the resources needed to implement forest biorefinery, as highlighted in the literature review.

Table 13. Financial information for indicators

	Weyerhaeuser	**Lignol**	**BASF Chemicals**
Profit Margin: *(Net Profit/Revenue)X100*	**+5.43**	**-82.7**	**+6.19**
Average Annual Growth Rate- last 3 years: *Growth rate in (2010 +2011+2012)/3*	**+12.26**	**-75.3**	**+16.06**
Return on Assets: *(Net income/Total Assets)X100*	**+3.05**	**-22.02**	**+14.06**
Current Ratio: *(Current Assets/Current Liabilities)X100*	**+1.7**	**+0.27**	**+1.65**

Table 14. Indicators data and information

	Weyerhaeuser	**Lignol**	**BASF Chemicals**
R&D expenditure growth rate	**+6.6 percent**	**-41.3 percent**	**+8.8 percent**
R&D expenditure as a percentage of sales	**+0.4 percent**	**+36.1 percent**	**+2.2 percent**
Selling expenses as a percentage of sales	**+2.7 percent**	**Not reported**	**+9.7 percent**
Number of Partners in forest biotechnology	**6**	**3**	**3**
Product Portfolio: Industries specifically for lignin products	**5**	**5**	**6**
Possession of Lignin Biorefining technology	**Yes**	**Yes**	**No**
Strategic Interest in Biotechnology	**Yes**	**Yes**	**Yes**
Product Markets access - relevant to lignin products	**5**	**4**	**5**

6.4.2 Results

The rankings were assigned to the organizations based on the weights established by surveyed participants and information gathered about finance, technology, marketing and distribution, and R&D activities of the organizations. Figure 14 presents the ranking of the three organizations. The left side of the figure presents aggregate weights assigned to the top five criteria. The right side of the figure shows the ranking of each company. According to the weights Weyerhaeuser is the most preferred organization with 36.6 percent, closely followed by BASF with 35.5 percent and the least preferred organization is Lignol with 27.8 percent.

There is a need to further understand the performance of organizations on each criterion and Figure 15 provides these details. As highlighted in the SWOT analysis the Case Mill need technology, capital, and marketing and distribution infrastructure, hence it is essential to understand which organization provides a balance of these needed resources. There is a need to stress that any change in the priority to any criterion could affect the ranking. The figure shows that Weyerhaeuser has the greatest amount of complementary resources needed to implement a lignin-based forest biorefinery. However, Weyerhaeuser's research commitment is at par with Lignol, but lags behind BASF, which leads in terms of R&D initiatives. Additionally, Weyerhaeuser lags behind BASF in financial performance and marketing and distribution infrastructure. However, BASF does not possess the technology to produce lignin-based products.

A close examination reveals that if the Case Mill is interested in a partner with R&D capabilities, and marketing and distribution infrastructure then BASF is the best alternative. However, if the Case Mill is interested in partners with technological capabilities then either

Weyerhaeuser or Lignol is a good fit. Although, any change in priorities to any criterion will affect the ranking of each organization. The next section will assess various scenarios to illustrate how a change in ranking occurs due to a change in the priorities assigned to each criterion.

