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Annukka Näyhä

Towards Bioeconomy

A Three-Phase Delphi Study on Forest Biorefinery Diffusion in Scandinavia and North America

JYVÄSKYLÄN YLIOPISTO

ABSTRACT

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Bioenergy and bioproducts play an important role in society's transition towards a more bio-based economy. Correspondingly, a bioeconomy with related new opportunities can offer ways to diversify business in the forest cluster. Biorefineries, integrated into the pulp and paper industry in particular, seem to hold future potential. This study aims at sketching a holistic view of the issues affecting the diffusion of the forest biorefineries in Scandinavia and North America. In addition, environmental sustainability within the contexts of forest biorefineries and forest industry change with the needed resources are examined more closely. The Delphi method with related scenarios was chosen as a key research method. This study indicates that forest biorefineries have a multifaceted diffusion process affected by a variety of issues. Therefore, incentives that promote biorefinery business must come from several sources. First, there need to be encouraging signals from the macro-scale environment – the high price of oil, national security of fuel supply, and long-term and consistent federal and state energy and environmental policies are the most prominent macro-scale drivers. At the industries/sectors level, the successful implementation of a biorefinery business requires efficient exploitation of existing wood biomass resources, availability of private and public financing, and collaboration between different value chain actors. At the strategic level, an understanding of new markets and management of change, as well as the development of economic wood fractionation technologies with related innovations and process expertise facilitate best the diffusion process. Overall, incentives for the biorefinery business differ only slightly in the studied areas, and they both seem to have potential for success in the biorefinery business. However, identification of national strengths and the roles of the companies in the biorefinery value chains is crucial in order to succeed in the long term. Raw material availability and sustainability seem to be the most prominent criteria in the environmental sustainability assessment of the forest biorefinery business, followed by the importance of the life-cycle perspective and production of beneficial products. Furthermore, this study shows that the renewal of the forest industry is not possible without a readiness for change and a resilient attitude, which are embedded in the organizational culture and management. Moreover, success in the forest biorefinery business will be based on partnerships through which the right set of skills can be achieved. However, from the perspective of the forest industry, collaborative management in the consortia brings challenges: sharing profits and responsibilities between partners will be the most difficult issue to resolve.

Keywords: bioeconomy, forest biorefinery, diffusion, business environment, North America, Scandinavia, environmental sustainability, forest industry's change

Author's address Annukka Näyhä
Corporate Environmental Management
School of Business and Economics
University of Jyväskylä
P.O. Box 35, 40014 University of Jyväskylä
Finland
annukka.nayha@jyu.fi, annukka.nayha@uef.fi

Supervisor Professor Hanna-Leena Pesonen
Corporate Environmental Management
School of Business and Economics
University of Jyväskylä
Finland

Reviewers Assistant Professor Warren Mabee
Queen's University, Kingston
Canada

Adjunct Professor Jarmo Vehmas
Finland Futures Research Centre
University of Turku
Finland

Opponent Adjunct Professor Jarmo Vehmas

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Metsäpuro, October 2012
Annukka Näyhä

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LIST OF ORIGINAL PUBLICATIONS

The thesis is based on the following original manuscripts:

1. Näyhä, A., Hämäläinen, S. and Pesonen, H.-L. (2011). Forest biorefineries – a serious global business opportunity. In Alen, R. (Ed.), Chapter 4, Biorefining of Forest Resources, Bookwell Oy, Porvoo, pp. 132-149.

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CONTRIBUTIONS

1. The paper was jointly planned and written with **Professor Hanna-Leena Pesonen** and **Sari Hämäläinen**. **Annukka Näyhä** was primarily responsible for the initial design of the study and she chose the methodological approach. The data was collected together with the co-authors. Näyhä was responsible for the planning and conducting of most of the statistical analysis.

2. The paper was prepared together with **Professor Hanna-Leena Pesonen**. **Annukka Näyhä** was responsible for the planning and the data analysis, and she is also the primary author of the paper.

3. The manuscript was prepared together with **Susanna Horn**. **Annukka Näyhä** took the initiative, provided the interview data for the analyses and chose the methodological approach. The data was analyzed with the co-author, and the paper was jointly planned and written with the co-author.

4. The paper was prepared together with **Professor Hanna-Leena Pesonen**. **Annukka Näyhä** was the main contributor to the planning of the study, the data gathering and the analysis as well as the writing of the paper.

DEFINITIONS

Diffusion An expansion of the utilization of a new innovation, be it a new product, new processes or new management methods (Rogers, 2003; Stoneman, 1986).

Forest biorefinery A multi-product factory that integrates biomass conversion processes and equipment in order to produce bioenergy and bioproducts from wood-based (lignocellulosic) biomass (e.g. NREL, 2012).

Forest biorefinery value chain In this study a forest biorefinery value chain is understood as a string of diverse companies that, beginning from forestry, working together to satisfy market demand for wood-based biofuels and bioproducts.

Forest industry A forest industry includes pulp, paper, paperboard and wood products industries. The latter contains sawmilling, plywood, chipboard, fiberboard and construction products industries. (Kärkkäinen, 2005)

Forest sector In this study a forest sector covers forestry and forest industry activities.

Forest cluster A forest cluster is the gathering of industries and production facilities around the forestry and the forest industry. A forest cluster includes mechanical, chemical and packaging industries related to the forestry and the forest industry. A forest cluster also includes related energy, logistics and consulting companies, as well as research institutes and universities. (Kärkkäinen, 2005)

1 INTRODUCTION

1.1 Background

The emerging bio-based economy (bioeconomy) is a promising sector with notable future potential and many business opportunities (Luoma et al., 2011). Already today, the bioeconomy is providing growth and employment to millions of people (European Commission, 2011). Due to the novel nature of the sector, the understanding and definitions of bioeconomy are being continuously developed as they confront new issues and as a variety of instances approach the bioeconomy sector. In general bioeconomy can be defined as the exploitation and management of renewable natural resources in a sustainable way. It includes producing different products and services by using various biological and technical applications. (Kuisma, 2010) According to the European Commission (2011), the concept of bioeconomy brings under one umbrella all sectors – agriculture, forestry, fisheries, food, biotechnology and the chemical industry– of the economy that process biological resources from different ecosystems. It relies on research from bio-sciences, information technologies, robotics and materials and aims to transform the knowledge and new technologies into agricultural, industrial and social innovation. The bioeconomy can also be seen as a strategy used by society to fight against urgent problems such as climate change, competition for natural resources and regional development (Luoma et al., 2011). OECD (2009) highlights the biotechnology aspect in the bioeconomy as follows: The application of biotechnology to primary production, health and industry could result in an emerging bioeconomy, in which biotechnology contributes to a significant share of economic output. Furthermore, it is believed that for the bioeconomy to develop into a national strength, those working in the sector need new ways of thinking, challenging of current practices, collaboration and a mutual understanding of the future vision (Luoma et al., 2011).

Biomass-based energy (bioenergy) and products (bioproducts) play an important role in society's transition towards a more bio-based economy. Firstly, it is obvious that we are facing challenging times when it comes to meeting our energy needs. There will be heavy pressure for an increase in the price of oil in the future. Added to this concern is the increased environmental threat to climate change related to the contribution of combustion CO_2 from fossil fuels. Likewise, use of fossil fuels will be highly regulated with related costs in the future. In countries rich in biomass resources, biomass-based fuels can replace expensive imported energy and improve the national security of the fuel supply, while at the same time mitigate greenhouse gas emissions. In addition to bioenergy, the movement towards a bio-based economy has also increased interest in other bio-based products, such as chemicals and fibers. Biomass-based energy and products can also foster social and economic development in rural communities and help in waste management. Widely studied at the moment are lignocellulosic, non-food biomass feedstocks and technologies for converting these sources into economical, low-carbon biofuels (carbon is used as a shorthand for life cycle global warming impact, see Farrell et al., 2007) and bioproducts. (See e.g. FAO, 2011; Hetemäki et al., 2011; Hetemäki and Verkasalo, 2006; Johnson et al., 2009; Mabee et al., 2006; Metsäneuvosto, 2006; Perlack et al., 2005; Söderholm and Lundmark, 2009; Thorp, 2007)

Despite the global trend of market liberalization, politics will play an ever increasing role of importance in the development of bioenergy and bioproducts markets (Hetemäki, 2010; Lewis and Wiser, 2007; Söderholm and Lundmark, 2009). A significant goal of the European Union's energy policy is to promote renewable energy sources, and the use of biomass is expected to constitute a major share of the future total use of renewable energy sources in Europe. The European Union's climate package "20/20 by 2020" includes proposals for reducing the EU's greenhouse gas emissions by 20% and for increasing the proportion of renewable energy in the EU's total energy consumption to 20% by 2020. (European Commission, 1997; 2007, a; 2009; Star-COLIBRI, 2011) There is also a variety of efforts towards encouraging other bio-based products. Accordingly, many innovation and R&D policies address societal challenges and building the bioeconomy. (European Commission, 2007, b; Star-COLIBRI, 2011) In the United States the key goal of the Biomass Program is to develop renewable non-food biomass resources into sustainable, cost-competitive biofuels, bioproducts and biopower. The Program emphasizes support through public and private partnerships and deployment of technologies in integrated biorefinery facilities. The Program has the strategic goal of developing commercially viable biomass technologies that will enable the production of biofuels nationwide and reduce dependence on oil through domestic bioenergy industry, thus supporting the Energy Independence and Security Act of 2007 (EISA) goal of 36 billion gallons per year of renewable transportation fuels by 2022. (DOE, 2007; 2011) In Canada the Renewable Fuels Strategy and related Renewable Fuel Regulations play a key role in the government's commitment to reduce Canada's greenhouse gas emissions and in encouragement towards a bio-based economy in general (Environment Canada, 2011).

Very recently both the United States and the European Union have published their strategic plans for the development of their bioeconomies, which have many similar aspects. In the U.S. the 2012 National Bioeconomy Blueprint has two main purposes: first, to lay out strategic objectives that will help realize the full potential of the U.S. bioeconomy and second, to highlight early achievements of those objectives. Accordingly, these purposes are aimed at being realized by supporting the R&D investments for bioeconomy, facilitating commercialization of bio-innovations, developing a regulatory framework, emphasizing education and training, and supporting public-private partnerships. (White House, 2012) Likewise, the European Union's Bioeconomy Action plan describes the Commission's main actions for the implementation of the Bioeconomy Strategy objectives and existing policy initiatives. The plan focuses on three key aspects: developing new technologies and processes for the bioeconomy, developing markets and competitiveness in bioeconomy sectors, and pushing policymakers and stakeholders to work more closely together. (European Commission, 2012) Accordingly, various policies in different countries and at the global level are, and will be, implemented in order to facilitate the development and construction of forest biorefineries (Hetemäki, 2010).

Consistently, a bio-based economy with related new opportunities in bioenergy and bioproduct markets offer ways for diversifying business in the forest cluster. There are many different driving forces that shape the developments in the forest-based industries with consequences for their continuity. Some of the most prominent forces are mostly negative and can only be addressed by changes within the industries. (FAO, 2011) For decades, the success of the forest cluster has been based on steadily growing demand for forest-based products, a sustainable supply of raw wood material, comparatively low energy prices, advanced forest industry technologies, efficient production machinery and, in some countries, also on the special status of the forest sector in the national economic policy (particularly in Finland and Sweden). However, these elements, which have guaranteed the success of the forest cluster, have largely disappeared. The forest clusters in Scandinavia and North America have global competitors in Latin America and Asia, which have modern and large industries, as well as wood and labor cost advantages. The need to innovate and redefine business models and culture is particularly urgent in the mature pulp and paper industry, with its frequent mill closures and profitability problems. (See e.g. Chambost and Stuart, 2007; van Heiningen, 2006; Metsäneuvosto, 2006; Toland, 2007)

Therefore, in many areas the forest industry has long been characterized as a mature industry with production-oriented, low-cost strategies (Bush and Sinclair, 1992; Cohen and Kozak, 2001; Cohen and Sinclair, 1989; Juslin and Hansen, 2003; Niemelä, 1993). In the countries that can no longer compete with the emerging economies, a restructuring of the industry is likely to be a major change. For the global forest industry, wood energy production is the single biggest opportunity in the next decade, followed by the importance of other bio-based products – for example, chemicals and fibers – in the longer time perspective. Biorefineries, integrated into the pulp and paper industry in particular, seem to hold future potential. In this study, *a forest biorefinery* is defined as a multi-product factory that integrates biomass conversion processes and equipment in order to produce a variety of bioproducts such as fuels, fibers, and chemicals from wood-based (lignocellulosic) biomass. (FAO, 2011; van Heiningen, 2006; NREL, 2012; Ragauskas, 2006; Sorenson et al., 2007; Thorp, 2005)

There are no nation- or industry-wide solutions for how a forest biorefinery should be developed and implemented. In the literature, three different generations of biorefineries have been identified. In general, *first generation biorefineries* are based on direct utilization of classical forms of agricultural biomass (conversion of sugar-rich biomass by fermentation to bio-ethanol or conversion of oil-rich biomass by transesterification to bio-diesel). *Second generation biorefineries* are defined as facilities that utilize lignocellulosic biomass as a raw material, one of the biggest advantages being that this reduces dependence on food crops required for first generation biorefineries. *Third generation biorefineries* have the advantage of utilizing agricultural, forestry, petrochemical, and urban wastes. (e.g. CRIP, 2012; Naik et al., 2010) An important goal of a forest biorefinery is to more efficiently utilize the entire potential of raw materials and by-streams of the forest-based sector for a broad range of products (Hetemäki 2010; Mensink et al., 2007). The conversion technologies can be classified into three different pathways: biochemical, thermochemical, and physical-chemical. In addition, the different processes can be to some extent combined. Some of the conversion technologies are already mature and commercial, whereas others require development to move to commercial applications. Overall, within the forest biorefinery context, there are a number of different product and technological possibilities. (See e.g. Larson et al., 2006)

However, in addition to considerable opportunities, there are also many risks related to biorefinery implementation. The viability of each specific forest biorefinery product-technology mix depends on end markets (demand, supply, prices), substitute markets (e.g. oil), biomass markets, as well as on global, national, and regional policies. These may vary between and even within countries. Accordingly, forest-based industries need to redefine their current business models and strategies in a way that preserves their core business while allowing profitable manufacture of new biorefinery products. (Bozell and Petersen, 2010; Chambost and Stuart, 2007; Hetemäki, 2010) Moreover, various stakeholders, including academia, NGOs and even public authorities have also been increasingly critical of environmental impacts related to the biorefining business (e.g. FAO, 2011; IEA, 2011, a; b).

Thus, as the emerging biorefining economies continue to take shape, there is a growing need for realistic estimates of the factors that affect the diffusion process of forest biorefineries. Successful introduction of biorefineries and related new products and business models requires information about the global business environment in addition to the national one. Overall, the challenges related to biorefineries must not be seen as purely technical problems nor as issues unconnected to society. The diffusion of biorefineries, like the diffusion of new technologies in general, is affected by several factors. Both research and development work (technology push) and activities which encourage commercialization and implementation of innovations (market pull) are needed. (Rogers, 2003) Markusson et al. (2012) argue that it is necessary to involve a multi-faceted, socio-technical framework to help analyze the possible future development of technologies and to facilitate decision-making. The diffusion process is influenced by state policies and subsidy mechanisms, collaboration between different actors, economic factors, the organizational culture and stakeholders' views. Ecological aspects and the need to secure the sustainable use of natural resources are other significant issues that influence the success of new technologies. To promote biorefineries, information must be readily available on economically efficient incentives and new business models. The effects of biorefineries on the national economy, wood raw materials markets and other forms of forest utilization should also be considered. (See e.g. Freeman, 1996; Peres et al., 2010; Rennings, 2000)

Nevertheless, studies related to forest biorefineries have largely been technologically focused until recent years (See e.g. Söderholm and Lundmark, 2009). Many studies have focused on developing processes and technologies for the conversion of biomass into various types of bioproducts (See e.g. van Heiningen, 2006; Larson et al., 2006; Ragauskas et al., 2006; Saxena et al., 2009). Furthermore, biorefineries have been approached from the business perspective in some studies (e.g. Chambost et al., 2008; Hytönen and Stuart, 2009; Kangas et al., 2011; Thorp, 2005). In 2008, when this study was initiated, there had been several announcements about lignocellulosic bioefinery development projects in Scandinavia and North America. For example, the DOE announced its investment in six commercial scale biorefinery projects and four small scale biorefinery projects in the U.S. in 2007-2008. However, there were no commercial scale biorefineries utilizing lignocellulosic feedstock in operation. Now, when many technologies are close to the stage of commercial applications, there is a need for a synthesis of current knowledge and analytical assessment of future environmental and policy prospects (Hetemäki, 2010).

It is apparent that the biorefining business needs to pay attention to many concerns that have been raised regarding the sustainability of bio-based industries in terms of negative environmental, social and economic impacts. Bioenergy and bioproducts are questioned particularly with adverse issues related to raw material, land use and carbon footprint. (See e.g. Bright and Stromman, 2009; Doornbosch and Steenblik, 2008; Farrell et al., 2006; Johnson, 2009; Searchinger et al., 2008) Nevertheless, studying the impacts of forest biorefineries from the environmental sustainability perspective has not received the attention to which it is entitled. Moreover, many studies have indicated that there is an increasing call for the development of reliable sustainability criteria and indicators for biomass-based industries (e.g. Buchholz et al., 2009, a; b;

Lewandowski and Faaij, 2006; Mikkilä et al., 2009). Different sustainability criteria, indicators and frameworks would be important tools for organizations themselves as well as for politicians and the public in recognizing, assessing and monitoring the impacts of industries on the surrounding society and environment. They also enable investors to evaluate a company's role in sustainable development and assess long-term liabilities. (Singh et al., 2007)

There is a clear consensus that the pace of change has never been greater than in the current continuously evolving business environment. According to Grant (2010), understanding and predicting changes in the industry environment is only one aspect of the management challenge. By far the greater challenge is ensuring the adaptation of the company to these changes. Change is disruptive, costly and uncomfortable for individuals; for organizations the inertia is even stronger. (Grant, 2010) Many studies have shown that the management of organizational change currently tends to be discontinuous and reactive with a high failure rate of the change programs initiated (Balogun and Hope Hailey, 2008; Beer and Nohria, 2000; Todnem By, 2005). Styles and Goddard (2004) suggest that firms falling into the maturity trap do so because they compete in an industry with many firms pursuing same strategy, i.e. they attempt to compete by "being better at the same game". A consequence of mainstream thinking can be a loss of the excitement of creating something new, which does not facilitate innovation (Fonseca, 2002). Therefore, for a company entering into the biorefining business successful implementation of new business strategies and models with required new capacities and capabilities will be challenging. According to Söderholm and Lundmark (2009) the development of forest-based biorefineries may imply a fundamental structural change in the traditional forest-based industries, but so far our understanding of these potential changes is limited.

1.2 Aims of the study and research questions

Overall, this study contributes to the understanding of the different options and business potential for realizing future bioeconomy. The main aim of this study is to sketch a holistic view of the issues and challenges affecting the diffusion and implementation of the forest biorefineries in Scandinavia and North America. The study concentrates on countries (Finland, Sweden, the U.S., Canada) with good preconditions for the establishment of forest biorefineries: high-quality research and development, similar structures and mature state in the forest-based industries, and abundant lignocellulosic biomass resources. During the three phases of the study, global and national drivers for forest biorefineries are outlined and compared between the studied areas.

Altogether the research explores economic, political, technological and ecological and raw material related factors as well as business capacities and capabilities, all of which can have an effect on the diffusion process of forest biorefineries. As a main result, the key promoting factors in the business environment are recognized at three levels: macro-environment, levels of industries/sectors and strategic groups. Accordingly, models for wood-based biorefineries, future views for the forest cluster, and scenarios for the future of lignocellulosic biofuel production capabilities are presented. In addition, two issues that affect the diffusion and success of forest biorefineries are examined more closely: environmental sustainability within the context of forest biorefinery value chain companies and current forest industry change and the needed resources.

The main research question is:

- What are the main factors that affect the diffusion of forest biorefineries in Scandinavia and North America?

This main research question is addressed through the following sub-questions:

- What are the key *promoting factors* in the forest biorefinery business environment at *different levels*: macro-environment, levels of industries/sectors and strategic groups?
- What are the most significant *aspects and criteria of environmental sustainability* in the forest biorefinery context?
- What are the most prominen*t change features and resources of the forest industry* when aiming towards biorefining business?

A description of each research phase with detailed research goals and related manuscripts are presented in Section 3.

1.3 Outline of the study

This thesis consists of two parts. Part 1 is an overview of the thesis in which the synthesis of the entire dissertation is presented and discussed. Part 1 has five chapters: this first is an introduction that describes the background, the motivations, the aims and the research questions. Chapter 2 presents the theoretical framework with different approaches on which this thesis is built. Chapter 3 covers overall research design and related strategies and methods. It also includes a detailed presentation of each research phase with an exact description of the aims and related research papers. Chapter 4 presents the key findings of the research with a discussion. Chapter 5 concludes by presenting the main contributions, an evaluation of the study and its future research potential. In Part 2 the research papers that form the basis of the thesis and address the research questions, are presented.

2 THEORETICAL FRAMEWORK

2.1 Outline for the theoretical foundation

In the contextual background of the present study is society's aspiration to become a bioeconomy (as described in the previous section). The main theoretical foundation that covers the ultimate goal of the thesis is innovation diffusion, and – more specifically – new technology diffusion (e.g. Geroski, 2000; Rogers, 2003). All the other theoretical approaches that have been exploited in this research fall under the umbrella of this main approach of technology diffusion (Figure 1). I have structured the business environment of forest biorefineries and different factors that affect the diffusion process on different levels: macro-level, levels of industries/sectors and strategic groups (See Johnson et al., 2008). Furthermore, macro-level diffusion factors have been explored using the PESTEL framework as a guideline (e.g. Thomas, 2007). A closer analysis of environmental factors is based on environmental sustainability aspects and assessment (e.g. Ness et al., 2007; Singh et al., 2007). Examination of strategic change towards the forest biorefinery business at the forest industry level has been approached using change management approaches, the change kaleidoscope framework in particular, and a resource-based view (e.g. Balogun and Hope Hailey, 2008; Lockett et al., 2009).

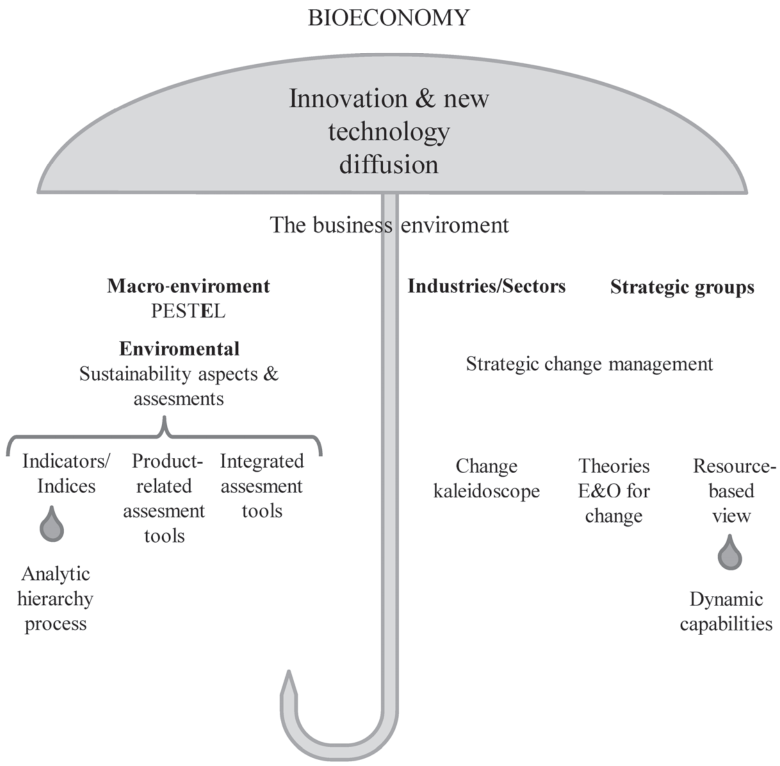

FIGURE 1 The theoretical approaches of the study.

2.2 Innovation and new technology diffusion

The modeling and forecasting of the *diffusion of innovations* has been a topic of practical and academic interest since the 1960s, when the pioneering works of Fourt and Woodlock (1960), Mansfield (1961), Floyd (1962), Rogers (1962), Chow (1967) and Bass (1969) appeared. The diffusion phenomenon has thus been approached from a variety of different perspectives. Fields that have discussed the subject include sociology (Rogers, 2003), geography (Brown, 1981; Clark, 1984), marketing and consumer behavior (Majahan et al., 1990). Likewise, the research on *new technology diffusion* is vast, and it is spread across many disciplines (Geroski, 2000). Earlier studies often emphasized the explanation of the past rather than a forecast of the future. In terms of practical impact, the main application areas are the introduction of consumer durables and telecommunications. In the recent years, new product applications in marketing have tended to dominate the overall diffusion literature. However, future directions of research are likely to include forecasting new product diffusion with little or no data, forecasting with multinational models, and forecasting with multi-generational models (Meade and Islam, 2006).

An *innovation* is an idea, practice, or object that is perceived as new by an individual or other unit of adoption. The key is the perceived newness of the idea; therefore it does not matter if an idea is "objectively" new. (Rogers, 2003)

Innovations can be categorized as *process* (an improved method of production or logistics, or supporting activities such as maintenance and operations for purchasing, accounting, or computing), *product* (a new or improved good or service) or *organizational* innovations (new business practices, knowledge management systems, methods of workplace organization and management of external relations) (e.g. OECD, 1997; 2005; Polder et al., 2010; Rennings, 2000). Innovations can be further divided as *technological* (new technical solutions in services or products), *social* (e.g. changes in life-styles or in consumer behavior) and *institutional* (e.g. new types of networks between stakeholders) innovations (Edquist, 1997; Rennings, 2000). The general definition of innovation is neutral in terms of the content of change, whereas the *eco-innovation* definition also includes the aim of an innovation: eco-innovations are all measures of relevant actors, which develop new ideas, products and processes or introduce them and which contribute to a reduction of environmental burdens or to ecologically specified sustainability targets (Klemmer et al., 1999; Rennings, 2000). Further, more recent approaches consider the eco-innovations from the perspective of increased sustainability and competitiveness (e.g. Carrillo-Hermosilla et al., 2009).

According to Rogers (2003), *diffusion* is the process by which innovation is communicated through certain channels over time among the members of a social system. Technological diffusion can be also understood as referring to the expansion of the utilization of a new concept, be it a new product, new processes or new management methods within and across economies (Stoneman, 1986). Furthermore, diffusion can be seen as a selection process between substitute technologies (Arthur, 1989; Katz and Shapiro, 1986; Nelson and Winter, 1982). Economic theory has concentrated on the explanation of the diffusion sequence of new technology and on the individual adoption decision (Baptista, 1999).

According to Rogers (2003), *the innovation-development process* consists of all decisions and activities as well as their impacts, and proceeds as follows: from the recognition of a need or problem, to the research, development and commercialization of an innovation, to the diffusion and adoption of the innovation by the user, to, finally, its consequences. Baptista (1999) believes that diffusion involves the initial *adoption of a new technology* by a firm and the subsequent *diffusion of the innovation* within the firm. Therefore, diffusion itself results from a series of individual decisions to begin using the new innovation or technology and decisions, which often result from a comparison of the uncertain benefits of the new invention with the uncertain cost of adopting it. An understanding of the factors affecting this choice is essential when exploring the diffusion process. (Carter Jr. et al., 2001; Kalish, 1985; Lai and Guynes, 1997; Rogers, 2003) Likewise, heterogeneity in the population of potential adopters should not be ignored because it first has an effect on the individual adoption decision, and then, on the consequent patterns of diffusion at the aggregate level (Baptista, 1999).

Different theoretical approaches have been pursued in order to rationalize the main characteristics that describe the diffusion process. It has been well documented in the literature on technology diffusion that one of *the key features of technological diffusion* is the apparently slow speed at which firms adopt new technologies. The two most commonly noted "stylized facts" are, first, that the intensity at which usage or ownership of a new technology spreads across an economy changes over time (Mansfield, 1961; 1968). Second, the time path of adoption typically follows an S-curve, where a slow take-off is followed by a period of relatively rapid adoption and then a slow-down to satiation (Davies, 1979; Gort and Klepper, 1982; Mansfield, 1961).

Although classic models of technological development suggest a straightforward, linear path from basic research and development to technology commercialization and adoption, in practice, technology diffusion is more often a complex and iterative process. Innovation processes should be viewed as a multifaceted interaction between potential consumers and new technologies. Technology can diffuse in multiple ways and with significant variations – depending on the particular technology – across time, over space, and between different industries and types. In addition, the effective use of diffused technologies by firms frequently requires organizational, workforce, and follow-on technical changes. (Baptista, 1999; Freeman, 1996; Peres et al., 2010; Shapira and Rosenfeld, 1996)

According to Rogers (2003), one of the most important factors that affect the diffusion of innovation is the *relative advantage*. The relative advantage is the degree to which an innovation is perceived as being better than the idea it supersedes. The degree of relative advantage is often expressed as economic profitability, as conveying social prestige – the bigger the attained benefit, the faster the diffusion process. Rogers (2003) also highlights the importance of *compatibility*, which is the degree to which an innovation is perceived as consistent with the existing values and needs of potential adopters. An innovation's incompatibility with cultural values can block its adoption and diffusion process. Further, *complexity* is the degree to which an innovation is perceived as relatively difficult to understand and use, and is negatively related to its rate of adoption. Complexity may not be as important as relative advantage or compatibility for many innovations, but for some new ideas complexity is a very significant barrier to adoption. *Trialability* is defined as the degree to which an innovation may be experimented with on a limited basis. New ideas that can be tried on the installment plan are generally adopted more rapidly than innovations that are not divisible. *Observability* is the degree to which results of an innovation are visible to others, and it is positively related to its rate of adoption. (Rogers, 2003)

Accordingly, many studies have highlighted the interplay between two types of effects on the rate of diffusion. On one end uncertainty connected to the rapid introduction of incremental innovations has slowed the diffusion process due to expectations of continuing incremental change. On the other hand, increased profitability resulting from early adoption might reinforce the rate of diffusion. (Baptista, 1999) Kapur (1995) believes that because profitability of new technologies is uncertain and firms can learn progressively by observing the adoption experience of others, each company would prefer that other companies adopt before it does. According to Rosenberg (1976), a technology that is expected to improve over time will tend to diffuse more slowly than one that is not. In general, technology diffuses faster in less concentrated markets and large firms tend to adopt innovations earlier than smaller ones. Overall, the speed of diffusion and the shape of the diffusion curve will depend on a distribution of benefits and the rate at which movement down distribution occurs (Baptista, 1999).

Various studies have investigated strategic reasons why even firms with identical capital characteristics might differ in dates of adopting new technologies. According to Quirmbach (1986), a joint venture among adopters delays the rate of diffusion of a capita-embodied process innovation, as it is in the interest of adopters to protect investments in existing equipment. As long as the equipment employed in an older process remains operable, a new process will not be introduced until its average total cost of production is lower than the average cost of production for the older process.

Often, innovation research has focused on technical issues and primarily concentrated only on those stakeholders directly involved in the value-adding activities or market relationships, such as the customers, complimentary innovators and suppliers. Further, technological innovation processes have been studied many times by exploring the importance and relation of research and development (technology push) and activities that encourage commercialization and implementation of new innovations (market pull). (Dosi, 1982; Freeman, 1996; Inoue and Miyazaki, 2008; Mowery and Rosenberg, 1979; Pavitt, 1984; Shapira and Rosenfeld, 1996) Other *environmental*, *political, economic, social, networking* and *institutional* factors are often given less emphasis. Technology as such cannot guarantee success of an innovation if other aspects related to the innovation are not accepted by stakeholders (e.g. Baptista, 1999; Carter Jr. et al., 2001; Coria, 2009; Freeman, 1996; Goldenberg et al., 2010; Majahan et al., 2000; Midgley et al., 1992; Peres et al., 2010; Rennings, 2000). Peres et al. (2010) state that research in diffusion modeling will have to expand its horizons in the future and this field of study has much more to offer, particularly in terms of describing current market trends. As well, Baptista (1999) highlights the importance a broader institutional scope that is needed for evaluating technology diffusion.

Moreover, innovations are not invariant qualities that do not change during the process. Innovations are changed and modified by a user and interaction with other innovations in the process. Products and processes can be also re-invented when previously started innovation processes are adopted anew and further developed. (Antonelli, 1993; Rennings, 2000; Rogers, 2003; Shapira and Rosenfeld, 1996)

The diffusion of an innovation rarely takes place in a stable, unchanging environment (Meade and Islam, 2006). Furthermore, diffusion processes of new products and services have become increasingly complex and multifaceted in recent years (Peres et al., 2010). The importance of incorporating current market trends – such as the opening up of new markets and complex product service structures – should be taken into account. Cross-market and cross-country influences and differences in growth across countries should be also considered. (Dekimpe et al., 2000; Goldenberg et al., 2002; Peres et al., 2010)

In this thesis the aim was to build a holistic view of forest biorefinery development and implementation, and of the factors that promote biorefinery diffusion. Therefore, understanding of new technology diffusion and its most central premises were the applicable theoretical basis of the research. However, the aim in this study was not to apply a specific diffusion model or models; rather innovation diffusion brought a broad socio-economic framework that help to understand and analyze the diversity of factors that affect the diffusion process of forest biorefineries. Respectively, in this context innovation was also understood more broadly: all the new practices related to forest biorefineries – whether they be new products, processes or management activities – were seen as innovations.

2.3 Analyzing the business environment

In order to survive and be competitive, companies, from their perspective, must carefully identify the forces that are shaping the business environment. Particularly when setting up a new business or entering new markets, knowing the key factors in the business environment is extremely important. Exploring the business environment can be challenging for several reasons. First, the business environment encapsulates a variety of influences and the difficulty lies in understanding this diversity. Identifying various environmental influences may be possible, but attaining an overall picture of the important influences on the organization can be much more challenging. The second difficulty is the speed of change. Business leaders feel that the pace of technological change and the speed of global communications are faster than ever. Accordingly, the outlook for the future is highly uncertain, which in turn leads to a third problem: complexity. Managers typically try to simplify what is happening by focusing on those few aspects of the environment that have been important historically. However, it is important to achieve an understanding of the environment that is both usable and future-oriented. (See e.g. Grant, 2010; Hamel and Prahalad, 1994; Johnson et al., 2008; Porter, 1980)

2.3.1 Layers of the business environment

Johnson et al. (2008) have provided a framework for understanding the environment of the organizations with the aim of helping to identify key issues and ways of coping with change and complexity (See also Macmillan and Tampoe, 2001). Environmental influences and trends can be thought of as *layers* *around the organization*. The outer layer is referred to as the *macro-environment*, which is the most general layer, consisting of broad environmental factors that impact to some extent nearly all organizations. Within the macro-environment sit *industries or sectors*, and the inner layer stands for further *strategic groups*. These are organizations with similar strategic characteristics, following similar strategies or competing similar bases. (Johnson et al., 2008)

2.3.2 PESTEL framework and scenarios

The *PESTEL framework* can be a useful tool when approaching the most general layer of the framework. PEST stands for "Political, Economic, Social, and Technological analysis", with Environmental and Legal factors expanding the acronym to PESTEL. PESTEL analysis gives an overview of the different macro-environmental factors that the company has to take into consideration. The framework can be part of the external analysis when conducting a strategic analysis or doing market research. It is a useful strategic tool for understanding market growth or decline, business position, potential and direction for operations. The framework can be used for reviewing a situation, and it can be especially useful in strategic planning when a company decides to enter its business operations in new markets and new business areas. It is particularly important that PESTEL is used to look at the future impact of environmental factors, which may be different from their past impact. Scenarios may help with this future-oriented approach. (Johnson et al., 2008; Thomas, 2007)

When there are long-term strategic horizons but high levels of uncertainty around key environmental factors, scenarios can be a useful way of understanding the implications of these influences on strategy. This includes the need for organizations to be prepared to face more than one situation in their future environment. In the other words, the aim of the scenarios is to give a detailed and plausible view of how the business environment of an organization might develop in the future, based on groupings of key environmental influences and drivers of change, about which there is a high level of uncertainty. (Burt et al., 2006; Johnson et al., 2008; Walsh, 2005)

In this thesis the approach presented by Johnson et al. (2008) guided the structuring diffusion factors and trends at the different levels around the forest biorefineries. Further, factors that were included in the PESTEL framework proved to be beneficial in the approach for planning research and in understanding the big picture of the macro-environment in which companies work. For example, survey questionnaire questions from the first Delphi round included many elements of the PESTEL and results from the first Delphi phase are presented mainly by following the PESTEL framework. In addition, considering a long-time perspective and future uncertainties faced by the forest cluster, scenarios and future views were a useful approach for studying macro-scale diffusion factors of emerging biorefinery business (See also Section 3.2 about scenarios).

2.4 Environmental sustainability in the biorefinery context: aspects and assessment

2.4.1 Aspects of environmental sustainability

Initially the principle of sustainable forest management emerged during the 18th century in Germany, where the mining industry consumed plenty forest resources. Accordingly, traditional sustainable forestry, also referred to as sustainable yield management, was introduced to Finnish forestry in the beginning of the 20th century to guarantee a continuous timber supply. (Sample et al., 1993; Vehkamäki, 2006) The modern concept of sustainability was formally introduced in 1987 by the World Commission on Environment and Development (WCED, 1987). Currently there are many definitions and descriptions of sustainability according to the subject and the context. Likewise, the definition of sustainability is changing over time. (Abouelnaga, 2010; ESI, 2005; Soimakallio et al., 2009; Sutter, 2003) Further, sustainability is difficult to define or measure because it is inherently a vague and complex concept. Even though the scope has broadened and the usage has become sometimes random, the principal goal behind sustainability or sustainable development remains clear: to meet the needs of the present generation without compromising the ability of future generations to meet their own needs. Practical implications for this definition are diverse, ranging from the consumption of resources with respect to their rate of renewal, the efficiency of resource use, and the equity of their use across societies and generations (Ulgiati and Brown, 1998). In its most traditional form, sustainability is seen to include three different perspectives: *environmental, societal and economic sustainability* (UNDESA, 2001).

According to Kellomäki (2005), a necessary precondition for the development of forest-based industries is to follow ecological sustainability in forest utilization. Kellomäki (2005) believes that forestry can be considered sustainable if forests and forestlands are exploited locally and globally in such a way that in the long term (i) biological diversity, production, renewal and health are sustained, (ii) ecological, economic, and social benefits can be utilized, (iii) ecosystems that are outside the forest ecosystems are not damaged.

However, the harvest of wood biomass affects the environment and its sustainability in various ways. Forest utilization affects biochemical cycles of forest ecosystems, e.g. generating nutrient emissions into the surface and ground waters. Biomass harvesting also has an effect on biodiversity, and species endangerment is connected largely to the loss of old-growth forests, decaying wood, fragmentation of the forest cover and a stand-level decrease in the diversity of tree species. The use of wood-based biomass also has implications for the carbon balance. While sustainable management, planting and rehabilitation of forests conserve or increase forest carbon stocks, they are reduced by deforestation, degradation and poor forest management. (See e.g. FAO, 2011; Kataja-aho et al., 2011; Keith et al., 2009; Kellomäki, 2005;

Soimakallio et al., 2009) In Scandinavia the loss of biodiversity of forest ecosystems is seen as a bigger problem than deforestation itself, as the absolute amount of wood biomass is not decreasing – in Finland, for example, absolute growing stock has increased by 60% during the last century (Metla, 2011). Biomass use also has indirect effects due to e.g. land-use controversies and market mechanisms (e.g. Soimakallio et al., 2009).

In Finland three forest industry companies (Stora Enso, Metsäliitto, UPM Kymmene) have started or concluded several environmental impact assessment processes for their planned forest biorefineries in different locations. According to these assessments, the environmental impacts of biomass harvesting will depend generally on the intensity and scale of the disturbance. All members of the supply chain need to commit themselves to rules given by the PEFC (Programme for the Endorsement of Forest Certification Schemes) standard, and to take into consideration the sustaining ecological diversity and natural values of forest ecosystems. Forest BtL, a company owned by the Metsäliitto and Vapo consortium, estimates that the most important environmental impacts will be through air- and water-borne emissions, as well as through increasing levels of noise and ashes (Forest BtL, 2011). Raw material harvesting will also impact forest ecosystems. According to the environmental assessment (Porvoo and Imatra facilities) by NSE Biofuels Ltd (2011), a joint venture by Stora Enso and Neste Oil, increasing use of forest-based biomass will not cause "unreasonable risks" for forest ecosystems and recreational or other use of forest resources. However, there will be many impacts caused by harvesting, e.g. diversity and the number of soil microbes can change. Forest biorefineries are predicted to have a positive effect on mitigating climate change through decreasing CO_2 emissions in transportation. (UPM Kymmene, 2009)

2.4.2 Assessment of environmental sustainability

There is a widely recognized need for individuals, organizations and societies to find models, metrics and tools for defining the extent and the ways in which present human activities are unsustainable (Singh et al., 2009). This need arises from a variety of directions that range from international, national and sub-national levels (Ramachandran, 2000). According to Kates et al. (2001), the purpose of sustainability assessment is to provide decision-makers with an evaluation of globally to locally integrated nature-society systems over short- and long-term perspectives, in order to advise them on which actions should be taken in an attempt to make society sustainable. Originally, the debate emerged in the 1990s over how to assess the development of sustainability, and the idea of indicators to evaluate sustainability appeared in the Earth Summit in 1992 (IISD, 1997; UN, 1992). For the past two decades there have been many local, state/provincial, national and international efforts to find useful sustainability indicators and frameworks (Mayer, 2008; Singh et al., 2009; Warhurst, 2002).

Nevertheless, it is still unclear how sustainability should be assessed, measured, and monitored now and in the future, nor is it clear what the criteria for certain dimensions of sustainability should be (Soimakallio et al., 2009).

However, *sustainability indicators, criteria and frameworks* are increasingly recognized as useful tools for policy-making and public communication in conveying information on countries and corporate performance in fields such as the environment, economy, society, or technological improvement. Indicators and frameworks allow organizations to identify environmental impacts and indicate opportunities for improvement. These tools can also produce information for investors about a company's status. (Singh et al., 2007) By visualizing phenomena and highlighting trends, sustainability indicators simplify, quantify, analyze and communicate otherwise complex and complicated information (Mayer, 2008; Singh et al., 2009; Warhurst, 2002).

Frameworks (on the contrary to indices) *for sustainability evaluation* do not involve any quantitative aggregation of data, but rather provide qualitative ways of presenting large numbers of indicators (Olalla-Tarraga, 2006). For example, The Pressure-State Response (PSR) framework groups indicators according to whether they describe pressures or stressors on systems or resources (e.g. intensity of logging), the status of the system or resource (e.g. forest area), or the efforts of the inhabitants or governments to improve the situation (e.g. laws against illegal logging) (Hukkinen, 2003; OECD, 2008; UN, 2001). Frameworks have an advantage over indices in that the values of all indicators are easily observed and not "hidden" behind an aggregated index; there is no loss of information (Anand and Sen, 1994). Thus, the use of single indices has been criticized, and assessing the processes with a single metric in a holistic manner is seen as a very difficult task which is also likely to lead to misleading messages (Gasparatos et al., 2009). However, using frameworks to observe trends over time in either the indicators themselves or in overall conditions can be difficult and only qualitative (Mayer, 2008).

Ness et al. (2007) present a holistic framework of sustainability assessment tools, which consists of three general categorization areas. The first categorization area comprises *indicators and indices*, which are further broken down into non-integrated (e.g. environmental pressure) and integrated tools (e.g. substance flow, input output energy). The second area covers *product-related assessment tools* with a focus on the material (e.g. material intensity analysis) and/or energy flows (e.g. process energy) of a product or service from a life-cycle perspective (e.g. life-cycle assessment, life-cycle costing). The third categorization area in the Nesses et al. (2007) approach is *integrated assessment tools* (e.g. multi-criteria), which are a collection of tools usually focused on policy change or project implementation.

According to Singh et al. (2009), two distinct main approaches can be distinguished when developing an assessment tool and selecting sustainable development indicators (See also Lundin, 2003): first, the *top-down approach* in which experts and researchers define the tool and the set of sustainable development indicators, and second, the *bottom-up approach,* which features participation from different stakeholders in the design of the tool and a sustainable development indicators selection process (Singh et al., 2009). In addition, Fraser et al. (2006) highlight the importance of community input in selecting relevant indicators to monitor and guide planning for sustainable development. Accordingly, they note that indicators should be collected at as local level as possible, thus creating the opportunity for community empowerment.

There are a number of *frameworks of sustainability assessment* that evaluate the performance of *companies*. The World Business Council for Sustainable Development (WBCSD, 1997), the Global Reporting Initiative (GRI, 2002; 2011), and development of standards (OECD, 2002) were the foundation for sustainability reporting. Nowadays many companies monitor different sustainability aspects by using sustainability indicators to provide information on how the company contributes to sustainable development (Azapagic and Perdan, 2000). Azapagic (2004) developed a framework for sustainability indicators for the mining and minerals industry, which is also compatible with GRI. Krajnc and Glavic (2005, a) developed a standardized set of sustainability indicators for companies that feature all main aspects of sustainable development - economic, environmental, and societal. Furthermore, Krajnc and Glavic (2005, b) present a model for integrated assessment of sustainable development in which comparison among countries on economic, environment and social issues is also performed quantitatively.

Accordingly, Singh et al. (2007) developed a methodology for sustainable assessment and quantified evaluation of the steel industry. The approach aimed at constructing an industry-specific composite index by an *analytic hierarchy process*, in which first the key sustainability performance indicators are identified, and then, through several steps, various indicators are aggregated into the *composite sustainability performance index*. The process also includes stakeholder engagement procedure in which experts from different functional areas of a steel company identify the relevant stakeholders and key sustainability attributes, issues, and themes of the industry.

Likewise, the biomass-based industries suffer from a lack of holistic concepts as well as unanimous indicators and criteria for an environmental sustainability evaluation that would consider the different components of complex biomass-based systems (e.g. Buchholz et al., 2009, a; b; Soimakallio et al., 2009). Environmental sustainability assessments often concentrate on a carbon footprint calculation despite the great variety of other environmental impacts being produced (Finkbeiner, 2009). Accordingly, a lack of agreement on sustainability indicators produces frameworks in which some environmental sustainability indicators and criteria focus only on the final products, some emphasize the harvesting and use, and some highlight both. Furthermore, some criteria are quantifiable and measurable – e.g. carbon and energy cycles of liquid biofuels – whereas other sustainability criteria can be evaluated only in qualitative terms. The data available for assessments is often limited, incomplete or inconsistent. (Buchholz et al., 2009, a; b; Soimakallio et al., 2009) Therefore, the chosen sustainability indicators and criteria often yields a large number of issues that are chosen on the basis of subjective perception, which in turn can lead to treating some topics in depth while ignoring others. Poorly chosen criteria relate to problems such as over-aggregation, measurement of unimportant parameters, dependence on false models and diverting attention from direct experience, overconfidence and incompletion. Furthermore, a long list of indicators and criteria results in confused priorities and overwhelming details and is difficult to apply in practice for users (e.g. companies) and developers. Many of these challenges can be avoided if an individually applicable set of criteria is used, thus enabling stakeholders to detect important trends in complex structures. (Meadows, 1998; Soimakallio et al., 2009) Accordingly, it becomes evident that criteria should be in general sector-specific and reflect the national scope. This is the case particularly in the forest biorefinery sector, as the chosen raw materials and end products vary greatly depending on the specific case and location of the biorefinery facility.

In the last years biomass-based systems have been extensively analyzed from an environmental *life-cycle perspective* concentrating mainly on bioenergy, particularly on biofuels (See e.g. Cherubini and Jungmeier, 2009; Cherubini and Stromman, 2011; Gnansounou et al., 2009; Larson et al., 2006; Soimakallio et al., 2009; Spatari et al., 2009; Uihlein and Schebek, 2009; van Vliet et al., 2009). The life-cycle framework is one of the most well-known approaches for environmental assessment, and it has been part of the general guideline of sustainability since the United Nations confirmed sustainability as a guiding principle in 2002 (UNEP, 2002). Life-cycle approaches for the holistic identification and evaluation of environmental impacts of different products and services vary from approaches that feature qualitative decision support and screening methods to detailed inventory-based life cycle assessment (LCA) (Hunkeler and Rebitzer, 2005). The life-cycle-based methodologies have primarily contributed to the evaluation framework through the development of LCA, which is defined by the ISO 14040 standard as "the compilation and evaluation of the inputs, the outputs and potential environmental impacts of a product's system throughout its life cycle." Therefore, LCA can be understood as a tool to analyze the environmental burden of products at all stages in their life cycle: starting from the extraction of the raw materials, through the production of materials, product parts, and the products itself, to the use of the product to the management after it is discarded either by reuse, recycling or final disposal. There is also a variety of other life-cycle-based assessment tools in addition to LCA that in general assess the environmental impacts of a product's system, for example carbon footprint, water footprint, material flow analyses, input-output LCA (hybrid LCA) and ecological footprint. (Baumann and Tillman, 2004; Hunkeler and Rebitzer, 2005)

However, there are many issues and methodological assumptions that cause uncertainties in biomass-based system LCAs. Studies indicate that it is not possible to provide exact quantifications of the environmental impacts of bioenergy because, for example, too many variables are involved, some of the key parameters (such as indirect effects), are not well known and key parameters strongly depend on local and climate conditions. (Cherubini and Stromman, 2011; Cherubini et al., 2009) For example, the biofuel LCA results show a large difference in the reduction of the GHG emissions with a high sensitivity to the following factors: the method used to allocate the impacts between the co-products, the type of reference systems, the choice of the functional unit and the type of blend (Gnansounou et al., 2009). Many other studies have also indicated a need for a more complete methodology and case-specific analysis in order to account for all environmental implications of the processes under consideration (See e.g. Carpentieri et al., 2005; Larson et al., 2006). In addition many uncertainties will remain until the actual implementation of various biomass-based systems (See e.g. Uihlein and Schebek, 2009; van Vliet et al., 2009). Therefore, it is obvious that in the future, biomass-based systems need to be evaluated with LCAs that overcome many shortcomings detected in the previous studies. However, in addition to LCA studies, there needs to be consideration of the suitability of various different assessments approaches, methods and criteria in biomass-based systems, such as forest biorefineries.

Thus, in addition to the widespread LCA approach, new assessment approaches particularly relevant for biomass-based industries have been introduced, aiming at managing the complexity of biomass-based industries. For example, tools based on *Multi Criteria Analysis* (MCA) have shown potential for finding sustainable solutions in a broad range of fields including forest management and renewable energy systems. (Gamboa and Munda, 2007; Mendoza and Prabhu, 2006) MCA can be defined as "formal approaches that seek to take explicit account of multiple criteria in helping individuals and groups explore decisions that matter" (Belton and Stewart, 2002). Even though it is clear that MCA tools can contribute to sustainability assessments of bio-based systems, many constraints still exist and tools needs to be developed further (Buchholz et al., 2009, b).

The present study focused on aspects of environmental sustainability and on creating initial evaluation criteria for environmental sustainability assessment in the forest biorefinery sector. Though the emphasis of this thesis is on the environmental dimension, environmental, economic and social dimensions of sustainability are understood as being complimentary elements and strongly interlinked. The holistic framework of sustainability assessment tools presented by Ness et al. (2007), which consists of three general categorization areas, was helpful in understanding the big picture and classification of different sustainability assessment methodologies. Identification and categorization of different environmental sustainability criteria of the forest biorefinery sector was done by using a bottom-up approach that included the involvement of experts (See the detailed description in Section 3), which is also part of the generic hierarchy model (Singh et al., 2007). Accordingly, Singh's et al. (2007) analytic hierarchy process helped to understand the multi-phased and complex nature of the environmental assessment tool development process, and particularly, offered help with creating initial evaluation criteria for biorefinery sector.

2.5 Strategic organizational change: management, features and resources

2.5.1 Change management and features

Change is an ever-present element that affects all organizations with a constantly increasing pace, as described before. Thus, there is an obvious need for each organization to identify its future directions and the ways in which it manages the changes along the way. Increasing globalization, deregulation, the rapid pace of technological innovations, a growing knowledge workforce, and shifting social and demographic trends are issues that further highlight the importance of managing organizational change. (Todnem By, 2005)

Traditionally the management of organizational change has been viewed as a distinct area of management. Organizational development comprises a variety of methodologies through which an internal or external consultant acts as a catalyst for systemic change within a team or an organizational unit (Cummings and Worley, 2005). Moran and Brightman (2001) have defined *change management* as "the process of continually renewing an organization's direction, structure, and capabilities to serve the ever-changing needs of external and internal customers". Accordingly, due to the importance of organizational change, its management is becoming a highly required managerial skill (Senior, 2002). In recent years the management of organizational change has been viewed as a continuous activity that forms the central component of a manager's responsibilities (Grant, 2010). Overall, the management of organizational change is challenging, and companies need to continually consider and regenerate carefully their change management strategies (See e.g. Beer and Nohria, 2000; Todnem By, 2005).

The early theories of organizational change management suggested that organizations could not be effective nor could they improve their performance if they were constantly changing (Rieley and Clarkson, 2001). Accordingly, it was argued that people need routines to be effective and to be able to improve performance (Luecke, 2003). However, it is now argued that it is of vital importance to organizations that people are able to undergo continuous change (Burnes, 2004; Rieley and Clarkson, 2001).

While there is a growing body of literature that emphasizes the importance of change and suggests ways to approach it, very little empirical evidence has been provided in support of the different theories and suggested approaches (Guimaraes and Armstrong, 2008). Currently there is a wide range of contradictory and confusing theories and approaches often based on unchallenged hypotheses regarding the nature of contemporary organizational change management (Todnem By, 2005).

Beer and Nohria (2000) suggest that there are two archetypes, or *theories*, *of change*. These archetypes are based on very different and often unconscious assumptions by senior executives, and the consultants and academics who advise them about why and how changes should be made. According to *Theory E*, change is based on economic values, whereas according to *Theory O*, change is based on organizational capability. “Hard” change strategies of Theory E usually involve the heavy use of economic incentives, drastic layoffs, downsizing, and restructuring. Accordingly, the shareholder value is the only legitimate measure of corporate success. The “soft” change strategies of Theory O are geared towards building up the corporate culture: employee behaviors, attitudes, capabilities, and commitment. An organization’s ability to learn from its experiences is a legitimate yardstick of corporate success. Most companies use a mix of both of these strategies, even though theories E and O are so different that it is difficult to manage them simultaneously. However, Beer and Nohria (2000) believe that that it is possible for companies to effectively combine hard and soft approaches and, further, that those companies able to do so are more likely to achieve a sustainable competitive advantage.

Balogun and Hope Hailey (2008) emphasize that due to the complexity of the change task, successful change requires the development of a *context-sensitive approach*. In other words, the design and management of any change process should be dependent on the specific situation of each organization. The change formulae that worked in one context should not be applied directly to another situation (See also e.g. Jick, 1993; Pettigrew and Whipp, 1991; Todnem By, 2005). Consequently, organizational change cannot be separated from organizational strategy, nor vice versa (Burnes, 2004; Rieley and Clarkson, 2001).

Balogun and Hope Hailey (2008) present a framework, the *change kaleidoscope*, which can be used to help achieve successful change. The contextual features in the change kaleidoscope do not carry equal weight in all organizations – this is why the framework is called a kaleidoscope, as its configuration features will constantly shift according to the organization being analyzed. The kaleidoscope will also change through time in response to change interventions, offering a non-static change management tool. Even though in each change situation the configuration of the contextual features will be unique, there are questions that remain constant in any change context. These questions include the amount of *time* available for change, the *scope* of the change required, the *degree of diversity* within an organization, the staff’s *readiness f*or change, the *capability* and *capacity* to undertake change within the organization, *power relations* and what needs to be *preserved* within the organization. None of the individual features can be considered in isolation; i.e. the interrelated nature of all the kaleidoscope features should always be observed. Furthermore, the contextual features may differ within one company, which increases the complexity of the change process. (Balogun and Hope Hailey, 2008)

According to Balogun and Hope Hailey (2008), *scope* is the required outcome of change that can vary from realignment through more radical change aimed at transformation of a company. Scope is affected by an entire organization’s need to change, or only a certain part of a company’s necessity for change. *Preservation,* which is often strongly interlinked with scope, refers to the extent to which it is important to maintain continuity in certain practices or preserve specific assets – either because they form invaluable resources, or because they contribute to valued stability of culture or identity within an organization. Assets can be tangible (e.g. technology, infrastructure, financial resources) or intangible (e.g. know-how, staff loyalty to the employer). (Balogun and Hope Hailey, 2008) Consequently, Dunphy and Stace (1993) believe that change can be divided into four different characteristics by scale: *fine-tuning, incremental adjustment, modular transformation,* and *corporate transformation*. Fine-tuning describes organizational change as an ongoing process to match the organization's strategy, processes, people and structure. Fine-tuning is usually manifested at a departmental or divisional level of an organization. Incremental adjustment involves distinct modifications to management processes and organizational strategies, but does not include radical change. Modular transformation is a change identified by major shifts in one or several departments or divisions and can be of a radical nature. However, it focuses on part of an organization rather than on the organization as a whole. (Senior, 2002) When the change is corporate-wide and characterized by radical alterations in the business strategy, it is described as corporate transformation. Examples of this type of change can be reorganization, reformed core values or altered power and status (Dunphy and Stace, 1993).

Readiness for change exists at two different levels: awareness and commitment, which means the extent to which personnel are aware of the need for change and the amount of personal commitment there is towards changing individual skills and attitudes. The concept of readiness can be also divided into two forms: receptivity to a particular change initiative and the continuous readiness for change. Both of these are critical features within the change context, and accurate assessment of personnel readiness at the earliest opportunity can make a fundamental difference to the design of change, and thus the likelihood of success. (Balogun and Hope Hailey, 2008) Consequently, Todnem By (2005) has identified from various studies several different approaches to characterize readiness for the change. The change can be characterized into four types by how it arises: *planned, emergent, contingency* and *choice.* Bullock and Batten (1985) developed a four-phase model of planned change that splits the process into exploration, planning, action and integration. According to Burnes (2004), this is a highly applicable model for most change situations. The emergent approach of change sees change as driven from the bottom-up (Bamford and Forrester, 2003; Burnes, 2004). The approach suggests change to be so rapid that it is impossible for senior managers to effectively identify, plan and implement the necessary organizational responses (Kanter et al., 1992). The emergent approach stresses the unpredictable nature of change, and views it as a process that develops through the relationship of a multitude of variables within an organization. The contingency approach to change is founded on the theory that sees the structure and the performance of an organization to be dependent on the situational variables that it faces. Accordingly, organizations do not face the same variables and thus their operations and structures may be different (Dunphy and Stace, 1993). Choice theory emphasizes the opportunities that companies have over issues; i.e. what kinds of internal practices they will choose in order to accommodate external variables (Burnes, 1996).

In the change kaleidoscope (Balogun and Hope Hailey, 2008), *capability* describes how capable the organization is at managing change. An organization and the individuals within it can be very good at delivering operational change, such as sharing best practices from one part of the organization to another. However, this does not give the organization a capability for more transformational change. Furthermore, delivering change as a planned intervention requires one set of capabilities, and delivering change on a more continuous basis to keep pace with a changing environment requires a different set. Capabilities can be seen at two different levels: individual and organizational. At the individual level can be explored e.g. how flexible and adaptable managers and non-managerial personnel are in terms of their skills, behaviors and attitudes. The more adaptable the staff, the better they will be at handling transition. The second form of capability is located within the organization itself. The organization can, for example, be an expert at particular types of change such as mergers and acquisitions. Organizations may also have systems, such as information systems, business planning systems or production systems that allow it to coordinate change on a more continual basis in response to a changing environment. Such systems can contribute to an organization's dynamic capability, which is its capability to reconfigure existing processes and create new ones, thus yielding an on-going competitive advantage. (Wright and Snell, 1998) Consistently, *capacity* in the change kaleidoscope (Balogun and Hope Hailey, 2008) considers the amount of resources – such as cash, time, people – that the organization can invest in the proposed change. This has become a more important factor in recent years for many reasons. One is that change management activity in organizations has increased as the external environment changes faster and becomes more complex. This in turn has increased change activities in organizations. However, it seems that companies have not simultaneously increased their capacity-building activities to correspond to this increase in change initiatives. (Balogun and Hope Hailey, 2008)

2.5.2 Resource-based view

The *resource-based view* (RBW) of the company has its beginning in the early development of strategic management, which was first called the "business policy" in the 1960s. The resource-based view was largely introduced to the field of strategic management in the 1980s and became a dominant framework in the 1990s. (Hoskisson et al., 1999; Peteraf, 1993) Over the last 20 years, the resource-based view has reached a pre-eminent position among theories in the field of strategy. However, debate still continues about its precise nature. (Locket et al., 2009; Wright et al., 2005)

The notion that companies are fundamentally heterogeneous in terms of their resources and internal capabilities has long been at the core of the field of strategic management (Hoopes et al., 2003; Peteraf, 1993). Resources of the companies that are distinctive or superior, relative to those of rivals, may become the basis of competitive advantage if they are matched appropriately to environmental opportunities (Andrews, 1971; Thompson and Strickland, 1990). These ideas can be seen as basic principles upon which resource-based research continues to build (Peteraf, 1993). Therefore, the relationship between the opportunities faced by the company, the strategic behavior to be implemented by managers and the outcome - in terms of competitive advantage or performance - have been at the heart of resource-based view studies (e.g. Barney, 1986; Collins, 1994; Peteraf, 1993; Wernefelt, 1984). Eisenhardt and Martin (2000) define the resource-based view of a firm as an influential theoretical framework for understanding how competitive advantage within companies is achieved and how advantage might be sustained over time (See also Barney, 1991).

Altogether, *resources* are the key focus of the RBV (Barney, 1991; Eisenhardt and Martin, 2000). Grant (2010) believes that resources are the productive assets owned by the firm, whereas capabilities are what the company can do. Individual resources do not confer competitive advantage, instead they must work together to create an organizational capability, which in turn is the essence of superior performance. Further, Grant (2010) classifies resources into tangible (financial, physical), intangible (technology, reputation, culture) and human resources (skills/know-how, capacity for communication and collaboration, motivation). Accordingly, Helfat and Peterraf (2003) define a resource as an asset or input to production (tangible or intangible) that an organization owns, controls or has access to on a semi-permanent basis. An organizational capability refers to the ability of an organization to perform a coordinated set of tasks, utilizing organizational resources, for the purpose of achieving a particular end result. Respectively, some researchers distinguish between fully appropriable (e.g. physical capital, brand names) and less tangible resources (e.g. organizational routines) (Lockett et al., 2009; Teece et al., 1997). In addition, organization resources may not be perfectly mobile across companies and can be also historically determined (Barney, 1991; Helfat and Peteraf, 2003; Lockett et al., 2009; Peteraf, 1993).

Likewise, Grant (1991) believes that the resources of a firm are the central considerations in formulating its strategy. The resources are primary constants upon which a company can establish its identity and frame its strategy, and they are the primary sources of a firm's profitability. The key to a resource-based approach to strategy formulation is an understanding of the relationship between resources, competitive advantage, and profitability – in particular, an understanding of the mechanisms through which a competitive advantage can be sustained over time. This requires the design of strategies that exploit to maximum effect each company's unique characteristics. (Grant, 1991) If organizations are to achieve a competitive advantage, they require resources and competences which are both valuable to customers and difficult for competitors to imitate – these are called company's *core competences* (Hamel and Prahalad, 1994).

A company's success – even survival – over the long term requires that it upgrades its resources and capability base (Grant, 2010). Therefore, RBV have been extended into dynamic markets (Teece et al., 1997). The rationale is that RBV has not adequately explained how and why certain companies have a competitive advantage in situations of rapid and unpredictable change. In these kinds of markets in which the competitive landscape is shifting rapidly, the *dynamic capabilities* by which a company's managers integrate and reconfigure internal and external resources and capabilities to address changing environments become the source of a competitive advantage. (Eisenhardt and Martin, 2000; Helfat and Peteraf, 2003; Teece et al., 1997) Therefore, dynamic capabilities can be seen as the drivers behind the creation, evolution, and recombination of other resources into new sources of competitive advantage (Henderson and Cockburn, 1994; Teece et al., 1997). According to Grant (1996), the manipulation of knowledge resources, in particular, is critical in such markets. Dynamic capabilities include well-known organizational and strategic processes such as alliancing and product development, whose strategic value lies in their ability to manipulate resources into value-creating strategies (Eisenhardt and Martin, 2000). Accordingly, Helfat and Peteraf (2003) introduce the concept of the capability lifestyle (CLC), which aims at offering a more comprehensive approach to the dynamic resource-based view. The capability lifestyle approach identifies three initial stages of a capability life-cycle: founding, development and maturity. These stages can be further divided into six additional stages that aim at reflecting the notion that the life-cycles of capabilities may extend beyond that of the companies and industries in which they originated, and also beyond the products to which they originally applied. Overall, the CLC framework seeks to explain the emergence of a sustained heterogeneity of capabilities. All in all, dynamic capabilities are important; that is, the ability to change strategic capabilities continually (Johnson et al., 2008). The critical management challenges are in developing existing capabilities and acquiring or creating new ones. Therefore, it is very understandable that some of the most important developments in strategic management research in recent years lie in deepening our understanding of what organizational capabilities are, and how they develop. (Grant, 2010)

In this study, a company's resources are classified into capabilities that are needed for managing change in terms of a new business, and capabilities that are required in operating a successful forest biorefinery facility (e.g. financing, skills and know-how, raw material availability, research and collaboration). Figure 2 presents the explicit analytical framework followed in this study when forest industry's current change features, management and resources were explored. In the framework, both features from the change management approaches – particularly from the change kaleidoscope – and the elements from the resource-based approach were included. This framework enabled exploration of both change management capabilities and new capabilities necessary for operating forest biorefineries.

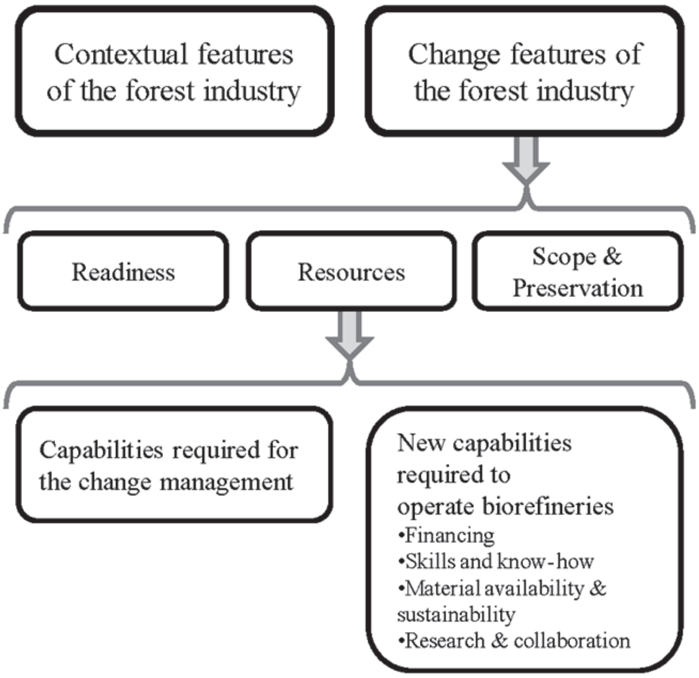

FIGURE 2 The analytical framework for the study of the forest industry's change.

3 RESEARCH DESIGN

3.1 Research strategy

The Delphi method with related scenarios was key in the methodology of this study. The research was conducted in three phases: First, an internet survey with related quantitative analyses was conducted. The following two phases were qualitative in their nature with themed interviews and email inquiries, and related thematic analysis. A detailed description of the Delphi method and each phase with its goals and approaches are presented in Sections 3.2 and 3.3. The topic is examined from different, yet closely related, perspectives in the complementary research papers that are introduced in Section 3.3, along with the corresponding Delphi phase.

According to Decrop (1999), methodological eclecticism is desirable: research questions or, more precisely, the relationship between the knowledge (phenomenon) and the knower (person possessing the knowledge) must direct the choice of appropriate research design and methods. Equally, also in this study eclecticism has been promoted in the research design. The research topic is explored from different angles and levels, changing the techniques along the phases in order to describe the phenomenon as realistically as possible. Accordingly, a characteristic of the research design has been that the research combines macro-, industry/sector -and strategic group-level examination: it begins with a wider examination of the overall macro-scale diffusion drivers for the biorefineries and then moves on to a more detailed analysis of environmental sustainability of biorefineries and strategic change issues specific to the forest industry.

This study thereby combines both quantitative and qualitative research techniques; likewise it uses several angles and theories to examine forest biorefinery diffusion. An approach that combines multiple tools has been defined as *mixed-methods research, triangulation, a multi-method or multi-trait matrix* and *convergent validation*, for instance (See e.g. Campbell and Fiske, 1959; Creswell, 2009; Decrop, 1999; Hanson et al., 2005; Jick, 1979; Rudd and Johnson, 2009). One of the most important aspects of all these approaches is the viewing of quantitative and qualitative methods as complementary and strength-forming and not as competing (Decrop, 1999; Jick, 1979; Rudd and Johnson, 1999).

The concept of combining approaches for complementary strengths and non-overlapping weaknesses has been called the fundamental principle of *mixed methods research* (Johnson and Turner, 2003). According to Creswell (2009), mixed methods research is designed with philosophical assumptions as well as methods of inquiry. As a methodology, it involves philosophical assumptions that guide the direction of the collection, data analysis and the mixture of qualitative and quantitative approaches in multiple phases during the research process. As a method, it focuses on collecting, analyzing, and mixing both quantitative and qualitative data in a single study or series of studies. Its central premise is that the use of quantitative and qualitative approaches in combination provides a better understanding of research problems than either approach alone. This better understanding can be achieved because mixed methods offers strengths that offset the weaknesses of separately applied quantitative and qualitative research methods. It also encourages the collection of more comprehensive data for study problems, helps answers questions that quantitative or qualitative methods alone cannot answer, and reduces adversarial relationships among researchers and promotes collaboration. Mixed methods encourage the use of multiple worldviews and perspectives, and it is believed to be a practical and natural approach to research. Today mixed methods research is seen as important due to the complex nature of problems that need to be addressed, the increasing interest in qualitative research, and the practical need to gather multiple forms of data for diverse audiences. (Creswell, 2009; Rudd and Johnson, 2009)

Triangulation in general means combing multiple methods, data sources, observers or theories to examine the same phenomenon, and it may be featured throughout the research or only at the analysis phase. Both validation of results and the completeness of results can be supported by triangulation. (Ammenwerth et al., 2003; Begley, 1996; Denzin, 1970; Greene and Clintock, 1985; Knafl and Breitmayer, 1991) Triangulation is, based on work by Denzin (1970), generally divided into the following four types, which can be applied at the same time. According to Decrop (1999), all these triangulation types can offer richer and more valid interpretations. *Method triangulation*, which is the most common type, involves the use of a variety of research methods for data collection and analysis combined to explore a single problem. Here, two types are distinguished: *within-method* triangulation (combining approaches from the same research tradition), and *between-method* triangulation (combining approaches from both quantitative and qualitative research traditions, also called *across-method triangulation*). *Data triangulation* involves using multiple data sources: the method or researcher usually stays the same but the empirical unit varies in that data is gathered at different times and from different contexts and subjects. *Investigator triangulation* means that various researchers with their own particular professional methodological background take part in the study, gathering and analyzing the data together. *Theoretical triangulation* means that data is analyzed based on various perspectives, hypotheses or theories. (Denzin, 1970)

During the three Delphi phases of this study (See detailed description in the following Section 3.3) the data was collected by different methods: internet survey, email inquiries and themed interviews *(method triangulation)*. The data collection took place at three different points in time during the years 2008-2011. Moreover, the sample of respondents changed because in the second and third phases only part of the initial respondents participated in the study. In addition, the sample was complemented in the last phase by six new respondents (*data triangulation*). Both statistical analysis and thematic analysis were conducted (*method triangulation*). Different theoretical frameworks and approaches were used when the data was analyzed (*theoretical triangulation*) and there was collaboration between other researchers during the research project (*investigator triangulation*). Overall, taking into consideration the interdisciplinary nature of the phenomenon in this study – and the fact that forest biorefineries are just emerging and have a scarcity of comprehensive data – the mixed research approach with related triangulation proved to be a very applicable approach that increased the validity and objectivity of the study in general.

3.2 Delphi method

The aim of futures research is to help inform perceptions and choices about the future (Amara, 1991). It aids us in understanding alternatives or preferences for the future, probable developments and to articulate and work towards a desired future (Bell, 1993). Accordingly, futures studies can be considered an activity that aims at supporting strategic future-oriented actions both in business management and in governmental policy-making (Schwarz, 2008). Currently there is a whole genre of research methodologies that assist us in planning for the future. Methods in futures studies include e.g. growth curves, relevance trees, quantitative forecasting, simulation and gaming, scenario techniques and the Delphi technique (Cheng et al., 2008; Schwarz, 2008).

The main aim of *scenarios* is to identify existing trends and key uncertainties and combine them in pictures of the future. The goal is to discover the boundaries of future outcomes, not to cover all eventualities. Essentially, scenarios should cover generic different futures instead of variations of one of them. (Schoemaker, 1992; 1995) Often scenarios and alternative future views are applied together with the Delphi method, thus they can be considered complementary to each other (Kuusi, 2002).

One of the core tools of futures forecasting is the *Delphi method*, which is used in obtaining forecasts from selected experts. Usually the Delphi method is composed of two or three stages, during which experts' opinions are collected and information is combined, and then returned to the experts for re-evaluation. By virtue of their expertise and experience, experts possess wide knowledge and capabilities and therefore can understand the structure of present conditions and also determine the direction of future outcomes. (See e.g. Gordon, 1994; Gupta and Clarke, 1996; Kuusi, 2002; Rowe and Wright, 1999) Linstone and Turoff (1975) characterize Delphi as a method for structuring a group communication process so that the process is effective in allowing a group of individuals, as a whole, to deal with a complex problem (See also Kuusi, 1999; Rowe and Wright, 2001; Tapio, 2003). The Delphi method has been extensively used in planning, policy analysis, and long-range forecasting, in both the public and private sectors (Gupta and Clarke, 1996).

The key features of traditional Delphi process are *anonymity, iteration and feedback and group statistical response*. *Iteration* means that the research process is repetitive with several research rounds. Thus, the experts are consulted at least twice on the same question and they are given the opportunity to change their opinions. *Anonymity* refers to maintaining the anonymity of participants or at least of their answers. The aim of anonymity is to avoid the social pressure and potential negative influence in the individual answers in terms of personality and status of the participating experts. *Controlled feedback* means that the panelists are given feedback between each round informing them of their anonymous colleagues' opinions. The study coordinator is responsible for transmitting and editing the information for the experts. The Delphi answers may be processed quantitatively and statistically in a *group statistical response*, and all the opinions form part of the final outcome. (Landeta, 2006; Rowe and Wright, 1999; Woudenberg, 1991)

Delphi, as it was originally practiced, sought a *consensus* from a homogenous group of experts (e.g. Kuusi, 2002; Landeta, 2006). Nevertheless, the conventional Delphi has been widely criticized for focusing too much on consensus seeking, and thus many later Delphi applications emphasize a variety of ideas that the Delphi process generates. Turoff (1970) introduced the *dissensus-based Policy Delphi* in the 1960s, representing a significant departure from the understanding of the Delphi technique as practiced at that point in time. In contrast to seeking consensus, Policy Delphi aims at persuading the experts to come up with various options; therefore Policy Delphi is a tool for the analysis of policy issues and not a mechanism for decision-making. In fact, the structure of the communication process, as well as the choice of the respondent group, may be as such to make consensus on a particular resolution very unlikely. Dissensus-based Delphi processes are currently widely used: *Argument Delphi* (Kuusi, 1999) is based on the Policy Delphi approach. In addition, *Disaggregative Policy Delphi* is a variant of the traditional Policy Delphi (Tapio, 2003).

In this research the goal was not to elicit a single answer to certain questions or problems or to arrive at a consensus in general. The aim was simply to obtain as many high-quality responses and opinions as possible for a given research question from a panel of experts to create a realistic description of the current as well as future state of the biorefinery business. Therefore, the present research can be considered a dissensus-based Delphi study.

Like any other method, also the Delphi method has both advantages and disadvantages. Advantages include anonymity facilitating honest opinion without group pressure; the Delphi process allows idea sharing by a large number of geographically distant stakeholders and the methodology is flexible in terms of arrangement. On the other hand, negative sides of the method can be, for example, that it requires participant commitment for several research rounds; conducting a process can be time-consuming; there are inadequacies in methodology and concepts; and there are no general guidelines for sample size or sampling techniques. (See e.g. Gordon, 1994; Gupta and Clarke, 1996; Landeta, 2006; Rowe and Wright, 1999) Methodological and conceptual issues that often arise in the Delphi context include the choice of experts, the number of research rounds, questionnaire development and quality, analysis of the results, feedback, and the achievement of consensus (See e.g. Gupta and Clarke, 1996; Kuusi, 2002).

Another challenge related to the Delphi method is that variance in responses increases along with time (i.e. the longer the time frame for the forecasts, the bigger the variance); experts tend to be pessimistic in the long time frame and optimistic in the short time frame; human nature desires security and simplicity (in contrast to insecurity and complexity)-all these features can be reflected in the responses and forecasts given by Delphi experts. (Linstone, 1978; Mannermaa, 1991)

The Delphi technique is generally considered to be an appropriate method for long-range forecasting studies that lack historical data and require the collection of expert opinions (See e.g. Blind et al., 2001; Gallego et al., 2008; Gupta and Clarke, 1996; Landeta, 2006). Therefore, the Delphi process is very applicable for investigating novel forest biorefinery diffusion with the possibility of including geographically dispersed specialists that have backgrounds in different fields.

3.3 Phases of the Delphi study with their subsequent goals, approaches, data and publications

3.3.1 The main goals of the study

In its entirety, the goal of this Delphi study is to compose a holistic view of the issues affecting the diffusion and implementation of forest biorefineries in Scandinavia and North America as described in Section 1. During the three phases of the study (Table 1), global and national drivers for forest biorefineries were outlined, and compared between the studied areas. Therefore, the differences between the studied areas will be highlighted in the findings whenever they are observed. The research explores factors and challenges related to the economy, politics, technology and ecology and raw materials as well as business strategies and resources, all of which can have an effect on the diffusion process of forest biorefineries. As a main result the key promoting factors in the business environment are recognized at three levels: Macro-environment, levels of industries/sectors and strategic groups. Accordingly, models for wood-based biorefineries and scenarios for the future production capabilities are presented. In addition, two issues that affect diffusion and success of forest biorefineries were examined more closely: environmental sustainability aspects and criteria within the context of forest biorefineries and strategic change features, management and resources in the forest industry.

TABLE 1 The research phases with subsequent goals, approaches and publications. The list of the original publications, that corresponds to the publication numbers of the table, is introduced in the beginning of the thesis.

Phase	Main goals	Approach	Method of data collection	Method of data analysis	Respon-dents	Related publica-tions
PREPARA-TION 2007-2008	-Increasing understanding of the phenomenon under research: forest biorefinery diffusion	Qualitative	-Literature review -Themed interviews	Thematic analysis method	10	-
FIRST DELPHI ROUND 2008	-Creating a holistic view of the issues affecting the diffusion of forest biorefineries in Scandinavia and North America. -Developing future scenarios	Quantitative	Internet survey	Statistical analysis	125 *	1 2
SECOND DELPHI ROUND 2009	-Evaluation of the first Delphi round results -Exploring factors that promote biorefinery diffusion on different levels	Qualitative	Email inquiry (Open-ended questions by email)	Thematic analysis method	9	2
THIRD DELPHI ROUND 2011	-Consolidating the data from three research rounds -Detailing future scenarios -Deepening understanding about environmental sustainability performance in the biorefinery context and the change features and resources of the forest industry	Qualitative	Themed interviews	Thematic analysis method	23	3 4

* The number does not include the Brazilian respondents

3.3.2 The first Delphi phase

Preliminary themed interviews were conducted before the first Delphi round in order to shed light on the phenomenon, which has previously been studied from a mostly technological perspective. The interviews were conducted in Finland (5 interviews) and in the U.S. (5 interviews) in the beginning of 2008. The interviewees were forest and bioenergy sector representatives from private companies, the government and academia.

The first Delphi round was conducted in June-July 2008. The main purpose of the first research round was to challenge and test the prevailing views of current society in order to obtain new information about the requirements of and barriers to the forest biorefineries and related new business models. *Research paper 1* is based on the first Delphi round results. Accordingly, in manuscript 1 the aim was to create a holistic view of the issues affecting the diffusion of forest biorefineries in the studied areas. Therefore drivers, barriers, weaknesses and strengths of the forest cluster in biorefinery development, as well as scenarios for liquid cellulosic biofuel production, were outlined. The paper also explored technical and raw material choices in biorefineries in the studied areas. In addition of Scandinavia and North America, the paper 1 includes the data and the results from Brazil, but these results are out of the scope of this thesis, and therefore will not be further discussed[1].

Internet survey was chosen for a data collection method because large sample of geographically dispersed experts were aimed to be reached (See e.g. Buckinghamn and Saunders, 2004). The mrInterview web program was used for conducting the survey. The prevailing views regarding biorefinery diffusion – which were gathered from the preliminary interviews, the expertise of the project steering group, and previous studies and literature – were used as background information when planning the questionnaire. The questionnaire (Appendix 1) consisted of five separate parts including the following modules: *Background*, *Forest biorefinery diffusion*, *Feedstock & technologies*, *Scenarios*, and *Business models*. In the questionnaire, the phrasing of the questions was as clear as possible, with defined alternatives and statements. In most of the questions respondents could indicate their degree of agreement on a five-point scale. In addition, there were multiple-choice questions and open-ended questions in the questionnaire. Quantitative development assessments, based on published scenarios and literature, were presented for cellulosic biofuel production. The respondents also had the opportunity to make open comments.

The survey questionnaire was sent to 511 respondents. The specific aim was to generate a heterogeneous sample of forest and bioenergy sector experts-researchers, company representatives, authorities, association representatives-in North America and Scandinavia. According to Kuusi (2002) the method for selecting Delphi experts is one of the most critical phases in the Delphi process.