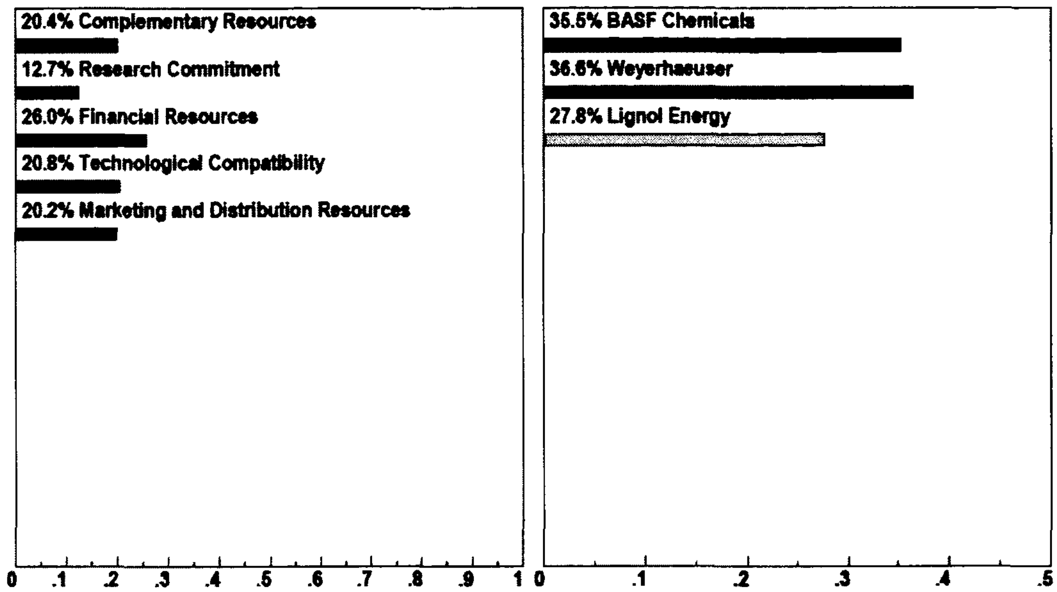


Figure 14. Overall ranking of potential partners

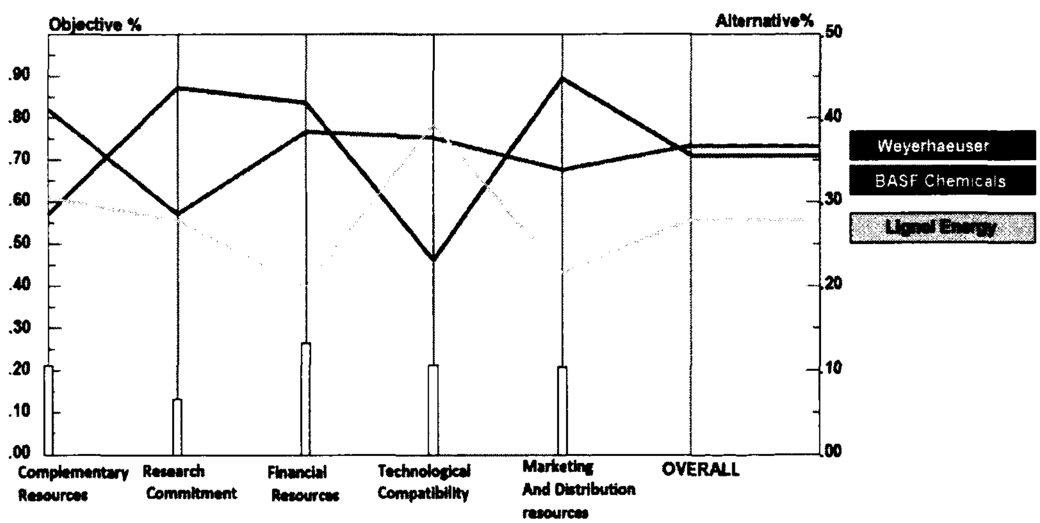


Figure 15. Performance of each organization against each criterion

6.4.3 Scenario analysis

This subsection is to understand the impact of a change in priority assigned to each criterion on the overall ranking of the organizations. The AHP methodology relies on weights assigned to each criterion to rank alternatives. we further analyzed the results of the previous example to measure the impact of change in weights assigned to each criterion. For this purpose we created several scenarios to examine the change in ranking of the organizations with respect to change in weights assigned to each criterion.

There could be several sources of uncertainty in AHP methodology such as rank reversal due to the addition or deletion of an alternative or criterion, and using of different scale to assign ranking and weights. This example of scenario analysis is done to test the uncertainty in ranking when different weights are assigned to each criterion. As defined by Saltelli et al. (2004) that the scenario analysis is "the study of how the uncertainty in the output of a model (numerical or otherwise) can be apportioned to different sources of uncertainty in the model input". The scenario analysis will help a Kraft pulp mill to plan for different scenarios while implementing a forest biorefinery at the mill. This analysis will help a Kraft mill to understand the impact of a particular criterion to the rankings compared to others. This analysis was done with the help of *'Expert Choice'* module on scenario analysis.

Scenario 1: Emphasis on complementary resources

Figure 16 represents results of the scenario analysis 1; where the Case Mill rely more on complementary resources followed by financial performance and technological compatibility. The weights assigned to each criterion were decreased to increase the weight assigned to complementary resources. It can be seen from this Figure that there is no change in ranking of the organizations. But preference to BASF is reduced by 2.4 percent while at the same time it has increased by 1.0 and 1.5 percent for Weyerhaeuser and Lignol respectively. This scenario does not affect the ranking of the organizations drastically. This implies that even if the Case Mill would like to keep complementary resources as their top priority, Weyerhaeuser is still provide the maximum value to the partnership compared to BASF Chemicals and Lignol Energy.

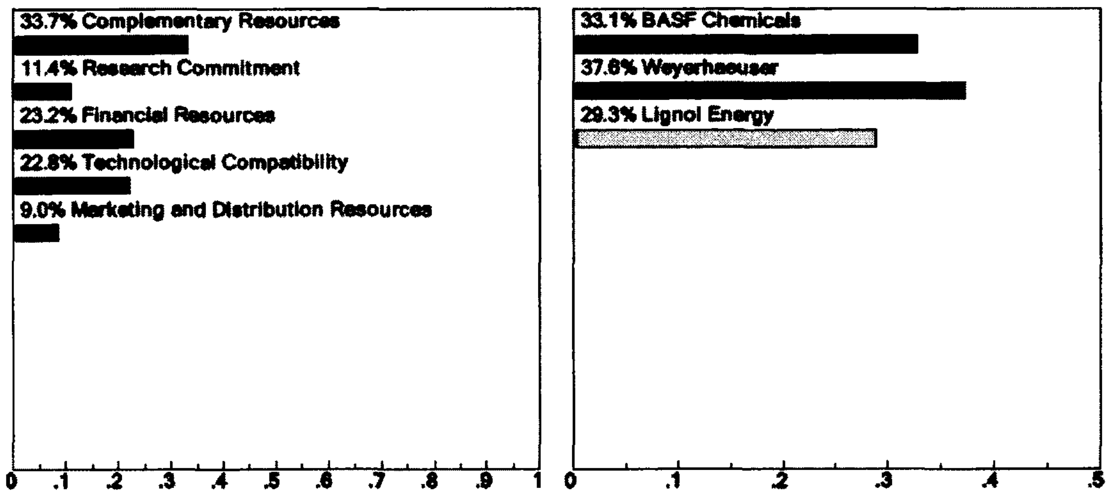


Figure 16: Scenario analysis 1

Scenario 2: Emphasis on technology

Figure 17 represents results of scenario analysis 2 where technological compatibility is considered the top priority and 50 percent of the decision relies on this criterion. The weights to each criterion were decreased to increase the weight assigned to technological compatibility. The result changes the ranking of the organizations, but Weyerhaeuser is still the best alternative since it owns technology related to lignin bioproducts. Lignol is now the second best alternative in this scenario even with the poorer financial performance. This is due to the fact that Lignol has technology to develop lignin-based products. This scenario is highly likely during the implementation of lignin biorefinery at the mill since the case-study Kraft pulp mill does not possess technology for lignin-based products manufacturing.