1 Brazil was included in the survey (first research phase) and manuscript 1 due to interests of all the research parties participating the first phase, particularly company partners. The main focus of this PhD research has initially been in Scandinavian and North American mature forest sectors and their novel biorefinery business.

The Delphi coordinator should consider in the actor analysis the most important stakeholders and interest groups as well as the most important competencies of the experts. Thus, in this study purposive sampling technique, which allows a researcher to choose a case based on specific features of interest to the researcher, was used, and the individuals that have particular expertise could be chosen (See Silverman, 2006). Furthermore, the snow balling sampling technique was applied. In this technique, the selection process is based on asking each respondent in a selected group to identify further individuals who meet the criteria of being suitable representatives for the panel. (Kuusi, 2002; Meriö 2000, Metsämuuronen, 2006; Teddlie and Yu, 2007) A total of 125 forest and bioenergy sector representatives responded to the survey, yielding a response rate of 24.5%.[2] The distribution of respondents by country and by sector is presented in Table 2.

2 The number of experts who received the survey questionnaire and the total number of respondents do not include the Brazilian experts (20) who initially participated in the research, as Brazil is out of the scope of this thesis.

TABLE 2 Respondents by country and by sector in three Delphi phases.

The first Delphi phase					
	Finland	Sweden	U.S.	Canada	**Total**
Car industry	1				**1**
Chemical industry	1	1			**2**
Energy industry	4		4	1	**9**
Forest industry	15	3	10	2	**30**
Investor	1	1			**2**
Oil industry	2		1		**3**
Public authorities	1		2		**3**
Research	22	10	15	5	**52**
Technology provider in the forest cluster	6	1	2		**9**
Other	9	2	1	2	**14**
Total	**62**	**18**	**35**	**10**	**125**
The second Delphi phase					
	Finland	Sweden	U.S.	Canada	**Total**
Consultant			1		
Forest cluster	3				
Research	2	2	1		
Total	**5**	**2**	**2**	**0**	**9**
The third Delphi phase					
	Finland	Sweden	U.S.	Canada	**Total**
Association				1	
Consultant	2		1		
Forest/bioenergy sector company	3	2	4		
Investor			1		
Research	3	1	4	1	
Total	**8**	**3**	**10**	**2**	**23**

The data was analyzed by using SPSS statistical software. The following analyses were conducted: frequencies, cross tabulation, Analysis of Variance (ANOVA), the Kruskall-Wallis test, and Multivariate Analysis of Variance (MANOVA). *Cross tabulation* displays the joint distribution of two or more variables. Crosstabs are usually presented as a contingency table in a matrix format. Where a *frequency distribution* provides the distribution of one variable, a contingency table describes the distribution of two or more variables simultaneously. *ANOVA* is a statistical technique used to determine whether samples from two or more groups come from populations with equal means.

Like ANOVA, the *Kruskall-Wallis* test is used to determine if population means are equal, however, it is a non-parametric method and thus does not assume a normal population, as does the analogous ANOVA. In this study both parametric and non-parametric tests were conducted, as in many instances assumptions for the parametric test were not fulfilled. Where ANOVA employs one dependent measure, *MANOVA* is a generalized form of ANOVA methods and covers cases in which there is more than one (correlated) dependent variable and the dependent variables cannot simply be combined. In addition to identifying whether changes in the independent variables have a significant effect on the dependent variables, the technique also seeks to identify the interactions among the independent variables and the association among dependent variables, if any. (See e.g. Brown and Melamed, 1990; Metsämuuronen, 2006; Ranta et al., 2005) Analyses were conducted both at a single country level (Finland, Sweden, Canada, the U.S., Brazil) and between North America, Scandinavia and Brazil. The respondents were categorized into three different sectors: the forest industry, researchers and other. MANOVA was conducted by using the sum of variables for questions with multiple claims as well as by using single variables.

3.3.3 The second Delphi phase

The second Delphi phase was conducted in February-March 2009. The purpose of the second Delphi phase was to further explore the biorefinery business environment and factors that promote diffusion of emerging biorefineries. Therefore, the aspiration was to evaluate the uniformity of the first Delphi round's survey results with the respondent's current views, to highlight surprising and improbable results, to introduce potential new ideas, and to evaluate on-going changes in the business environment.

The overall aim of the manuscripts 1 (based on the first research phase) and 2 (based on research phases 1 and 2) was to sketch a holistic view of the issues affecting the diffusion of forest biorefineries in the studied areas. In *manuscript 2* the main goal was to further clarify the factors that contribute to the establishment and success of forest biorefineries in Scandinavia and North America. Particularly, the goal was to recognize key promoting factors in the forest biorefinery business environment at three different levels: Macro-environment, levels of industries/sectors and strategic groups.

Data was collected through *email inquiry* by sending to the respondents the full report of the survey results from the first research phase for evaluation. They were asked five open-ended questions that were as follows:

1. In your opinion, which of the results are surprising?
2. In your opinion, which of the results seem improbable?
3. Are the results in line with your own views in general?
4. Did some of your views change after reading the report? If yes, how?
5. Has something changed radically since June-July 2008 that would also change the results of the research?

6. Please provide any additional comments that might be helpful

The respondents gave their answers and comments by email. The length of the written responses varied from a few words to 2000-word essays.

The survey respondents were emailed to determine if they were willing to participate in the second phase. The nine respondents, who participated in the first phase, answered the questions (Table 2).

Data gathered by the e-mail inquiry was examined using the *thematic analysis method.* According to Braun and Clarke (2006) thematic analysis is a qualitative method for identifying, analyzing and reporting patterns (themes) within the data. By using the thematic analysis method, data can be organized and described in detail. However, analysis frequently goes further than this, and interpretations of various aspects of the research topic are formulated. A theme captures something important about the data in relation to the research question and represents some level of patterned response or meaning within the data set. (Braun and Clarke, 2006) In other words the thematic analysis method can be described as a means of deriving a pattern or theme in seemingly random information. Thus, the analysis is based on coding; themes and patterns are found in the data in order to organize and interpret the information (Boyatzis, 1998; Patton, 2002; Sayre, 2001).

My aspiration was to approach the data without preconceived theoretical assumptions. The starting point of the analysis was to identify the material that was the most relevant in terms of the main research questions. Therefore, the data was first classified under the main themes that were defined in the interview structure. Next, the data was carefully re-explored in order to derive other interesting and relevant patterns. After the data was organized, it was combined and compared with the data gathered in the first Delphi phase. Overall, the data gathered through the internet survey in the first Delphi phase (with related statistical analyses, described in Section 3.3.2) and the data obtained through interviews in the second Delphi phase together comprise the data for Publication 2. The statistical analyses for Paper 2 were otherwise similar to the statistical analysis for Paper 1, but the data from Brazil was excluded.

3.3.4 The third Delphi phase

The third research phase was conducted in February-June 2011. The aim of the last research phase was to detail and consolidate data from all the research rounds in order to obtain a deep understanding about the diffusion and key promoting factors of forest biorefineries in the studied areas. Accordingly, models for wood-based biorefineries and scenarios for the future production capabilities were included in the respondents' evaluation. In the last phase, the aim was also to focus on issues that were emphasized during the previous research rounds. Sustainability, particularly its environmental dimension, was one of the fundamental topics that respondents in the first and second rounds considered a requirement for successful forest biorefinery business. Likewise, the forest industry's change towards new business and related strategies and resources were considered an interesting topic.

The aim of *Manuscript 3* was to increase an understanding of environmental sustainability performance within the context of forest biorefineries. The goal was to describe the most prominent aspects of environmental sustainability and formulate a sector-specific guideline for the most important criteria to be included in environmental sustainability assessment of forest biorefinery value chain companies. Respectively, in *Manuscript 4* the main aim was to explore the current forest industry change towards biorefining business and needed resources. The research explores the forest industry's move across product generations and recognizes related challenges, particularly in the management. The aim was not only to explore the change process and related change management capabilities within the forest industry, but also to evaluate actual new skills and know-how that are needed when developing and operating a commercial scale forest biorefinery facility.

The themed, semi-structured expert interviews were conducted face-to-face or on the phone in Finnish or English. Different types of interviews are the most important data-gathering tools in the qualitative research. Moreover, interview techniques are considered a successful way of obtaining a deep understanding of the participants' thoughts, feelings and ideas. (Eskola and Vastamäki, 2001; Hirsjärvi and Hurme, 2001; Silverman, 2006) Hirsjärvi and Hurme (2001) distinguish between unstructured, semi-structured/themed and structured interviews. In themed interviews specific themes are determined in advance, but the precise form and order of the questions are not known (Hirsjärvi and Hurme, 2001; Eskola and Suoranta, 1998). Themed interviews have their initial basis in "focused interviews" (See Merton et al., 1990). Accordingly, Patton (1990) introduces "the general interview guide approach," which is very similar to the themed interview approach.

There were many reasons to choose themed semi-structured interviews as the method. Due to the different backgrounds and knowledge of the respondents, responses were assumed to be variable and divergent. Therefore, it was important that during the interview responses could be clarified and additional questions could be asked if needed. Correspondingly, depending on the respondents' backgrounds, certain themes could be discussed in more detail in order to get a fuller and deeper understanding. On the other hand, conducting themed interviews is very time-consuming, and themed interviews required a great amount of work in both the planning and analysis phases.

The interview consists of three main parts (Appendix 2): *1. Key Diffusion Factors Promoting Forest Biorefineries; 2. Forest Industry Corporate and Business Strategies and 3. Environmental and Economical Sustainability in the Forest Biorefinery Value Chain Companies.* In the first part of the interview the respondents evaluated the key promoting factors in the business environment of forest biorefineries. They were presented a figure that describes promoting factors for biorefinery diffusion at three levels based on the previous research rounds' results: Macro-environment, levels of industries/sectors and strategic groups (Appendix 3). The respondents were able to choose the factors they considered the most important. Accordingly, they were able to freely indicate issues that were not mentioned in the figure. The second part of the interview (*Forest Industry Corporate and Business Strategies)* comprised the data for Manuscript 4 and Manuscript 3 builds mainly on the data gathered in the third part of the interview (*Environmental and Economical Sustainability in the Forest Biorefinery Value Chain Companies*)

A total of 23 representatives from the forest, bioenergy and bioproducts sectors participated in the themed, semi-structured expert interviews in the U.S., Canada, Finland and Sweden. Interviewees were chosen among the 125 survey respondents of the first Delphi round, aiming at a comprehensive sample of respondents from different backgrounds and countries. The respondents who participated in both previous research rounds were preferred. Six new respondents were also added to the sample; they were recommended by the other respondents and therefore presumed to have highly competent information about the evolving forest biorefinery business. The distribution of respondents by country and sector is presented in Table 2.

Data was examined using the *thematic analysis method* (See previous section).

4 RESULTS AND DISCUSSION

In this section findings from the all three phases of the study are combined and discussed. In Section 4.1 the respondents' understanding about the forest biorefineries is presented. In Section 4.2 the key factors that promote diffusion of biorefineries are discussed. Sections 4.3 and 4.4, respectively, describe environmental sustainability aspects and criteria in the forest biorefinery context, as well as define the most prominent change features and resources regarding biorefining business in the forest industry. Finally, in Section 4.5 future views for the forest cluster and scenarios for cellulosic biofuel production, together with the estimations about the number of future biorefinery facilities, are presented and discussed.

4.1 Forest biorefinery facilities

The main focus of this study was not to examine different technical options and models for the forest biorefineries. However, exploring diffusion of forest biorefineries and recognizing the most prominent factors that promote the development and implementation of biorefineries would not have been possible without first describing and defining the object of the research, namely forest biorefineries as understood by the experts of the study. Therefore, this results section begins with the introduction of forest biorefinery facility properties: products, raw materials, capacity, consortia partners and location.

In the beginning of the study respondents indicated two forest biorefinery *products* that were likely to hold the greatest market potential: Fischer-Tropsch (F-T) diesel and, particularly in North America, fuel ethanol. In addition, in Sweden DME (dimethyl ether) was considered a product with significant potential. However, in the last research round ethanol was not seen as a potential product, whereas *biodiesel* (or F-T diesel) got most support. In the later phases of the study respondents also increasingly highlighted the significance of various *value-added, low volume bioproducts* (e.g. synthetic polymers, viscose fiber derivatives, chemicals, medicines, cosmetics, nanotechnology products and composite materials). However, the production model and end products will be crucially dependent on the local raw material availability and the specific features of the facility with which biorefinery will be integrated.

Forest residues – namely logging tops, pre-commercial thinnings, stumps, and mill residues – are considered the most significant wood-based *biomass source* in biorefineries. However, the experts in the third research round increasingly highlighted the importance of evaluating various feedstocks and their applicability for biorefinery raw materials. Particularly urban organic waste and fast growing tree farms as sources of cellulosic biomass will have potential in the future. There were also country-specific biomass sources that are believed to have potential: peat in Finland, black liquor in Sweden and disease-killed timber in Canada. Like traditional forest industry facilities, the biorefineries will also be eventually located mainly in areas with plenty of affordable biomass and low labor costs, even if the first demonstration facilities will be built in Scandinavia and North America.

This study shows an obvious change in estimated biofuel production *capacities* of forest biorefineries during the research period; in the last research round production capacity was seen as notably larger than three years earlier. In 2008 most respondents believed that biorefineries will have a production capacity around 100,000-200,000 tons per year in the areas studied. Respectively, in 2011 respondents increasingly indicated 200,000-300,000, or even 500,000 tons per year production capacity as the probable size of a forest biorefinery facility.

In the first research round the forest industry was considered the most potential *dominant actor* in a forest biorefinery consortium following the importance of the petrochemical and energy industries. However, in the last phase of the study the dominance of the petrochemical and energy industries was highlighted, whereas the forest industry's role was seen rather as a biomass provider, which manages raw material harvesting and logistics. Respectively, the production will mainly take place in the facilities *integrated* with forest industry facilities, particularly in the pulp and paper complexes. Yet, the degree and site of integration will be very case-specific. In their recent study, Donner-Amnell et al. (2011) suggest that new forest-based businesses can largely be established by new actors that come from outside of the traditional forest industry because new products and services are closer to other industries than to the traditional forest industry.

In sum, this Delphi study created a picture of a forest biorefinery in the studied areas as a multi-product facility, in which high value-added bioproducts together with biofuels are produced from forest-based feedstock jointly with the other locally available biomasses. Seeing biorefineries as more versatile facilities with a diversified product portfolio is understandable as biorefinery diffusion progresses: increasing knowledge with rising availability of the results and experiences from research and demonstration projects provide the basis for wider understanding. Many other studies have also shown that innovations are modified through various interactions in the diffusion process, and understanding of them changes during the process (e.g. Rennings, 2000; Rogers, 2003).

4.2 Key diffusion factors for the forest biorefineries

It has been shown by this study that the forest biorefineries can be implemented in different ways with case specific variation in raw materials, products, degree of integration and consortia partners. Respectively, many types of innovations – such as product, process and organizational innovations – are involved in the diffusion process. The innovations related to the forest biorefineries can also be seen as eco-innovations that aim to contribute ecologically specified sustainability targets (See also Klemmer et al., 1999; Rennings, 2000). In addition, biorefinery business requires involvement of different industries and collaboration between partners. Therefore, diffusion of forest biorefineries is a multifaceted and complex process that is affected by a variety of issues. The complexity of the diffusion process has been addressed in many other studies concerning the diffusion of new technologies (e.g. Baptista, 1999). It has also been shown that the diffusion processes of new products and services have become increasingly variable in recent years, as business environments have become more competitive and less predictable (e.g. Peres et al., 2010).

The results from all the Delphi rounds indicate that the key factors for forest biorefinery development and biofuel production are quite similar in the studied countries. Based on the three research rounds, the key elements that promote faster development of forest biorefineries are presented in Figure 3, where in the upper part of the figure the findings from the first and second Delphi rounds are summarized, and the final results from the last research round are presented in the lower part. The aim in this figure is to describe the Delphi process, combine data from the different Delphi rounds, and at the same time indicate practices for promoting the biorefinery business. In the upper part of the Figure 3, the most significant drivers and competences reflected by the respondents are highlighted. However, it should be noted that the order of issues in the upper part is not meant to reflect the exact order of importance of the promoting factors. Furthermore, in the figure, the key issues are organized following a framework adapted from the Johnson et al. (2008) model, in which environmental influences are organized in layers around an organization. In general, diffusion factors in the macro-scale business environment are better understood, particularly during the first research round, compared to more industry- or sector-specific strategic factors, which are closely related to certain organizations.

Along with the high price of oil creating a market opportunity for biofuels, other *macro-environment* incentives for biorefinery business differ slightly in the studied areas. In the first research phase, environmental aspects – for example, climate change and sustainability – were emphasized in Scandinavia, whereas in the U.S., the national security of fuel supply and the competitiveness of the forest cluster were highlighted. As indicated by the experts in the last round, the final result is that the high price of oil is a permanent, key macro-level driver. However, in the shorter time span, there will be fluctuations in the price of oil; a glut of crude oil in the markets can cause temporary decreases in prices, which in turn can hinder biorefinery development. Accordingly, the national security of fuel supply and long-term and consistent federal and state energy and environmental policies are also considered important.

At the *industries/sectors level*, the capability to harvest and utilize existing wood biomass resources, as well as the availability of private and public financing, are the most important promoting factors according to all research rounds. Furthermore, collaboration between different actors in the value chain and R&D for demonstration and consultancy for biorefinery development are also important factors. Knowledge of forest management in society, improvements in forest management practices and maintenance of infrastructure are also the issues that were seen as prominent for biorefinery diffusion.

Issues concerning corporate *strategies,* such as the need for and ways of sharing responsibilities, revenues and synergy benefits between biorefinery value chain actors were difficult to predict in the beginning of the Delphi study, as many respondents had a neutral opinion of these issues. Further, in the beginning of the study, issues such as change management, creation and management of networks, and ability to interact with and actively shape the business environment were not considered important. However, it seems that strategic issues that are closer to the core of companies became more realistic as the biorefinery business developed during the research frame, and therefore easier to elaborate for the respondents in the last research phase. Overall, at the strategic level an understanding of new markets and management of change and development of economic wood fractionation technologies were considered the most important factors based on the latest research round. Accordingly, increased innovations and process expertise were also highlighted, particularly in Scandinavia. In North America re-evaluation of the current practices in the forest cluster were also considered important. The forest industry's change management and needed capabilities are discussed in more detail in Section 4.4.

Overall, the outlook for *barriers* to biorefinery diffusion from all Delphi rounds is very similar in the studied areas. Insufficient financing and other economic factors as well as many political factors comprise the main barriers to biorefineries. Additionally, lack of R&D expertise and consultancy can create problems. Furthermore, lack of raw material can create a barrier, as the results indicate that demand of biorefineries cannot be fulfilled solely by wood-based biomass. Uncertainties related to sustainable use and availability of forest-based biomass was increasingly highlighted in the last research phase. This was also indicated by a more careful consideration of the potential held by the non-wood raw materials (See Section 4.1). Collaboration both between different partners in biorefinery consortia and between the private sector and academia also seems to be a significant factor in the diffusion of forest biorefineries, and needs to be further encouraged. The main market barriers defined at the federal, state, and local levels by DOE (2011) for biorefineries using cellulosic biomass as a feedstock are largely similar to those in the present study: feedstock availability, production costs, investment risks, consumer awareness and acceptance, and infrastructure limitations are indicated to pose significant challenges for the emerging bioenergy industry.

Every studied country strongly believes in its individual capabilities and success in the evolving biorefinery business. During the Delphi process, these previously mentioned issues were also criticized, and more realistic evaluations of actualizing biorefinery projects and biofuel production volumes were desired for the future. Particularly technological knowledge, biomass availability, existing infrastructure and biomass logistics are highlighted as *strengths* in all countries. These statements indicate that, additionally, a more realistic identification of individual, unique strengths and continuous development of competencies – while avoiding an overly optimistic attitude – would be crucial. Likewise, the ability to promote and market the national know-how through international networks would be important in order to succeed in the biorefinery business. In addition to the issues in common, existing networks and collaboration are seen as strengths in Finland and Sweden. Long traditions and knowledge about solid biomass gasification technology is one of the biggest strengths in Finland. Identified *weaknesses* are also very similar in the countries studied: lack of R&D and innovations, competition for raw material, lack of capital and an unwillingness to change were the most commonly mentioned weaknesses.

In sum, this research shows that forest biorefinery diffusion is a challenge that is connected to all of society and thus needs to be explored holistically. Likewise, actions that promote biorefinery business must stem from several sources. There needs to be support from the macro-scale environment, particularly from governments; but on the other hand, the involved industries themselves need to be active. Furthermore, it can be seen that there is a strong aspiration towards bio-based economy in a present society (See Section 1). It would be important for long-term energy and environmental policies as one of the key biorefinery promoters (as indicated by this study) to encourage the pursuit of bioeconomy and thus express a strong signal for companies to aim their resources at greener processes and products. The European Union's recently published Bioeconomy Strategy (European Commission, 2012) seems to be a step in the right direction by calling for a more informed dialogue, in particular regarding the role of scientific advancement, and better interaction between existing bioeconomy-supporting policies at the level of the EU and Member States. This aims at providing stakeholders with a more coherent policy framework and encouraging private investments.

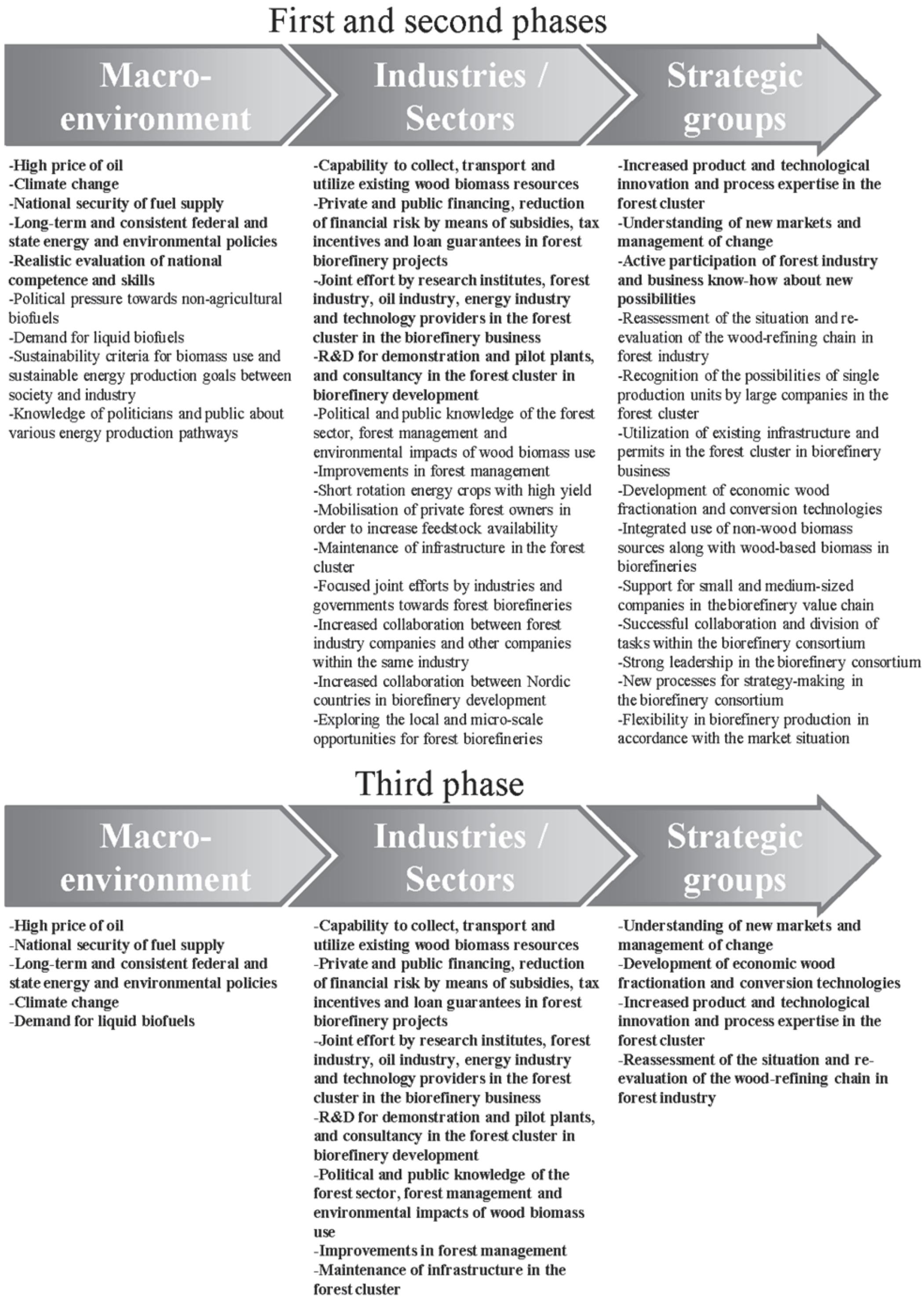

FIGURE 3 The key promoting factors for forest biorefinery diffusion.

4.3 Environmental sustainability aspects and assessment in the forest biorefinery business

According to the respondents of the present study, environmental sustainability is an important driver for the forest biorefinery business in general. A company's environmentally sustainable image can also be a competitive advantage. Biorefinery value chain companies are believed to be pursuing the common good of society by moving towards the environmentally sustainable biorefining business, which also indicates respondents' understanding about the significance of sustainability's social dimension. This aspiration of the companies in turn is strongly linked to the current development of bioeconomy in society. Accordingly, production of biofuels in biorefineries is seen as a sustainable business when taking into consideration environmental as well as economic dimensions. Therefore, despite the fact that the focus in this study was on environmental sustainability aspects, the results indicate that different aspects of sustainability are intertwined and environmental sustainability assessments without consideration of other sustainability aspects can be inadequate.

Even though the biorefinery business was considered to be sustainable in general terms, the responses also indicated that feedstock harvesting is the part most challenging to manage in the value chain, and its environmental impacts are not sufficiently known. According the respondents, there should exist applicable sustainability criteria for biomass raw material and its use. Furthermore, it was believed that raw material demand of biorefineries cannot be satisfied solely with wood-based biomass. Overall, in every research round several statements of the respondents indicated that forest biorefinery business will further intensify the pressure of forest-based industries towards forest-ecosystems which in turn can lead to various environmental impacts and challenges. Accordingly, the role of NGOs, particularly various environmental groups, was considered important, especially in the U.S. However, there is a large controversy over the ideologies and ideas of environmental groups: part of the respondents considered their role to be important in laying the ground for sound environmental policies and environmentally sustainable business, whereas others believed that environmental groups disturb the development of business that is widely considered to be environmentally sustainable, e.g. the forest biorefinery business. In the U.S., environmentalists seem to be more of a threat whereas in Scandinavia those groups are seen to go more hand-in-hand with other stakeholders. There are also numerous other recent studies that indicate environmental challenges related to biomass-based industries (e.g. Bright and Stromman, 2009; Farrell et al., 2006; Searchinger et al., 2008; Soimakallio et al., 2009; Uihlein and Schebek, 2009). Correspondingly, the forest industry companies that are establishing biorefineries have indicated various environmental impacts in their environmental assessments procedures for forest-based biorefineries (See Section 2.4.1).

However, currently there is a lack of systematic approaches to assessing the environmental impacts of forest biorefineries, and in many instances indicators and criteria that do not consider sector-specific features and variation are used. However, using non-specific criteria in assessments can create many problems, e.g. the most relevant concerns do not emerge in evaluations. Use of LCA approaches have dominated environmental assessments of biomass-based industries, but due to many shortcomings related to LCA studies, they should not be used as an exclusive approach; and development of a holistic approach with different criteria would be important (See also e.g. Carpentieri et al., 2005; Larson et al., 2006).

In this study *raw material availability and sustainability* was seen as the most prominent criterion in assessing the environmental sustainability of the forest biorefinery business. This criterion includes a variety of issues, for example ranging from raw material harvesting and logistics to land use and loss of biodiversity. Descriptions in this context covered e.g. availability of the raw material, better feedstock for fuel, sustainability of the resource, efficient use of the raw material, raw material logistics and environmental impacts of harvesting. Thus, despite the fact that forest-based biorefineries have the advantage of intrinsically sustainable raw material, wide-ranging studies (e.g. Cherubini and Stromman, 2011; Soimakallio et al., 2009) in addition to this one, relating to raw material availability and sustainability suggest that resource use is a complex issue, for which there is no unanimous approach. This is understandable, because forest biorefineries cannot be strictly limited to a certain end product, raw material or location. First, there are various feedstocks that can be used as raw material for forest biorefineries (depending on, for example, location and end products of a facility) and certain environmental impacts are connected to the specific biomass type. Particularly the use of peat as potential biomass has aroused plenty of concern due to its negative environmental impacts. Second, the variety of technologies and processes that can be used for production also have their characteristic impacts. Third, a degree of intensity of biomass harvesting and management practices will largely define environmental impacts. Correspondingly, three Finnish forest industry companies (Stora Enso, Metsäliitto, UPM Kymmene) have found in their environmental impact assessment processes for their planned forest biorefineries that, in general, the environmental impacts of biomass harvesting will depend on the intensity and scale of disturbance (Forest BtL, 2011; NSE Biofuels, 2011; UPM Kymmene, 2009). Fourth, impacts are also dependent on the quality and natural values of the ecosystem under biomass harvesting. Furthermore, it needs to be taken into consideration that the complications relating to the initial stages of the raw material extraction will be emphasized even further due to the growth in planned factory sizes and intensified use of raw materials. However, it seems that there are increasing efforts in evaluating the potentials of different biomass materials in order to meet the growing need for biomass. In addition, there is growing interest in high-value, low-volume bioproducts, which in turn can relieve the pressure caused by large-scale biomass harvesting.

The second important criterion according to the present study – the *life cycle perspective* – was also approached by the respondents from several different perspectives, such as life-cycle assessments, LCA, entire production chains, life-cycle thinking and overall life-cycle impacts. The result, which includes several issues pertaining to the entire concept of life-cycles, indicates that it is not the intention of the respondents to carry out full-scale LCAs for their entire product portfolio and make decisions according to these. Nor will it be a recommendation in this research: The key idea here is that the organization would be able to recognize its environmental impacts and challenges of the entire life cycle and value chain, and therefore it could improve its practices. Accordingly, in the long term companies could benefit from this information in the strategic planning and envisioning.

The third significant criterion that should be part of the environmental sustainability evaluation of forest biorefineries was the production of *beneficial products* within the sector. The respondents considered forest biorefinery products to be environmentally beneficial in general. It was also highlighted in this context that the emphasis should not only be on the environmentally friendly manufacturing process, but on the environmental impacts of the end product itself as well. Therefore, this criterion can be also seen to be closely connected to the previous criterion, the life-cycle perspective. However, it must kept in mind that environmental impacts depend on what the actual end product will be; in the future, there will be a larger selection of potential biorefinery products with various impacts.

In addition, economic and social aspects were suggested by the respondents as part of the evaluation criteria for biorefineries (i.e. the criterion categories of "*locality, social costs, health and safety*" and "*self-sufficiency*"). Despite the fact that they are not included in the suggested final criteria due to the study's focus on the environmental perspective, these findings further highlight the interlinked nature of different sustainability aspects and a need for integrated assessment tools.

It is important that case-specific evaluation of raw material-related properties, particularly availability, land-use issues and diversity, are taken into consideration when planning future studies on environmental sustainability in the forest biorefinery context. Accordingly, in the coming years biorefineries will be increasingly developed into multi-product facilities with specific site-dependent features and therefore approaches to evaluation need to be developed for a multi-product system. Moreover, due to the multi-dimensional nature of sustainability, an obvious need for approaches that include criteria for assessment of different sustainability dimensions are indicated as important both by this study and by many others (See also e.g. Halog, 2009; Mendoza and Prabu, 2006). Collaborative work is needed at both the national and international levels in order to develop a common and appropriate methodology (Gnansounou et al., 2009).

In sum, the presented criteria can be seen as an initial step towards a more elaborate evaluation framework, which can provide more accurate information about the sustainability performance of biorefinery value chain companies. In the analytic hierarchy process (Singh et al., 2007), the first task is to identify the key sustainability performance indicators, and then, later through several steps in the hierarchy process, various indicators can be aggregated into the composite sustainability performance index. Therefore, criteria defined in this study can be further developed. For example, in the next phases the key criteria could be finalized, quantitative data for criteria could be collected, and the weighting procedure for the criteria could be conducted in order to create a sector-specific sustainability index. Furthermore, it is important to include input and knowledge of related stakeholders when creating sustainability criteria. In that way the criteria that pay attention to the most relevant concerns from the perspective of stakeholders can be developed.

4.4 The forest industry's change towards forest biorefineries

North American and Scandinavian forest industries are facing a situation in which new business development and start-ups are crucial due to the mature or even declining state of many parts of the business. In the last research round the need and drivers for the change were widely recognized, but pathways and practices for the new business and product generations still need to be largely created. The forest industry's reactions towards biorefineries, and its readiness and resources for the change comprise one of the most interesting aspects to arise from this study. Accordingly, this change is interesting not only from the perspective of the forest industry itself and its potential partners in biorefinery consortia – the change can be also explored from the wider social context as one of the phenomena that embodies society's transition towards bio-based economy. This aspiration is recognized for example in the Finnish National Forest Program and the Government's report on natural resources: The forest-based industry needs to have a new course largely by means of bioeconomy, because old strategies do not guarantee growth and welfare in the field (MMM, 2010; TEM, 2010).

In the beginning of the study expectations about the business opportunities offered by forest biorefineries were more positive in Scandinavia than in North America, whereas the North Americans contradictorily expected biorefineries to play a significant role in their forest cluster's competitiveness within a shorter timescale. Further, in North America biorefineries were more strongly regarded as a way to avoid massive shutdowns and loss of forest cluster facilities. A decade ago in North America, the forest industry began to face challenges – such as decreased demand for forest industry products, increased production costs, offshore developments, shutdowns of pulp and paper mills – similar to those currently faced by the Scandinavian forest industry. This is certainly one of the reasons why the North American forest industry highlighted biorefineries as a way to avoid shutdowns of facilities. Interestingly, in the U.S some respondents advocated considering the present situation of the forest industry as a strength with many challenging opportunities. Correspondingly, Casti and Ilmola (2011) indicate that while the forces in the business environment ("external shocks") can have some negative effects on the businesses, they can also simultaneously generate various new opportunities.

In the first and second research rounds many statements from the forest industry indicated a rather passive role of the forest cluster, while a more proactive attitude and visions from forest sector companies would be necessary for entering a new business. An interesting aspect arising particularly from the second Delphi round was that the future of the forest cluster has been envisioned by researchers, not by those in the cluster itself, even though a clear vision of forest sector companies would be needed in the future. It has been shown (e.g. Johnson et al., 2008) that fast-changing, diverse business environments should be faced with a fresh attitude and swift action. Moreover, achieving an understanding of the environment that is both usable and future-oriented is important. This study clearly indicates that the forest industry should evaluate the business environment and its strategies from a new perspective. Accordingly, it has been shown, for example by Rogers (2003), that an innovation's incompatibility with cultural values and needs can hinder its adoption and diffusion process. Therefore, it is obvious that the forest industry's attitudes towards the business potential of biorefineries and their willingness to invest in this new business will have a decisive impact on the diffusion process of the forest biorefineries. These findings from the first and second phases of the study encouraged moving the research focus further towards the forest industry's change features, management and resources in the last research round.

The results of the last research round further indicated that although the changes in the forest industry business environment have not been sudden – nor surprising – pursuing new business and creating related change strategies and procedures are neither simple nor effortless for any forest industry organization. The very well-known fact that change is disruptive, costly and uncomfortable for individuals – and that for organizations these forces of inertia are even stronger – seems to hold true in the context of the forest industry as well (See e.g. Grant, 2010). For the traditional, capital-intensive forest industry, a conservative organizational culture and lack of financial resources seems to create prominent barriers for the change according to this study. It is understandable that the capital-intensive industry cannot make investments without careful consideration. However, in the beginning of the study the majority of the respondents believed that large companies have enough investment capacity for the new business. Moreover, excessive carefulness and change resistance can deteriorate the forest industry's future survival. The danger of the mature mindset has been also recognized by various other studies (See e.g. McGahan, 2000; Söderholm and Lundmark, 2009).

Interestingly, there were also respondents who believed that the forest industry has been more future-oriented and strategic than it has been publicly indicated. It was also articulated that many organizations have explored new business opportunities, but they have been discovered to be unprofitable.

It is not possible to create exact forecasts and propose detailed business strategies towards biorefineries that would be applicable for every situation; rather, a case-by-case evaluation is needed. The scope of the change with needed transformation activities and resources depends largely on the specific forest industry company and its culture, as well as the biorefinery location, degree and site of integration, chosen technologies, availability of raw materials and specific knowledge of the biorefinery partners. In other words, there will be great variation in the scope of the change, starting from its fine-tuning into corporate transformation (See also Dunphy and Stace, 1993). Accordingly, strategic approaches suggested by respondents varied greatly, ranging from the rationalization of assets to encouragement of employees to bringing up their ideas as the most necessary actions in the forest industry for promoting forest biorefineries. In addition, Beer and Nohria (2000) believe that it is possible but challenging for companies to effectively combine different approaches, namely Theory E's hard change strategies (e.g. heavy use of economic incentives, down-sizing) and Theory O's soft approaches (e.g. employee behavior). Beer and Nohria (2000) also further indicate that those companies that combine different approaches are more likely to achieve a sustainable competitive advantage.

There should be also an aspiration towards focusing and differentiation in organizations: pursuing the same models and strategies as competitors is not the best pathway to follow. Particularly in Finland, forest industry companies were criticized for copying the practices and business models of one another. However, since profitability of new technologies is uncertain and companies can learn by observing the adoption experience of others, it is understandable that companies are carefully observing the others and their choices (See e.g. Kapur, 1995). Also Rogers (2003) believes that observability is one of the key factors that affects the diffusion process: the degree to which results of an innovation are visible to others are positively related to its rate of adoption. Moreover, starting a new biorefinery business is believed to be very erratic: there will be lots of false starts before the most ideal models can be found.

Accordingly, there were arguments equally on behalf of and against the feasibility and fit of biorefineries in the forest industry's core businesses and organizational culture. It was believed that the operations and scale when producing biofuels in particular will fit well in traditional operations. One advantage of the biorefining business is that because the business is challenging enough, unique know-how and technologies cannot be easily copied by other sectors. It was also believed that pieces were beginning to fall into their places: the vision and the goals to embrace the new technology and business, though changes will happen gradually. On the other hand, it was indicated that the organizational values and culture in the forest industry will not support biorefining business. Particularly, production of high value-added products was seen to be very different for the industry that traditionally concentrates on bulk production. Accordingly, forest biorefineries were believed to require a very different set of skills that are challenging to find in the forest industry. However, the role of the forest industry was largely seen as a biomass provider with a strong knowledge of wood raw material management, harvesting and logistics. The estimates of the importance of new products for the forest industry varied, starting from 10% of the total production to the highest estimates of 50%. It was also highlighted that even though new products will have a relatively small share in terms of quantity (10%), they will have a disproportionately large share in terms of value. Overall, even though bioproducts definitely have a role in the future portfolios of forest industry, the respondents believed that the biorefining business needs to be planned to support traditional core businesses.

The need for the organizational change and diversifying product portfolios in the forest industry sets many requirements for forest industry management. Casti and Ilmola (2011) also recognized in their recent study resilience to change, management of diverse portfolios and broad visions of future development as the greatest challenges in forest industry management. Readiness for the change and enthusiasm need to be embedded into the organizational culture; as well the key for attaining this is open-minded, multi-disciplinary organizational management. There needs to be open and innovative dialogue both inside the organization and with potential partners outside the organization. Particularly in Scandinavia, the forest industry companies are believed to have strong networks and long traditions in collaboration. Correspondingly, the important skills at the managerial level will be an understanding of market development in the global arenas, as well as an ability to commercialize and market new products. Interestingly, despite the prevailing opinion of the slowly changing organizational culture and resistance to change, visionary and innovative personnel are believed to be found in forest industry companies, but the current culture does not encourage these people to put forward their ideas. Management should encourage these individual capabilities and take advantage of them on the organizational level. Furthermore, finding new, capable, multi-competent staff through education and collaboration is also important. All in all, operating a commercial scale forest biorefinery facility requires both new managerial- and operational-level capabilities. Correspondingly, Pätäri (2009) noted that in the bioenergy business the existing experience and knowledge of the forest and energy industries in terms of bioenergy production is considered favorable, but in the future the resource base of the companies must be extended beyond the traditional firm and industry boundaries.

Domsjö in Sweden is often considered a model example of a forest industry company that has successfully changed its product portfolio and strategies. The pulp mill is transformed into a biorefinery that produces, for example, lignin and bioethanol using conifer wood fibers as raw material. There are several issues that can be considered to be the grounds for the company's success. First, it was acquired by new owners who saw new business opportunities outside of the traditional core business. There has also been emphasis on their own R&D and aspiration towards broad product portfolio (Domsjö, 2012; Donner Amnell et al., 2011; Hetemäki et al., 2011). It is interesting that similar aspects are considered important in this study as well.