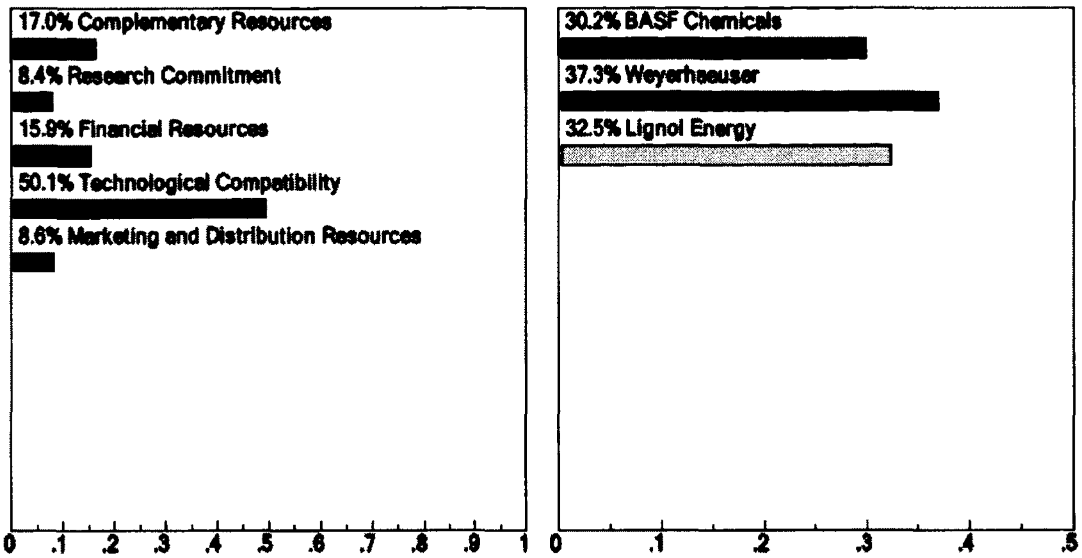


Figure 17. Scenario analysis 2

Scenario 3: Emphasis on financial resources

Figure 18 represents results of the scenario analysis 3 in which the financial performance is considered as the most important criterion, followed by technological compatibility. The weights to each criterion were adjusted accordingly to increase the weight assigned to financial resources, 44 percent of the decision about partner selection relies on financial performance of the company. The result of this analysis is similar to actual overall results presented in Figure 14. The result implies that both Weyerhaeuser and BASF Chemicals are financially comparable to each other. This scenario does not affect ranking of the organizations since both Weyerhaeuser and BASF generated strong financial results compared to Lignol Energy

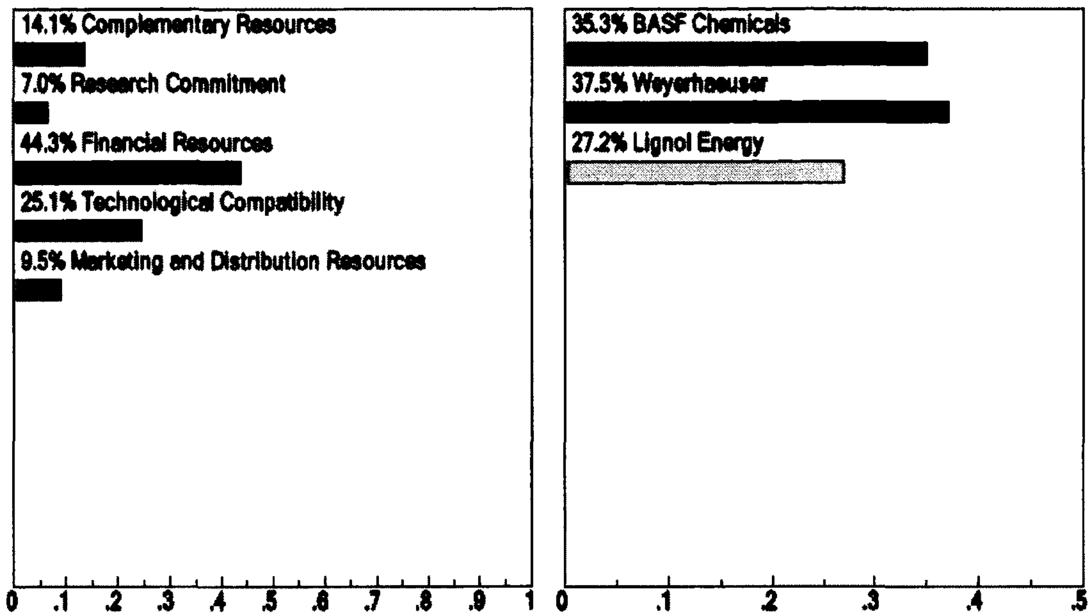


Figure 18: Scenario analysis 3

Scenario 4: Emphasis on marketing and distribution

Figure 19 shows the results of scenario analysis 4 where marketing and distribution is assigned top priority closely followed by technological compatibility. The weights to each criterion were adjusted to increase the weight to marketing and distribution resources and technological compatibility. Again, the change in weight to both of the criteria does not affect final decision about the ranking of the organizations since both Weyerhaeuser and BASF possess strong distribution and marketing infrastructure.

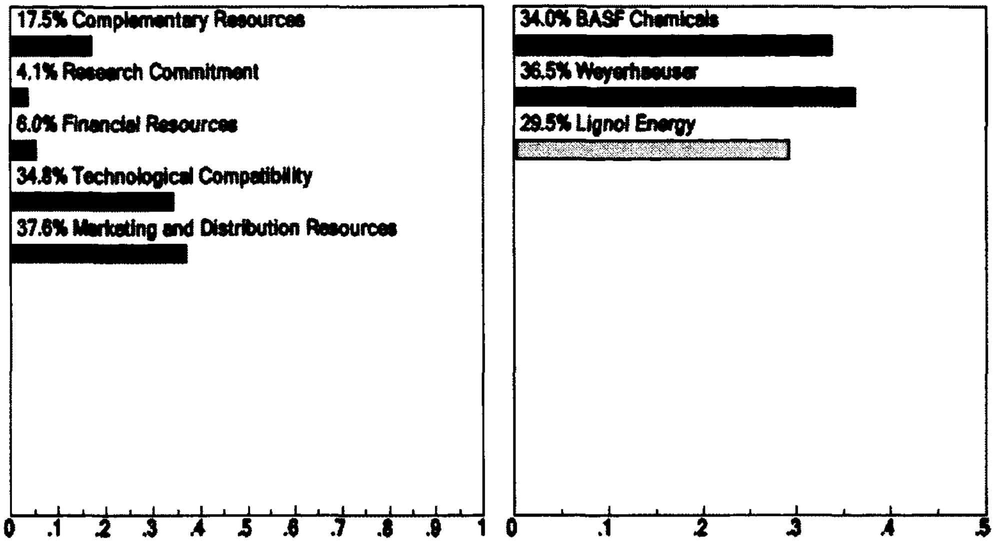


Figure 19: Scenario analysis 4

6.4 Conclusion

An attempt has been made in this chapter to establish partner evaluation criteria for the Case Mill. AHP methodology has been used to assign weight to each criterion. The financial resources of the prospective partners are considered as the top priority by the survey participants. This is closely followed by complementary resources. The technical criteria which comprise technological compatibility, marketing and distribution infrastructure, and financial resources account for 52.5 percent of the decision while selecting partners for forest biorefinery. On the other hand, strategic criteria which comprise cultural compatibility, research commitment, complementary resources, and history of partnership account for 47.5 percent of the decision while selecting partners for forest biorefinery. This chapter also demonstrated the effect of change in weight assigned to each criterion on the ranking of alternatives with the help of scenario analysis. The result highlighted the consistency in ranking generated with AHP methodology even with diverse group of survey participants and companies with diverse strengths and weaknesses.