Many respondents indicate that forest biorefineries have very high investment costs, and revenues from the new business are not currently considered sufficient in the capital-intensive forest industry. The capital cost of the current business has been high, and therefore many organizations will largely concentrate on producing traditional products and fulfilling the demand for current markets as optimally as possible. Fittingly, the respondents unanimously indicated that forest industry companies largely lack the financial resources for research and development.

Despite that some respondents considered wood biomass to be an almost untapped raw material source, the high price of raw material was named as one of the biggest threats to new biorefinery business from the forest industry perspective. Further, it was believed that along with the increasing demand there will be more pressure on prices. In addition, from the environmental perspective, using wood as a raw material was seen as a prominent challenge (as described in the previous Section 4.3). Therefore, the forest industry needs to pay close attention to the environmental considerations. In this light it is interesting that at the beginning of the study, the forest industry was the only sector that believed that the environmental impacts of harvesting wood biomass are sufficiently known. On the other hand, many respondents believed that the forest industry has a long tradition of managing forests in an environmentally sound way, and that there is also knowledge about the required environmental practices, certifications and regulations in the forest industry.

In summary, it seems that biorefineries integrated into the pulp and paper industry can play a significant role in the future continuity of the forest clusters both in Scandinavia and North America. Both studied areas seem to have potential for success in the biorefinery business. In general, success will be based on national strengths, continuous development and swift entry into the biorefinery markets. On the other hand, the respondents thought that the biorefineries will eventually be mainly located in areas with plenty of affordable biomass and low labor costs, although the first demonstration plants will be built in Scandinavia and North America. Therefore, it is obvious that companies need to carefully evaluate their long-term potential and roles in the biorefinery business. Accordingly, for companies to be prosperous it requires that they upgrade their resource and capability bases as previously described in this section, therefore making management of dynamic capabilities one of the greatest challenges for forest industry managers (See also e.g. Eisenhardt and Martin, 2000; Helfat and Peteraf, 2003). Further, it was also highlighted that at this point it would be important among the forest industry to trust its own capabilities and not fall into despair, because the advantage of the emerging forest biorefinery business should be taken early enough. However, planning and establishing a functional organizational structure for forest biorefineries will be challenging and the most prominent dilemma related to the emerging biorefinery business seems to be intertwined with the following issues from the perspective of the forest industry: first, the success in biorefinery business cannot be achieved without collaboration and partnerships that combine the right set of skills and knowledge. Second, the biggest challenge seems to be sharing profits between these partners in forest biorefinery consortia. Those companies who will solve this dilemma by finding and sustaining a successful consortia will likely be the future success of the biorefining business. Correspondingly, Pätäri (2009) found that value creation through collaboration has become increasingly important as a means of filling the resource gap in energy and forest sectors in bioenergy business. For example, there will be interesting opportunities in the interface of the forest industry and chemical industry (Argyropoulos, 2007; STAR-Colibri, 2011). Other studies have also indicated that forest industry companies do not have to necessarily develop new technologies by themselves when they are restructuring their businesses. They can obtain knowledge through patents and other immaterial rights or they can acquire companies with the defined competitive knowledge and technologies. (Eloranta et al., 2010; Hetemäki et al., 2011) These companies can come from outside the traditional forest sector (Hetemäki et al., 2011). Overall, the forest industry needs to transform its business in one way or another. Respectively, there is a growing call in our society towards a bio-based, green economy with related new business strategies and models. The biorefining business can be one of the most successful strategies towards achieving these goals.

4.5 Future views and scenarios

In order to discern the main developmental paths towards future forest biorefineries, and also to get a starting point for the research process, future views for the forest cluster as well as scenarios for lignocellulosic biofuel production were formulated in the beginning of the study.

Therefore, in the first research round the respondents were asked to choose from four future views – defined as *Business as Usual, Restructuring the Business, Sustainability, and Domestic Competencies* (views are based partly on work of Häyrynen et al., 2007, see Appendix 1, module 4/5 in the questionnaire for a detailed description of the views) – the one that corresponds to their impression regarding the future of the forest cluster. *Sustainability* and *Restructuring the Business* best describe the future development of the forest cluster, as 80% of the respondents chose one of the two options. In Scandinavia, the Sustainability view got more support compared to North America: nearly 50% of the Scandinavian respondents chose this view, compared to about 20% of the North Americans. According to this future view, sustainability is the key issue in financial decision-making. The forest cluster is successful in a society that respects ecological values and sustainable forest utilization. Production will be further developed towards energy and raw material efficiency. Biorefineries and related new energy products sustainably guarantee the forest cluster's success. According to the Restructuring the Business view, the competitiveness of the national, traditional forest cluster will disappear, and reliance on old production structures remains highly risky. Investments are aimed at new markets' business concepts. According to this view, there is a strong interest in an increasing amount of projects geared towards forest biorefinery concepts and new bioenergy products. The results indicate that in North America, where half of the respondents chose this option, the view was more common compared to Scandinavia (38% chose this option).

Interestingly, recent developments in the forest biorefinery sector and the current trends wider in society indicate that the future views chosen as most likely in 2008 have started to actualize in many contexts. A transition towards bioeconomy – which in a broad sense means the exploitation and management of renewable natural resources in a sustainable way – is one of the most prominent trends of the current society (See Section 1). Respectively, many ideas that are presented in the sustainability view of this research are consistent with the bioeconomy efforts. According to the Restructuring the Business view, there is rising interest in and projects working with forest biorefinery concepts and products. These statements have been realized in many terms, as there are many on-going biorefinery projects both in Scandinavia and North America. It is also worth noting that in the beginning of this research, technical studies on forest biorefineries dominated the field, and those that considered other aspects of forest biorefineries were rare. Now, five years later, multi-perspective studies considering different aspects of the biorefinery business are more common (See e.g. Fritsche et al., 2012; Pätäri, 2009).

During the first research phase in 2008, 55% of the respondents believed that the role of biorefineries in the forest cluster's competitiveness and biofuel production will become significant during the next five years. However, already in the second Delphi round at the beginning of 2009, the near-to-midterm potential of biorefineries was considered less optimistic, and the postponement of biorefinery projects was seen as a likely future outcome. When reflecting on these initial views from the first Delphi phase in the context of the current situation, it seems that the estimates have been overly optimistic in many respects. There have been plenty of developments in the field in both studied areas; for example, UPM will invest in a biorefinery producing biofuels from crude tall oil in Lappeenranta, Finland. The biorefinery facility will produce annually approximately 100,000 tons of advanced second generation biodiesel for transport. Construction of the biorefinery will begin in the summer of 2012 at UPM's Kaukas mill site and will be completed in 2014. Furthermore, the respondents in the last research round indicated that many organizations have also recently started to aim more resources towards new business options and there are many initiatives towards forest biorefineries. In addition, many respondents expected to see several biorefinery projects started in a three- to-five-year time frame and it was believed that in ten years' time there will be three large-scale biorefinery facilities operating both in Finland and Sweden. However, it would be too strong to state that in general the role of forest biorefineries in the forest cluster's competitiveness is currently significant, as was forecast in the first research phase.

In the beginning the survey respondents estimated the volume of cellulosic biofuel production in the forest biorefineries in their country for the next 12 to 15 years. They were presented with several optional development paths (Development paths are presented in Appendix 1, module 4/5), which were outlined with respect to each region's political goals for biofuel production (Directive 2003/30/EC; Government of Canada, 2008; Renewable Fuel Association, 2008). The respondents were asked to evaluate the realistic future development in production volumes in their own countries/regions, assuming no radical changes to the business environment. Scandinavian respondents evaluated the production volumes in the whole EU region, because there were no country specific political goals available for the lignocellulosic biofuel production in Finland and Sweden. Estimates of liquid cellulosic biofuel production in the EU totaled nearly seven million tons in 2020 (51%), in the U.S. about 30 million tons in 2022 (46%), and in Canada about 16 million tons in 2022 (60%)[3]. However, most of the respondents in the second Delphi phase believed that the production volumes of lignocellulosic biofuels indicated by survey results were overly optimistic or surprisingly high in every studied area. On the contrary, in the last phase of the study most of the American respondents believed that a production capacity of 30 million tons would be possible in 10 years' time in the case that governmental actions and legislation favor developments in lignocellulosic biofuels. Likewise, a capacity of 16 million tons in Canada was believed to be realistic; however, in Scandinavia most of the experts still believed that the seven-million-ton production capacity, indicated as realistic in 2008, cannot be achieved in 10 years' time.

3 The percents in the parenthesis indicate the share of the respondents that chose the presented production volume.

5 CONCLUSIONS

5.1 Main contributions

There is a strong aspiration to move towards a bio-based economy in present society, and bioenergy and bioproducts play an important role in this transition. Though the forest biorefineries will certainly play a role in this process in the coming years, at this point it is very difficult to give exact estimates of how prominent this role will be and how development and implementation of forest biorefineries will explicitly proceed. This research has approached the phenomenon – namely the diffusion of forest biorefineries – from different perspectives, theoretical frameworks and levels, aiming at creating a holistic understanding of the novel biorefinery business and its diffusion in Scandinavia and North America.

During the five-year research period the perceptions of academics, politicians and the involved industries themselves of forest biorefineries have widened from an exploration of biorefineries from a purely technical perspective to more holistic approaches. Moreover, this study indicates that forest biorefineries – which cannot be limited to one raw material, process or product, nor can the involved industries with their specific resources remain constant – have a multifaceted and complex diffusion process in which a variety of issues affect the diffusion.

Therefore, incentives that promote the biorefinery business must stem from several sources. First, there needs to be encouraging signals from the *macro-scale environment* – the high price of oil, national security of the fuel supply as well as long-term, consistent federal and state energy and environmental policies are the most prominent macro-scale drivers. *At the industries/sectors level* successful implementation of the biorefinery business in particular requires the efficient exploitation of existing wood biomass resources, availability of private and public financing and collaboration between different value chain actors. *At the strategic level* the diffusion process is most facilitated by an understanding of new markets and management of change as well as the development of economic wood fractionation technologies with related innovations and process expertise.

Incentives for the biorefinery business differ only slightly in the studied areas, and there were no significant differences in the opinions between the sectors that were involved in the study. Thus it can be concluded that both studied areas seem to have potential for success in the biorefinery business. The studied countries have common *strengths*: technological knowledge, biomass availability, existing infrastructure and biomass logistics. Therefore, realistic identification of individual, unique strengths and continuous development of competencies would be crucial at the national level. Likewise, the ability to promote and market the national know-how through international networks would be important in order to succeed in the biorefinery business. Also, the respondents thought that the biorefineries will eventually be mainly located in areas with plenty of affordable biomass and low labor costs, even if the first facilities will be built in Scandinavia and North America. This further highlights the need of countries and organizations to carefully consider their roles in the biorefinery value chains and their long-term potential in the biorefinery business.

Environmental sustainability is an important driver for the forest biorefinery business in general, and a company's environmentally sustainable image, achieved through sustainable production, in biorefineries can also be a competitive advantage. However, forest biorefinery activities affect the environment and its sustainability in various ways. Biorefinery business with related feedstock harvesting will further intensify the pressure of forest-based industries on forest ecosystems, leading to various environmental impacts and challenges. Thus there is a need for systematic, sector-specific approaches in assessing the environmental sustainability of forest biorefineries. As a contribution from this study, assessment criteria that can be considered to be the initial step towards a more elaborated evaluation framework were suggested. *Raw material availability and sustainability* seem to be the most prominent criterion in environmental sustainability assessment of the forest biorefinery business following the importance of the *life-cycle perspective* and the production of *beneficial products*. The initial framework presented in this thesis needs further development in order to be a more practical evaluation tool that can yield more accurate information on the sustainability performance of biorefinery value chain companies. Still, even in this initial form the criteria can offer the basis for discussion both among the involved industries, academics and in wider society on the different options that can realize a bioeconomy. In addition, even though the present study focused on the environmental dimension, the findings from this research – for example, the companies' pursuit of society's common good through the biorefining business – clearly point to the interlinked nature of different sustainability aspects, and moreover, a need for the development of integrated sustainability assessment tools for the biorefinery sector in the future.

In biorefinery consortia the role of the forest industry is largely seen as a *biomass provider* rather than a dominant actor, as indicated in the beginning of this study. Biorefinery production technologies and end products will be dependent on local raw material availability and the specific features of the facility with which the biorefinery will be integrated. The forest industry will have a *diversified product portfolio*, and biofuel production and various high value-added bioproducts will play a prominent role in the portfolio. Nevertheless, the respondents believed that the biorefining business needs to be planned to support traditional core businesses.

One of the most striking aspects to emerge from this study is the rather languid attitude of forest industry companies towards new business and inertia in the strategic management, despite the mature or even declining state of North American and Scandinavian forest industries. This is interesting, as the involved industries themselves should work to actively create strategies for managing change and aiming resources towards new business. However, it was also believed that the forest industry has been more future-oriented than has been publicly indicated. To add recent actions among the forest industry give indications that the conservative industry has moved in a new direction towards novel businesses. Altogether, this study shows that the renewal of the forest industry is not possible without a readiness for the change and a resilient attitude, which both need to be embedded into the organizational culture. Key aspects for attaining this are the managers with broad visions, capabilities to manage diverse portfolios, marketing skills and open dialogue with internal and external stakeholders. As innovative and visionary personnel are believed to be found in the forest industry, these employees should also be considered a significant resource for the future development. Moreover, it is obvious that forest biorefinery success will be based on partnerships through which the right set of skills can be achieved. Nevertheless, collaborative management in the consortia has its own challenges – sharing the profits and responsibilities between the partners will be the most difficult issue to solve. Furthermore, a lack of financial resources in the capital-intensive forest industry and concerns related to raw material price, availability and sustainability seem to create barriers to the change from the perspective of the forest industry.

Overall, it seems that the hype that was related to renewables in general and to the biorefinery business has passed, and at all the levels of the business environment more realistic plans and approaches are being made, with the actual steps in the form of commercial scale biorefineries. The results of this study indicate that many organizations have recently started to aim more resources towards new business options and that there are many forest biorefinery initiatives underway. Moreover, various biorefinery projects are expected begin in the near future. The forest biorefineries alone cannot solve the profitability problems of the forest industry – and they are even less able to take sole responsibility for the transition to bioeconomy. Instead, they can do their part in the change to a modern and sustainable forest industry as well as in the transition to a more bio-based economy. It seems that the present views on the biorefinery business are positive and realistic in general; therefore it is highly probable that what is now considered the "green business" of forest biorefining will in the future be "business as usual". Where there's a will, there's a way.

5.2 Implications

This study brings to light many new perspectives and views on emergent forest bioenergy business on both the global and national scales. It can therefore help politicians when contemplating policy decisions and financial incentives as well as help private sector managers recognize the key factors in the business environment. This in turn will help managers in strategic change management, for example, in allocating resources successfully, identifying the strengths and weaknesses of their business operations, developing new business concepts, and analyzing the competitive situation of the global markets. Moreover, this study provides information about environmental sustainability of the biorefinery business for stakeholders when considering the various options for implementing and actualizing practices for the bioeconomy.

5.3 Limitations of the study

This study aimed at *reliability* by making the research process as transparent as possible, describing the research strategies and design and data analysis in detailed manner. In addition, the basis for interpretations was given as elaborately as possible. (See e.g. Moisander and Valtonen, 2006) There were plenty of fixed-choice answers in the survey, whereas in the interviews the same main themes were included in each interview in order to increase reliability. Further, the interviews were recorded and transcribed, and quotes were included in the related research papers for greater reliability (See Silverman, 2006).

In this research, triangulation was used as a primary way to increase *validity*. Method, data, theoretical and investigator triangulation were applied during the research process (See detailed description in Section 3.1). R*espondent validation* was also applied, as the respondents evaluated the study findings during the Delphi phases, i.e. results constituted from respondents' opinions were taken back to the respondents' evaluation. Even though some researchers (e.g. Silverman, 2006) criticize triangulation and respondent validation as fallible paths to validity in qualitative analysis, in this study, which uses both quantitative and qualitative methods, they were seen as an attempt to yield more valid findings.

This study, like any other, is subject to potential limitations. The phenomenon was explored through a variety of theoretical foundations, and therefore conducting a more in-depth analysis of all the theoretical approaches was not possible. However, due to multiple approaches the phenomenon could be explored holistically, and the different theoretical frameworks worked together to enable understanding and analysis of the multifaceted diffusion process of forest biorefineries.

One potential limitation concerns the selection of respondents: while each studied country yielded respondents, researchers and forest industry representatives were most dominant, perhaps not reflecting a true representation of all the study sectors. In addition, the countries with the highest number of respondents were Finland and the U.S. Moreover, it is likely that private sector (particularly from the forest industry) representatives did not reveal details on strategic issues, therefore the truth of some of the responses can be called into question. On the other hand, the confidential atmosphere in the mutual interviews encouraged respondents to express their opinions freely.

Moreover, due to the different backgrounds of the respondents, certain topics were discussed in depth while others were only brought up briefly. As well, the complex nature of forest biorefinery facilities with related product, technological and raw material variation also had an effect on the formulation of some questions, and all the aspects could not be fully evaluated – for example, future scenarios were created only for cellulosic liquid biofuel production. In addition, the experts could have been more explicitly encouraged to think future alternatives in the longer term, and therefore e.g. backcasting method (Quist and Vergragt, 2006) could have been applied for that purpose.

5.4 Future research

In the future it would be important to explore potential biorefinery actors in a more holistic manner, not only from the perspective of the forest or energy industry. Forest biorefineries seem to offer possibilities for many businesses, and the resource base offered by all the potential actors should be explored. Also, examining which part of the biorefinery value chain offers most potential for participating countries and companies requires careful consideration. Biorefinery related services (e.g. offering technologies and know-how, maintenance, education) can create prominent possibilities for the Scandinavian and North American companies in addition to production in future. There also needs to be more emphasis on small and medium-sized companies in addition to large companies. It would also be interesting to take a more local approach; for example the potential and effects of the forest biorefinery business in particular counties could be studied. Moreover, the applicability of different raw materials in addition to wood-based biomass should be carefully explored. In the future, the development and launching of new bio-based products should always include credible sustainability assessment in order to provide the stakeholder with adequate information to make their decisions. Exploring new strategies and business models in operating biorefinery consortia would also be interesting in terms of, for example, how companies succeed in sharing responsibilities and profits. At this point, however, commercial scale business is only just emerging, and the experiences of consortia strategies are largely lacking.

YHTEENVETO (SUMMARY IN FINNISH)

Bioenergia ja biopohjaiset tuotteet ovat keskeisessä osassa siirryttäessä kohti biotalousyhteiskuntaa. Biotalous tuo myös metsäklusterille monia mahdollisuuksia liiketoimintansa monipuolistamiseen. Erityisesti sellu- ja paperiteollisuuden yhteyteen integroitavien biojalostamoiden mahdollisuuksiin uskotaan.

Tämä tutkimus pyrkii luomaan kokonaisvaltaisen kuvan metsäbiojalostamoiden diffuusioprosessista Skandinaviassa ja Pohjois-Amerikassa. Lisäksi biojalostamoiden ympäristöllistä kestävyyttä sekä metsäteollisuuden muutosta kohti uutta biojalostamoliiketoimintaa, ja siihen tarvittavia resursseja tarkastellaan yksityiskohtaisemmin.

Lähestymistavaksi valittiin Delfoi-metodi skenaariotarkasteluineen. Tutkimuksen ensimmäisessä vaiheessa tehtiin tutkimuskysely verkkoympäristössä, mistä saadut vastaukset analysoitiin käyttäen tilastollisia menetelmiä. Toinen ja kolmas tutkimuskierros olivat luonteeltaan laadullisia, ja ne toteutettiin sähköpostikyselyinä sekä teemahaastatteluina.

Tutkimus osoittaa, että metsäbiojalostamoiden diffuusio on monitahoinen prosessi, johon vaikuttavat lukuisat asiat. Tämän vuoksi myös diffuusiota edistävien tekijöiden täytyy tulla usealta taholta. *Makroympäristön* keskeisimpiä kannustimia ovat korkea öljyn hinta, halu kehittää kansallista polttoaineomavaraisuutta sekä pitkälle luotaava, yhdenmukainen energia- ja ympäristöpolitiikka niin kansallisella kuin osavaltiotasollakin. *Teollisuudenalojen tasolla* asiaa tarkasteltaessa menestyksekkään biojalostamoliiketoiminnan toteutumisen edellytyksenä on puubiomassavarojen tehokas hyödyntäminen, riittävä yksityinen ja julkinen rahoitus sekä yhteistyö arvoketjun toimijoiden välillä. Organisaatioiden *strategisella tasolla* ymmärrys uusista markkinoista sekä muutoksen hallinta, samoin kuin taloudellisten puun fraktiointiteknologioiden, ja niihin liittyvien innovaatioiden ja prosessien hallinnan kehittäminen ovat keskeisimpiä diffuusiota edistäviä tekijöitä.

Biojalostamoiden diffuusiota edistävät tekijät eroavat kaiken kaikkiaan vain vähän tarkasteltujen alueiden välillä ja molemmat niistä voivat menestyä biojalostamoliiketoiminnassa tulevaisuudessa. Menestyksen kannalta on kuitenkin olennaista, että kansalliset vahvuudet ja kunkin toimijan rooli biojalostamoarvoketjussa kyetään tunnistamaan pitkällä tähtäimellä.

Raaka-aineiden saatavuus ja kestävyys on tärkein kriteeri arvioitaessa biojalostamotoiminnan ympäristöllistä kestävyyttä. Samoin elinkaarinäkökulma ja hyödylliset lopputuotteet ovat keskeisiä kriteerejä kestävyyttä arvioitaessa. Tämä tutkimus osoittaa myös, että metsäteollisuuden uudistumiseen tarvitaan muutosvalmiutta ja joustavuutta organisaatiokulttuurissa ja -johdossa. Lisäksi, biojalostamotoiminnassa menestymisen edellytyksenä on yhteistyö eri toimijoiden välillä ja sitä kautta saavutettavat resurssit ja osaaminen. Metsäteollisuuden näkökulmasta yhteistyö ja konsortioiden johtaminen tuovat monia haasteita; erityisesti liikevoittojen ja vastuiden jakaminen partnereiden kesken koetaan haasteellisiksi.

Avainsanat: biotalous, metsäbiojalostamo, diffuusio, liiketoimintaympäristö, Pohjois-Amerikka, Skandinavia, ympäristöllinen kestävyys, metsäteollisuuden muutos

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ORIGINAL PAPERS

I

FOREST BIOREFINERIES – A SERIOUS GLOBAL BUSINESS OPPORTUNITY

by

Annukka Näyhä, Sari Hämäläinen & Hanna-Leena Pesonen, 2011

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CHAPTER 4

Forest biorefineries — a serious global business opportunity

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Annukka Näyhä, Sari Hämäläinen and Hanna-Leena Pesonen

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1 Background

Because of the global warming, there is widespread interest in promoting biomass-based energy sources. Especially lignocellulosic non-food biomass feedstocks and technologies for converting these feedstocks into economical, low-carbon biofuels are being widely studied at the moment. The dwindling availability of easily exploitable oil reserves, combined with the rapidly increasing use of oil in many countries, is further boosting the interest in biofuels. Though we have seen a rapid drop in the price of oil since 2008, there will be strong pressure for price increases in the future. In countries rich in biomass resources, biomass-based fuels can replace expensive imported energy and improve the national security of the fuel supply[1–4]. Replacing fossil fuels by renewable sources of energy can help to improve the security of the energy supply, while at the same time mitigating greenhouse gas emissions.

One of the key goals of the European Union's (EU's) energy and environment policy[5] is to promote the utilisation of *renewable energy sources* as a means to reduce carbon dioxide emissions and to improve the national security of the fuel supply. The objective is to increase the share of renewable energy resources in the EU's total energy consumption from 6 % to 12 % by 2010[6]. In addition, the EU has committed itself to decreasing greenhouse gas emissions by 8 %, also by 2010, compared to the 1990 levels according to the Kyoto Protocol. Consistent with this, the G8 countries have conducted negotiations concerning common climate goals and a new climate agreement, originally aiming to complete their deliberations by the end of 2009. The G8 countries are planning to decrease their greenhouse gas emissions by 50 % from 1990 levels by the year 2050. In January 2008, the European Union Commission published its 20/20 by 2020 package[7]. This includes proposals for reducing the EU's greenhouse gas emissions by 20 % and for increasing the proportion renewable energy of the EU's total energy consumption to 20 % by 2020. The European Parliament adopted the EU climate change package in December 2008.

For decades, the success of the forest sector has been based on steadily growing demand for forest-based products, a sustainable supply of raw wood material, comparatively low energy prices, advanced forest industry technologies, efficient production machinery and, in some countries, also on the special status of the forest sector in national economic policy (especially in Finland and Sweden). However, these elements, which have guaranteed the success of the forest cluster, have largely disappeared[8]. Because of global competition, the forest industry has started to relocate part of its activities to new areas (eastern Europe, South America and Asia), where production costs are lower, biomass resources are abundant and demand for forest products will increase strongly in the near future. Nordic and North American forest companies are facing similar challenges. The forest clusters in the Nordic countries and North America are facing global competitors in Latin America and Asia who have modern and large industries, and wood and labour cost advantages. As a result of the growing competition, the prices of forest products are expected to continue decreasing. In addition, the low level of investment over the past 10 years has brought many forest sector companies to the edge of obsolescence[9–11].

In response to this uncertain environment, many forest industry companies have developed new survival strategies involving mergers, acquisitions and belt-tightening to consolidate their assets and reduce their operating costs. However, in the long term, the vitality of the forest cluster has to be secured through new investments, products and business operations. Bioenergy and biomass-based products offer the best possibilities for diversifying business operations and exporting technologies. Especially *biorefineries*, which can be integrated into the pulp and paper industry, seem to have great potential in the future[9,12–14].

A biorefinery can be implemented in many alternative ways. There are also considerable technology and business risks related to its implementation. Forest industry companies need to restructure their current business models and strategies in a way that preserves their core business while allowing profitable manufacture of new biorefinery products. There are no country- or industry-wide solutions for how a forest biorefinery should be developed and implemented.

There is plenty of ongoing research on lignocellulosic bioproducts in the United States, Canada and Sweden[2]. In these countries, governments have also invested strongly in R&D. In the United States, the paper industry, together with the Department of Energy and the Department of Agriculture, has started to develop the manufacture of forest bioproducts[4,15,16]. The Department of Energy announced in the course of the years 2007–2008 that it will invest USD 385 million in six large-scale biorefinery projects over the next four years and that it will invest USD 114 million in four small-scale biorefinery projects over four years.

To ensure successful implementation, the challenges related to biorefineries must not be seen as purely technical problems nor as issues unconnected to society. The diffusion of biorefineries, like the diffusion of new technologies in general, is affected by several factors. Both research and development work (technology push) and activities which encourage commercialisation and implementation of innovations (market pull) are needed. The diffusion process is influenced by state policies and subsidy mechanisms, collaboration between different actors, economic factors, organisational culture and stakeholders' views. Ecological aspects and the need to secure sustainable use of natural resources are other significant issues, which influence the success of new technologies[17–20]. To promote biorefineries, information must be readily available on economically efficient incentives and new business models. The effects of biorefineries on national economy, wood raw materials markets and other forms of forest utilisation should also be considered[2].

To revitalise the traditional forest sector, and to successfully introduce biorefineries and related new products and business models, there must be up-to-date information on the global business environment as well as the national one. Knowledge of the international business environment and research programmes improves the possibilities for cooperation between countries, helps in identifying national strengths and promotes integration of companies to abroad.

In this chapter, we aim to contribute to meeting these business challenges by presenting a biorefinery concept and related new products and business opportunities in the forest cluster, as well as new business strategies and models for companies which are part of the biorefinery value chain. Attention is paid both to national and international factors, which have an effect on the success of forest biorefineries.

The contents of this chapter are largely based on the results of an international internet survey conducted in June 2008 (see details of the survey in ref.[21]). In this survey, the factors which contribute to the establishment and success of forest biorefineries were compared between the Nordic countries, North America and South America. The results reflect the opinions of 145 forest- and bioenergy-sector experts (academia, authorities and company representatives) in countries, which have good conditions for establishment of forest biorefineries, high-quality research and development, similar forest industry structures and abundant biomass resources (Finland, Sweden, the United States, Canada and Brazil).

2 Drivers for forest biorefineries

The *increasing price of oil* is considered the greatest incentive for forest biorefineries and wood-based biofuels. *Climate change*, *increasing demand for biofuels* and *the national security of the fuel supply* are other important drivers for forest biorefineries. *Climate change* seems to be a more important driver in the Nordic countries and Brazil than in the United States. Correspondingly, the national security of the fuel supply is a more important driver in the United States than in the other countries. In Brazil, international environmental and energy policies are considered an important driver for forest biorefineries. Interestingly, the forest industry considers climate change as a less important incentive for the diffusion of biorefineries than other sectors. Especially researchers highlight the importance of the national security of the fuel supply.

It seems obvious that there is a need for re-evaluating the utilisation of wood and the wood-refining chain from a fresh perspective in the forest cluster. Forest biorefineries will be a way to avoid a massive shut-down and loss of forest cluster assets. The consensus about this issue is strongest in North America. In the Nordic countries, especially in Finland, wood-based biofuel production is regarded as the most serious business opportunity in the forest cluster.

In Brazil and the Nordic countries, sustainability (future view of the forest sector modified from Häyrynen et al.[22]) is the key issue in financial decision-making in the forest sector. The forest cluster is successful in a society which respects ecological values and sustainable forest utilisation. Production will be further developed towards energy and raw material efficiency. Biorefineries and related new energy products guarantee the forest cluster's success in a sustainable way.

In North America, the competitiveness of the national traditional forest cluster is weakening and relying on old production structures involves a high risk (in accordance with the future view of the need for restructuring the business modified from Häyrynen et al.[22]). Investments are aimed towards new markets and new business concepts. There is strong interest and an increasing number of projects related to forest biorefinery concepts and new bioenergy products.

3 Scenarios for biofuel production in forest biorefineries

The role of biorefineries in the forest cluster's competitiveness and biofuel production will remain insignificant for the next five years, but already within ten years their role will be significant. In the near future, the role of forest biorefineries is estimated to be greatest in the United States. However, in 20 years, forest biorefineries will also have a significant role in the Nordic countries and South America.

The respondents of the survey[21] were asked to evaluate the volume of cellulosic biofuel production in forest biorefineries in their country within the next 12–15 years. They were presented with a number of optional development paths, which were outlined considering each region's political goals for biofuel production[1,7,23]. The respondents were asked to evaluate which would be the realistic development in production volumes, assuming that there will be no radical changes in the business environment. These expert opinions are presented as "Basic scenarios" in Figure 1. Without any radical changes in the business environment, liquid cellulosic biofuel production in the EU is estimated to be around 4 million tons in 2010, and around 7 million tons in 2020. In the United States, the production of cellulosic biofuels is estimated to be 10 billion gallons (about 30 million tons), and in Canada around 5 billion gallons (about 14 million tons), in 2022.

Based on the results, we also outlined "best-case scenarios" for cellulosic biofuel production for each area studied, assuming that changes in the business environment favour biorefinery development. These scenarios are also presented in Figure 1. The respondents were asked what would be the prerequisites for realisation of the "best-case scenarios" in their country. These are summarised in Table 1.

In Brazil, there are no official targets for future production and/or use of ethanol. Therefore, the Brazilian respondents were not given any predefined development paths but simply asked to evaluate the potential production volumes in 2020. The results indicate that in Brazil, the production of cellulosic biofuels is estimated to be less than 20 million tons, according to the "basic scenario", and more than 25 million tons according to the "best-case scenario" in 2020.

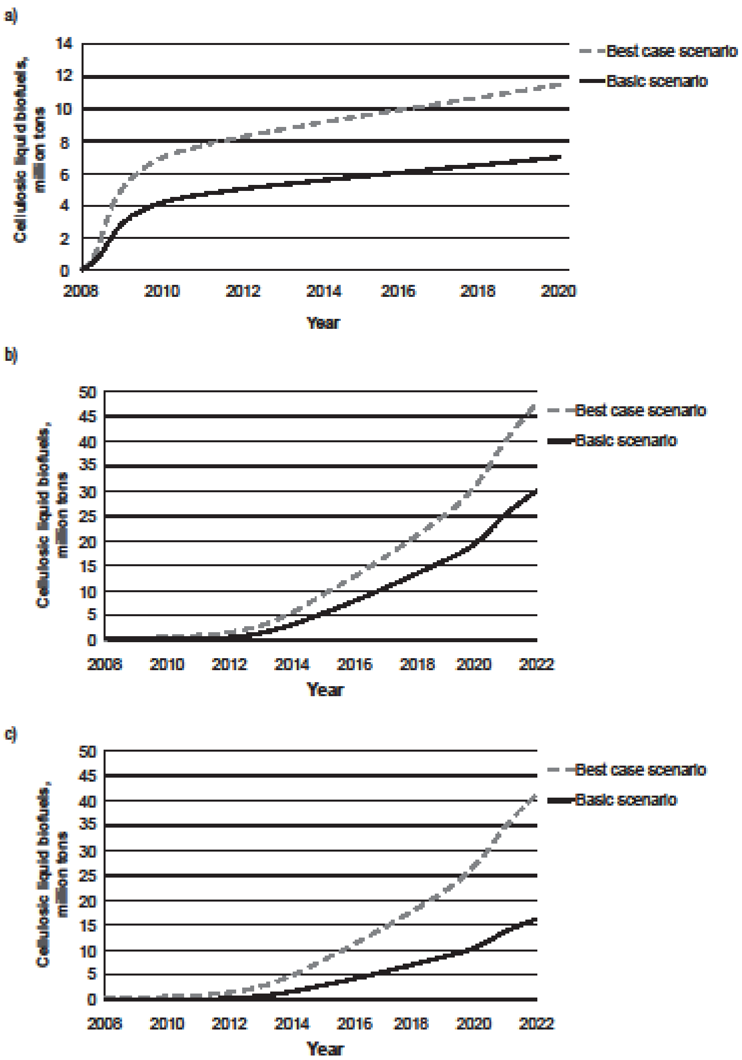

Figure 1. Scenarios for production of cellulosic biofuels in the areas studied, a) EU, b) USA and c) Canada.

Table 1. Prerequisites for realisation of the best-case scenarios in the areas studied.

Key elements in external business environment
High price of oil forcing an intensive search for new energy production options
Sufficient demand for liquid biofuels
Consensus on the goals of sustainable energy production between society and industry
Long-term and consistent (integration between federal and state policies) energy and environmental policies
Strong political pressure towards non-agricultural biofuels
Increased private and public financing, reduction of financial risk (subsidies, tax incentives and loan guarantees) in forest biorefinery projects
Focused joint efforts by industries and governments towards forest biorefineries
Support for small and medium-size companies in biorefinery value chain
Support for production of biofuels over electricity production in pulp and paper industry
Increased R&D (demonstrations and pilot plants), e.g., applications for micro-geography and local opportunities, economic wood fractionation and conversion technologies and short-rotation crops with high yield
Increased knowledge of politicians and public about the forest sector, forest management and various energy pathways in general
Criteria for sustainability of biomass raw material and for its use
Increased knowledge of environmental impacts of collecting of wood biomass
Increased capability to collect, transport and utilise existing wood biomass resources
Improvements in forest management and mobilisation of private forest owners in order to increase feedstock availability
Integrated use of other biomass sources along with wood-based biomass in biorefineries
Increased collaboration between forest industry companies and other companies in the same industry and between other stakeholders (energy industry, oil industry and research institutes)

Key elements in internal business environment
Reassessment of the situation and re-evaluation of the wood-refining chain in forest industry
Active participation in and fresh attitudes to new business opportunities in the forest industry
Efficient utilisation of existing infrastructure and permits in the forest cluster in biorefinery business
Building and maintaining infrastructure in the forest cluster
Improvements in energy efficiency and production technologies in forest industry
Recognition of the possibilities of single production units by large companies in the forest cluster
Increased R&D expertise and availability of consultancy services in the forest cluster
Increased product and technological innovation, process expertise, understanding of new markets and business know-how and management of wood supply in the forest cluster
Management of change
Increased joint efforts by forest industry, oil industry, energy industry and technology providers in the forest cluster in the biorefinery business
Successful collaboration and division of tasks within the biorefinery consortium
Strong leadership in biorefinery consortium
New processes for strategy making in biorefinery consortium
Flexibility in production in biorefineries according to the market situation

How will these prerequisites be fulfilled in practice and what are the challenges related to these issues? What kind of strategic choices need to be made to ensure success in the biorefinery business? Which sectors will be successful? Which countries will be the winners and which the losers in the biorefinery business? What will the biorefinery business look like in each country? These questions and other relevant will be discussed in the following Sections.

4 Products, technologies and raw materials of forest biorefineries

According to current knowledge, two forest biorefinery products are likely to have future market potential: *Fischer-Tropsch (F-T) diesel* and *fuel ethanol*. In North America and Brazil, the most important forest biorefinery product is fuel ethanol. In Finland, F-T diesel is considered the most important product, and in Sweden *dimethyl ether* (DME). In biochemicals, polymers seem to offer the greatest market potential.

The production will mainly take place in *plants integrated with a pulp mill or a pulp and paper mill complex*. In Brazil and North America, a smaller part of the production will take place in *plants integrated with a sawmill or some other type of sawn timber industry*. There is also some support for stand-alone plants in North America. Most biorefineries will have *a production capacity exceeding 100 000 tons per year* in the areas studied, except in Canada where most of the future plants will have a production capacity between 50 000 and 100 000 tons per year.

In the survey[27], the timeframe for commercial-scale implementation of the following technologies was studied: *solid biomass gasification*, *black liquor gasification*, *fast pyrolysis*, *acid hydrolysis and fermentation* and *enzymatic hydrolysis and fermentation*. According to the results, all of these technologies will be implemented in less than five or in five to ten years. Solid biomass gasification and gas cleaning for synthesis applications will be commercialised first. Enzymatic hydrolysis and fermentation will probably take more time to implement than the other technologies. In Brazil, solid biomass gasification will be commercialised later than in the United States and Finland. Enzymatic hydrolysis and fermentation will be implemented faster in the United States than in other countries. In Sweden, black liquor gasification is expected to be implemented at a commercial scale in less than five years. Consequently, black liquor gasification and gas cleaning for synthesis applications will be implemented earlier in Sweden than in the other countries. Interestingly, the Finns are the most sceptical about the implementation of black liquor gasification.

The most important aspect when choosing production technology is that the technology must be able to accommodate *a wide variety of feedstocks*. *Production costs* and *capacity* are other important issues when considering production technology.

Forest residues will be the most important source of wood-based biomass in biofuel production in the future. *Biomass from dedicated energy crops*, *black liquor* from pulp industry and *urban organic waste* are also important sources of wood-based biomass. Biomass from dedicated energy crops has clearly stronger support in North America and Brazil than in the Nordic countries. In Sweden, black liquor from pulp industry is seen as the most significant source of biomass. Urban organic waste has the strongest support in Finland. Besides the already mentioned sources of wood-based biomass, in Brazil and Canada sawmill residues are considered as one of the most significant sources of wood-based biomass for biofuel production. Timber killed by disease is regarded as another possible source of raw material in North America.

The greatest challenges in the utilisation of feedstocks both in the Nordic countries and North America are related to *logistics* and *transport*. *Accessibility and competition for raw material* are also major challenges. In North America, public perceptions and the environmental debate are regarded as greater challenges than in the Nordic countries. One of the reasons is that in North America, especially in the United States, there is a strong ongoing political debate about forest management and utilisation, and a balanced solution still remains to be found.

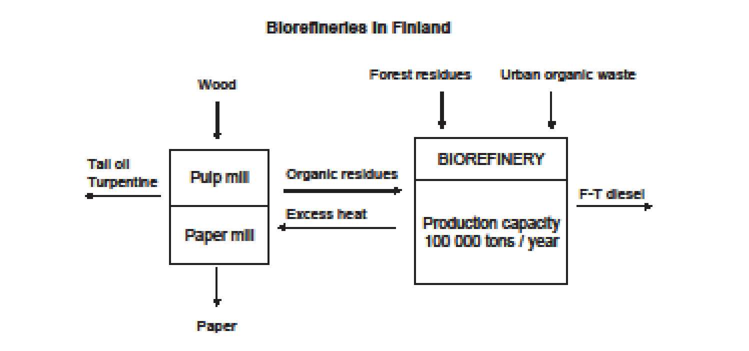

Figure 2. Technical and raw material choices in Finnish biorefineries.

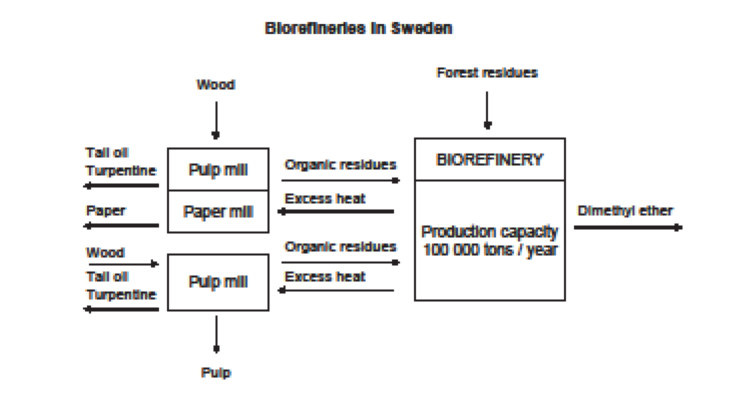

Figure 3. Technical and raw material choices in Swedish biorefineries.