Chapter 7: Conclusions

The goal of this research was to answer some of the important questions for a Kraft pulp mill that is trying to implement a lignin-based biorefinery: what types of partners are needed to implement a lignin-based forest biorefinery at a Kraft pulp mill; where to find potential partners for a Kraft pulp mill; what is the process of partner selection; and how to evaluate potential partners? The study is conducted using diverse quantitative and qualitative methods including, interviews, surveys, document analysis, government and industry reports, and literature on the subject.

The research focused on a case-study approach and a Kraft pulp mill in western Canada has been used as a base case and referred as Case Mill throughout this research. This Case Mill produces pulp from softwood, that is further used to manufacture paper and paper based products. In order to implement a biorefinery at the Case Mill, there are several technologies available, but the selection of technology depends on the feedstock type and availability, implementation challenges, costs involved, and the type of products the mill wants to produce.

What is the process of partner selection for a Kraft pulp mill interested in transforming its pulp mill into a lignin forest biorefinery? There is limited research on partner selection process. The process suggested in this research has eight steps. This process is based on previous literature and case studies on partner selection process. The most important steps identified in this process are SWOT analysis of the mill, identification of partner evaluation criteria, and identification of potential partners. However, each Kraft pulp mill is unique and may choose to create its own selection partner selection process. Some of the steps from this process were followed to accomplish objectives of this research and answer research questions.

What types of partners are needed to implement a lignin biorefinery at a Kraft pulp mill? The Case Mill's strengths, weaknesses, opportunities, and threats were examined and information was gathered through interviews of Case Mill representatives, documents and annual reports, and press releases. Based on the analysis and observations we came to the conclusion that the Case Mill should consider partnering with a technology company and a company with marketing and distribution infrastructure and financial resources. This is due to the reason that the mill does not possess the technology, and marketing and distribution infrastructure needed to commercialize lignin-based products. A partner with financial resources can help the mill to mitigate financial risks involved with biorefinery implementation. This can be done through several collaborative strategies that may include joint venture, licensing, or joint R&D initiative.

Our recommendation based on the examination of case studies and examples from the forestry industry is that the Case Mill should consider creating a multi-company joint venture where the Case Mill can be used as a production facility and provides feedstock, manpower, and machinery. The other companies should include a technology provider and either a petrochemical or forestry company. This way the mill can mitigate the financial, technological, and commercial risks involved with forest biorefinery implementation and have access to technology, capital, and marketing and distribution resources. Another alternative for the Case Mill is to get a license for lignin technology from a technology provider and partner with a petrochemical or forestry company that can provide capital and marketing and distribution support.

Where to find potential partners for lignin-based forest biorefinery? The answer to this question was found in the analysis of the value chains related to lignin-based products. There are several products that can be manufactured with lignin as mentioned in Chapter 1, but there are very few that can be profitably produced due to technological and cost constraints. This research concentrated on two products that are carbon fibers and PF resins, based on their current and future market prospects. Both products have a wide range of applications in several industries such as petrochemicals, forestry, construction, automobile, aerospace and aircrafts, agribusiness, defense, and oil and gas. The geographical focus of this research was western Canada and this region has strong presence of similar industries. To find potential partners we used value chain analysis of lignin-based products in BC and Alberta. Based on this analysis we have identified several companies that could either be potential partners or potential customers. Our recommendation to the Case Mill is to search for partners within the existing value chain of carbon fiber and PF resins.

How to evaluate potential partners? The evaluation criteria for potential partners in this research are based on strategic and technical needs of the Case Mill. The evaluation criteria were based on the previous research, and case studies. The criteria comprise several quantitative and qualitative criteria, therefore, there was a need to assign weights to each criterion. For this purpose MCDM AHP survey was conducted. The weights were assigned to each criterion through this survey. The evaluation criteria for demonstration were confined to the top five criteria according to the surveyed participants that are: financial resources, technological compatibility, research commitment, complementary resources, and marketing and distribution infrastructure. The weights were assigned to each criterion based on AHP MCDM survey results. Financial resources were considered the most important criterion while selecting partners, followed by complementary resources, and marketing and distribution infrastructure. Since each Kraft pulp mill is unique, the criteria used should be based on its specific needs and requirements. For the Case Mill, lignin production technology, capital, and marketing and distribution resources are needed for the mill to successfully implement a lignin biorefinery. The survey results underscore the importance of these three criteria. Also highlighted that there is difference in literature and survey results especially for cultural compatibility which according to the literature is one of the most important criterion, but survey participant consider it least important in decision making.

In a nutshell, if a company is interested in implementing a lignin-based forest biorefinery, firstly, it needs to understand its own requirements. Secondly, it must identify how and with which partners they can fill these needs. Finally, it must use evaluation criteria to choose from several alternatives.

The research provides a partner selection process specially designed for Kraft pulp mills interested in lignin biorefinery. This research contributes to the existing knowledge on strategic partnerships within the existing value chain of a company. The process suggested in this research can be used by other Kraft pulp mills to find and select partners for implementing a forest biorefinery. The research developed criteria with the help of MCDM AHP methodology, which is unique and has never been attempted before within the biorefinery context. The evaluation criteria developed in this research can be used as guidance for future research on the topic. The results highlighted the most important criteria for selecting partners for a mill interested in developing a forest biorefinery. Similar methodology can be adopted by other industries to develop partner evaluation criteria.

There are several limitations within this research. The conducted interviews and surveys leading to some research biases. The information collected for assigning weight to each criterion might be biased due to personal judgments of the experts. The selection of survey participants is based on our personal judgment that might have led to a selection bias. This bias can be reduced by increasing the number of participants to accommodate other industries experts in future research and also by asking references from industry experts. The geographic scope of the research was western Canada and this might have affected selection of potential partners. Furthermore, some of the criteria might have been omitted due to their qualitative nature or non-availability of data-set needed for the indicators. This research can further be broadened in two main directions: by expanding the geographical scope of the study, and applying similar selection process and evaluation criteria to other industries using MCDM AHP methodology. The other area that needs to be further explored is by expanding the scope of SWOT analysis of a Kraft mill by including political and environmental aspects to the analysis. In order to do so PESTLE analysis can be used to understand the impact of forest biorefinery at a mill level and community level.