The technical and raw material choices of each country are summarised in Figures 2–6.

When examining natural conditions, available raw materials and the history of biofuel production, some of the differences between the countries studied here seem obvious. First, it is easy to understand that production of ethanol is highlighted in Brazil and North America. Biofuel production in Brazil is strongly based on sugar-cane ethanol, which has been used there as a fuel since the 1970s. Respectively, in

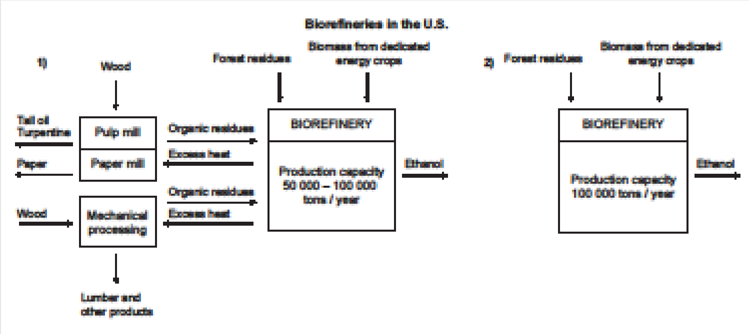

Figure 4. Technical and raw material choices in US biorefineries.

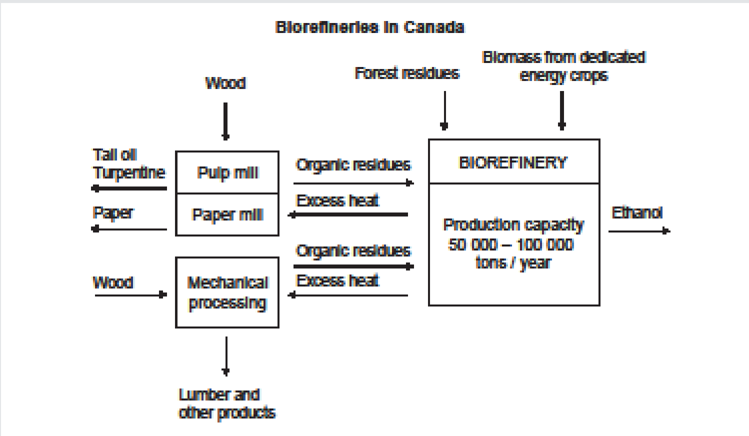

Figure 5. Technical and raw material choices in Canadian biorefineries.

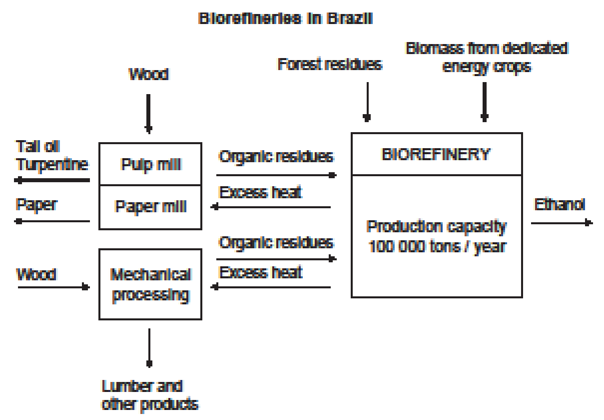

Figure 6. Technical and raw material choices in Brazilian biorefineries.

the United States, corn-based ethanol is the main biofuel. In Finland, research on gasification technologies and production of F-T liquids started already in the early 1980s, which makes F-T diesel an obvious first choice for a biorefinery product in this country. Sweden has a long tradition in black liquor gasification research and the production of related biofuels. One of the reasons for the greater interest in black liquor in Sweden compared to Finland is that there are also many stand-alone pulp mills in Sweden, meaning that there is no need for the surplus energy in paper mills. In Finland, utilisation of urban organic waste in energy production is being actively discussed, and there would be room for new solutions, because incineration of waste is not as common as, for example, in Sweden. Therefore, it is understandable that utilisation of waste is also seen as a possibility for Finnish biorefineries.

5 Barriers and prerequisites for biorefinery diffusion

Barriers affecting the diffusion of forest biorefineries arise from economic, technological, political, ecological, raw material and collaboration-related issues. In summary, the most important prerequisites for realising the political goals for the production of liquid biofuels include public and private financing, development and demonstration of technology and collaboration between the forest industry and petrochemical industry. Other important prerequisites include education of politicians and the public, high oil prices and a long-term predictable environmental policy and legislation. In addition, there are opinions that the forest industry and government should sharpen their focus and prioritise efforts in this sector.

5.1 Economic and market factors

As mentioned in the foregoing, the *rising price of oil* is considered the most powerful global driver for forest biorefineries and new bioenergy products. The price-competitiveness of wood-based biofuels was attractive in the market situation prevailing in summer 2008[21]. Wood-based biomass as a raw material and the production costs of wood-based biofuels were not considered too expensive for the production of biofuels. However, it has to be kept in mind that this reflects the market situation at the time of the survey. In June-July 2008, when the survey was conducted, the price of oil peaked at almost USD 150/barrel, but has since then dropped dramatically. The global economic crisis currently at hand, which is also responsible for the decline in the price of oil, might have some effect on the development of biorefineries by delaying temporarily efforts towards renewable energy sources in general. In the long run, however, the price of oil is expected to rise steadily, which will support the competitiveness of biofuels and biorefineries.

The main economic barrier for the diffusion of forest biorefineries is *insufficient public and private financing*. The insecurity related to biorefinery investments represents a significant barrier for the establishment of forest biorefineries. Especially in Sweden, the lack of financing is highlighted. The inadequate investment capacity especially of small and medium-size companies is an economic barrier for the diffusion of forest biorefineries. Also, support for demonstration and pilot plants is inadequate.

It is commonly believed in the forest sector that production of electricity for pulp and paper industry will be more profitable than the production of biofuels. In contrast, experts outside of the forest sector believe that production of biofuels will be more profitable for the pulp and paper industry. Against this background, this issue may become a barrier for the diffusion of forest biorefineries.

5.2 Technological factors

The technology as such seems unlikely to become a barrier to biorefineries. Instead, *lack of R&D expertise* may create a barrier for diffusion of forest biorefineries. Especially in the United States, the lack of R&D is seen as a problem. Forest-cluster companies also seem to have difficulties in finding consultancy services for biorefineries. In addition, the variety of technical choices can be a barrier, because companies in the forest cluster are confused about the variety of technical combinations offered for the production of biofuels and chemicals.

5.3 Political factors

There are many *political barriers* for the diffusion of forest biorefineries. Energy and environmental policies are often claimed to be neither long-term nor predictable. Unpredictable policies are considered a problem, especially in the United States. There are also political tensions between different parties concerning the industrial utilisation of forests, as well as inconsistencies between state (province) and national energy and environmental regulations in North America. Also, in North America, strong political pressure for production of agricultural-based biofuels hinders the diffusion of forest biorefineries. Politicians and other decision-makers have insufficient knowledge about the forest sector and forest management issues, which may also affect the diffusion of forest biorefineries.

5.4 Ecological and raw material-related factors

The *raw material demand of forest biorefineries* cannot be satisfied solely with wood-based biomass. As a result, there will be a need for non-wood raw materials, for example agri-feedstocks. The capability to collect and utilise existing wood biomass resources seems to be a limiting factor for the diffusion of forest biorefineries, rather than the absolute amount of wood biomass. According to a common view, only wood biomass that cannot be used for higher-value products should be utilised for biofuel production. In the Nordic countries, there is a stronger consensus on this issue than in North America.

Many experts in the forest and bioenergy sector believe that the environmental impacts of collecting wood biomass are not sufficiently known, which can hinder the establishment of forest biorefineries. Increasing the public's awareness of forest management issues and environmental aspects related to biorefineries would be an advantage.

5.5 Collaboration

Collaboration seems to be a decisive factor in the diffusion of forest biorefineries. Interestingly, forest industry companies do not seem very willing to cooperate with other companies in the same industry in developing forest biorefineries. However, the forest industry is willing to cooperate with companies outside the forest industry and research institutes. What seems striking is that the North American forest industry is not willing to cooperate with companies outside the forest industry or research institutes. Moreover, the petrochemical industry's willingness to cooperate with the forest industry in the production of wood-based traffic biofuels is questioned in the United States and Brazil. Overall, North Americans have the most negative attitude, whereas the Nordics have the most positive attitude to collaboration. Attitudes to collaboration are particularly positive in Finland.

6 Business models

Production of wood-based biofuels and chemicals is considered a serious business opportunity in the forest cluster worldwide[27], especially in the Nordic countries. Wood-based biofuels produced in biorefineries will be mainly used in the domestic market, but in Finland also exports of biofuels will offer potential in the future. Biorefineries and related new energy products are considered a way to guarantee the forest cluster's success in a sustainable way. Wood-based biofuels offer the greatest potential for replacing liquid fossil traffic fuels, in comparison with conventional or cellulosic agri-based fuels, municipal waste-based biofuels, green electricity and hydrogen. Only the Brazilians place more hope on conventional agri-based biofuels. The business opportunities in the production of biochemicals divide opinions more than those in the production of wood-based biofuels. However, the forest biorefinery business seems to have great market potential, so global competition can be expected in this sector too.

Though the Nordics have more positive expectations about the business opportunities offered by forest biorefineries, the North Americans expect biorefineries to play a significant role in their forest cluster's competitiveness within a shorter timescale. Also, in North America biorefineries are more strongly regarded as a way to avoid a massive shut-down and loss of forest cluster assets. The North American forest industry was faced by the challenges currently facing the Nordic industry (decreased demand for forest industry products, increased production costs, offshore developments and shutdowns of pulp and paper mills) one decade earlier than its Nordic competitors. This is certainly one of the reasons why the North American forest industry sees biorefineries as a way to avoid shut-downs.

Experts in all countries trust their own national strengths and their chance to take a leading role in the forest biorefinery business worldwide. The most important strengths and weaknesses of the forest cluster related to the development of forest biorefineries in different countries are presented in Table 2. Especially technological knowledge, biomass availability, existing infrastructure and biomass logistics are highlighted as strengths in all countries. In addition to the common issues, existing networks and collaboration are seen as strengths in Finland, Sweden and Brazil. Finland also has a strong forest cluster and a lot of technological knowledge, which are believed to offer the potential to be a leader in the forest biorefinery business. The Swedish respondents also believe in their technology leadership. The Americans are the only ones who consider the present situation in the forest sector as a strength, so they take the situation more as a challenge than a threat. The strengths of Brazil are the favourable climate for fast growth of biomass and the lower costs of production and raw materials than in other countries studied.

Weaknesses are also very similar in the countries studied: lack of R&D and innovations, competition for raw material, lack of capital and an unwillingness to change were the most commonly mentioned weaknesses. Lack of raw material can also form a barrier, since the results indicate that the raw material demand of biorefineries cannot be fulfilled solely with wood-based biomass. The Americans consider the unwillingness to take risks a their most significant weakness, which could make them overcautious in investing in forest biorefineries. This offers other countries a possibility for gaining a competitive advantage. The potential threat to environmental sustainability is mentioned as an important weakness especially in Brazil. This could affect their ability to grow biomass in the future, if more forests are protected from commercial utilisation. In addition, sugarcane ethanol has such a strong position in the Brazilian market that it can be difficult to get enough support for wood-based biofuels there.

Table 2. Most important strengths and weaknesses of the forest cluster related to the development of forest biorefineries.

	Finland	Sweden	USA	Canada	Brazil
Strengths	Technological and chemical know-how Availability of biomass Raw material logistics	Knowledge of biomass handling Process expertise Existing infra-structure Technological leadership	The ability to harvest, transport and handle large amounts of wood biomass Availability of biomass Process engi-neering expertise	Availability of biomass Existing infra-structure Existing supply chain	Forestry activities Know-how Collaboration between indus-tries, research centres and tech-nology providers
Weaknesses	Lack of public and private funding Low investment capability Resistance to change New business area and tech-nologies outside the current competence	Unwillingness to change from business as usual (inability to grasp new possi-bilities)	Unwillingness to take risks Resistance to change (conserv-ative industry) Lack of vision	Lack of capital	Lack of R&D Competition for raw material Inflexibility of the pulp and paper industry Environmental sustainability

Many of the challenges in the external business environment for the diffusion of forest biorefineries appear to have been recognised, but issues related to management and leadership, as well as sharing of responsibilities, revenues and synergy benefits in biorefinery consortia are largely undefined.

The most important competences needed in the forest cluster/biorefineries are *product and technological innovation, understanding of new markets* and *business know-how*. Other important competences are process expertise, skills to manage the wood supply chain and the ability to take a long-term perspective. In addition, when looking at the biorefinery supply chain, the *production and collection of raw materials* are the most challenging parts of the chain, so competences in these two areas would seem to be vital.

Competences in managing change, creating and managing networks and in interacting with and actively shaping the business environment are considered the least important by forest-sector and bioenergy experts. This is interesting, since these are crucial skills when entering a new business. All of them are "soft" issues related to management and leadership, not technologies, so their importance is not always recognised. Forest-sector experts[27] do identify these issues at some level, but fail to see their true significance for the future of the forest cluster.

It is obvious that the forest biorefinery consortia will lead to a growing dependence on cooperation within the *biorefinery value chain*. The forest industry has a positive attitude to collaboration in developing biorefineries; especially the Nordic forest industry considers creation and management of networks an important competence. Interestingly, though, forest industry companies are not willing to cooperate with other companies in the same industry in developing forest biorefineries.

There are also business opportunities for new actors in the forest biorefinery value chain. Forest biorefinery consortia offer small and medium enterprises (SMEs) possibilities to enter new, larger markets, for example, in the area of raw material acquisition, technology innovations, consultancy services and biochemical production. However, the SMEs would need support from strong networks for commercialisation of their know-how.

In forest biorefinery consortia tasks are divided in a new way within the biorefinery value chain. Forest biorefinery consortia will also need new processes for *strategy-making* and *strong leadership*. The dominant companies in the forest cluster are responsible for introducing and putting into practice new business ideas, so whoever wishes to become the leader in the biorefinery business, should carefully re-evaluate the practices in strategic planning. Strong and visionary leaders are needed for the new business. The most important actors in the biorefinery business are expected to be forest industry companies and technology providers in the forest cluster. In Sweden, the importance of the auto industry, and in Brazil the importance of the biotech industry, are also highlighted. Overall, the forest industry is considered the most potential dominant actor in a forest biorefinery consortium. Other possible dominant actors in forest biorefinery consortium are the petrochemical industry and energy industry.

One of the most interesting aspects rising from the results of the international survey[21] is the forest industry's attitude to biorefineries, its willingness to change and above all, the rate of this change. It is obvious that the forest industry's view of the business potential of biorefineries and its willingness to take risks in investing into this new business will have a decisive impact on the diffusion of forest biorefineries. According to the forest industry, production of electricity for pulp and paper industry will be more profitable than the production of biofuels. In addition, large companies in the forest cluster seem to concentrate on optimising the whole organisation's business operations, while the possibilities of single production units are not adequately recognised. These statements indicate a rather passive role of the forest cluster, while a more proactive attitude would be necessary for entering a new business.

Without continuous regeneration and innovations, the forest cluster will be unable to maintain its lead in forest technology solutions[24]. In the long term, the vitality of the forest cluster will be dependent on new investments, products and business operations. Bioenergy and biomass-based products offer the greatest possibilities for diversifying business operations and exporting technologies[12,13]. There is a strong need for innovativeness and out-of-the-box thinking in the forest sector, since the possibilities of the wood-processing chain and forest biorefineries have not yet been fully explored. Both national and international networks need to be actively created within the forest sector and beyond. In addition, the sector's know-how needs to be efficiently commercialised and marketed. One-third of the experts participating in the survey[21] foresee radical innovations in wood-based biofuel production in the near future. Innovations are expected especially in new methods for extraction of hemicelluloses or lignin, and in the development of new enzymes. Interestingly, the Finnish respondents do not expect any radical innovations in this sector. The Brazilians are also sceptical about this issue.

The attitudes of the forest industry reflect a certain resistance to change, but the inevitable need for new business operations seems to be widely recognised and admitted. The forest industry believes that traditional products such as paper and paperboard will continue to play an important role in the future, but besides the traditional business, new business with new products, such as wood-based biofuels, will also be needed. Existing infrastructure and permits in the forest cluster provide significant competitive advantages for the forest cluster compared to other actors, and the forest industry is regarded as the most important actor in the biorefinery business.

The profitability of forest biorefineries and the sensitivity of new business operations to changes in the business environment need to be carefully evaluated by the forest industry. Forest biorefineries are sensitive to changes in the business environment, so flexibility in production according to the market situation will improve the profitability of forest biorefineries. According to the forest-sector experts, an acceptable return on investment (ROI) for forest biorefineries is in the range 10 % – 15 %, which is higher than traditionally in the forest industry[21]. This probably indicates the higher level of risk associated with the new business and the uncertainty concerning its profitability. In the Nordic countries, the acceptable level of ROI is lower than in the other countries studied, which is consistent with the finding that the Nordics consider the production of biofuels a serious business opportunity, and therefore perceive the risks involved as lower. When asked about the strengths and weaknesses of the forest sector, the Americans indicated the unwillingness to take risks as their most significant weakness, which is consistent with the finding concerning the desired ROI.

7 Conclusions and future perspectives

To be able to create a successful business of forest biorefineries, it is important to look at the current situation as a challenge, not as a threat. Especially biorefineries which can be integrated with pulp and paper industry seem to offer great potential, which gives the forest sector a natural position as a forerunner. However, the forest sector needs to act, sooner rather than later, because there are eager competitors who also wish to be world leaders in the forest biorefinery business.

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II

DIFFUSION OF FOREST BIOREFINERIES IN SCANDINAVIA AND NORTH AMERICA

by

Annukka Näyhä & Hanna-Leena Pesonen, 2012

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DIFFUSION OF FOREST BIOREFINERIES IN SCANDINAVIA AND NORTH AMERICA

Abstract

Biomass-based energy has become a major focus of attention from a variety of directions due to the global challenges of meeting our energy needs. Bioenergy and bio-products are also currently being explored intensively in the forest cluster, as many elements that have in the past guaranteed success have largely disappeared. As the bioenergy and biorefining economies are evolving, there is a need for realistic estimates regarding the factors which affect the diffusion of forest biorefineries. This paper outlines global and national drivers for forest biorefineries in Scandinavia and North America. It explores the financial, political, technological, and ecological and raw-material related factors, as well as business competencies, challenges and changes in the business environment. This study is based on data from an expert opinion survey and comments from the experts about the survey results yielded by a Delphi method. According to our results, key factors for the development of forest biorefineries are very similar in both studied areas. There needs to be support from the macro-scale environment particularly from governments, but also the involved industries themselves need to be active. Diffusion factors in the macro-scale business environment are better understood when compared to more industry-specific strategic factors. Both studied areas seem to have potential for success in the biorefinery business. However, a more realistic identification of national strengths as well as continuous development of competencies – while avoiding an overly optimistic attitude – is crucial.

Keywords: Forest biorefinery, Diffusion, Scandinavia, North America, Business Environment

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1 INTRODUCTION

Recent energy price trends are making it increasingly apparent globally that we are facing challenging times when it comes to meeting our energy needs; further, there will be heavy pressure for an increase in the price of oil in the future. Coupled with these concerns is the increased environmental threat to climate change that is related to the contribution of combustion CO_2 from fossil fuels. Biomass-based energy has become a major focus of attention from a variety of directions due to these global challenges. Particularly widely studied at the moment are lignocellulosic, non-food biomass feedstocks and technologies for converting these sources into economical, low-carbon biofuels (carbon is used as a shorthand for life cycle global warming impact, see Farrell et al. [1]).

Bioenergy and biomass-based products are currently being intensively explored in the forest cluster because many of those elements which have guaranteed past successes have largely disappeared. In this research "forest cluster" is understood as a gathering of industries and production facilities around forestry and forest industry, including mechanical, chemical and packaging industries. A forest cluster also includes related energy, logistics and consulting companies, as well as research institutes and universities. The forest clusters in Scandinavia and North America have global competitors in Latin America and Asia, which have modern and large industries, as well as wood and labour cost advantages. The need to innovate and redefine business models is especially urgent in the mature pulp and paper industry, with its frequent mill closures and persistent profitability problems. [see references 2-5]

Bioenergy and biomass-based products offer new opportunities for diversifying business in the forest cluster. Biorefineries integrated into the pulp and paper industry seem to hold great future potential. A biorefinery is a facility that replaces petroleum as a feedstock with renewable material. In this research, a forest biorefinery is defined as a multi-product factory that integrates biomass conversion processes and equipment in order to produce variety of bioproducts like fuels, fibres, and chemicals from wood-based biomass. [see references 6-8]

As the emerging bioenergy and biorefining economies continue to take shape, there is a growing need for realistic estimates regarding the factors that affect the diffusion process of forest biorefineries. In this study, "diffusion" is understood to refer to the expansion of the utilisation of a new concept, be it a new product, new processes or new management methods [9]. Successful introduction of biorefineries and related new products and business models requires information about the global business environment in addition to the national one. This paper outlines global and national drivers for forest biorefineries. It explores the financial, political, technological and ecological and raw material related factors as well as business competencies, challenges and changes in the biorefinery business environment, all of which can have an effect on the diffusion process of forest biorefineries.

Those factors that contribute to the establishment and success of forest biorefineries are compared between Scandinavia and North America. The study concen-

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trates on countries (Finland, Sweden, the U.S., Canada) with excellent preconditions for the establishment of forest biorefineries: high quality research and development, similar structures in the forest industry, and abundant lignocellulosic biomass resources. The goal of this study is to sketch a holistic view of the issues affecting the diffusion of forest biorefineries rather than to outline precise information regarding a time frame, specific diffusion models or detailed information about industry-specific strategic issues.

2 DIFFUSION PROCESSES IN DIVERSE BUSINESS ENVIRONMENTS

2.1 Technology diffusion

One of the key features of technological diffusion is the apparently slow speed at which firms adopt new technologies. The two most commonly noted "stylised facts" are, first, that the intensity at which usage or ownership of a new technology spreads across an economy changes over time. Second, the time path of adoption typically follows an S-curve, where a slow take-off is followed by a period of relatively rapid adoption and then a slow-down to satiation. [10]

According to Rogers [11], the innovation-development process consists of all decisions, activities and their impacts that occur and proceeds as follows: from the recognition of a need or problem, to the research, development and commercialisation of an innovation, to the diffusion and adoption of the innovation by the user, to, finally, its consequences. An understanding of the factors affecting this process is essential when exploring diffusion process.

Although classic models of technological development suggest a straightforward, linear path, technology can diffuse in multiple ways and with significant variations – depending on the particular technology – across time, over space, and between different industries and countries. Accordingly, diffusion processes have become increasingly complex in recent years. [12]

According to Rogers [11], one of the most important factors affecting the diffusion of innovations is the relative advantage. The relative advantage is the degree to which an innovation is perceived as being better than the idea it supersedes. The degree of relative advantage is often expressed as economic profitability, as conveying social prestige; the bigger the attained benefit, the faster the diffusion process. Rogers [11] also highlights the importance of compatibility, which is the degree to which an innovation is perceived as consistent with the existing values and needs of potential adopters. An innovation's incompatibility with cultural values can block its adoption and diffusion process.

Often, innovation research has focused on technical issues and primarily concentrated only on those stakeholders directly involved in the value adding activities or market relationships, such as the customers, complimentary innovators and sup-

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pliers. Environmental, political, economical, social, networking and institutional factors are often neglected. Technology as such cannot guarantee success of an innovation if other aspects related to the innovation are not accepted by stakeholders. [11-13]

2.2 Business environment

Exploring the business environment can be challenging for several reasons. First, the business environment encapsulates a variety of influences and the difficulty lies in understanding this diversity. Identifying various environmental influences may be possible, but attaining an overall picture of the important influences on the organisation can be much more challenging. The second difficulty is the speed of change. Business leaders feel that the pace of technological change is faster than ever. Accordingly, the outlook for the future is highly uncertain, which in turn leads to a third problem: the problem of complexity. It is important to achieve an understanding of the environment which is both usable and future-oriented. [14-17]

Johnson et al. [15] have provided a framework for understanding the environment of the organisations with the aim of helping to identify key issues and ways of coping with change and complexity. Environmental influences and trends can be thought of as layers around the organisation. The outer layer is referred to as the macro-environment, which is the most general layer, consisting of broad environmental factors that impact to some extent nearly all organisations. Within the macro-environment sit industries or sectors, and the inner layer stands for further strategic groups. These are organisations with similar strategic characteristics, following similar strategies or competing similar bases.

The PESTEL framework can be a useful tool when approaching the most general layer of the framework. PEST stands for "Political, Economic, Social, and Technological analysis"; adding Environmental and Legal factors expands the acronym to PESTEL. PESTEL analysis gives an overview of the different macro-environmental factors that the company has to take into consideration. It is a useful strategic tool for understanding market growth or decline, business position, potential and direction for future operations, and it can be especially useful in strategic planning when a company decides to enter its operations into new markets. Accordingly, scenarios may help with this future-oriented approach by aiming to give a view of the development of business environment in the future, based on groupings of key environmental influences and drivers of change. [15]

Although PESTEL analysis was not actually carried out in this study, factors included in the PESTEL framework proved to be beneficial in the approach for planning research and in understanding the big picture of the environment in which companies are working. Accordingly, the framework developed by Johnson et al. [15] helped in structuring environmental influences at the different levels. Considering a long-time perspective and future uncertainties interfaced by the forest cluster, sce-

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narios and future views were a useful approach to study macro-scale diffusion factors of emerging biorefinery business.

3 DATA AND METHODS

3.1 Delphi method

The research uses the Delphi method, which is a technique for obtaining forecasts from selected experts. Usually the Delphi method is composed of two or three stages, during which experts' opinions are collected and information is combined, and then returned to the experts for re-evaluation. By virtue of their expertise and experience, experts possess wide knowledge and capabilities and therefore can understand the structure of present conditions and also determine the direction of future outcomes. [18]

The Delphi technique is generally considered to be an appropriate method for studies that lack historical data and require the collection of expert opinions [19]. Therefore, Delphi is very suitable for investigating the emerging biorefining industry, given the scarcity of previous research from a similar approach. Accordingly, the possibility of including specialists with backgrounds in different fields, as well as the anonymity of the respondents, were advantages of the chosen methodology.

The analysis of this study is based on data from the expert survey (the first Delphi round, see also [20]) and comments by the experts about the survey results (the second Delphi round). Preliminary interviews were conducted before the first research round. The research will be continued on thematic expert interviews (the third Delphi round), but this last research phase is not reported in this manuscript.

3.2 The first Delphi round

Preliminary interviews were conducted before the first Delphi round in order to shed light on the phenomenon, which has previously been studied from mostly a technological perspective. The preliminary themed interviews were conducted in Finland (5 interviews) and in the U.S. (5 interviews) in the beginning of 2008.

The prevailing views regarding biorefinery diffusion – which were gathered from the preliminary interviews, the expertise of the project steering group, and previous studies and literature – were used as background information when planning the questionnaire. The questionnaire consisted of five separate parts including the following modules: *Background*, *Forest biorefinery diffusion*, *Feedstock & technologies*, *Scenarios*, and *Business models*. The main purpose of the survey was to challenge and test the prevailing views in order to obtain new information about the requirements of and barriers to the forest biorefineries and related new business models. In the

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survey, the phrasing of the questions was as clear as possible, with defined alternatives and statements. In most of the questions, respondents could indicate their degree of agreement on a five-point scale. Quantitative development assessments, based on published scenarios and literature, were presented for cellulosic biofuel production. Respondents also had the opportunity to make open comments.

TABLE 1 Respondents by country and by sector in the first Delphi round.

	Finland	Sweden	U.S.	Canada	**Total**
Car industry	1				**1**
Chemical industry	1	1			**2**
Energy industry	4		4	1	**9**
Forest industry	15	3	10	2	**30**
Investors	1	1			**2**
Oil industry	2		1		**3**
Public authorities	1		2		**3**
Research	22	10	15	5	**52**
Technology providers in the forest cluster	6	1	2		**9**
Other	9	2	1	2	**14**
Total	**62**	**18**	**35**	**10**	**125**

In the first phase the survey questionnaire was sent to 511 forest and bioenergy sector experts (researchers, company representatives, authorities) in North America and Scandinavia in June 2008.

A total of 125 forest and bioenergy sector representatives responded to the survey, thus yielding a response rate of 24.5%. The distribution of respondents by country and by sector is presented in Table 1. The data were analysed with SPSS statistical software. The following analyses were conducted: frequencies, cross tabulation, Analysis of Variance (ANOVA), Kruskal-Wallis test, and Multivariate Analysis of Variance (MANOVA). Analyses were conducted both at a single country level and by using a division between North America and Scandinavia. The respondents were sorted into three different sectors: forest industry, researchers and other. MANOVA was conducted by using sum of variables for questions with multiple claims as well as by using single variables.

3.3 The second Delphi round

In the second phase (February to March 2009), eight respondents, who participated in the survey in the first phase, evaluated the survey results. The purpose of the commentary round was to evaluate the uniformity of the survey results with the respondent's current views, highlight surprising and improbable results, introduce possible new ideas, as well as evaluate ongoing changes in the business environment.

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The willingness of all the survey respondents to participate in the second phase was inquired. Thus, these eight respondents were not specifically chosen. The respondents represented three different sectors: researchers (5), chemical industry (1) and other (2). Four of the respondents were from Finland, two from the U.S., and two from Sweden. The respondents were sent a questionnaire with five open questions which could be answered by email.

Data from the commentary round were examined using the thematic analysis method. Thematic analysis is based on coding; themes and patterns are found in the data in order to organise and interpret the information [21]. After data were organised, they were combined and compared with the data gathered in the first Delphi round.

4 RESULTS

4.1 Factors affecting the business environment of forest biorefinery diffusion

4.1.1 Results from the first Delphi round

In majority of the survey questions respondents could indicate their degree of agreement on a five-point scale. The statements and results (percentages indicating the degree of agreement) based on these type of questions are presented in Appendix 1. In Appendix 1 percentages indicating the degree of agreement are combined into three categories. The statements are introduced in the Appendix 1 corresponding to their order of appearance in the text sections. Differences between countries and sectors are indicated in the result sections only if Analysis of Variance (ANOVA), Kruskal-Wallis or MANOVA tests indicated statistically significant difference. In addition, the information of the result sections is completed with data based on multiple choice questions and open-ended questions of the survey questionnaire.

4.1.1.1 Financial factors and business competencies

This study shows that the increasing price of oil was considered the greatest global incentive for forest biorefineries and wood-based biofuels. Almost half of the respondents considered the price competitiveness of wood-based biofuels attractive during the market situation of summer 2008. Wood-based biomass as a raw material was not considered too expensive for biofuel production, and it seems that the production costs of wood-based biofuels are not too high. However, it has to be kept in mind that this reflects the market situation at the time of the survey. In June-July 2008, when the survey was conducted, the price of oil peaked at nearly $150 per barrel, but has since then lowered substantially. In the long run, however, the price of oil is expected to rise steadily, which will support the competitiveness of biofuels

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and biorefineries. Particularly in the U.S., the national security of fuel supply was also seen as a significant driver.

The results indicate that the majority of wood-based biofuel production will take place in large-scale (i.e. a capacity of over 100,000 tons per year) biorefineries, which are integrated into the pulp and paper industry. According to the respondents, the most significant actors in the biorefinery business will be forest industry and technology providers in the forest cluster. The respondents considered forest industry also to be the most potential dominant actor in a forest biorefinery consortium. Thus, forest biorefineries were also considered a way to avoid massive shutdown and loss of forest cluster facilities in the future. The greatest consensus on the issue was found in North America. Considering the sectors, the forest industry was the only group that does not fully agree with this view. In Scandinavia, and in Finland in particular, wood-based biofuel production was more strongly regarded as a serious business opportunity for the forest cluster. Accordingly, wood-based chemical production was more strongly considered an important business opportunity in Scandinavia than in North America.

Forest biorefineries are sensitive to changes in the business environment and, thus, flexibility in production according to the market situation clearly increases the profitability of forest biorefineries. The accepted level of ROI (return of investment) for the forest biorefineries is according to the respondents 10-15%, which is higher than traditionally found in the forest industry. In Scandinavia, the acceptable level of ROI is lower than in the other studied countries.

The most significant economic barriers to forest biorefinery diffusion are insecurity of biorefinery investments, inadequate support for demonstration and pilot plants and insufficient public and private financing. Especially in Sweden lack of financing was seen as a problem. Inadequate investment capability of small and medium-sized companies was also seen as a barrier, since half of the respondents evaluated SMEs (small and medium sized companies) as incapable of investing in forest biorefineries. However, over 80% of the respondents believed that large companies have enough investment capability. Investment capability of the large companies was questioned most in the U.S.

Another aspect that can hinder diffusion arose from the survey: according to the forest industry representatives, production of electricity for the pulp and paper industry will be more profitable compared to the production of biofuels. On the contrary, the other sectors believed that production of biofuels will be more profitable for the pulp and paper industry. This study also indicates that large companies in the forest cluster concentrate on optimising the whole organisation's business operations, and that the possibilities of the single production units in the biorefinery business are not adequately recognised. Scandinavian forest industry strongly agreed with the view.

The forest industry has a positive attitude towards collaboration in developing biorefineries. Attitudes towards collaboration are in general the most positive in Finland. However, only one third of the respondents believed that the forest industry companies are willing to cooperate with other companies within the same industry to develop forest biorefineries. Also, the forest industry's willingness to cooperate

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with research institutes, the oil industry, and other companies outside the forest cluster is questioned in North America.

According to this study, important economical skills needed in the evolving biorefinery business will be the understanding of new markets and business know-how. The North American respondents also highlighted risk management skills, business model innovations and financial expertise.

According to the survey results, it seems that issues relating to management and sharing responsibilities within forest biorefinery consortia are difficult to foresee. However, it is obvious that the forest biorefinery consortia will lead to a growing dependence on cooperation within the biorefinery value chain. There are also business opportunities for new actors in the forest biorefinery value chain. The respondents believe that forest biorefinery consortia offer small companies a possibility to enter new, larger markets. In forest biorefinery consortia, tasks are divided in a new way within the biorefinery value chain. The forest biorefinery consortia will also need new processes for strategy-making and strong leadership. These capabilities were seen as important particularly in North America. The majority of the respondents also believed that the dominant companies in the forest cluster are responsible for introducing and putting into practice new business ideas. In general, issues related to the sharing of responsibilities, revenues and synergy benefits between biorefinery value chain actors are difficult to foresee, because there were many respondents who gave a neutral opinion of the claims addressing these issues. On the other hand, the competences considered least important were change management, creation and management of networks, and ability to interact with and actively shape the environment.

4.1.1.2 Political factors

This study indicates several political barriers to the diffusion of forest biorefineries, and many of them are emphasised in North America.

According to the respondents, energy and environmental policies are neither long-term nor predictable, and there are political tensions between different parties regarding the utilisation of forests. There are also inconsistencies between federal and national energy and environmental regulations. Almost 40 % of the respondents believed that political pressure towards agricultural-based biofuels also hinders biorefinery diffusion. The majority of the respondents believed that politicians and other decision-makers have insufficient knowledge about the forest sector and forest management issues, which can also affect the diffusion of forest biorefineries.

4.1.1.3 Technological factors

According to this study, the most important technical competences needed in the forest cluster and biorefineries are product and technological innovations and process expertise. Production was also seen as the part most difficult to manage in the forest biorefinery supply chain. All the studied countries considered technological know-how and existing infrastructure to be their particular strengths. According-

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ly, the respondents believed that technology as such will not become a barrier to the diffusion of forest biorefineries; rather, lack of R&D expertise and consultancy can create problems. Especially in the U.S., lack of R&D was seen as a problem, whereas the Swedish respondents did not view the issue to be a major barrier. However, unlike the other sectors the forest industry considered technological challenges significant barrier.

In addition, the variety of technical choices can create a barrier, as many respondents believed that forest cluster companies are confused about the numerous technological options available for biofuel and chemical production. However, this did not seem to be a major problem in Finland.

Lack of innovativeness can also hinder diffusion in some areas; only one-third of the experts participating in the survey foresaw radical innovations in wood-based biofuel production in the near future. Interestingly, the Finnish respondents did not believe that there will be any radical innovations in this sector.

4.1.1.4 Ecological and raw material-related factors

This study shows that climate change and increasing demand for biofuels are important global drivers for forest biorefineries. According to the survey results, climate change is a more important driver in Scandinavia than in the U.S. Comparing the respondent sectors, the forest industry indicated climate change as a less important incentive than the other sectors.

Forest residues were considered the most significant wood-based biomass source in future biofuel production. In addition, biomass from dedicated energy crops (highlighted in North America), black liquor from the pulp industry (highlighted in Sweden), and urban organic waste (highlighted in Finland) are important wood-based biomass sources. All the studied countries considered the availability of biomass and biomass logistics to be their particular strengths.

However, lack of raw material can form a barrier to forest biorefineries, since the respondents believed that demand of biorefineries cannot be satisfied solely with wood-based biomass; thus, there will be need for non-wood raw materials in forest biorefineries, e.g. agri-feedstocks. The majority of the respondents also believed that only the wood biomass unfit for higher-value products should be utilised for biofuel production. In Scandinavia, there was a stronger consensus about the issue compared to in North America. In addition, the forest industry, especially in Finland, strongly agreed with this.

Yet, the results also indicated that the capability to collect, transport and utilise existing wood biomass resources will be limiting factors for the forest biorefinery diffusion both in Scandinavia and North America, rather than the absolute amount of wood biomass. In fact, when considering the whole forest biorefinery supply chain, the collection of raw materials was seen as one of the most challenging parts to manage in the forest biorefinery supply chain. Accordingly, respondents mentioned accessibility and competition for raw material as significant challenges. Consistent with this, the most important aspect when choosing production technology is that the technology be able to accommodate a wide variety of feedstock. Respond-

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ents also believed that there is an obvious need for re-evaluating wood utilisation and the wood-refining chain from a fresh perspective in the forest cluster.

Except for the forest industry, the respondents believed that environmental impacts of collecting the wood biomass are not sufficiently known, which can also hinder forest biorefinery diffusion. Despite this, respondents were almost unanimous in their belief that wood-based biofuels produced in biorefineries will receive a positive public response. In North America, public perceptions and environmental debate were regarded as greater challenges than in Scandinavia. Increasing public awareness of forest management issues and environmental aspects related to biorefineries was believed to promote the diffusion of biorefineries.

4.1.2 Results from the second Delphi round

4.1.2.1 Challenges and changes in the biorefinery business environment

The purpose of the second Delphi round was to assess the uniformity of the survey results with the respondents' current views, highlight surprising and improbable results, introduce possible new ideas, and evaluate ongoing changes in the business environment.

In sum, the outlook for barriers to and prerequisites for biorefinery diffusion from the first and second Delphi rounds are very similar in both studied areas. Insufficient financing and other economic factors as well as many political factors comprise the main barriers to biorefineries. Additionally, lack of R&D expertise and consultancy can create problems. Furthermore, lack of raw material can create a barrier, since our results indicate that demand of biorefineries cannot be fulfilled solely with wood-based biomass. Collaboration also seems to be a significant factor in the diffusion of forest biorefineries.

Respondents in the second Delphi round were also in almost unanimous agreement on the three most significant issues in the global business environment both in Scandinavia and North America at the end of 2008 and the beginning of 2009. First, Obama's presidency in the U.S. was believed to change the business environment more favourably towards wood-based biofuels world-wide, but particularly in the U.S. Respectively, the global recession and related drop in oil price were seen as temporary negative factors for the development of biorefineries and lignocellulosic biofuels. At that point, however, it was too early to fully evaluate the effects of the above mentioned issues.

4.2 Future views and paths

4.2.1 Results from the first Delphi round

The survey respondents were asked to choose from four future views – defined as Business as Usual, Restructuring the Business, Sustainability, and Domestic Com-

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petencies [22] – the one that corresponds to their impression regarding the future of the forest sector. Sustainability and Restructuring the Business describe best the future development of the forest cluster, as 80% of the respondents chose one of the two options.

In Scandinavia, the Sustainability view got more support compared to North America: nearly 50% of the Scandinavian respondents chose this view, compared to about 20% of the North Americans. According to this future view, sustainability is the key issue in financial decision-making. The forest cluster is successful in a society that respects ecological values and sustainable forest utilisation. Production will be further developed towards energy and raw material efficiency. Biorefineries and related new energy products sustainably guarantee the forest cluster's success.

According to the Restructuring the Business view, the competitiveness of the national, traditional forest cluster will disappear, and reliance on old production structures remains highly risky. Investments are aimed towards new markets' business concepts. According to this view, there is a strong interest in an increasing amount of projects geared towards forest biorefinery concepts and new bioenergy products. Our results indicate that in North America, where 51% of the respondents chose this option, the view was more common compared to Scandinavia (38%).

Fifty-five percent of the respondents believed that the role of biorefineries in the forest cluster's competitiveness and biofuel production will become significant during the next 5 years. In the U.S., the role of the forest biorefineries is evaluated to be more significant in the near future compared to the other studied areas, particularly Finland. Moreover, biofuel production technologies, which were included in our study, will be implemented in either fewer than five or within 5 to 10 years.