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Appendix I – QUESTIONNAIRE

Forest Biorefinery[1] – Partner Selection Criteria Ranking Survey

The purpose of this research is to create partner selection criteria for forestry companies interested in a forest biorefinery. The goal of this questionnaire is to compare and rank criteria[2] for selecting partners for an existing Kraft pulp mill[3]. These criteria will be used while evaluating and comparing prospective partners. We have developed a set of 7 criteria and 13 sub-criteria based on case studies and previous research: (Definitions are provided on page 3 and page 4)

1) Complementary resources[4]
2) Cultural compatibility[5]:
   a) Compatible goals[6] b) Decision making[7]
3) Research commitment[8]:
   a) History of Research and development b) Relationship with outside organizations
4) History of successful and failed partnership[9]
5) Financial resources:
   a) Profit margin[10], b) Average annual growth rate[11],
   c) Return on assets[12], d) Current ratio[13]
6) Technological compatibility:
   a) Type of technology, b) Implementation challenges,
   c) Safety, security, and environmental implications[14]
7) Marketing and distribution resources:
   a) Brand image[15], b) Distribution infrastructure[16]

Please take a few minutes to complete this questionnaire. Your response will provide us some valuable information to help us rank the proposed criteria in order of importance and utility.

This questionnaire uses pairwise comparisons[17]. Please mark your preference between criteria by using the scale from 1-9. Please refer example 1 and 2.

<u>This is an electronic questionnaire. You can submit this form electronically by clicking on the SUBMIT FORM BUTTON in the top right corner or you can submit this form manually by saving it and attaching it in an email to shahz@unbc.ca)</u>

Please mark the right answer in Table 1 on page 2 and page 3.

1:1—Equally Preferred
2:1—Equally to Moderately Preferred
3:1—Moderately Preferred
4:1--Moderately to Strongly Preferred
5:1--Strongly Preferred
6:1--Strongly to Very Strongly Preferred
7:1--Very Strongly Preferred
8:1--Very to Extremely Strongly Preferred
9*:1—Extremely Preferred

Example 1. – <u>**Complementary resources**</u> **is moderately preferred to** <u>**Cultural compatibility**</u>

1	Complementary Resources	9:1	8:1	7:1	6:1	5:1	4:1	X 3:1	2:1		1:2	1:3	1:4	1:5	1:6	1:7	1:8	1:9	Cultural Compatibility

Example 2. - <u>**Cultural compatibility**</u> **is moderately preferred to** <u>**Complementary resources**</u>

1	Complementary Resources	9:1	8:1	7:1	6:1	5:1	4:1	3:1	2:1		1:2	X 1:3	1:4	1:5	1:6	1:7	1:8	1:9	Cultural Compatibility

Table 1

Extremely Preferred ← **Equally** → **Extremely Preferred**

1	Complementary Resources	9:1	8:1	7:1	6:1	5:1	4:1	3:1	2:1		1:2	1:3	1:4	1:5	1:6	1:7	1:8	1:9	Cultural Compatibility
2	Complementary Resources	9:1	8:1	7:1	6:1	5:1	4:1	3:1	2:1		1:2	1:3	1:4	1:5	1:6	1:7	1:8	1:9	Research Commitment
3	Complementary Resources	9:1	8:1	7:1	6:1	5:1	4:1	3:1	2:1		1:2	1:3	1:4	1:5	1:6	1:7	1:8	1:9	History of Successful or failed partnership
4	Complementary Resources	9:1	8:1	7:1	6:1	5:1	4:1	3:1	2:1		1:2	1:3	1:4	1:5	1:6	1:7	1:8	1:9	Technological Compatibility
5	Complementary Resources	9:1	8:1	7:1	6:1	5:1	4:1	3:1	2:1		1:2	1:3	1:4	1:5	1:6	1:7	1:8	1:9	Financial Resources
6	Complementary Resources	9:1	8:1	7:1	6:1	5:1	4:1	3:1	2:1		1:2	1:3	1:4	1:5	1:6	1:7	1:8	1:9	Marketing and Distribution infrastructure
7	Cultural Compatibility	9:1	8:1	7:1	6:1	5:1	4:1	3:1	2:1		1:2	1:3	1:4	1:5	1:6	1:7	1:8	1:9	Research Commitment
7a	Decision Making	9:1	8:1	7:1	6:1	5:1	4:1	3:1	2:1		1:2	1:3	1:4	1:5	1:6	1:7	1:8	1:9	Compatible goals
8	Cultural Compatibility	9:1	8:1	7:1	6:1	5:1	4:1	3:1	2:1		1:2	1:3	1:4	1:5	1:6	1:7	1:8	1:9	History of Successful or failed partnership
9	Cultural Compatibility	9:1	8:1	7:1	6:1	5:1	4:1	3:1	2:1		1:2	1:3	1:4	1:5	1:6	1:7	1:8	1:9	Technological Compatibility
10	Cultural Compatibility	9:1	8:1	7:1	6:1	5:1	4:1	3:1	2:1		1:2	1:3	1:4	1:5	1:6	1:7	1:8	1:9	Financial Resources