When compared to the other renewable transportation fuel options, wood-based biofuels have the greatest potential in compensating for fossil fuels in future. Respondents chose given options as follows: wood-based biofuels (40%), cellulosic agri-based biofuels (17,6%), green electricity (17,6%), municipal waste-based biofuels (6,4%), hydrogen (7,2%), conventional agri-based biofules (1,6%) and other fuels (9,6%). Wood-based biofuels produced in biorefineries will be used mainly in the domestic market, but in Finland the exportation of biofuels also holds future potential.

The survey respondents were asked to evaluate the volume of cellulosic biofuel production in the forest biorefineries in their country for the next 12 to 15 years. They were presented with several optional development paths, which were outlined with respect to each region's political goals for biofuel production (Directive 2003/30/EC, Government of Canada, Renewable Fuel Association). The respondents were asked to evaluate the realistic future development in production volumes, assuming no radical changes in the business environment. According to the respondents' estimation liquid cellulosic biofuel production in the EU is estimated to total nearly seven million tons, in the U.S. about 30 million tons, and in Canada about 16 million tons in 2022.

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4.2.2 Results from the second Delphi round

In general, the respondents for the second Delphi round found most of the first Delphi round's survey results to be in line with their own views. However, most of the respondents evaluated production volumes of lignocellulosic biofuels indicated by survey results to be overly optimistic or surprisingly high. Accordingly, near-to-midterm potential of biorefineries was considered rather optimistic, and the postponement of biorefinery projects was seen as a likely future outcome.

The second Delphi round's results further highlighted the importance of active participation from the forest industry in the future development of biorefinery business. The significance of chemicals in the biorefining industry was highlighted, as revenues yielded solely from biofuel production were considered inadequate. In addition, the importance of fast-growing tree farms as sources of cellulosic biomass was further emphasised in the second round. Also in the second round, some of the respondents identified CHP plants as potential biorefinery facilities.

An interesting aspect arising from the second Delphi round was that the future of the forest cluster has been envisioned by researchers, not by the cluster itself, even though a clear and independent vision of forest sector companies would be needed in the future. Accordingly, it was pointed out that every country has a strong belief in their individual, unique expertise and leadership in the biorefinery business, even though weaknesses and strengths in developing biorefinery business found in the first Delphi round were pretty similar in every area. Respondents in the second round further highlighted a need for careful evaluation of the key national competencies on which success can be based in every country. For example, in Finland fluidised bed technology is considered highly successful, and as such, the biorefining sector should take advantage of this. Global technology providers were seen as key players in bioenergy business. In Scandinavia, collaboration of the Nordic countries could promote global success. There would be new business opportunities in R&D and engineering services related to biorefineries in the future.

5 DISCUSSION

This research indicates that a variety of issues has an effect on the diffusion process of forest biorefineries. Accordingly, research clearly shows that forest biorefinery diffusion is a challenge that is connected to all of society and thus needs to be explored holistically. The complexity of the diffusion process has been addressed in many other studies concerning the diffusion of new technologies. It has also been shown that the diffusion processes of new products and services have become increasingly variable in recent years as business environments have become more competitive and less predictable. [e.g. 11-13]

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5.1 Key promoting factors in the forest biorefinery business

Results from both Delphi rounds indicate that the key factors for forest biorefinery development and biofuel production are quite similar in all the studied countries. The key elements that promote faster development of forest biorefineries and biofuels production are summarised in Figure 1. Our purpose in this figure was to combine data from both Delphi rounds, and yield from the results practical recommendations for promoting the biorefinery business. In the Figure 1, the key issues are organised following a framework adapted from the Johnson et al. model [15], in which environmental influences are organised in layers around an organisation. In Figure 1, the most significant drivers and competences according to our findings are highlighted.

Actions that promote biorefinery business must stem from several sources, as clearly indicated in Figure 1. There needs to be support from the macro-scale environment, particularly from governments; but on the other hand, the involved industries themselves need to be active. In general, diffusion factors in the macro-scale business environment (indicated in the upper part of the Figure) are better understood compared to more industry- or sector-specific strategic factors, which are closely related to certain organisations (lower part of the Figure).

Along with the high price of oil creating a market opportunity for biofuels, other macro-environment incentives towards biorefinery business differ slightly in the studied areas. In Scandinavia, environmental aspects – for example, climate change and sustainability – were emphasised, whereas in the U.S., the national security of fuel supply and the competitiveness of forest cluster were highlighted.

Notably, issues concerning the need for and ways of sharing responsibilities, revenues and synergy benefits between biorefinery value chain actors seem to be difficult to predict, as many respondents had a neutral opinion about claims considering these issues. It is understandable that these strategic issues at the core of emerging biorefinery value chain companies are more difficult to foresee in the current early phase of biorefining business. When the biorefinery business further evolves, strategic issues that are closer to the core of companies can be expected to be revealed. However, it would be important to pay attention to issues concerning strategic management early enough, in order to avoid struggles in management in the first steps of biorefinery consortia.

When evaluating important competencies, issues such as change management, creation and management of networks, and ability to interact with and actively shape the business environment are considered the least important. This is interesting, as these would be the crucial skills needed to undertake a new business.

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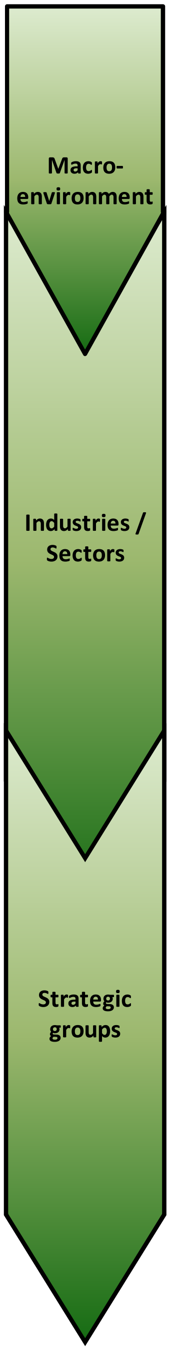

-**High price of oil**
-**Climate change**
-**National security of fuel supply**
-**Long-term and consistent federal and state energy and environmental policies**
-**Realistic evaluation of national competence and skills**
-Political pressure towards non-agricultural biofuels
-Demand of liquid biofuels
-Sustainability criteria for biomass use and sustainable energy production goals between society and industry
-Knowledge of politicians and public about various energy production pathways

-**Capability to collect, transport and utilise existing wood biomass resources**
-**Private and public financing, reduction of financial risk by means of subsidies, tax incentives and loan guarantees in forest biorefinery projects**
-**Joint effort of research institutes, forest industry, oil industry, energy industry and technology providers in the forest cluster in the biorefinery business**
-**R&D for demonstration and pilot plants, and consultancy in the forest cluster in biorefinery development**
-Political and public knowledge of the forest sector, forest management and environmental impacts of wood biomass use
-Improvements in forest management
-Short rotation energy crops with high yield
-Mobilisation of private forest owners in order to increase feedstock availability
-Maintenance of infrastructure in the forest cluster
-Focused joint efforts by industries and governments towards forest biorefineries
-Increased collaboration between forest industry companies and other companies within the same industry
-Increased collaboration between Nordic countries in biorefinery development
-Exploring the local and micro-scale opportunities for forest biorefineries

-**Increased product and technological innovation and process expertise** in the forest cluster
-**Understanding of new markets** and management of change
-**Active participation of forest industry** and business know-how about new possibilities
-Reassessment of the situation and re-evaluation of the wood-refining chain in forest industry
-Recognition of the possibilities of single production units by large companies in the forest cluster
-Utilisation of existing infrastructure and permits in the forest cluster in biorefinery business
-Development of economic wood fractionation and conversion technologies
-Integrated use of non-wood biomass sources along with wood-based biomass in biorefineries
-Support for small and medium-sized companies in biorefinery value chain
-Successful collaboration and division of tasks within the biorefinery consortium
-Strong leadership in biorefinery consortium
-New processes for strategy-making in biorefinery consortium
-Flexibility in biorefinery production in accordance with the market situation

FIGURE 1 Key promoting factors in the forest biorefinery business environment

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Every studied country strongly believes in its individual capabilities and success in the evolving biorefinery business. During the Delphi process, these previously mentioned issues were also criticised, and more realistic evaluations about actualising biorefinery projects and biofuel production volumes were desired for the future. These statements indicate that also more realistic identification of individual, unique strengths and continuous development of competencies – while avoiding an overly optimistic attitude – would be crucial. Likewise, the ability to promote and market the national know-how through international networks would be important in order to succeed in the biorefinery business.

5.2 Forest industry's attitudes and role in the forest biorefinery business

The forest industry's reactions toward biorefineries, as well as its willingness to change and the rate of this change comprise one of the most interesting aspects to arise from the results of this study. It has been shown, for example by Rogers [11], that an innovation's incompatibility with cultural values and needs can block its adoption and diffusion process. Thus it is obvious that the forest industry's attitudes towards the business potential of biorefineries and their willingness to take risks in investing in this new business will have a decisive impact on the diffusion process of the forest biorefineries.

Even though the Scandinavians have more positive expectations about the business opportunities offered by forest biorefineries, the North Americans expect biorefineries to play a significant role in their forest cluster's competitiveness within a shorter timescale. Further, in North America biorefineries are more strongly regarded as a way to avoid massive shutdowns and loss of forest cluster facilities. A decade ago in North America, the forest industry began to face similar challenges (decreased demand for forest industry products, increased production costs, offshore developments, shutdowns of pulp and paper mills) to those that the Scandinavian forest industry is currently facing. This is certainly one of the reasons why the North American forest industry highlights biorefineries as a way to avoid shutdowns of facilities.

In this study, many statements from the forest industry indicate a rather passive role of the forest cluster, while a more proactive attitude and an independent vision from forest sector companies would be necessary for entering a new business. It has been shown [see e.g. 14-17] that fast-changing and diverse business environments should be faced with a fresh attitude and swift action. Also, achieving an understanding of the environment that is both usable and future-oriented is important. This study clearly indicates that the forest industry should evaluate the business environment and its strategies from a new perspective.

However, the findings from this study seem to indicate that an unavoidable need for new business operations is both widely recognised and acknowledged within the forest industry. The forest industry believes that traditional products like

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paper and cardboard play an important role in the future, but in addition to the traditional business, new business with new products such as wood-based biofuels are also needed. Existing infrastructure and permits in the forest cluster create significant competitive advantages for the forest cluster compared to other actors, and the forest industry is evaluated to be the most significant actor in the biorefinery business, thus creating a new serious business opportunity for this mature sector. The existing procurement and logistics of forest raw materials were also considered among the key success factors in the bioenergy business in Pätäri's research [23] on the development of the forest energy business.

Yet, findings of this research also seem to indicate that in the evolving biorefinery business, companies are continuously looking to redefine their roles and positions. It is likely that competition will intensify in the future as more players become involved in the new business. Even though it seems that the forest industry can develop the required know-how and capabilities more quickly than companies with different industrial backgrounds or new entrants, it must be kept in mind that there will be other companies capitalising on this new business opportunity if the forest industry does not exploit the option. These study findings are consistent with Pätäri's study [24] on the potential players in the bioenergy business.

Overall, one of the most important factors affecting the diffusion of innovations is the relative advantage [11]: the bigger the attained benefit, the faster the diffusion process. In the forest cluster it is evident that the challenging economic situation has forced companies to seek new alternatives, such as those previously described. During the last few years, along with the deteriorating business opportunities in the traditional pulp and paper industry, forest cluster companies have been taking big steps towards the biorefining business. However, one can always wonder if those steps were taken early enough and if they were big enough.

6 CONCLUSIONS

In summary, it seems that biorefineries integrated into the pulp and paper industry will play a significant role in the future success of the forest clusters both in Scandinavia and North America. The forest industry is evaluated to be a dominant actor in the forest biorefinery business. Both studied areas seem to have potential for success in the biorefinery business. Above all, success will be based on national strengths, continuous development and swift entry into the biorefinery markets.

This study brings to light many new perspectives and views on emergent forest bioenergy business on the global scale. Thus it can help politicians when contemplating policy decisions and financial incentives. It can also help industry leaders and managers to recognise the key factors in the business environment. This in turn will help managers e.g. foresee changes in their business environment, allocate resources in a successful way, identify the strengths and weaknesses of their business operations, develop new business concepts, strengthen their business competences and analyse the competitive situation in the global markets.

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This research, like any other, is subject to potential limitations. One potential limitation concerns the selection of respondents: while each studied country yielded respondents, researchers and forest industry representatives were most dominant, perhaps not reflecting a true representation of all the study sectors. Moreover, the countries with the highest number of respondents were Finland and the U.S. The number of respondents who evaluated the survey results in the commentary round could also be examined in order to determine if the number was adequate. In the future, this research will be complemented by the 3rd Delphi round results in order to obtain a clearer picture of national competencies and the role of the forest industry in the biorefinery business.

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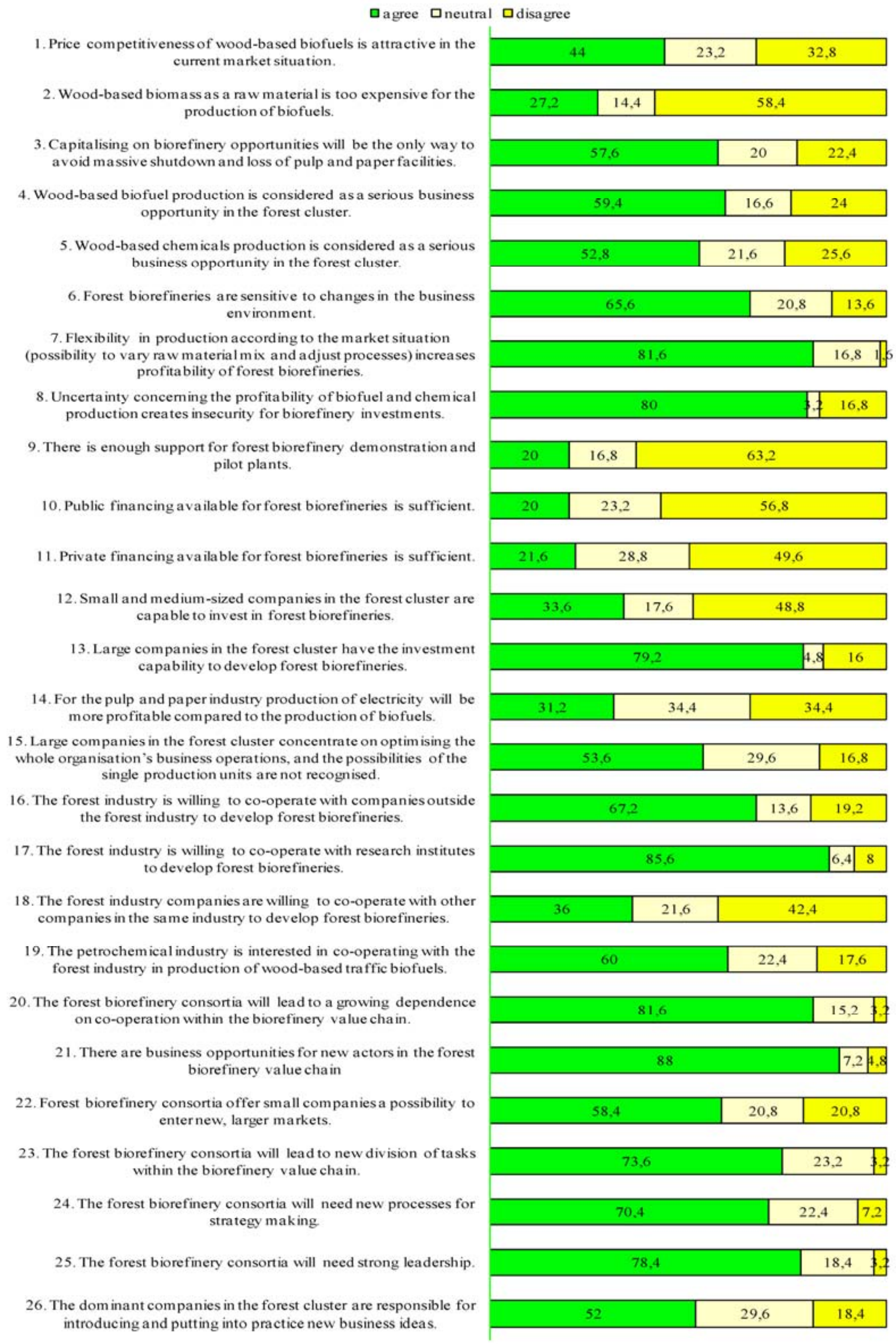
Appendix 1. Statements related to sections 4.1.1.1 (statements 1-26), 4.1.1.2 (27-31), 4.1.1.3 (32-35), 4.1.1.4 (36-42) and 4.2.1 (43).



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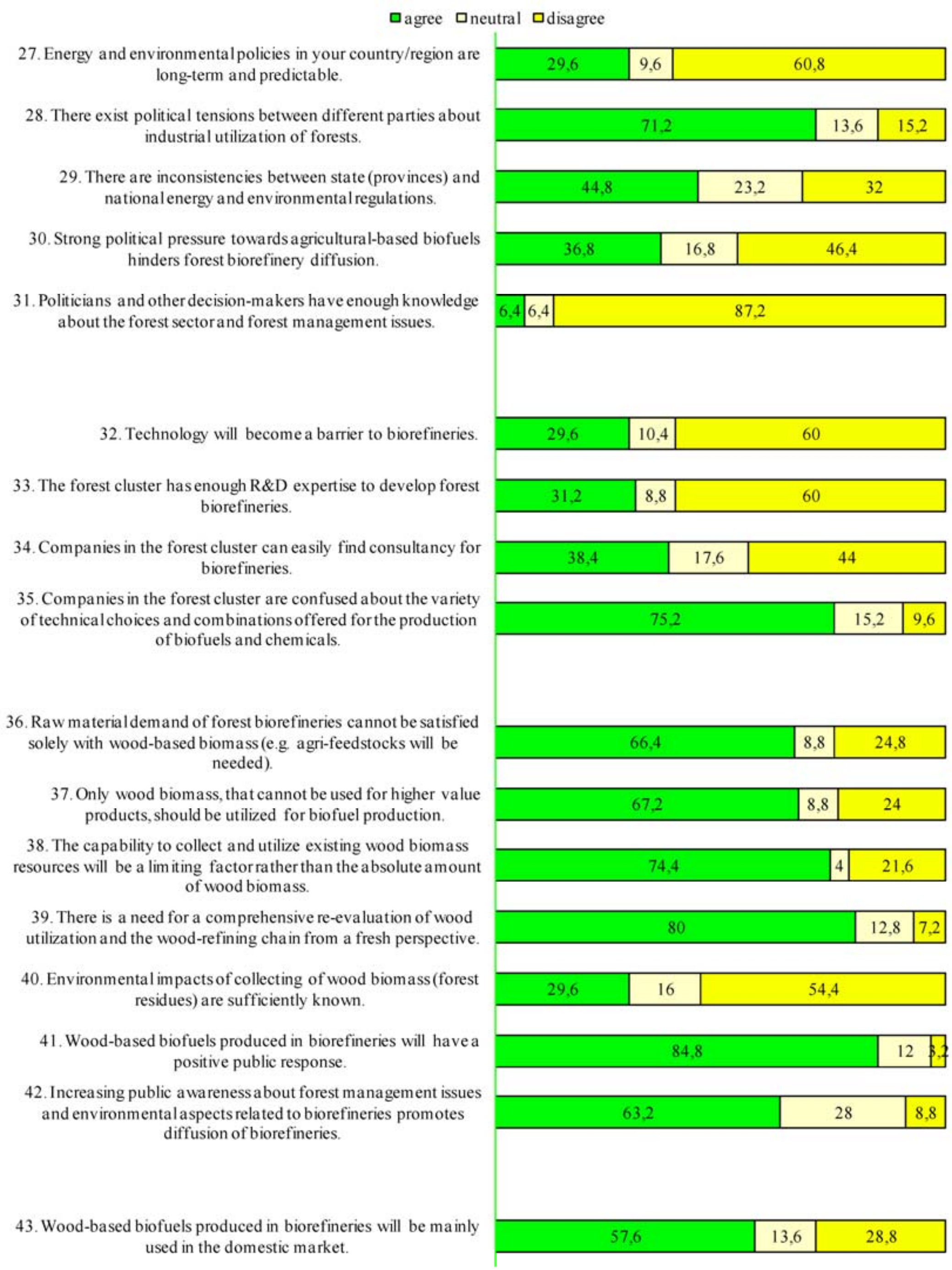

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III

ENVIRONMENTAL SUSTAINABILITY – ASPECTS AND CRITERIA IN FOREST BIOREFINERIES

by

Annukka Näyhä & Susanna Horn, 2012

Sustainability Accounting, Management and Policy Journal. Accepted for publication in the forthcoming issue (Vol. 3, Iss. 2)

ENVIRONMENTAL SUSTAINABILITY – ASPECTS AND CRITERIA IN FOREST BIOREFINERIES

Structured Abstract:

Purpose: The purpose of this study is to examine what the most significant aspects of environmental sustainability in the forest biorefinery sector are and what kind of criteria should be applied to an evaluation of environmental sustainability in the forest biorefinery context.

Design: The topic is approached by themed interviews in Scandinavia and North America with 23 representatives from the forest and bioproducts sectors. The interviews were examined using the thematic analysis method.

Findings: The study indicates that environmental sustainability may be an important driver for the forest biorefinery business. From the perspective of environmental sustainability, harvesting feedstock will be the most challenging part of the value chain to manage. Raw material availability and its sustainability, life-cycle perspective and beneficial products were the most important criteria in the environmental sustainability assessment of forest biorefinery value chain companies.

Practical implications: A sector-specific guideline was formulated for the most important criteria to be included in an environmental sustainability assessment of forest biorefinery value chain companies. The criteria comprise the first step of a more elaborate evaluation framework, which can provide more accurate information about the sustainability performance of biorefinery value chain companies. The criteria can encourage companies to analyze environmental sustainability challenges holistically, increase a company's transparency for its stakeholders and offer information to investors about the environmental status of the company.

Originality: The novelty of the study lies in the sector-specific, holistic environmental sustainability evaluation in the emerging forest biorefineries.

Keywords: forest biorefineries, environmental sustainability aspects & criteria, raw material availability & sustainability

1 INTRODUCTION

Bioproducts (biomass-based products like fuels, fibers and chemicals) and bioenergy can play an important role in combating climate change and competing against rising energy price trends, as well as in improving the security of energy supply. They can also make a notable contribution by providing opportunities for social and economic development in rural communities and helping with waste management. In particular, lignocellulosic, non-food biomass feedstocks and technologies for converting these sources into sustainable biofuels are being widely studied at the moment.

Bioenergy and bioproducts are intensively explored in the forest cluster[1] because many of the elements which have guaranteed past successes have largely disappeared. Steadily growing demand for forest-based products, a sustainable supply of raw wood material, comparatively low energy prices, advanced forest industry technologies, efficient production machinery and, in some countries, the special status of the forest sector in national economic policy do not support businesses in the forest cluster any longer (e.g. FAO, 2011; Metsäneuvosto, 2006; Thorp, 2007; Toland, 2007). The need to redefine business models is especially urgent in the mature pulp and paper industry, with its frequent mill closures and persistent profitability problems (FAO, 2011). The traditional forest clusters in Scandinavia and North America have global competitors in Latin America and Asia, whose modern and large industries have led to technological and scale advantages, as well as wood and labor cost advantages (see e.g. Chambost and Stuart, 2007; van Heiningen, 2006; Metsäneuvosto, 2006; Thorp, 2007; Toland, 2007).

Bioenergy and bioproducts offer new opportunities for diversifying business in the forest cluster (FAO, 2011). Forest biorefineries integrated into the pulp and paper industry seem to hold great future potential (FAO, 2011; Ragauskas, 2006; Sorenson et al., 2007; Thorp, 2005; 2007). In this research, a forest biorefinery is defined as a multi-product factory that integrates biomass conversion processes and equipment in order to produce a variety of bioproducts from wood-based biomass (Hetemäki et al., 2006; Ragauskas et al., 2006; Rodden, 2008; Sorenson et al., 2007; Thorp, 2005). Many studies indicate that forest biorefineries will be large-scale plants (i.e. 100,000-300,000 tons of fuel production per year) that are integrated in forest industry facilities (e.g. Forest Industries, 2012; Näyhä et al., 2011; Näyhä and Pesonen, 2012). The degree of integration will probably vary case by case. During the last five years, production capacity estimates have been increasing, which in turn creates more challenges for biomass harvesting (as indicated also by this study). Forest and mill residues are considered the most significant wood-based biomass source in future biorefineries (Larson et al., 2006; Näyhä et al., 2011; Näyhä and Pesonen, 2012; Ragauskas et al., 2006). Fischer-Tropsch diesel[2] is the main product, but interest is also

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1 In this research, "forest cluster" is understood as being an aggregation of industries and production facilities around forestry and the forest industry, including mechanical, chemical and packaging industries. A forest cluster also includes related energy, logistics and consulting companies, as well as research institutes and universities.

2 The Fischer-Tropsch process converts carbon monoxide and hydrogen, called synthesis gas (syngas), into liquid hydrocarbon fuels (e.g. synthetic diesel). Prior to the F-T process, coal, gas, or biomass is gasified to produce syngas; using intense heat and pressure, these feedstocks are transformed into hydrogen and carbon monoxide. Synthetic fuels burn cleanly, so they offer

growing in a variety of other bioproducts (e.g. Bozell and Petersen, 2010; Larson et al., 2006; Näyhä et al., 2011; Näyhä and Pesonen, 2012; Ragauskas et al., 2006).

The study is based on data from the last round of a three-phase Delphi study concerning the diffusion (development and implementation) of forest biorefineries in Scandinavia and North America (Näyhä et al., 2011; Näyhä and Pesonen, 2012). Two previous research rounds indicated that climate change and increasing demand for biofuels are important global drivers for forest biorefineries. The forest cluster was believed to be successful in a society that respects ecological values and sustainable forest utilization (Näyhä et al., 2011; Näyhä and Pesonen, 2012). The previous rounds also indicated that biorefineries and related new energy products could sustainably guarantee the forest cluster's success and restructure its business models. However, at the same time it was indicated that the environmental impacts of collecting wood-based biomass for forest biorefineries are not sufficiently known. The previous research rounds clearly revealed that as the emerging biorefining economies continue to evolve, there is a need for realistic estimates regarding the environmental and economic sustainability of the forest biorefinery business (Hämäläinen et al., 2011; Näyhä et al., 2011; Näyhä and Pesonen, 2012). Our understanding of environmental sustainability is presented in Section 2.1.

Many other studies have indicated that although the rapid development of modern bioenergy and bioproducts worldwide clearly presents a wide range of opportunities, they also entail many tradeoffs and risks (e.g. Chambost et al., 2008; IEA, 2011a, b; Soimakallio et al., 2009a, b). As bioenergy and bioproducts have become significant elements of the energy and climate strategies of many nations, increasing criticism towards these strategies has been put forth in recent years by different stakeholders, including academics, NGOs and even public authorities (e.g. IEA, 2011a, b; Soimakallio et al., 2009a, b). Accordingly, the forest biorefinery business presents significant challenges in technological, environmental, economic, financial, cultural, and operational issues (Chambost et al., 2008; Näyhä and Pesonen, 2012). Nevertheless, studying the effects of forest biorefineries from the perspective of environmental sustainability has not received enough attention in society. Forest biorefineries have primarily been researched from the technical perspective (e.g. van Heiningen, 2006; Larson et al., 2006; Liu et al., 2012; Ragauskas et al., 2006) and, more recently, also from the business perspective (e.g. Chambost et al., 2008; Kangas et al., 2011). Biorefineries and their final products may be associated with negative environmental impacts, particularly increased land use and loss of diversity (see Section 2.1).

Furthermore, various studies have demonstrated that there is a growing call for the development of credible sustainability criteria for industries (e.g. Buchholz et al., 2008, 2009; Delzeit and Holm-Müller, 2009; Lewandowski and Faaij, 2006; Mikkilä et al., 2009). At best, these would allow for continuous assessment and monitoring of organizations, based on their impacts on the surrounding society and environment. These criteria are not only important for organizations themselves, in terms of streamlining their activities, but for the investment community as well. From a value creation perspective, there has evolved a branch of empirical research to study the relationship between environmental

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improved environmental performance.

sustainability ranking and corporate value by means of event studies (e.g. Guenster et al., 2006), regression analysis (e.g. Ziegler et al., 2008), and portfolio performance evaluation (Derwall et al., 2005). Findings from these aforementioned studies reveal clear and immediate decreases in stock prices following negative corporate environmental news and weaker, positive reactions following positive news. The second conclusion is that corporate value is positively related to corporate environmental responsibility (Guenster et al., 2006; Ziegler et al., 2008; Derwall et al., 2005). Additionally, a branch of management and accounting studies seeks to locate a conceptual link between environmental management and the manner in which corporate environmental management is practiced with business, competitive strategy and, in fact, shareholder value (Allen et al., 2007; Figge et al., 2002; Schaltegger and Burritt, 2000; Schaltegger and Figge, 1998, 2000; Schaltegger and Synnestvedt, 2002; Schaltegger and Wagner, 2006). Information about the corporate environmental impact is important in order to assess its economic consequences and to use it as an indicator of potential future economic impacts on a company (Allen et al., 2007; Figge et al., 2002; Schaltegger and Burritt, 2000; Schaltegger and Figge, 1998, 2000; Schaltegger and Synnestvedt, 2002; Schaltegger and Wagner, 2006). Both of these research branches justify the study of environmental issues from an economic perspective as well.

The aim of this study is to explore environmental sustainability within the context of forest biorefineries. The topic is approached through the following main research questions:

1. What are the most significant aspects of environmental sustainability in the forest biorefinery sector?
2. What kinds of criteria should be applied to environmental sustainability evaluation in the forest biorefinery context?

The paper is structured as follows. First, the aspects of environmental sustainability will be introduced and related specifically to the biorefinery sector. In addition, current assessment methodologies are discussed particularly in context of the biorefinery sector. Second, the data and methodological choices of the study are introduced. Third, the paper examines the empirical results of the interviews and describes aspects of environmental sustainability (Section 4.1). Then it proposes tentative criteria for environmental sustainability evaluation (Section 4.2) in the biorefinery context. Finally, in the last section of the paper the results are discussed and concluded, and the need for more research in the field is highlighted.

2 THEORETICAL BACKGROUND

2.1 Aspects of environmental sustainability in the biorefinery sector

The principle of sustainability was formulated originally in the context of forest management during the 18th century in Saxony (nowadays part of Germany), due to the mining industry's extensive use of wood. J. L. Carlowitz developed the idea of balancing annual wood use with growth and became a pioneer of the concept's operationalization

(Sieferle, 2007). The modern concept of sustainability was used for the first time in 1980 by the World Conservation Strategy (IUCN et al., 1980), but was formally introduced in 1987 by the World Commission on Environment and Development (WCED, 1987). Even though its scope has broadened and the usage of the term has become diverse, the fundamental goal behind sustainability or sustainable development remains clear and valid: to meet the needs of the present generation without compromising the ability of future generations to meet their own needs. In its most basic and traditional form, sustainability is understood as having three pillars: environmental, societal and economic (WCDE, 1987). In the broader context, however, it is also possible to include the institutional aspect, which refers to human interaction and the rules by which they are guided (Faucheux, 1998), as well as future risks, correlation between themes, sustainability goals and basic social needs (UNDESA, 2001; Valentin and Spangenberg, 2000). It can be observed that the meaning of the term is, in fact, highly dependent on the context in which it is used. In this study, the focus was on environmental sustainability and, more specifically, on aspects and criteria of environmental sustainability in the forest biorefinery sector. Environmental sustainability and its evaluation were viewed as important contemporary issues that have not been adequately approached in the emerging forest biorefinery sector, although the need for such evaluation has been clearly indicated in the former phases of this Delphi study, as well as by many other studies (Näyhä et al., 2011; Näyhä and Pesonen, 2012; Soimakallio et al., 2009a; Uihlein and Schebek, 2009). It was also held that more explicit analysis could be carried out when the focus was not too broad; for this reason, emphasis was placed on only one dimension of sustainability. Even if in this initial research phase the study was primarily limited to the environmental dimension, we have understood that the environmental, economic and social dimensions of sustainability are strongly linked and complementary, and in subsequent research phases they could be included. Overall, our own understanding about environmental sustainability is that it is a prominent dimension of sustainability with a multifaceted and interrelated nature.

Forest-based industries continue to demand a reliable supply of raw material input for their traditional operations (FAO, 2011; Kärkkäinen, 2005). At the same time, the use of wood for energy is intensifying in order to meet ambitious renewable energy targets (Soimakallio et al., 2009a). The use of biomass affects the environment and its sustainability in various ways; it has direct implications on soil through harvesting and cultivation, acidification impacts, eutrophication impacts, life-cycle toxic impacts (e.g. in the use of peat), toxic impacts caused by use of pesticides, implications for biodiversity, sustainability of resources, indirect impacts due to markets mechanisms, land-use controversies and a specific set of co-products to compensate for some of the impacts (e.g. Bright and Stromman, 2009; Buchholz et al., 2009; Farrell et al., 2006; Searchinger et al., 2008; Soimakallio et al., 2009a; Uihlein and Schebek, 2009). While sustainable management, planting and rehabilitation of forests can conserve or increase forest carbon stocks, they are reduced by deforestation, degradation and poor forest management. A thorough understanding of the carbon dynamics of forests is therefore important, particularly as regards how carbon stocks vary in relation to environmental conditions and human land-use activities (Keith et al., 2009). Another issue to be taken into consideration is the impact of drastic biomass use on forest ecosystems and biodiversity (Kataja-aho et al., 2011). In Scandinavia, the loss of biodiversity of forest ecosystems is seen as a bigger problem than deforestation itself because the absolute amount of wood biomass is not decreasing. In Finland, for example, absolute growing stock has increased by 60% during the last century (Metla, 2011). Overall, forest-based industries—such as forest biorefineries—have various environmental impacts that need to be taken into consideration in business operations. Likewise, the performance of these industries needs to be evaluated and measured from the perspective of environmental sustainability.

2.2 Assessment of environmental aspects of sustainability in the context of biorefineries

The debate over how to measure, monitor and assess the development of sustainability first emerged in the 1990s (IISD, 1997; United Nations, 1992). In 1997, the Bellagio Principles for assessing progress towards sustainable development were formulated as common guidelines for assessing the achievement of sustainable development, including the choice and design of indicators, their interpretation and the communication of results (IISD, 1997).

Sustainability indicators, criteria and frameworks are increasingly recognized as useful tools for policy-making and public communication in yielding information on countries and corporate performance in fields such as the environment, economy, society, or technological improvement. Indicators and frameworks allow industries to identify opportunities for improvement as well as enable investors to evaluate the company's role in sustainable development or alternatively assess long-term liabilities (Singh et al., 2007). Likewise, Lee and Saen (2012) state that companies may establish key criteria for corporate sustainability management to measure any progress towards sustainable business development. According to Ilinitch et al. (1998), there is an obvious need for explicit environmental performance metrics in order to provide stakeholders with more reliable, accurate and consistent information for comparing companies and making key strategic decisions. Overall, by allowing phenomena to be visualized, sustainability indicators simplify and quantify otherwise complex information, as well as facilitate analysis and communication (Mayer, 2008; Singh et al., 2009; Warhurst, 2002). For the past two decades, there have been many local, state/provincial, national and international efforts towards developing useful sustainability indicators and frameworks (Mayer, 2008; Singh et al., 2009; Warhurst, 2002).

Ness et al. (2007) present a holistic framework of sustainability assessment tools, which comprise three general categorization areas. This framework gives a comprehensive overview of potential approaches for sustainability evaluation. The first categorization area is *indicators and indices*, which are further subdivided into non-integrated tools (e.g. environmental pressure) and integrated tools (e.g. substance flow, input-output energy). The second area covers *product-related assessment tools* with a focus on the material (e.g. material intensity analysis) and/or energy flows (e.g. process energy) of a product or service from a life-cycle perspective (e.g. life-cycle assessment, life-cycle costing). The third categorization area is *integrated assessment tools* (e.g. multi-criteria), which are a collection of tools usually focused on policy change or project implementation.

According to Singh et al. (2009), two main approaches can be distinguished when developing an assessment tool and selecting *sustainable development indicators* (see also Lundin, 2003). First is the *top-down approach*, by means of which experts and researchers define the tool and create the set of sustainable development indicators. The alternative is the *bottom-up approach*, which features the participation of different stakeholders in the design of the tool and the selection process of the sustainable development indicators (Singh et al., 2009). In addition, Fraser et al. (2006) highlight the importance of community input when selecting relevant indicators to monitor and guide planning for sustainable development.

Currently many companies monitor different sustainability aspects by using sustainability indicators, criteria and frameworks that provide information on how the company contributes to sustainable development (Azapig and Perdan, 2000). Azapig (2004) developed a framework for sustainability indicators for the mining and minerals industry, and Singh et al. (2007) developed a methodology for sustainable assessment and quantified evaluation of the steel industry. The approach of Singh et al. (2007) aimed at constructing an *industry-specific composite index by an analytic hierarchy process*, in which key sustainability performance indicators are first identified and subsequently, through several steps, various indicators are aggregated into the composite sustainability performance index. The process also included a stakeholder engagement process, in which 15 experts from different functional areas of a steel company identified relevant stakeholders and key sustainability attributes, issues, and themes of the industry (Singh et al., 2007). Furthermore, the model has been evaluated in a case study for the steel industry. Overall, according to our understanding after exploration of numerous studies (e.g. Illinitch et al., 1998; Labuschagne et al., 2005; Lee and Saen, 2012; Ness et al., 2007; Sing et al., 2007), the question is not so much whether different industries should be evaluated in terms of environmental sustainability, but rather which aspects should be included in the assessment in order to make it comprehensive and comparable (i.e. if different actors/businesses are performing better than others).

The choice of indicators and criteria to be included in an environmental sustainability assessment is far from being unanimous in the biomass-based industries as well, and there is an increasing call for criteria to be developed in all of the basic aspects of sustainability (e.g. Buchholz et al., 2008, 2009; Delzeit and Holm-Müller, 2009; Lewandowski and Faaij, 2006; Mikkilä et al., 2009). Despite the variety of environmental impacts being produced, environmental sustainability assessments are often reduced to a carbon footprint calculation (Finkbeiner, 2009). The reason may not lie only in the lack of relevant data, but also in the lack of unanimous perspectives and goals. Some environmental sustainability criteria focus only on final products, some on the harvesting and use phase, some on both and still others on different parts of the life-cycle of the products (Buchholz et al., 2008). While some criteria can be quantified and measured, such as carbon and energy cycles of liquid biofuels, other sustainability criteria cannot be measured by such tools and are measurable only in qualitative terms (Buchholz et al., 2008). The selection of criteria often results in long lists of issues chosen on the basis of subjective perception; some topics are treated in an in-depth manner and others are ignored. Having too many issues to cover is difficult for businesses to handle and can result in confused priorities and overwhelming details, including over-aggregation, measurement of unimportant parameters, dependence on false models and diversion of attention (Soimakallio et al., 2009a). Many of these problems can be avoided by using an individually applicable selection of criteria, which enables stakeholders to detect important trends, lags or changes in complex structures. The assessment can be carried out by either quantitative or qualitative means. It becomes evident that criteria should in general reflect national and sector-specific scopes and goals (Soimakallio et al., 2009a). This is particularly the case in the forest biorefinery sector, as the chosen raw material and end-products vary greatly depending on the specific case and location of the biorefinery facility (Näyhä and Pesonen, 2012).

In recent years, biomass-based systems have been extensively analyzed from an environmental *life-cycle perspective*, concentrating mainly on bioenergy and particularly on biofuels (e.g. Cherubini and Stromman, 2011; Felder and Dones, 2007; Gnansounou et al., 2009; Gonzalez-Garcia et al., 2011; Larson et al., 2006; Soimakallio et al., 2009b; Spatari et al., 2009; Uihlein and Schebek, 2009; van Vliet et al., 2009). The life-cycle framework is one of the most well-known foundations for environmental assessment (Finnveden et al., 2009), and has been included in the general guidelines since the United Nations (UN) confirmed sustainability as a guiding principle in Johannesburg in 2002 (UNEP, 2002). The life-cycle-based methodologies have primarily contributed to the evaluation framework through the development of LCA as an assessment tool for the environmental impacts of any given product or service system, and the methodological development in the area has been strong (Finnveden et al., 2009).[3] Other life-cycle-based assessment tools, which in general assess the environmental impacts of a product system, include carbon, water and ecological footprints; material flow analyses; and input-output LCA (hybrid LCA) (Baumann and Tillman, 2004).

However, there are many issues and methodological assumptions that cause uncertainties in biomass-based system LCAs. For example, studies indicate that it is not possible to provide exact quantifications of the environmental impacts of bioenergy because too many variables are often involved, some of the key parameters (such as indirect effects) are not well known, and they strongly depend on local and climate conditions (Cherubini and Stromman, 2011; Cherubini et al., 2009). Many other studies have also indicated the need for a more complete methodology and case-specific analysis in order to account for all environmental implications of the processes under consideration (e.g. Carpentieri et al., 2005; Larson et al., 2006). In addition, many uncertainties will remain until the actual implementation of various biomass-based systems (e.g. van Vliet et al., 2009; Uihlein and Schebek, 2009). Therefore, it is evident that in the future, biomass-based systems will need to be evaluated with LCAs that overcome many of the shortcomings found in previous studies.