11	Cultural Compatibility	9: 1	8: 1	7: 1	6: 1	5: 1	4: 1	3: 1	2: 1		1: 2	1: 3	1: 4	1: 5	1: 6	1: 7	1: 8	1: 9	Marketing and Distribution infrastructure
12	Research Commitment	9: 1	8: 1	7: 1	6: 1	5: 1	4: 1	3: 1	2: 1		1: 2	1: 3	1: 4	1: 5	1: 6	1: 7	1: 8	1: 9	History of Successful or failed partnership
12 a	History of R&D	9: 1	8: 1	7: 1	6: 1	5: 1	4: 1	3: 1	2: 1		1: 2	1: 3	1: 4	1: 5	1: 6	1: 7	1: 8	1: 9	Relationship with outside organizations
13	Research Commitment	9: 1	8: 1	7: 1	6: 1	5: 1	4: 1	3: 1	2: 1		1: 2	1: 3	1: 4	1: 5	1: 6	1: 7	1: 8	1: 9	Technological Compatibility
14	Research Commitment	9: 1	8: 1	7: 1	6: 1	5: 1	4: 1	3: 1	2: 1		1: 2	1: 3	1: 4	1: 5	1: 6	1: 7	1: 8	1: 9	Financial Resources
15	Research Commitment	9: 1	8: 1	7: 1	6: 1	5: 1	4: 1	3: 1	2: 1		1: 2	1: 3	1: 4	1: 5	1: 6	1: 7	1: 8	1: 9	Marketing and Distribution infrastructure
16	History of Successful or failed partnership	9: 1	8: 1	7: 1	6: 1	5: 1	4: 1	3: 1	2: 1		1: 2	1: 3	1: 4	1: 5	1: 6	1: 7	1: 8	1: 9	Technological Compatibility
17	History of Successful or failed partnership	9: 1	8: 1	7: 1	6: 1	5: 1	4: 1	3: 1	2: 1		1: 2	1: 3	1: 4	1: 5	1: 6	1: 7	1: 8	1: 9	Financial Resources
18	Marketing and Distribution infrastructure	9: 1	8: 1	7: 1	6: 1	5: 1	4: 1	3: 1	2: 1		1: 2	1: 3	1: 4	1: 5	1: 6	1: 7	1: 8	1: 9	History of Successful or failed partnership
18 a	Distribution infrastructure	9: 1	8: 1	7: 1	6: 1	5: 1	4: 1	3: 1	2: 1		1: 2	1: 3	1: 4	1: 5	1: 6	1: 7	1: 8	1: 9	Brand Image

Extremely Preferred ← **Equally** → **Extremely Preferred**

19	Technological Compatibility	9: 1	8: 1	7: 1	6: 1	5: 1	4: 1	3: 1	2: 1		1: 2	1: 3	1: 4	1: 5	1: 6	1: 7	1: 8	1: 9	Financial Resources
19 a	Type of Technology	9: 1	8: 1	7: 1	6: 1	5: 1	4: 1	3: 1	2: 1		1: 2	1: 3	1: 4	1: 5	1: 6	1: 7	1: 8	1: 9	Implementation Challenges
19 b	Implementation Challenges	9: 1	8: 1	7: 1	6: 1	5: 1	4: 1	3: 1	2: 1		1: 2	1: 3	1: 4	1: 5	1: 6	1: 7	1: 8	1: 9	Safety, Security, and Environmental concerns
19 c	Safety, Security, and Environmental concerns	9: 1	8: 1	7: 1	6: 1	5: 1	4: 1	3: 1	2: 1		1: 2	1: 3	1: 4	1: 5	1: 6	1: 7	1: 8	1: 9	Type of Technology

20	Technological Compatibility	9: 1	[illegible]	7: 1	[illegible]	5: 1	[illegible]	3: 1	[illegible]		[illegible]	1: 3	[illegible]	1: 5	[illegible]	1: 7	[illegible]	1: 9	Marketing and Distribution infrastructure
21	Financial Resources	9: 1	[illegible]	7: 1	[illegible]	5: 1	[illegible]	3: 1	[illegible]		[illegible]	1: 3	[illegible]	1: 5	[illegible]	1: 7	[illegible]	1: 9	Marketing and Distribution infrastructure
21 a	Profit Margin	9: 1	[illegible]	7: 1	[illegible]	5: 1	[illegible]	3: 1	[illegible]		[illegible]	1: 3	[illegible]	1: 5	[illegible]	1: 7	[illegible]	1: 9	Average Annual Growth Rate
21 b	Average Annual Growth Rate	9: 1	[illegible]	7: 1	[illegible]	5: 1	[illegible]	3: 1	[illegible]		[illegible]	1: 3	[illegible]	1: 5	[illegible]	1: 7	[illegible]	1: 9	Return on Assets Ratio
21 c	Return on Assets Ratio	9: 1	[illegible]	7: 1	[illegible]	5: 1	[illegible]	3: 1	[illegible]		[illegible]	1: 3	[illegible]	1: 5	[illegible]	1: 7	[illegible]	1: 9	Current Ratio
21 d	Current Ratio	9: 1	[illegible]	7: 1	[illegible]	5: 1	[illegible]	3: 1	[illegible]		[illegible]	1: 3	[illegible]	1: 5	[illegible]	1: 7	[illegible]	1: 9	Profit Margin
21 e	Profit Margin	9: 1	[illegible]	7: 1	[illegible]	5: 1	[illegible]	3: 1	[illegible]		[illegible]	1: 3	[illegible]	1: 5	[illegible]	1: 7	[illegible]	1: 9	Return on Assets Ratio
21 f	Average Annual Growth Rate	9: 1	[illegible]	7: 1	[illegible]	5: 1	[illegible]	3: 1	[illegible]		[illegible]	1: 3	[illegible]	1: 5	[illegible]	1: 7	[illegible]	1: 9	Current Ratio

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Definitions

1. **Forest biorefinery:** A forest biorefinery is a facility that converts wood based biomass to produce fuels, power, and chemicals.
2. **Criteria:** An indicator, rule, or test which can be used to make a decision.
3. **Kraft pulp mill:** Is a manufacturing facility that produces wood pulp from wood chips cooked in an alkaline solution.
4. **Complementary resources:** Critical resources which create a unique competitive advantage for both firms when resources are combined together. Example: Company "A" possesses unique technology and company "B" possesses feedstock and facility. "A" and "B" together can create new products.
5. **Cultural compatibility:** Culture is composed of organizations' beliefs and values. It is the way organization resolve day-to-day problems and it is driven by employees at the organization. Culture represents for an organization what personality is to individuals.
6. **Compatible goals:** The end result that companies would like to achieve. The goal could be financial or strategic. It is one of the indicators of cultural compatibility.
7. **Decision making:** The way decisions are reached by an organization. It could be **authoritative**: the organization's leader is the sole decision maker; **facilitative**: the organization's leader and subordinates work together to such a decision; **delegative**: the organization's leader passes on the responsibility of decision making to subordinates.