Thus, in addition to the widespread LCA approach, new assessment approaches have been introduced that are particularly relevant for biorefineries. Many of these

3 In addition to environmental impacts, the Life Cycle Initiative emphasizes that an integrated framework should also include the economic and social impacts of a given system. These have been discussed since the mid-90s (Benoit et al., 2010). However, as the scope of this research primarily focuses on environmental sustainability and how it should be measured in the emerging field of biorefineries, these economic and social impact assessment methodologies (e.g. Life Cycle Costing, Social Life Cycle Assessments) are not discussed in further detail.

frameworks explore several dimensions of sustainability simultaneously. Giampietro and Ulgiati (2005) assess the desirability of biofuels by introducing a multi-criteria approach that requires defining a set of performance criteria for such an energy sector. As a result, a method is proposed for characterizing the pros and cons of biofuel by means of five criteria which can be used to make informed choices. Whitehead et al. (2010) propose work on a new approach on the basis of an integrated hybrid assessment with unitized impact metrics (based on impact rating). They conclude that improved methodologies for determining system boundaries grounded in a comprehensive system impact assessment are necessary to adequately assess biofuels and their environmental effects. Whitaker et al. (2010) examine global interest in developing a sustainability assessment protocol for biofuels. Their study indicates that system expansion provides a more consistent and accurate assessment of the savings made by co-product utilization, and that residues such as straw should be incorporated in an LCA through system expansion. The Netherlands Environmental Assessment Agency (2010) has undertaken work to generate an assessment framework, using available methodologies particular to biodiversity assessment caused by land-use change in order to integrate the effects of different pressures. This would enable comparison and assessment across spatial and temporal scales, but it would be reduced to a single biodiversity indicator. Vierikko et al. (2010) propose collection in the form of a "shopping basket" of regional indicators for environmentally sustainable activities in the forestry sector. Halog (2009) proposes an integrated and structured methodological framework to assist in formulating integrative and transparent policies for sustainable biomass certification, in order to determine the critical criteria and indicators that represent conflicting stakeholders' interests. Other important indicators, which have been developed for the assessment of biofuels and are currently being used, include the EU Renewable Energy Directive (RED); national-level criteria from the Netherlands, United Kingdom and Germany; criteria prepared by certain NGOs (Roundtable of Sustainable Biofuels and Swan Labeling); and certification systems for biomass energy crops (RSPO; palm oil, BSI; sugar cane and RTRS; soy) and forests (FSC and PEFC).

In sum, despite the new assessment methods recently introduced for biomass-based industries, there is an obvious need for environmental sustainability criteria in emerging forest biorefineries that are sector-specific and take location, necessary raw material and end-products of the biorefinery facility into consideration. This study attempts to tackle the challenge by soliciting expert participation in an initial development of the criteria, which are described more closely in the following section.

3 DATA AND METHODS

The research project uses an explanatory three-phase Delphi method, which is a technique for obtaining forecasts from selected experts. During the Delphi phases, experts' opinions are collected, and information is combined and then returned to the experts for re-evaluation. The Delphi technique is generally considered to be an appropriate method for studies that lack historical data and require the collection of expert opinions (Blind et al., 2001; Gallego et al., 2008; Gupta and Clarke, 1996; Landeta, 2006). Therefore, the Delphi process is very suitable for investigating the novel forest biorefinery business and its environmental sustainability aspects and criteria, given the scarcity of previous research from a similar approach. Accordingly, the opportunity to include geographically dispersed specialists with backgrounds in different fields was a benefit of the chosen methodology. Also the analytic hierarchy process developed by Singh et al. (2007) contains expert engagement in identifying key sustainability attributes, issues, and themes of the steel industry (bottom-up approach). Correspondingly, Labuschange et al. (2005) assessed the sustainability of operations in the manufacturing sector by requesting 23 professionals to rate the relevance of the different criteria in the proposed framework. The analysis in this manuscript is based on data from the third Delphi round. The first and second rounds were reported earlier in different manuscripts that described drivers for forest biorefineries on different levels (Näyhä et al., 2011; Näyhä and Pesonen, 2012). The environmental sustainability performance of the forest biorefineries, the main topic of this research paper, was one of the issues indicated by the respondents as a prominent driver for the forest biorefineries in the first two research rounds.

In this study, there were several reasons to choose *themed semi-structured interviews* (Hirsjärvi and Hurme, 2001; Merton et al., 1990; Patton, 1990) as the data collection method. In themed interviews, specific themes are determined in advance, but the precise form and order of the questions are not known (Hirsjärvi and Hurme, 2001). Due to the different backgrounds and expertise of the respondents, as well as the novelty of the biorefining business and its environmental sustainability evaluation, responses were assumed to be variable and divergent. Thus it was important that during the interview, responses could be clarified and additional questions could be asked. Furthermore, depending on the respondents' backgrounds, certain themes were discussed in more detail in order to get a deeper understanding.

A total of 23 representatives from the forest, bioenergy and bioproducts sectors participated in the interviews in the U.S., Canada, Finland and Sweden from March to June 2011. The distribution of respondents by country and sector is presented in Table 1.

The interviews were conducted face-to-face or over the phone in Finnish or English. The study concentrates on countries (Finland, Sweden, the U.S., Canada) with good preconditions for the establishment of forest biorefineries: high-quality research, development and demonstrations, similar structures in the forest industry, and abundant lignocellulosic biomass resources. Interviewees were chosen from among the 125 survey respondents of the first Delphi round, the aim being a comprehensive sample of respondents from different backgrounds and countries. Respondents who participated in both previous Delphi research rounds were preferred. Six new respondents who were recommended by the other respondents, and therefore presumed to have highly competent information about the evolving forest biorefinery business, were also added to the sample.

The interview consisted of five main questions:

1. Do you consider environmental sustainability to be an important driver for the forest biorefinery business?
2. Do you consider production of biofuels in the forest biorefineries to be environmentally and economically sustainable?
3. Define the greatest environmental challenges related to the biorefinery value chain.

4. How does environmental sustainability relate to the aspiration for the common good and strategic purpose of the biorefinery value chain companies?
5. How has/should the environmental sustainability of the business been/be measured in the forest biorefinery value chain companies?

The first research question (outlined in Section 1) is addressed with questions 1-4 above, whereas the second research question is addressed with question 5. Section 4.1 includes the responses for interview questions 1-4, and therefore answers the first research question. Section 4.2 includes the responses for interview question 5, and thus answers the second research question. The focus of this study was not to examine different technical options and models for the forest biorefineries. Nevertheless, exploring environmental sustainability and its criteria of forest biorefineries would not have been possible without first defining and describing the forest biorefineries as understood by the experts of the study, because environmental impacts and performance of forest biorefineries are strongly connected to properties of biorefineries (including capacity, feedstock, products and integration). Therefore, respondents were asked to define potential forest biorefinery models in their countries before considering the questions related to environmental sustainability (see Section 4.1).

In question 5, the respondents were asked to estimate what kind of environmental sustainability criteria could be applicable when assessing the forest biorefinery business. As an example, the respondents were introduced to sector-unspecific factors that had been created by MSCI[4] for an environmental performance evaluation of businesses. The factors presented were divided into two categories: strengths (Beneficial Products and Services, Pollution Prevention, Recycling, Clean Energy, Communications, Property Plant and Equipment, Management Systems) and concerns (Hazardous Waste, Regulatory Problems, Ozone Depleting Materials, Substantial Emissions, Agricultural Chemicals, Climate Change). The respondents were encouraged to also indicate their own opinions and criteria.

Transcribed interview texts were examined using the thematic analysis method.[5] This is usually described as a means to derive a pattern or theme in seemingly random information. Thematic analysis is based on coding; themes and patterns are found in the data in order to organize and interpret the information (Boyatzis, 1998; Patton, 1990). The starting point of the analysis was to identify the material that is most relevant in terms of the main research questions. Thus the data was first classified under the main themes that were defined in the interview structure. In the following phase, the data was carefully re-explored in order to derive other interesting and relevant patterns.

Extracting a specific set of environmental criteria from the interview, results were approached in addition to thematic analysis by means of content analysis, a method of textual investigation (Silverman, 1985). By definition, content analysis is "based on a systematic examination of the whole set of empirical data [...] and the purpose is to inspect

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4 MSCI is a provider of investment support tools, such as indicators in environmental issue areas, which are used in this research.

5 A portion of the quotes presented in the manuscript are translations from Finnish. The respondents' sector and country are noted after each quote.

[it] for recurrent instances, such as words, themes or discourses" (Eriksson and Kovalainen, 2008).

TABLE 1 Respondents by country and sector.

	Finland	Sweden	U.S.	Canada	**Total**
Association				1	**1**
Consultant	2		1		**3**
Forest/bioenergy/bioproducts sector companies	3	2	4		**9**
Investors			1		**1**
Research	3	1	4	1	**9**
Total	**8**	**3**	**10**	**2**	**23**

4 RESULTS

4.1 Sustainability aspects of the forest biorefinery business

The research interviews indicated that environmental sustainability may be an important driver for the forest biorefinery business. Even though interview questions placed emphasis on environmental sustainability, most of the interviewees spontaneously recognized and elaborated on other dimensions and perspectives of sustainability as well. They also spontaneously cited problems about the variety of definitions for sustainability. Moreover, the respondents believed that environmental sustainability plays a significant role indirectly through political or economic factors. According to the respondents, having an environmentally sustainable image can also be a competitive advantage for companies.

> I think ultimately it (environmental sustainability) will be [an important driver]; in the long term, people are going to recognize the importance of industrial sustainability, that companies can continue to provide products in a way that doesn't take away from the ability of our grandkids to do the same thing (Researcher, Canada).

> If not directly, at least indirectly sustainability guides European Union legislation, and this in turn guides the business (Forest sector company representative, Finland).

> I think that measuring sustainability requires a lot of different perspectives and we should be constantly looking at these (Researcher, Canada).

In general, the production of biofuels in biorefineries was mainly seen as a sustainable business when taking both economic and environmental dimensions into consideration. The environmental and economic dimensions of sustainability were seen as complimentary elements that can be achieved through joint efforts. Biorefinery value chain companies were also believed to pursue society's common good by moving towards the environmentally sustainable biorefining business.

> For sure it can be sustainable…However, there are no free lunches. Human activities always have impacts. Now the aim is to move towards renewables. Nor should you be a fool, as was feared in the case of ethanol. But you try to produce a certain amount of energy and products with the smallest possible environmental impacts (Forest sector company representative, Finland).

> I think it (production of biofuels in biorefineries) will be environmentally sustainable in the U.S., but only if they can find a way to make it economical (Researcher, U.S.).

Many respondents were able to further explore the environmental sustainability of the forest biorefinery business: forest-based biorefineries have the advantage of intrinsic sustainable raw material, giving them an advantage compared to many other businesses. Future developments were also seen to lead towards better environmental sustainability.

Despite this, experts believed that harvesting feedstock will be the most challenging part of the value chain to manage from the environmental perspective. Forest residues (logging tops, pre-commercial thinnings, stumps) and mill residues were considered the most significant sources of wood-based biomass in future biofuel production (see also Näyhä & Pesonen, 2012). In Finland, many respondents also believed that peat will play a significant role in forest biorefinery facilities; this aroused many concerns in regard to its environmental sustainability, particularly among non-Finnish respondents.

> It (the most challenging part of the value chain) is the harvesting for sure (Forest sector company representative, U.S.).

> Sourcing. Where are you going to get all of this from (Researcher, Finland)?

> We got to use a heck of a lot of additional biomass and all that, and you want to get in there and get that material economically. You're going to impact the land (Researcher, U.S.).

In particular, large-scale utilization of forest biomass was believed to have significant environmental impacts on forest ecosystems. Respondents (see also Näyhä & Pesonen, 2012) indicated 200,000 to 300,000 or even 500,000 tons per year of biodiesel production capacity as the probable size of a forest biorefinery facility. This puts heavy pressure on forest ecosystems through intensive harvesting, which in turn creates a growing need for environmental sustainability evaluation.

> Problems related to raw material will be revealed in their totality after several years (Researcher, Finland).

However, experts highlighted the evaluation of applicability and the potential of various feedstocks in addition to forest residues. Urban organic waste in particular was believed to have future potential and, for its part, to mitigate pressure on forest-based biomass.

Even though Fischer-Tropsch diesel was seen as a principal product, respondents also increasingly highlighted the significance of various other possible low-volume, bio-based chemicals. Accordingly, it was pointed out by respondents that wood-based bioproducts could serve more as high value-added products than as bulk products. A change in emphasis from ethanol to F-T diesel in the United States is also an indication of increased environmental concerns, as corn-based ethanol is not seen as an environmentally sustainable option (e.g. problems related to land use, water footprint and food versus fuel).

> I think it's sustainable, like I said, at a small percentage of the market. It's going to be a value-added, kind of cream-at-the-top kind of a product, but it's not going to do much at the commodity level to relieve pressure (Forest sector company representative, U.S.).

The role of NGOs, particularly various environmental groups, was considered to be important, especially in the U.S. However, a large controversy surrounds the ideologies and ideas of environmental groups: part of the respondents considered their role to be important in laying the ground for sound environmental policies and environmentally sustainable business, whereas others believed that environmental groups disturb the development of business that is widely considered to be environmentally sustainable, e.g. the forest biorefinery business. In the U.S., environmentalists seem to be more a threat whereas in Scandinavia those groups are seen to go more hand-in-hand with other stakeholders.

> In fact, I think that the environmental groups are going to make sure that it [environmental sustainability] is important to all feedstock, but really have their guns pointed at the forest industry and anybody that uses feedstock—fuels, or whatever (Forest sector company representative, U.S.).

In general, according to the respondents, environmental sustainability seems to be an important driver for the forest biorefinery business. However, biorefineries have various environmental impacts, particularly because of biomass harvesting, which in turn creates a need for environmental sustainability evaluation.

4.2 Criteria for environmental sustainability assessment in the forest biorefinery business

In order to formulate a list of criteria for evaluating environmental sustainability in the forest biorefinery business, the respondents were asked to name important issues. As a starting point, they were able to use previous evaluation factors created by MSCI. The interviewees were able to give their opinion about each of the factors and their applicability to an assessment of biorefineries. However, rather than evaluating MSCI factors, they were encouraged to indicate new forest biorefinery-specific criteria that they thought would especially characterize important features for an assessment of biorefineries (see Section 3). Many respondents expressed a lack of connection between forest biorefinery activities and some of the given MSCI factors.

In the analysis, the criteria mentioned by the interviewees were grouped into 17 main-criteria categories. Five of these categories were new, created by the researchers, and 12 of them previously appeared in the MSCI list of factors. Table 2 presents all the criteria categories and the number of times that each criterion was mentioned in the interviews.

TABLE 2 Criteria categories and the number of times that each criterion was mentioned in the interviews. The criteria categories created by researchers are shown in bold and the MSCI factors are not.

Criteria category	References
Raw material availability & sustainability	11
Life-cycle perspective	9
Land use/deforestation/diversity	7
Beneficial products	8
Climate change	6
Clean energy	6
Communications	6
Locality, social costs, health and safety	4
Pollution prevention	4
Technology, research and development[6]	4
Recycling	4
Agricultural chemicals	3
Hazardous waste	3
Regulatory problems	3
Self-sufficiency (industry level/national level)	3
Management systems	2
Substantial emissions	1

It should be noted at this point that the criteria are not meant by any means to be approached in a directly quantitative manner. These are merely important issues that characterize the business as such and should be either approached in a qualitative manner (e.g. in questioning whether the business uses life-cycle approaches in its strategies or management applications, or if the use of the resources is sustainable) or then after quantitative indicators based on these criteria have been developed.

As a result, a sector-specific guideline could be established for the most important issues to be included in an environmental sustainability assessment of forest biorefinery value chain companies. In the final guideline, the *Land use/deforestation/diversity* category was combined with *Raw material availability and sustainability*, as these criteria categories were seen as partially overlapping and describing similar issues. In addition, the *Locality, social costs, health and safety* criteria category is not presented as part of the final guideline, due to the category's social rather than environmental aspect (see a more detailed discussion at the end of this section). The criteria can be divided into two main groups, based on the frequencies of the references: high-impact criteria and low-impact criteria (see Table 3). Mentioned most frequently, the high-impact criteria were *Raw material*

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6 Called *Property plant and equipment* by MSCI.

availability and sustainability, Life-cycle perspective and *Beneficial products.* The low-impact criteria, mentioned less often but still clearly distinguished due to the frequency of the references, were *Climate change, Clean energy, Communications, Pollution prevention, Technology, research and development, and Recycling*. The rest of the criteria were mentioned only occasionally. However, there is a need for a more systematic study in the future to support these results and also to provide more evidence for establishing a differentiation between high and low criteria. Likewise, aspects of high-impact criteria should get the most emphasis when further developing the forest biorefinery-specific environmental assessment approach.

TABLE 3 High-impact and low-impact criteria for environmental sustainability assessment.

High-impact criteria	References
Raw material availability & sustainability	18
Life-cycle perspective	9
Beneficial products	8
Low-impact criteria	
Climate change	6
Clean energy	6
Communications	6
Pollution prevention	4
Technology, research and development	4
Recycling	4

Raw material availability and sustainability composed the most important criterion in an environmental sustainability assessment of the forest biorefinery business. This criterion includes a variety of issues—ranging from raw material harvesting and logistics to issues such as land use and loss of biodiversity—combined by the researchers into a single new criterion of "raw material availability and sustainability" when data was analyzed. A deeper analysis of the content revealed a wide array of nuances in regard to the topic of raw materials availability and sustainability. Terms used in this context included availability of raw material, better feedstock for fuel, sustainability of resources, efficient use of raw material, raw material logistics and environmental impacts of harvesting.

The second most important criterion, namely the life-cycle perspective, was also approached from several different perspectives. It was used by discussing about e.g. life-cycle assessments, LCA, entire production chains, life-cycle thinking and overall life-cycle impacts. The result, which clearly includes several issues pertaining to the entire concept of life-cycles, indicates that it is not the intention of each respondent to carry out full-scale LCAs for their entire product portfolio and make decisions according to these.

> From a life-cycle perspective, there are big issues there (in the forest biorefinery business). From the sustainable source, meaning where the material came from, you keep re-growing your source… (Forest sector company representative, U.S.).

> Life-cycle thinking… Of course, there has to be life-cycle thinking, and many projects are already considering also this (Researcher, Finland).

The third high-impact criterion was the production of beneficial products within the sector. The respondents considered forest biorefinery products to be environmentally beneficial in general, making an assumption for the business: "*environmentally beneficial products and services – that's almost totally logical*." It was also mentioned in this context that the emphasis should not only be on the environmentally friendly manufacturing process, but on the environmental impacts of the end product itself as well.

> I would add another point to concerns, which is use of fossil fuels (Researcher, Canada).

During the analysis, two new criteria categories were spontaneously brought up by the respondents: "*locality, social costs, health and safety*" and "*self-sufficiency*". These criteria categories are more related to the social and the economic dimensions of sustainability than the environmental dimension. While they are discussed as part of the results of this study because these findings further highlight the interrelated nature of different aspects of sustainability, they are not included in the final criteria guideline, because interview question 5 only targeted the environmental dimension (and therefore part of the respondents limited their responses to environmental criteria, as asked). First, the impacts on local activities and locality in general, as well as social implications, were mentioned by many interviewees.

> Locality and domestic origin is the advantage and that should be the guarantee of responsible business[…] What is missing is the local view, how the locals see the issue[…] We have already approached the issue by trying to calculate the costs of our local emissions for society (Researcher, Finland).

Another issue which was seen as important was the increase of self-sufficiency in terms of national energy provision. A definite strength of the sector is that from the perspective of a country with an abundance of biomass resources, the ability of biorefineries to increase the security of energy supply is certainly in line with national policies.

In sum, according to the respondents of this study, the most important criteria in the environmental sustainability evaluation of forest biorefineries are *Raw material availability and sustainability, Life-cycle perspective* and *Beneficial products*, followed by the criteria categories of *Climate change, Clean energy, Communications, Pollution prevention, Technology, research and development, and Recycling.* In the following section, implications and future development of the presented framework are discussed in greater detail.

5 DISCUSSION AND CONCLUSIONS

5.1 Main findings

According to the results of the interviews in this study, environmental sustainability seems to be an important driver for the forest biorefinery business. However, the environmental challenges related to forest biorefinery activities were also widely recognized by this study and many others (see Section 2). At the same time, discussion of an environmental assessment of bioenergy and bioproducts clearly indicates that there is a lack of systematic approaches to assessing the environmental impacts of forest biorefineries. Currently, criteria that do not consider sector-specific features and variation are used. However, using non-specific criteria in assessments can create many problems, e.g. the most relevant concerns do not emerge in evaluations. Our results also clearly indicate that even though bio-based systems have been approached mainly from the life-cycle perspective, this alone is not a comprehensive approach for forest biorefinery evaluation (see Section 2.2); rather, a more particular approach would be applicable.

In addition, despite the fact that this study initially focused on environmental sustainability aspects, our results indicate that different aspects of sustainability are interrelated and environmental sustainability assessments without consideration of other sustainability aspects can be inadequate. The respondents of the study spontaneously discussed the importance of economic and social considerations of sustainability during the interviews. A need for integrated assessment tools is also indicated by many other studies (see Section 2.2). The production of biofuels in biorefineries was seen as a sustainable business when taking into consideration environmental as well as economic dimensions. Furthermore, the respondents believed that biorefinery value chain companies are seeking the common good of society by moving towards an environmentally sustainable biorefining business; this indicates the respondents' understanding of the significance of sustainability's social dimension. In addition, economic and social aspects were suggested by respondents as part of the evaluation criteria for biorefineries.

By analyzing the interview results of the study, we were able to propose criteria to be included in the environmental assessment of a forest biorefinery. The most distinct issue emerging from the analysis was the necessity to include the evaluation of *raw material availability and its sustainability* in an environmental sustainability assessment. Despite the fact that forest-based biorefineries have the advantage of intrinsically sustainable raw material, wide-ranging studies—in addition to this one—concerned with raw material availability and sustainability suggest that resource use is a very complex issue, which there is no unanimous method of dealing with. It is partially the availability of raw material from a productivity perspective that perplexed the respondents here. But also considered to be important were the environmental sustainability of resources and whether they will be there for future generations. As previously described, when evaluating raw material sustainability, a variety of issues ranging from raw material harvesting and logistics to land use and loss of biodiversity should be taken into consideration. This is understandable, because forest biorefineries cannot be strictly limited to a certain end product, raw material or location. First, there are various feedstocks that can be used as raw material for forest biorefineries (depending on, for example, location and end products of a facility). Respectively, certain environmental impacts are connected to the specific biomass type. In particular, the use of peat as potential biomass has aroused considerable concern, due to its negative environmental impacts. Second, the variety of technologies and processes that can be used for production also have their characteristic impacts. Third, the degree of intensity of biomass harvesting and management practices largely defines environmental impacts. Fourth, impacts are also dependent on the quality and natural values of the ecosystem that is under biomass harvesting.

Furthermore, it is necessary to take into consideration that the complications related to the initial stages of the extraction of raw materials will potentially become more pronounced due to growth in planned factory sizes and the increased use of raw materials. However, the respondents in this study indicated that there are growing efforts to evaluate the potentials held by different biomass materials in order to meet the growing need for biomass. Accordingly, this study shows that there is growing interest in high-value, low-volume bio-products (see also Bozell and Petersen, 2010; FAO, 2011; Näyhä and Pesonen, 2012), which in turn might relieve the pressure on large-scale biomass harvesting.

Likewise, the *life-cycle perspective* was seen as a significant criterion to be included in the evaluation. However, when talking about the inclusion of life-cycle-based impacts, the analysis clearly indicated that the respondents are not demanding a full-scale LCA *per se* for their entire product portfolio. In terms of the proposed framework, it should rather be the inclusion of life-cycle management and the awareness of environmental implications—positive or negative—along the value chain of biorefineries. Conducting a full-scale LCA is neither possible (e.g. due to financial limitations) nor reasonable in every situation. In other words, the idea is that the organization would become aware of the environmental impacts of the entire life-cycle and value chain, relate their activities to these and incorporate them on some level into their long-term strategic planning. Additionally, the use of a life-cycle perspective in the management applications should be transparent. The effective communication of life-cycle-based efforts to relevant stakeholders will, of course, become a dominant concern. Furthermore, there are many shortcomings (see Section 2.2) in LCA frameworks that need to be taken into consideration when interpreting the results.

The third significant criterion was the production of *beneficial products*. The respondents in general considered the biorefinery products to be environmentally beneficial, which would make this issue unnecessary in a sector-internal assessment. However, it must be kept in mind that the environmental impacts depend on what the actual end product will be. In the future, there will be increasing selection of potential biorefinery products with various impacts. Furthermore, even though the bio-based products are seen as intrinsically and environmentally beneficial, they do not necessarily promote a *sustainable* use of energy and products. The advantages of these products can be reversed if consumption drastically increases. This response is known as the rebound effect (e.g. Hertwich, 2005); essentially it means that after a more resource-efficient technology is introduced, the response can offset part of the beneficial effects, for example, due to consumption increases. More specifically in this case, if the use of bio-based products increases above initial consumption levels, this can also have direct consequences on the need for raw material (our first criterion).

5.2 Implications, limitations and future developments

It is likely that the number of studies dealing with environmental sustainability assessment of biorefinery systems will be expanded in the near future (Cherubini and Stromman, 2011). It is important that case-specific evaluations of raw material-related properties—in particular, availability, land-use issues and diversity—are taken into consideration when planning these studies. Accordingly, in the coming years biorefineries will be increasingly developed as multi-product facilities with specific site-dependent features (producing a variety of products, such as biofuels, chemicals and fibers). Therefore, approaches for evaluation need to be developed for multi-product systems. Accordingly, due to the multidimensional nature of sustainability, the need for approaches that include criteria for assessing different sustainability dimensions is obvious (see also e.g. Giampietro and Ulgiati, 2005; Halog, 2009). Collaborative work is needed at both the national and international levels in order to develop a common and appropriate methodology (Gnansounou et al., 2008).

The novelty of this study lies in the sector-specific aspects and evaluation of holistic environmental sustainability in the emerging forest biorefinery business. Until now, companies have primarily used sector non-specific frameworks and indicators. The criteria presented in this study (Table 3) for an environmental sustainability assessment of forest biorefineries can encourage companies to analyze environmental impacts and sustainability challenges holistically as well as to optimize their value chains. Accordingly, the framework can be used to assess which issues should be included and which should be emphasized more than others.

However, the framework needs to be further developed in order to be a more practical evaluation tool. Overall, the criteria presented in this study can be seen as comprising the initial step of a more elaborate evaluation framework, which can provide more accurate information about the sustainability performance of biorefinery value chain companies. Accordingly, in the analytic hierarchy process (Singh et al., 2007), the first task is to identify key sustainability performance indicators. Later, through several successive steps of the hierarchy process, various indicators can be aggregated into the composite sustainability performance index. Moreover, criteria defined in this study can be further developed. For example, in the next phases key criteria could be finalized, quantitative data for criteria could be collected, and a weighting procedure for criteria could be carried out in order to create a sector-specific sustainability index. Correspondingly, Labuschagne et al. (2005) proposed an initial framework for assessing the sustainability performances of a company and its operations, which was further developed through an extensive survey. In this survey, respective weighting values and subsequent relative importance of the different criteria were established. Moreover, Labuschagne et al. (2005) continued the work by developing a criteria framework that is appropriate for the intended application of project management in a specific company.

One potential limitation of this study concerns the selection of respondents: while each studied country yielded respondents, researchers and forest/bioenergy sector representatives were most dominant, perhaps not reflecting a true representation of all the study sectors. In addition, the countries with the highest number of respondents were Finland and the U.S. Therefore, a more equal representation of countries and sectors should be aimed at in the future.

Additionally, from an investor's perspective it would be encouraging to have a well-defined, sector-specific evaluation framework, based on which relevant, reliable and accurate information about the environmental status of the company can be disclosed and investment decisions can be made (e.g. Schaltegger and Burritt, 2000). In order to further study the links between environmental performance and a company's share value, a new field of research would emerge from complementing the original MSCI criteria with the new criteria found, as well as from higher weighting for the most important issues. Based on this, a sample set of companies active in the biorefinery business could be assessed. In the case that there are large differences between the original assessment results and the new ones, this would indicate that the original assessment factors do not do justice to the biorefinery companies. Taking the analysis even further, one could analyze (for example, through an event study) whether a change in the environmental assessment result—in other words, the rating—would lead to positive share value changes. In this case, it would give companies a clear motivation for improving their environmental aspects.

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IV

THE FOREST INDUSTRY'S STRATEGIC CHANGE TOWARDS THE BIOREFINING BUSINESS

by

Annukka Näyhä & Hanna-Leena Pesonen, 2012

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THE FOREST INDUSTRY'S STRATEGIC CHANGE TOWARDS THE BIOREFINING BUSINESS

Abstract

Some of the most prominent driving forces for the forest industry are largely negative – e.g. the maturity of certain product markets – and can only be addressed by changes within the industry. Biomass-based energy (bioenergy) and products (bioproducts) play an important role in society's transition to a greener, more bio-based economy, as well as in offering opportunities to the global forest industry. Particularly, biorefineries integrated into the pulp and paper industry seem to hold great future potential.

In this study the main aim was to explore the current forest industry's change features, necessary resources and management for the biorefining business in Scandinavia and North America. The aim was not only to explore the change process and related change management capabilities within the forest industry, but also to evaluate actual new resources that are needed when operating forest biorefinery facility.

A total of 23 representatives from the forest, bioenergy and bioproducts sectors participated in the themed interviews in the U.S., Canada, Finland and Sweden in 2011. The interviews were examined using a thematic analysis.

In both the Scandinavian and North American forest industries, the conservative organizational culture and lack of financial resources seem to create prominent barriers to change. The role of the forest industry in the forest biorefinery consortium is largely seen as a biomass provider. High value-added products and Fischer-Tropsch biodiesel will play a significant role, but in general the biorefining business needs to be planned to support traditional core businesses. The scope of the change with the needed transformation activities and resources depends largely on contextual features such as the location of the biorefinery, chosen technologies and raw material availability. Operating a commercial scale forest biorefinery facility requires both new managerial- and operational-level skills. Readiness for change and enthusiasm need to be embedded in the organizational culture – and the key for attaining this is open-minded, multi-disciplinary organizational management. Visionary and innovative personnel are believed to be found in forest industry companies, yet current culture does not encourage these people to put forward their ideas. The success in the biorefinery business cannot be achieved without collaboration that combines the right set of resources. However, it will be challenging to share profits among the partners in the biorefinery consortium.

Overall, the forest industry needs to transform its business in one way or another. Correspondingly, there is an increasing call in our society for bio-based economy with related new business strategies and models. The biorefining business can be one of the most successful strategies for achieving these goals.

Keywords: forest industry, bioeconomy, change resources, change management, forest biorefinery business, Scandinavia, North America

1 BACKGROUND

There are many different driving forces shaping developments in the forest industry[10], with consequences to the continuity of the industry. Some of the most prominent forces are largely negative – e.g. industry structure and the maturity of some product markets – and can only be addressed by changes within the industry. (FAO 2011; Näyhä and Pesonen, 2012)

Better corporate performance depends on understanding how industries evolve. Companies can improve their performance by adapting investments to follow industry trends rather than fight against them (McGahan, 2000). Several frameworks are developed in order to understand structural changes shaping the industries. Industries and sectors can be analyzed in terms of *Porter's five forces*: barriers to entry, substitutes, buyer power, supplier power and rivalry. Together, these forces determine industry or sector attractiveness, and can be influential for overall corporate performance (Porter, 1980). The five-forces approach is essentially static because it provides a framework for determining the financial performance of an industry at a certain point in time (Grundy, 2006; McGahan, 2000). However, industries and sectors are dynamic, and their changes can be analyzed in terms of the S-curve (Abernathy and Utterback, 1978; Foster, 1986) and the closely-related Product Life Cycle and Industry Life Cycle (Anderson and Zeithaml, 1984; Johnson *et al.*, 2008; Kotler, 1972; Polli and Cook, 1969; Porter, 1980). These concepts propose that industries start out small in their development stage, and then go through a period of rapid growth, culminating in a period of "shake-out". The last two stages are first a period of slow or even zero growth – the maturity stage – before the final stage of decline. Each of these stages has implications for the five forces (Klepper, 1996).

In some respects, the forest industry is facing challenges that have already been seen in other manufacturing sectors. In developed regions, the industry has significant capital assets and large domestic markets, but production costs are relatively high and markets are growing quite slowly or even declining (FAO, 2011). Therefore, in many areas the forest industry has long been characterized as a mature (Cohen and Sinclair, 1998) industry with production-oriented (Cohen and Kozak, 2001; Juslin and Hansen, 2003), low-cost strategies (Bush and Sinclair, 1992; Niemelä, 1993; Sierilä, 1987).

In contrast, markets in emerging economies are growing rapidly and production costs are generally lower, with the result that many new investments are being directed towards these countries, further increasing their competitiveness. The result of this is overcapacity in many emerging economies and a generally negative outlook for prices and profitability both globally and particularly in many developed countries. (FAO, 2011)

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10 In this study "forest industry" is understood to include pulp, paper, paperboard and wood products industries. The latter contains sawmilling, plywood, chipboard, fiberboard and construction products industries.

Overall, the structural change in the global forest products markets is still in its early stages. The general outlook for the forest industry is one of continued growth with some significant changes in the future. The existing structure and location of the industry are not in line with the main economic driving forces, thus new investment and production will continue to shift towards emerging economies. Pulp and paper production in OECD countries is declining, whereas it is rapidly increasing in non-OECD countries. There have also been indications that wood products manufacture may still increase in OECD countries due to e.g. beneficial climate impacts of renewable wood resources. (FAO, 2011)

Although the S-curve framework is dynamic, and it focuses on how industries evolve over time, it does not deal with how companies move across product generations, i.e. across S-curves. Industry leaders may become trapped in a kind of self-fulfilling logic of maturity if they take action based on an oversimplified S-curve. In the case that they believe an industry has reached the "mature" phase of the S-curve, they may wrongly assume it is past innovation. (McGahan, 2000) Styles and Goddard (2004) suggest that firms falling into the maturity trap do so because they compete in an industry with many firms pursuing same strategy, i.e. attempt to compete by "being better at the same game". Moreover, McGahan (2000) warns of the "maturity mindset," which can leave many managers complacent and slow to respond to new competition. A consequence of mainstream thinking can be a loss of the excitement of creating something new (Fonseca, 2002), which does not facilitate innovation (Näyhä and Pesonen, 2012).

However, it is obvious that no business survives over the long term if it cannot reinvent itself (e.g. Kotter, 2007; Lamberg and Ojala, 2006). Yet, maturity does not imply a lack of opportunity, nor does it mean a lack of innovation: many mature industries have been transformed by new technologies and new strategies (Grant, 2010). According to Söderholm and Lundmark (2009) preferences, markets, and technology change over time, and so does – and should – the flow of natural resources in the economy.

In those countries that can no longer compete with the emerging economies, restructuring the industry is likely to be a major change. A need to innovate and redefine business models is particularly urgent in the mature pulp and paper industry, with its frequent mill closures and profitability problems (Chambost and Stuart, 2007; van Heiningen, 2000; Metsäneuvosto, 2006; Toland, 2007). The emerging bio-based economy (bioeconomy) is a promising sector with notable future potential and many business opportunities (Luoma *et al.*, 2011). Biomass-based energy (bioenergy) and products (bioproducts) play an important role in society's transition towards a greener and more bio-based economy in general, and offer opportunities for the global forest industry from the long run perspective (FAO, 2011; Näyhä and Pesonen, 2012). For example, in North America bioenergy industry capacity is expected to more than double by 2015, creating tremendous demand growth for wood biomass and intensifying competition for fiber supply (RISI, 2012). Energy and forest sectors also seem to grow ever more integrated (FAO, 2011). In particular, biorefineries integrated into the pulp and paper industry seem to hold great future potential. In the present research, a forest biorefinery is defined as a multi-product factory that integrates biomass conversion processes and equipment in order to produce a variety of bioproducts like fuels, fibers, and chemicals from wood-based biomass (Ragauskas *et al*., 2006; Sorenson *et al*., 2007; Thorp, 2005). The development of forest-based biorefineries may imply a fundamental structural change in the traditional forest-based industries, but so far our understanding of these potential changes is limited (Söderholm and Lundmark, 2009).

It is evident that change is an ever-present element that affects all organizations. Likewise, there is a clear consensus that the pace of change has never been greater than in the current continuously evolving business environment. Thus, many organizations need to change their strategies just to remain competitive. However, the management of organizational change tends to be discontinuous, reactive and ad hoc with a reported failure rate around 70% of all change programs initiated (Balogun and Hope Hailey, 2008; Beer and Nohria, 2000; Todnem By, 2005). Accordingly, it has been said that, "Human nature being what it is, fundamental change is often resisted mightily by the people it most affects: those in trenches of the business (Kotter, 2007)." Or, as one of our interviewees describes the need for change in the forest industry:

> I would say it's clear that we know it's going to change. I would say it's not so clear what we need to do to get there. I think the way I would look at it, the key decision-makers in the forest industry are saying, OK, we know we have to be ready to change the business model. But they're not quite sure how it's supposed to go to yet and so I think nobody is, well, very few anyway, are blind, have put blinders on and are just kind of continuing business as usual, so I think the strategies are being almost constructed to have a lot of flexibility in them. (Forest sector representative, U.S.)

In this study the main aim was to explore the current forest industry change features, needed resources and management towards biorefining business in Scandinavia and North America. The research explores the forest industry's move across product generations and recognizes related challenges particularly in management. The change management approaches, specifically the change kaleidoscope of contextual change (Balogun and Hope Hailey, 2008), were used as a framework of analyzing the forest industry's change features regarding the biorefining business. The aim was not only to explore the change process and related change management capabilities within the forest industry, but also to evaluate the actual new skills and know-how that are needed when developing and operating commercial scale forest biorefinery facility.

2 ANALYZING INDUSTRIAL CHANGE: CONTEXTUAL AND CHANGE FEATURES

2.1 Strategic change features

Balogun and Hope Hailey (2008) emphasize that due to the complexity of the change task, successful change requires the development of a context-sensitive approach. In other words, the design and management of any change process should be dependent on the specific situation of each organization. It is dangerous to apply change formulae that worked in one context directly to another. (see also e.g. Jick, 1993; Pettigrew and Whipp, 1991; Todnem By, 2005.) Consequently, organizational change cannot be separated from organizational strategy, or vice versa (Burnes, 2004; Rieley and Clarkson, 2001).

Balogun and Hope Hailey (2008) present a framework, the *change kaleidoscope*, which can be used to help achieve successful change. The contextual features in the change kaleidoscope do not carry equal weight in all organizations – this is why the framework is named after the kaleidoscope, as its configuration features will constantly shift according to the organization being analyzed. The kaleidoscope will also change through time in response to change interventions, thus offering a non-static change management tool. Even though in each change situation the configuration of the contextual features will be unique, there are questions that remain constant in any change context. These questions include the amount of *time* available for change, the *scope* of the change required, *the degree of diversity* within an organization, the staff's *readiness f*or change, the *capability* and *capacity* to undertake change within the organization, the *power relations* and what needs to be *preserved* within the organization. None of the individual features can be considered in isolation, i.e. interrelated nature of all the kaleidoscope features should always be observed. Furthermore, the contextual features may differ within one company, which increases the complexity of the change process. (Balogun and Hope Hailey, 2008)

According to Balogun and Hope Hailey (2008), *scope* is a required outcome of change that can vary from realignment through more radical change aimed at the transformation of a company. Scope is affected by the whole organization or only a certain part of it, needing to change. *Preservation,* which is often strongly linked with scope, refers to the extent to which it is important to maintain continuity in certain practices or preserve specific assets – either because they form invaluable resources, or because they contribute to valued stability of culture or identity within an organization. Assets can be tangible (e.g. technology, infrastructure, financial resources) or intangible (e.g. know-how, staff loyalty in the employer) (Balogun and Hope Hailey, 2008). Consequently Dunphy and Stace (1993) believe that change can be divided into four different characteristics by scale: *fine-tuning, incremental adjustment, modular* *transformation, and corporate transformation*. Fine-tuning describes organizational change as an ongoing process to match the organization's strategy, processes, people and structure. Fine-tuning is usually manifested at a departmental or divisional level of the organization. Incremental adjustment involves distinct modifications to management processes and organizational strategies, but does not include radical change. Modular transformation is a change identified by major shifts in one or several departments or divisions and can be radical by its nature. However, it focuses on part of an organization rather than the organization as a whole (Senior, 2002). When the change is corporate-wide and characterized by radical alterations in the business strategy, it is described as corporate transformation. Examples of this type of change can be reorganization, reformed core values or altered power and status (Dunphy and Stace, 1993).