8. **Research commitment:** Measured by the company's involvement in research and development activities and initiatives.
9. **History of partnership:** An organization's prior experience in handling partnership process.
10. **Profit margin:** Is a measure of the amount of profit accruing to an organization from the sale of products or services.
11. **Average Annual Growth Rate (AAGR):** Measures the average increase in company's revenue over a period. It is useful for determining trends of growth for a certain company.
12. **Return on Assets:** An indicator of how effectively company is utilizing its assets. It gives companies an idea about what earrings can be generated from invested capital.
13. **Current ratio:** Is an indicator that measures whether a company can fund its day-to-day operation over the next 12 months.
14. **Safety, security and environmental concerns:** Some of the technologies might need additional safety and security measures at the production facility. Similarly, some technology might have some environmental positive and negative impacts.
15. **Brand Image:** A name, symbol, design, or some combination which identifies the product of a particular organization as having a substantial and differentiated advantage.
16. **Distribution infrastructure:** Infrastructure to distribute goods produced.
17. **Pair wise comparison**: Refers to the process of comparing entities in pairs to judge which of each entity is preferred over the other or which one is more important than the other.

Appendix II - An Example of AHP methodology

This example is based on arbitrary values used to explain the mathematical model and calculations in AHP method. Steps involved in AHP methods include:

Step 1: Stated the goal: *To select a partner for forest biorefinery from several potential partners*

Step 2: Established criteria: *Three criteria are chosen randomly for this purpose*

1) *Financial resources (FR)*
2) *Technology compatibility (TC)*
3) *Marketing and distribution infrastructure (MDI)*

Step 3: Created questionnaire: A questionnaire was created to assign weights to each criterion

Step 4: Selected participants: This example is based on preferences of one participant to simplify the calculations

Step 5: Pairwise Comparison of criteria: *Use 1 to 9 scale - These values are randomly assigned to each criterion.*

1	TC	9:1	8:1	7:1	6:1	5:1	4:1	3:1	2:1	1:1	X 1:2	1:3	1:4	1:5	1:6	1:7	1:8	1:9	FR
2	FR	9:1	8:1	7:1	6:1	5:1	X 4:1	3:1	2:1	1:1	1:2	1:3	1:4	1:5	1:6	1:7	1:8	1:9	MDI
3	MDI	9:1	8:1	7:1	6:1	5:1	4:1	3:1	2:1	1:1	1:2	X 1:3	1:4	1:5	1:6	1:7	1:8	1:9	TC

source: (Saaty, 1990; Triantaphyllou & Mann, 1995; Vaidya & Kumar, 2006)

This means that financial resources are preferred to technology compatibility and marketing and distribution infrastructure. Also technology is preferred over marketing and distribution infrastructure.

This information can be expressed in a pairwise matrix as shown below:

$$
\begin{array}{l c}
 & \begin{array}{ccc} \mathbf{TC} & \mathbf{FR} & \mathbf{MDI} \end{array} \\
\begin{array}{l} \mathbf{TC} \\ \mathbf{FR} \\ \mathbf{MDI} \end{array} & \begin{bmatrix} 1/1 & 1/2 & 3/1 \\ 2/1 & 1/1 & 4/1 \\ 1/3 & 1/4 & 1/1 \end{bmatrix}
\end{array}
$$

Adapted from: (Saaty, 1990)

Step 6: Assign ranking to each criterion.

The pairwise matrix can be used to assign ranking to each criterion with the help of Eigenvector values (Coyle, 2004). In order to obtain ranking in Eigenvector the pairwise matrix is successively squared (Triantaphyllou & Mann, 1995). This process must be iterated until eigenvector values are not significantly different from previous iteration (Saaty, 1990).

The pairwise matrix can be converted into fractions as follows.

$$\begin{array}{l} \\ \textbf{TC} \\ \textbf{FR} \\ \textbf{MDI} \end{array} \begin{array}{c} \begin{array}{ccc} \textbf{TC} & \textbf{FR} & \textbf{MDI} \end{array} \\ \begin{bmatrix} 1.0000 & 0.5000 & 3.0000 \\ 2.0000 & 1.0000 & 4.0000 \\ 0.3333 & 0.2500 & 1.0000 \end{bmatrix} \end{array}$$

Adapted from: (Saaty, 1990; Vaidya & Kumar, 2006)

Pairwise matrix is squared to obtain Eigenvector values up to 4 places of decimals.

Squaring result:

$$\begin{array}{l} \\ \textbf{TC} \\ \textbf{FR} \\ \textbf{MDI} \end{array} \begin{array}{c} \begin{array}{ccc} \textbf{TC} & \textbf{FR} & \textbf{MDI} \end{array} \\ \begin{bmatrix} 3.0000 & 1.7500 & 8.0000 \\ 5.3332 & 3.0000 & 14.0000 \\ 1.1666 & 0.6667 & 3.0000 \end{bmatrix} \end{array}$$

Adapted from: (Saaty, 1990; Vaidya & Kumar, 2006)

Calculate Eigenvector by first adding row values, second compute rows total, finally divide row sum by rows total (Triantaphyllou & Mann, 1995).

$$\begin{array}{l} \\ \textbf{TC} \\ \textbf{FR} \\ \textbf{MDI} \end{array} \begin{array}{c} \begin{array}{ccc} \textbf{TC} & \textbf{FR} & \textbf{MDI} \end{array} \\ \begin{bmatrix} 3.0000 & +1.7500 & +8.0000 \\ 5.3332 & +3.0000 & +14.0000 \\ 1.1666 & +0.6667 & +3.0000 \end{bmatrix} \end{array} \begin{array}{ll} \\ =12.7500 & 0.3194 \\ =22.3332 & 0.5595 \\ =4.8333 & 0.1211 \end{array}$$

Adapted from: (Triantaphyllou & Mann, 1995).

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Rows total 39.9165 1.00

Eigenvector Values

0.3194

0.5595

0.1211

The process of squaring the matrix must be repeated until there is no significant change in Eigenvector values from previous values (Saaty, 1990; Triantaphyllou & Mann, 1995).

Repeat squaring of previous matrix:

$$\begin{array}{cc} & \begin{array}{ccc} \textbf{TC} & \textbf{FR} & \textbf{MDI} \end{array} \\ \begin{array}{c} \textbf{TC} \\ \textbf{FR} \\ \textbf{MDI} \end{array} & \begin{bmatrix} 3.0000 & 1.7500 & 8.0000 \\ 5.3332 & 3.0000 & 14.0000 \\ 1.1666 & 0.6667 & 3.0000 \end{bmatrix} \end{array}$$

Results of squaring of matrix:

$$\begin{array}{ccc} & \begin{array}{ccc} \textbf{TC} & \textbf{FR} & \textbf{MDI} \end{array} & \\ \begin{array}{c} \textbf{TC} \\ \textbf{FR} \\ \textbf{MDI} \end{array} & \begin{bmatrix} 27.6653 & +15.8330 & +72.4984 \\ 48.3311 & +27.6653 & +126.6642 \\ 10.5547 & +6.0414 & +27.6653 \end{bmatrix} & \begin{array}{cc} =115.9967 & 0.3196 \\ =202.6615 & 0.5584 \\ =44.2614 & 0.1220 \end{array} \end{array}$$

Rows total	362.9196	1.000

Eigenvector Values

0.3196
0.5584
0.1220

Compute the difference between two eigenvector values.

$$\begin{array}{c} \textbf{Eigenvector} \\ 0.3194 \\ 0.5595 \\ 0.1211 \end{array} - \begin{array}{c} \textbf{Eigenvector} \\ 0.3196 \\ 0.5584 \\ 0.1220 \end{array} = \begin{array}{c} \textbf{Eigenvector values} \\ -0.0002 \\ 0.0011 \\ -0.0009 \end{array}$$

Since there is no significant difference between two eigenvector values, there is no need for squaring the matrix again. The relative ranking of each criterion is mentioned below:

Technological capabilities	0.3196 – **The Second most important criterion**
Financial Resources	0.5584 – **The most important criterion**
Marketing and Distribution Infrastructure	0.1220 – **The least important criterion**

Step 7 – Pairwise comparison of potential partners

Identify potential partners : *Four potential partners are chosen randomly to explain AHP method*

1) Weyerhaeuser (WH), 2) BASF, 3) Lignol (LI), and 4) FPInnovations (FPI)

The pairwise comparison of alternatives can be computed in the same manner as the pairwise comparison of criteria was done in the previous step. The four potential partners in this example are Weyerhaeuser (WH), BASF, Lignol (LI), and FPInnovations (FPI). Pairwise comparison of the potential partners according to the technological compatibility is as follows:

	Technological compatibility			
	BASF	**LI**	**FPI**	**WH**
BASF	1/1	1/4	4/1	1/6
LI	4/1	1/1	4/1	1/4
FPI	1/4	1/4	1/1	1/5
WH	6/1	4/1	5/1	1/1

Similarly, for financial resources and marketing and distribution infrastructure pairwise comparison can be computed.

Repeat **step 5** to assign weight to each potential partner in each criterion. The weights computed from the process are as follows:

$$\begin{array}{l} \\ \textbf{BASF} \\ \textbf{LI} \\ \textbf{FPI} \\ \textbf{WH} \end{array} \begin{array}{c} \begin{array}{ccc} \textbf{TC} & \textbf{FR} & \textbf{MDI} \end{array} \\ \begin{bmatrix} .1160 & .3790 & .3010 \\ .2470 & .2900 & .2390 \\ .0600 & .0740 & .2120 \\ .5770 & .2570 & .2480 \end{bmatrix} \end{array}$$

Adapted from: (Coyle, 2004)

Step 8- Ranking

Once the ranking for the criteria and potential partners are assigned, these rankings can be combined by multiplying both the rankings with each other (Coyle, 2004).

$$\begin{array}{cc} & \begin{array}{ccc} \textbf{TC} & \textbf{FR} & \textbf{MDI} \end{array} \\ \begin{array}{c} \textbf{BASF} \\ \textbf{LI} \\ \textbf{FPI} \\ \textbf{WH} \end{array} & \begin{bmatrix} .1160 & .3790 & .3010 \\ .2470 & .2900 & .2390 \\ .0600 & .0740 & .2120 \\ .5770 & .2570 & .2480 \end{bmatrix} \end{array} \times \begin{array}{c} \textbf{Criteria Ranking} \\ \begin{bmatrix} 0.3196 \\ 0.5584 \\ 0.1220 \end{bmatrix} \end{array} \begin{array}{c} \textbf{Technology} \\ \textbf{Finance} \\ \textbf{Marketing and distribution} \end{array}$$

Final ranking of the alternatives derived from multiplication of matrices

BASF	.3060
LI	.2720
FPI	.0940
WH	.3280

The ranking shows that Weyerhaeuser will provide the highest value with (.3280).

Similar methodology is used to assign ranking to each criterion and potential partners in this research.

Appendix III – AHP potential partners pairwise comparison

	Distributive mode		Pairwise	Pairwise	Pairwise
AID	**Alternative**	**Total**	**Complementary Resources (G: .204)**	**Research Commitment History of R&D (G: .051)**	**Research Commitment Relationship with outside R&D organizations (G: .076)**
A1	☑BASF Chemicals	.364	.696	1.000	1.000
A3	☑Weyerhaeuser	.363	1.000	.315	.883
A4	☑Lignol Energy	.273	.744	.397	.801

	Distributive mode	Pairwise	Pairwise	Pairwise
AID	**Alternative**	**Financial Resources Profit Margins (G: .073)**	**Financial Resources Average Annual Growth Rate (G: .055)**	**Financial Resources Return on Assets (G: .068)**
A1	☑BASF Chemicals	1.000	1.000	1.000
A3	☑Weyerhaeuser	.988	.830	.526
A4	☑Lignol Energy	.529	.534	.240

	Distributive mode	Pairwise	Pairwise	Pairwise
AID	**Alternative**	**Financial Resources Current Ratio (G: .063)**	**Technological Compatibility (G Implementation Challenges (G: .079)**	**Technological Compatibility (G Safety, security, and environmental considerations (G: .083)**
A1	☑BASF Chemicals	.634	.461	.788
A3	☑Weyerhaeuser	1.000	.998	.954
A4	☑Lignol Energy	.445	1.000	1.000

	Distributive mode	Pairwise	Pairwise	Pairwise
AID	**Alternative**	**Technological Compatibility (G Type of Technology (G: .045)**	**Marketing and Distribution Res Brand Image (G: .062)**	**Marketing and Distribution Res Distribution Infrastructure (G: .140)**
A1	☑BASF Chemicals	.439	1.000	1.000
A3	☑Weyerhaeuser	.896	.731	.767
A4	☑Lignol Energy	1.000	.532	.459

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