Readiness for change exists at two different levels: awareness and commitment, which means the extent to which the personnel are aware of the need for change and the amount of personal commitment there is towards changing individual skills and attitudes. The concept of readiness can be also divided into two: receptivity to a particular change initiative and the continuous readiness for change. Both of these are critical features within the change context, and accurate assessment of personnel readiness at the earliest opportunity can make a fundamental difference to the design of change, and thus the likelihood of success. (Balogun and Hope Hailey, 2008) Consequently Todnem By (2005) has identified from various studies several different approaches to characterize readiness for the change. There are four types of change as characterized by how it manifests: *planned, emergent, contingency* and *choice.* Bullock and Batten (1985) developed a four-phase model of planned change that splits the process into exploration, planning, action and integration. According to Burnes (2004) this is a highly applicable model for most change situations. The emergent approach of change sees it as being driven from the bottom-up (Bamford and Forrester, 2003; Burnes, 2004). The approach suggests change to be so rapid that it is impossible for senior managers to effectively identify, plan and implement the necessary organizational responses (Kanter et al., 1992). The emergent approach stresses the unpredictable nature of change, and views it as a process that develops through the relationship of a multitude of variables within an organization. The contingency approach to change is founded on the theory that the structure and the performance of an organization are dependent on the situational variables that it faces. Accordingly, organizations do not face the same variables and thus their operations and structures may be different (Dunphy and Stace, 1993). Choice theory emphasizes the opportunities that companies have over issues; i.e. what kinds of internal practices they will choose in order to accommodate external variables (Burnes, 1996).

In the change kaleidoscope (Balogun and Hope Hailey, 2008) *capability* describes how capable the organization is at managing change. It is important to distinguish between capability for different types and ways of delivering change. An organization and the individuals within it can be very good at delivering operational change, such as sharing best practices from one part of the organization with another. However, this does not give the organization capability for more transformational change. Furthermore, delivering change as a planned intervention requires one set of capabilities, and delivering change on a more continuous basis to keep pace with a changing environment requires a different set. Capabilities can be seen at two different levels: individual and organizational. At the individual level, managers and non-managerial personnel can be evaluated on e.g. how flexible and adaptable they are in terms of their skills, behaviors and attitudes. The more adaptable the staff, the better they will be at handling transition. The second form of capability is located within the organization itself. An organization can, for example, be an expert at particular types of change such as mergers and acquisitions. Organizations may also have systems – such as information systems, business planning systems or production systems – that allow it to coordinate change on a more continual basis in response to a changing environment (Wright and Snell, 1998). Consistently, *capacity* in the change kaleidoscope (Balogun and Hope Hailey, 2008) considers the amount of resources – such as cash, time, people – that the organization can invest in the proposed change. This has become a more important factor in recent years for many reasons. One is that change management activity in organizations has increased as the external environment changes faster and becomes more complex. This in turn has increased change activities in organizations. However, it seems that companies have not simultaneously increased their capacity-building activities to correspond to this increase in change initiatives. (Balogun and Hope Hailey, 2008)

According to Grant (1991) the resources of a firm are the central considerations for formulating its strategy. The resources are primary foundation upon which a company can establish its identity and frame its strategy, and they are the primary sources of the firm’s profitability. The key to a *resource-based approach* to strategy formulation is an understanding of the relationship between resources, competitive advantage and profitability – in particular, an understanding of the mechanisms that through competitive advantage can be sustained over time. This requires the design of strategies that exploit to maximum effect each company’s unique characteristics (Grant, 1991). If organizations are to achieve a competitive advantage, they require resources and competences which are both valuable to customers and difficult for competitors to imitate. These kinds of competencies are called a company’s *core competences* (Hamel and Prahalad, 1994). Likewise, a company’s success – or even survival – over the long term requires it to upgrade its resource and capability base (Grant, 2010). Thus *dynamic capabilities* are important; that is, the ability to change strategic capabilities continually (Eisenhardt and Martin, 2000; Helfat and Peteraf, 2003; Johnson *et al.*, 2008). The critical management challenges lie in developing existing capabilities and acquiring or creating new ones. Some of the most important developments in strategic management research in recent years are in deepening our understanding of what organizational capabilities are, and how they develop. (Grant, 2010)

2.2 Analytical framework of this study

Our aim was to explore the most interesting and prominent change features of the biorefining business that currently exist in the forest industry. Though the change frameworks are developed as tools to manage change, in this study they also proved to be beneficial as approaches for analyzing the forest industry's change features and related challenges, particularly *scope, preservation, readiness, capabilities* and *capacities* towards biorefining business. In this study (see Results, Section 4) *time* is explored as a part of the contextual features, whereas *diversity* and *power* features are interlinked with *capacities.* The *power* feature is explored only from the perspective of the forest industry's role in the biorefinery consortium, i.e. sharing responsibilities and dominance among different biorefinery actors. Accordingly, many change features are strongly interrelated, and will be thus discussed in various sections.

The analytical framework that we follow in this study is presented in Figure 1. In the framework we involved both features from the change management approaches – particularly from the change kaleidoscope – and the elements from the resource-based approach. By doing so we were able to explore both change management capabilities and new capabilities that are needed when operating forest biorefineries.

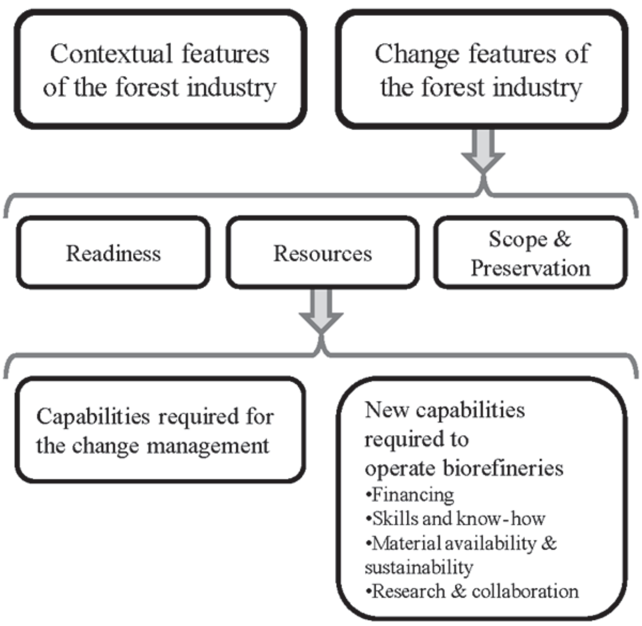

FIGURE 1 The analytical framework of the study.

3 DATA AND METHODS

As a whole, the research project uses a three-phase Delphi method, which is a technique for obtaining forecasts from selected experts. Typically the Delphi method is composed of two or three stages, during which experts' opinions are collected and information is combined, and then returned to the experts for re-evaluation. The analysis of this manuscript is based on data from the third Delphi round (Blind *et al.*, 2001; Landeta, 2006). The first two rounds were reported earlier, presenting key promoting factors for the forest biorefinery business (Näyhä and Pesonen, 2012).

A total of 23 representatives from the forest, bioenergy and bioproducts sectors participated in the themed expert interviews in the U.S., Canada, Finland and Sweden in March to June 2011. The interviews were conducted face-to-face or over the phone in Finnish or English. The study concentrates on countries (Finland, Sweden, the U.S., Canada) with good preconditions for the establishment of forest biorefineries: high-quality research, development and pilots, similar structures in the forest industry, and abundant lignocellulosic biomass resources. Interviewees were chosen among the 125 survey respondents of the first Delphi round, aiming at a comprehensive sample of respondents from different backgrounds and countries. Respondents who participated in both previous research rounds were preferred. Six new respondents who were recommend by the other respondents, and therefore presumed to have highly competent information about the evolving forest biorefinery business, were also added to the sample. The distribution of respondents by country and sector is presented in Table 1.

The interview consists of three main parts: 1. Key diffusion factors promoting forest biorefineries; 2. Forest industry corporate and business strategies; and 3. Environmental and economic sustainability in the forest biorefinery value chain companies. The results presented in this study are primarily based on topics and questions covered in Part 2.

Transcribed interview texts were examined using the thematic analysis method[11]. This is usually described as a means to derive a pattern or theme in seemingly random information. Thematic analysis is based on coding; themes and patterns are found in the data in order to organize and interpret the information (Boyatzis, 1998; Sayre, 2001). The interviews were conducted and analyzed by one person, thus there is no variation depending on interviewer. The starting point of the analysis was to identify the material that is most relevant in terms of the main research questions. Thus the data was first classified under the main themes that were defined in the interview structure.

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11 Some of the quotes presented in the manuscript are translations from Finnish. The respondents' sector and country are noted after each quote.

In the following phase the data was carefully re-explored in order to derive other interesting and relevant patterns.

TABLE 1 Respondents by country and sector.

	Finland	Sweden	U.S.	Canada	**Total**
Association				1	**1**
Consultant	2		1		**3**
Forest/bioenergy/bioproducts sector companies	3	2	4		**9**
Investors			1		**1**
Research	3	1	4	1	**9**
Total	**8**	**3**	**10**	**2**	**23**

4 RESULTS

4.1 Contextual features of the forest industry

4.1.1 Current situation

The respondents of this study strongly indicated that forest industries both in North America and Scandinavia are facing challenging times. Decreasing demand for paper products and cheaper raw materials and labor in new Asian and South American regions are the main reasons for the difficult situation and the need for change activities. The situation is acknowledged and widely discussed both by the forest industry representatives and other respondents of this study.

Beginning in the mid-2000s, and in the last couple of years in particular, there have been increasing effort and initiatives towards new products and business possibilities. This search for new alternatives is also considered the greatest positive action in the forest industry during the last decade. Accordingly, the respondents indicated a great variety of potential future outcomes, strategies and evaluations about new products, and more specifically the importance of bio-based products in the forest industry. It was also highlighted that at this point it would be important for the forest industry to trust its own capabilities and not fall into despair, as the emerging forest biorefinery business should be taken advantage of early enough.

However, most of the respondents believed that traditional products still play an important role in the forest industry's future in Scandinavia and North

America, despite relocation to South America and Asia and facility shutdowns. Production of long-fiber cellulose used for high quality papers was seen to remain almost as its current levels in the next decades. In addition, hygiene papers and packaging materials will play an important role in the forest industry's future. In addition, many respondents hoped that the significance of construction sector would increase and the use of wood as a building material would be encouraged.

4.1.2 The future of forest biorefineries

4.1.2.1 Basic concept for biorefinery facilities and potential products

As a basic biorefinery concept, respondents indicated facilities with 100,000-200,000 to 300,000 or even 500,000 tons per year of biofuel production capacity in which Fischer-Tropsch diesel[12] will be a principal product. Forest residues (logging tops, pre-commercial thinnings, stumps) and mill residues were considered the most significant wood-based biomass sources in future biofuel production. In Finland many respondents also believed that peat will play a significant role in forest biorefinery facilities. Moreover, experts highlighted the evaluation of suitability and the potential of various feedstocks in addition to forest residues. Urban organic waste in particular was believed to have future potential. (see also Näyhä and Pesonen, 2012)

However, the significance of various low-volume, high-value bioproducts in addition to high-volume bulk products were seen as crucial. A variety of new products were believed to have potential: synthetic polymers, viscose fiber derivatives, fuels, (butanol, ethanol) chemicals, medicines, cosmetics, nanotechnology products, intelligent paper and packaging, and composite materials. Accordingly, it was believed that the forest industry will have a diversified product portfolio: production model and end products will be crucially dependent on the local raw material availability and the specific features of the facility into which the biorefinery will be integrated. Many respondents presented scenarios about circular use or economy of wood, meaning recycling wooden materials through various processes and purposes before generating energy at the end. In turn, burning wood before processing was considered a significant threat.

The respondents also believed that in the beginning, before the most optimal biorefinery models and products are found, there will be plenty of fluctuation and start-ups that will not be successful in the long term. It was also believed that while governmental incentives can quicken and encourage start-

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12 The Fischer-Tropsch process converts carbon monoxide and hydrogen, called synthesis gas (syngas), into liquid hydrocarbon fuels e.g. synthetic diesel. Prior to the F-T process, the coal, gas, or biomass is gasified to produce this syngas using intense heat and pressure, turning these feedstocks into hydrogen and carbon monoxide. Synthetic fuels burn cleanly, so they offer improved environmental performance.

ups, without governmental intervention business develops more economically sustainably.

Estimates of the importance of new products varied greatly, starting from 10% of total production to the highest estimates of 50%. It was also mentioned that the most prominent factor when selecting product portfolio will be the market price of the end product. Some of the respondents also noted that even though new products will have a relatively small share in terms of quantity (10%), they will have a disproportionately large share in terms of value.

4.1.2.2 Location of the forest biorefineries

The location of the biorerefinery facilities and transporting of biomass divided opinions. There were respondents who believed that transporting bulky, low-density biomass will not be an economical option. The negative sides of raw material transporting would be destroying the national employment rate, averting growth of national products and security of energy supply. On the other hand, some of the respondents indicated that a major factor will be the labor costs, and thus biomass can be transported for processing to the countries in which labor costs are cheaper.

Further, in North America, the placement of the biorefineries divided opinions as well. Some respondents believed that the western United States and western Canada will be the first to see an emergence of the biorefining business and that the East Coast will be slower, as large pulp and paper mills in the southeastern U.S. were believed to protect their wood purchases. Instead, some respondents believed that the pulp and paper business on the East Coast will be the most favorable option for the co-location of biorefineries. This view supported the prevailing opinions that first demonstration facilities will be integrated with the current pulp and paper mills. Overall, first demonstration plants were believed to be located in Scandinavia and North America, but in the future fast-growing biomass may direct biorefining business to South America and Asia.

4.1.3 Need for change

All in all, it seems that the forest industry is in a situation in which new business development and start-ups are crucial, due to the mature – or even declining – state of many parts of the business. Forest biorefineries are seen in general as an environmentally and economically sustainable new business opportunity. However, due to its capital intensiveness and traditional business culture, these changes require powerful support from the core business, as well as a strong managerial effort. Interesting questions remain: is the forest industry ready for the change?; how does new business fit into the current business?; and what kinds of resources are needed for management of change as well as for maintaining new business operations?

> The pulp and paper industry is being displaced from all the production in China and in Asia, and in South America, and we haven't invested in a new mill here in ages, so I think they're bound to be displaced anyway. And the smart ones will get on the bandwagon, and find a way to integrate, but I think they'll be forced to change their habits more than anybody and be faced with the potential of losing more business. (Investor, U.S.)

> Are they really vigorously pursuing biorefining technologies and all of that? No. Maybe some are, but industry-wide, no – they're just trying to keep their noses above water and make it from quarter to quarter. (Researcher, U.S.)

4.2 Change features in the forest industry

4.2.1 Readiness for change

Most of the respondents evaluated readiness for change and number of future-oriented actions in the forest industry to have been low in general. The forest industry is seen as a conservative industry, one that has resisted change and been focusing on its current core businesses without long-term visions or strategic planning. Consistently, many respondents also indicated that there have not been enough activities towards and investments in new business, and forest biorefineries currently do not hold a prominent position as a part of the forest industry's strategies.

> I came from that industry and that's just the way it is. They're very difficult to change. Very, very difficult to change, even when it's staring them right in the face and they know they're going to fail, they know they're going to go bankrupt, they still cannot force themselves to change. It's the most insane thing I've ever witnessed in my life. (Forest sector representative, U.S.)

Many respondents believed that the main reason for this slowly changing culture is the industry's capital intensiveness. Furthermore, a lack of resources for their own research and development were seen as significant obstacles (see a more detailed description in Section 4.2.3.2). It was also mentioned that the forest industry itself has been overly optimistic about the pace of technology development and diffusion of new technologies, and thus not invested enough in new opportunities.

Interestingly, while there were several comments about the forest industry's conservativeness and change resistance at the corporate level, at the same time significance of innovativeness and visionariness of individual personnel members were seen as positive and important resources for future developments.

> It's not that there aren't visionary people and innovative people in these companies. It's just as a company philosophy, they're very slow to develop that and they have not supported their research and development. (Researcher, U.S.)

There were also respondents who believed that the forest industry has been more future-oriented and strategic than has been publicly indicated. Respondents also indicated that many organizations have explored new business opportunities, and they have been discovered to be unprofitable – thus opinions about industry conservativeness are not unanimously prevailing.

> I think they were forward-looking, and I think they have largely done the job. I think what they've discovered is how hard that job actually is. We've got a lot of people who are in the process of discovering that same thing. – Well, okay, first off, the paper industry has looked at biofuels pretty much continuously for over 50 years and has never found good ways to get it to work- they couldn't find a way to make it profitable. So I don't think we should be suggesting that they weren't looking at the business climate and they weren't looking at future possibilities. (Researcher, U.S.)

Likewise, according to many respondents, the need for change and key drivers for that are widely recognized within the forest industry, but actions and pathways need still largely to be created. Many organizations have also recently started to put more resources into new business options and there are many initiatives towards forest biorefineries. Many respondents expected to see several biorefinery projects started in three to five years.

4.2.2 Scope and preservation

4.2.2.1 Compatibility of forest biorefineries with the traditional organizational culture of forest industry

The respondents found arguments equally for and against the feasibility of forest biorefineries and their fit in the forest industry's current core businesses and organizational culture. The respondents believed that operations and scale when producing biofuels in particular will fit well into traditional operations. As an advantage of the biorefining business, the respondents remarked that the business is challenging enough, and thus unique skills, know-how and technologies cannot be easily copied by other sectors. Overall, it was believed that the pieces are starting to fall into their places – the vision and the goals to embrace the new technology and business – though changes will happen gradually.

However, there were respondents who believed that organizational values and culture in the forest industry will not support the biorefining business. Particularly, production of high value-added products was seen to be very different and challenging for the industry, which traditionally focuses on bulk production. Accordingly, forest biorefineries were believed to require a very different set of skills that are challenging to find in the forest industry.

> It's different and requires different skills. You know, it's a little bit scary. (Forest sector representative, U.S.)

> Maybe not... or let's say that yes and no; you see, if we're now talking about this Fischer-Tropsch fuel, such a big plant's production must be quite extensive. But then,

> if we start making some stuff that costs, say, 35,000 euros per kilo, then it's somehow completely different. There we have to consider everything in a different way. (Forest sector representative, Finland)

New products would also require new contacts and marketing channels that can be difficult to find.

> Well, it's partly quite suitable; because if you think of the raw material it uses, it is quite ok. The only concern there is that when you have a new product, you also have a brand-new market and new clients, and all this stuff; well that's what worries me the most for those who in a way don't have a partner there. (Forest sector representative, Finland)

Some respondents believed that biorefinery products will take only a very marginal segment of the forest industry's production in the future (see also Section 4.1.2 regarding the potential share of the new products).

4.2.2.2 The forest industry's role in the consortium and organizational structure of the biorefineries

The most important strategic competencies of the forest industry are the knowledge of raw material acquisition and logistics. In other words, the forest industry's role in the biorefinery business is predominantly seen as a raw material provider and initial processor. According to the majority of respondents, it is likely that energy or oil companies will dominate in the consortium, the most important reason being that they control distribution channels. However, some respondents believed that the forest industry will be an equal partner in the consortium, and contracts that protect the forest industry's rights will be negotiated. Most of the respondents highlighted the importance of strategic alliances and partnerships that can create a variety of synenergies.

Responses regarding the organizational structure in the biorefining business and the need for separate organizational units were varied, from separate companies or legal entities to the need for closely integrated units. It seems that at this point it is difficult to give a straightforward answer, as actual integration at the operation level is still unclear, and there exists no single biorefinery model. Some of the biorefining processes that are planned will involve modifying pulp mills, thus considerably affecting existing operations. According to most of the respondents, integration at the operational level will be needed to make biorefinery business profitable. Likewise, combining leadership and management with existing business largely depends on biorefinery partnership, model and degree of integration. Some of the respondents also believed that legal restrictions will shape the final organizational structure. Overall, the respondents believed that planning and establishing a functional organizational structure for forest biorefineries will be challenging.

4.2.3 Resources

4.2.3.1 Capabilities required for change management

Transition towards the forest biorefinery business and changing direction of large organization in general are great challenges for leadership and management in the forest industry. According to the respondents, the forest industry needs leaders and managers who have – and are able to encourage – vision and strategic knowledge, as well as innovativeness, an enthusiastic attitude and willingness to seize new opportunities. At the same time, the previously mentioned issues were seen as the most needed capabilities in current forest industry culture. In addition, the respondents believed that a variety of new options and the "hype" around the biorefining business further complicates finding new ways to operate and creating a future-oriented outlook.

Leaders and managers should have wide and multi-disciplinary knowledge: insights by the forest and chemical industries, as well as finding synenergies between different industries were highlighted as significant challenges for the management. Accordingly, it was emphasized that the forest industry should be well aware of the variety of different options in order to react and differentiate when needed. Still, profiling company specific core competences rather than following competitors was considered important. The forest industry needs leaders and managers, who understand also features of value-added production in addition to traditional bulk production. One of the prominent challenges that respondents indicated was that the higher-level management in the forest industry usually comes from within the industry: it was proposed that forest industry should hire management personnel outside the industry in order to widen the traditional product-oriented perspective of forest industry managers.

> If you think of executives as coming out of a single pool in the university – which isn't true, but it's a nice simple way to think of it – they've got their choice of where to go. And where do they go? Well, the very best ones are going into IT, bio-tech, you know, some of them are going into – it's the exciting areas, communication – that are really moving and happening quickly. The Blue Chip areas, the forest products companies and even the chemical companies to some extent, they don't get the same vision and leadership. You know, Steve Jobs isn't running Du Pont. (Researcher, Canada).

> We're going to have to switch from commodity thinking to how do you maxi- you know, how do you get the most out of a highly-valued product? And there's probably going to be more R&D necessary per ton of production for that. There will be more technical skills needed. There's more marketing skills, more international capabilities in terms of finding markets. (Investor, U.S.)

According to some respondents, the forest industry was seen as an adversarial business that concentrates on competition, where collaboration inside the industry as well as with other sectors is neglected. In general, finding a matching partner, coordinating different organizational policies, procedures and operation modes as well as investing equally in collaborative effort and defeating antitrust between potential partners are the issues that are seen as notable managerial challenges when establishing a new business.

The biggest challenge in operating the biorefinery consortium will definitely be sharing the profits between the partners. Some of the respondents believed that the chemical and oil industries will dominate within the consortium and take the biggest advantages. This naturally sets requirements for the biorefinery management that fair contracts would be negotiated.

> There will be no problem with the sharing of the profit. Exxon will take the profit. (Researcher, U.S.)

> I think we're probably more open at a production site to share technology, share leadership, but I know that one of the biggest challenges is who and how do they divide up the economic value that's created? You know, is it based on technology or is it based on the supply of the raw material and logistics afterwards? That's going to be a huge issue and the challenge to partnership is dividing up the pie. (Forest sector representative, U.S)

Likewise, sharing the managerial responsibilities between different actors will be difficult for top management. Accordingly, important skills at the managerial level will be an understanding of market development in the global arenas, as well as the ability to commercialize and market new products. It follows that challenges for the managers will be finding new customers and contacts in the new business areas.

It is also important that managers are able to recognize potential areas of top-level know-how, and that they provide enough resources to develop them. Management should put more effort towards developing human resources in general, and individual skills should be appraised. Encouraging people to study and enter the industry will be also important in order to have enough capable personnel to manage and operate new business. The important skills will also include the ability to interact with researchers and further communicate these ideas to the managerial level in order to find new possibilities, and understand the importance of renewables in particular. The forest industry should also actively inform and educate its stakeholders about the course of sustainability – social, environmental and economic – for emerging biorefinery business.

4.2.3.2 Capacities required for operating biorefineries

Financing

Many respondents indicate that forest biorefineries have very high investment costs, and revenues from the new business are not currently considered sufficient in the capital-intensive forest industry. The capital cost of current business has been high, and therefore many organizations will largely concentrate on producing traditional products and fulfilling the demand of current customers and markets as optimally as possible. It is also difficult to find private capital investors for new business. Some of the respondents suggested a rationalization of assets as the most needed actions in the forest industry in order to promote forest biorefineries.

> I think they were looking at it [developing biorefineries]. But you can't make money in the future. You have to make your money now. And the one thing that the paper industry is very much aware of is that they have to make the money now. They don't have enough other financial resources to tie them over 15 years until something turns around. (Researcher, U.S.)

As one of the biggest threats for the new biorefinery business the respondents considered high raw material price, and it was estimated that when demand increases there is even more pressure on wood biomass prices. On the other hand, some respondents considered wood biomass to be a nearly untapped raw material source with huge potential.

Skills and know-how

The respondents believed that in biorefineries more diverse skills are needed compared to traditional forest industry practices. Overall, in order to operate forest biorefinery facilities successfully there needs to be a balance between managerial and technical skills. Engineering, chemical engineers in particular, who are able to manage new processes, will be an important part of the forest biorefinery staff. Altogether, respondents highlighted that the right set of skills and knowledge can be achieved through collaboration and partnerships.

As previously mentioned, the forest industry by nature understands wood and related feedstock systems, logistics and refining processes. However, it also needs a general understanding of all value chain operations, not only those operations in which they have traditionally been involved.

Raw material availability and sustainability

There are both prominent opportunities and threats related to the wood raw-material of the biorefinery business. Many respondents believed that the use of wood is considered environmentally sustainable, given its intrinsic status as renewable natural resource. It was also mentioned that the forest industry has a long tradition in managing forests in an environmentally sound way. Moreover, there is knowledge about the required environmental practices, certifications and regulations in the forest industry. Overall, the respondents clearly indicated that environmental sustainability is an important driver for the forest biorefinery business in general.

However, in addition to price challenges related to raw material, using wood as raw material was seen as a threat from the environmental perspective (particularly in the U.S.). The role of NGOs, particularly various environmental groups, was considered important in the growing resistance to disturbing forest ecosystems. Correspondingly, many respondents believed that environmental regulations will not support the use of wood biomass in biorefineries in the long term.

Research and collaboration

The interview questions about research and collaboration prompted many respondents to reflect again on the forest industry's corporate strategies in general as well as its current state as a mature industry. The respondents were unanimous in that forest industry companies largely lack financial resources for research, and only a few of the largest ones have resources left for in-house development. Accordingly, resources were seen to be directed towards supporting current mills and the development of existing processes and products. Here again, some respondents highlighted that it is not visionaries and innovators who are missing in the forest industry, but rather company philosophies do not encourage new innovations and new ideas. Forest industry companies were also criticized for copying the business models, practices and products of one another.

> Less (research and development) now than they used to, much less now than they used to. I think that's part of the thinking of themselves as a mature industry, thinking that there's not much room for innovation has hurt them. I can't think of a company now that has a really active research program. Warehouser had the strongest one for many years, but they keep cutting back on their staff. (Forest sector representative, U.S.)

> Then, if we want to keep it (technology and technology providers) here, we really should allocate resources to research activities and these types of developmental projects. And otherwise we'll end up having that cluster in South America. Or if we are pessimists, then… or optimists, it will be in China. (Forest sector representative, Finland)

Some of the respondents also brought up that it is very understandable that forest industry companies do not invest in in-house R&D. First, the equipment suppliers will ultimately be able to take advantage of new technologies and accordingly, they will market the technologies worldwide. Second, forest industry stakeholders do not encourage investments in R&D because new technologies are available for competitors almost instantaneously.

In contrast, there were many respondents who believed that there is plenty of potentially successful projects and research being carried out through national programs, research institutes, universities and consortia in which different partners can collaborate. Finnish respondents in particular highlighted the traditions of the forest cluster for successful collaboration. However, it was also believed that collaboration can be done in basic research and development, whereas competition prevents collaboration when development comes closer to potential commercial processes and products.

5 DISCUSSION AND CONCLUSIONS

North American and Scandinavian forest industries are facing the situation in which business development and start-ups are crucial, due to the mature – or even declining – state of many parts of the business. The drivers for change are widely recognized, but pathways and processes for the new business and product generations largely still need to be created.

Although the changes in the forest industry business environment have not been sudden, nor surprising, pursuing new business and creating related change strategies and procedures are not easy for any organization. For the traditional, capital-intensive forest industry, the conservative organizational culture and lack of financial resources as well as concerns related to raw material price, availability and sustainability seem to create prominent barriers to change according to our results. It is understandable that the capital-intensive industry cannot make investments without careful consideration. However, excessive carefulness and change resistance can deteriorate the forest industry's future survival. The danger of a mature mindset has been also recognized by various other studies (see references in Section 1).

Overall, future business models of biorefineries both in Scandinavia and North America have many similarities and can be characterized as follows: In the biorefinery consortium the role of the forest industry is largely seen as biomass provider. High value-added products and Fischer-Tropsch biodiesel will be key, but in general biorefining business needs to be planned to support traditional core businesses. Like traditional forest industry facilities, the biorefineries will also eventually be located mainly in an area with plenty of affordable biomass and low labor costs, even if the first pilot and demonstration facilities will be built in Scandinavia and North America. The birth of the new business will be very erratic: there will be lots of false starts before the most ideal models can be found.

However, it is not possible to create exact forecasts and propose business strategies for biorefineries that would be suitable for every situation – instead, case-by-case evaluation is needed. The scope of the change with the necessary transformational activities and resources depends largely on the biorefinery location, degree and site of integration, chosen technologies, availability of raw materials and specific knowledge of the biorefinery partners. In addition, there should be an aspiration towards focusing and differentiation: pursuing the same models as those of the competitors will not be the best pathway to follow.

The need for change and diversifying product portfolios in the forest industry sets many expectations and requirements for forest industry management. Casti and Ilmola (2011) also recognized resilience to change, management of diverse portfolios and broad visions by management as one of the greatest future challenges in the forest industry. Readiness for change and enthusiasm need to be embedded in the organizational culture – and the key for attaining this is open-minded, multi-disciplinary organizational management.

There needs to be open and innovative dialogue both inside the organization and with potential partners outside the organization. Interestingly, despite the prevailing opinion of the slowly changing organizational culture and resistance to change, visionary and innovative personnel are believed to be found in forest industry companies, yet current culture do not encourage these people to put forward their ideas. Management should encourage these individual-level capabilities and take advantage of them on the organizational level. Accordingly, finding new, capable, multi-competent staff through education and collaboration is also important. All in all, operating a commercial scale forest biorefinery facility requires both new managerial- and operational-level skills.

The most prominent dilemma related to the emerging biorefinery business is intertwined with the following issues: first, success in the biorefinery business cannot be achieved without collaboration and partnerships that combine the right set of skills and knowledge. Second, the biggest challenge seems to be sharing profits between these partners in the forest biorefinery consortium. Those who will solve this dilemma by finding and sustaining a successful consortium will likely be the future leaders of the biorefining business. For example, there will be interesting opportunities in the interface of the forest industry and chemical industry (Argyropoulos, 2007; STAR-Colibri, 2011). Other studies have also indicated that forest industry companies do not have to necessarily develop new technologies by themselves when they are restructuring their businesses. They can obtain knowledge through patents and other immaterial rights or they can acquire companies with the defined competitive knowledge and technologies. (Eloranta et al., 2010; Hetemäki et al., 2011) These companies can come from outside the traditional forest sector (Hetemäki et al., 2011). Overall, the forest industry needs to transform its business in one way or another. Correspondingly, there is an increasing call in our society for a bio-based, green economy with related new business strategies and models. The biorefining business can be one of the most successful strategies towards these goals.

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APPENDIX 1 INTERNET SURVEY QUESTIONNAIRE OF THE FIRST DELPHI ROUND

BIOREFINERIES-FUTURE BUSINESS OPPORTUNITY FOR FOREST CLUSTER

Requirements to and barriers for diffusion of forest biorefineries in Scandinavia, North America and South America

DEFINITIONS

Biofuel:
Liquid, gas or solid fuel made from wood-biomass or heat generated by using wood biomass.

Forest industry:
A forest industry includes pulp, paper, paperboard and wood products industries (The latter contains sawmilling, plywood, chipboard, fiberboard and construction products industries).

Forest cluster:
A forest cluster is the gathering of industries and production facilities around the forestry and the forest industry. A forest cluster includes mechanical, chemical and packaging industries related to the forestry and the forest industry. A forest cluster includes also related energy, logistics and consulting companies, as well as research centers and universities.

Forest biorefinery:
A forest biorefinery is a multi-product factory that integrates biomass conversion processes and equipment to produce fuels and chemicals from wood-based biomass.

Forest biorefinery value chain:
A forest biorefinery value chain is a string of diverse companies, working together to satisfy market demand for wood-based biofuels and biomaterials.

Diffusion:
Expansion of utilization of a new concept.

Module 1/5 Respondent's background
It will take couple of minutes to answer to this module.

1. Your country?
Argentina
Brazil
Canada
Chile
Finland
Sweden
Uruguay
U.S.
2. Your province/territory (Canada)?
3. Your state (U.S)?
4. Field of activities / line of industry?
Forest industry
Energy industry
Oil industry
Chemical industry
Technology providers in the forest cluster
Car industry
Investor
Research
Public authority
Other, please specify

Module 2/5 Forest biorefinery diffusion
It will take 5-10 minutes to answer to this module.

1. In your opinion, what are the greatest incentives for forest biorefineries and wood-based biofuels in your country? You can choose as many options as you want.
Climate change
National security of fuel supply
Increasing price of oil
Increasing demand for biofuels
Decreasing demand for traditional wood-based products (e.g. pulp and paper)
Relocation of the traditional forest industry to South America and Asia
Encouraging national environmental and energy policies
Encouraging international environmental and energy policies
Other, please specify
2. What is your opinion about the following statements concerning economic and market factors that affect the diffusion of forest biorefineries (strongly disagree, somewhat disagree, neutral, somewhat agree, strongly agree).
1. Large companies in the forest cluster have the investment capability to develop forest biorefineries.
2. Small and medium size companies in the forest cluster are capable to invest in forest biorefineries.
3. Private financing available for forest biorefineries is sufficient.
4. Public financing available for forest biorefineries is sufficient.
5. Uncertainty concerning the profitability of biofuel and chemical production creates insecurity for biorefinery investments.
6. Price competitiveness of wood-based biofuels is attractive in the current market situation.
7. For the pulp and paper industry production of electricity will be more profitable compared to the production of biofuels.

8. Wood-based biomass as a raw material is too expensive for the production of biofuels.
9. The oil industry´s increasing control of the biofuel market reduces the forest cluster´s opportunities in the biofuel market.

3. What is your opinion about the following statements concerning technological factors that affect the diffusion of forest biorefineries (strongly disagree, somewhat disagree, neutral, somewhat agree, strongly agree).

1. Technology will become a barrier to biorefineries.
2. The forest cluster has enough R&D expertise to develop forest biorefineries.
3. Companies in the forest cluster can easily find consultancy for biorefineries.
4. Companies in the forest cluster are confused about the variety of technical choices and combinations offered for the production of biofuels and chemicals.

4. What is your opinion about the following statements concerning political factors that affect the diffusion of forest biorefineries (strongly disagree, somewhat disagree, neutral, somewhat agree, strongly agree).

1. Energy and environmental policies in your country/region are long-term and predictable.
2. There are inconsistencies between state (provinces) and national energy and environmental regulations.
3. There exist political tensions between different parties about industrial utilization of forests.
4. Strong political pressure towards agricultural-based biofuels hinders forest biorefinery diffusion.
5. Politicians and other decision-makers have enough knowledge about the forest sector and forest management issues.
6. There is enough support for forest biorefinery demonstration and pilot plants.
7. Subsidies for the production of biofuels will be more effective compared to the subsidies for investments of new biorefinery facilities.

5. What is your opinion about the following statements concerning ecological and raw material related factors that affect the diffusion of forest biorefineries (strongly disagree, somewhat disagree, neutral, somewhat agree, strongly agree).

1. The capability to collect and utilize existing wood biomass resources will be a limiting factor rather than the absolute amount of wood biomass.
2. Raw material demand of forest biorefineries cannot be satisfied solely with wood-based biomass (e.g. agri-feedstocks will be needed).
3. Only wood biomass, that cannot be used for higher value products, should be utilized for biofuel production.
4. Increasing public awareness about forest management issues and environmental aspects related to biorefineries promotes diffusion of biorefineries.
5. Environmental impacts of collecting of wood biomass (forest residues) are sufficiently known.

6. What is your opinion about the following statements concerning collaboration that affect the diffusion of forest biorefineries (strongly disagree, somewhat disagree, neutral, somewhat agree, strongly agree).

1. The forest industry companies are willing to co-operate with other companies in the same industry to develop forest biorefineries.
2. The forest industry is willing to co-operate with companies outside the forest industry to develop forest biorefineries.
3. The forest industry is willing to co-operate with research institutes to develop forest biorefineries.
4. The petrochemical industry is interested in co-operating with the forest industry in production of wood-based traffic biofuels.
5. The forest industry is in contact with top experts of the field worldwide.

Module 3/5 Feedstock & technologies
It will take around 5 minutes to answer to this module.

1. In your view, what kind of forest biorefineries will have the greatest potential in your country in the future? Please, choose one alternative.
Biorefineries which are integrated in pulp mill/pulp and paper mill
Biorefineries which are integrated in saw mill/lumber industry
Stand-alone forest biorefineries
Integrated and stand-alone biorefineries have equal potential
No opinion
2. In the future (2020), the majority of the wood-based liquid biofuel production capacity in your country will take place in
Biorefineries, where production capacity is less than 50 000 t/a
Biorefineries, where production capacity is between 50 000 and 100 000 t/a
Biorefineries, where production capacity is more than 100 000 t/a
No opinion
3. In your opinion, when will commercial scale implementation of the following technologies take place in wood-based biomass processing?
(<5, 5-10, 11-20, 20-30, more than 40 years, will not happen, no opinion)
Solid biomass gasification and gas cleaning for synthesis applications
Black liquor gasification and gas cleaning for synthesis applications
Fast pyrolysis
Acid hydrolysis and fermentation
Enzymatic hydrolysis and fermentation
4. This question relates to the previous question 3. In your view, what are the greatest advantages related to the technologies which are closest to the commercial scale implementation? Please, choose the three most important ones.
Less capital-intensive facilities will be needed compared to the other technologies.
Production costs are likely to decline faster than for the other pathways.
Potential to produce more fuel per tonne of biomass compared to the other pathways.
Technology is able to accommodate a wide variety of feedstock.
Quality of the end product is better compared to the other technologies.
Greenhouse gas emissions during the life cycle of the product are smaller compared to the other technologies.
Other, please specify
No opinion
5. Can you foresee any radical innovations that could be used in wood-based biofuel production in the near future? If yes, what could these wild cards be?
No
Yes, please specify
No opinion
6. In your view, which of the following wood-based biomass sources are the most significant in biofuel production in the future? Please, choose the three most important ones.
Forest residues (logging residues, forest reduction/restoration thinnings)
Disease-killed timber
Bark from pulp industry
Raw soap from pulp industry
Black liquor from pulp industry
Tree oils
Lumber industry/saw mill residues
Industrial organic sludges
Urban organic waste (e.g. waste paper, tree trimming residues, fuel management, construction lumber)
Biomass from dedicated energy crops (e.g. hybrid willow, poplar, eucalyptus)

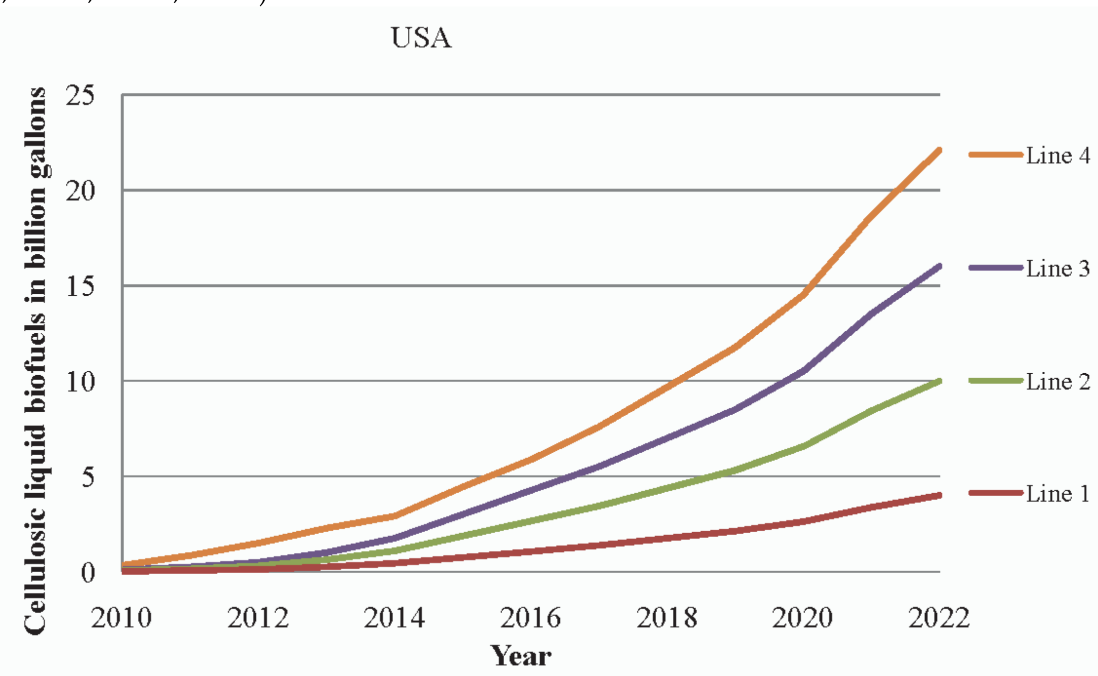
Other, please specify
No opinion
7. In your opinion, what are the greatest challenges related to the utilization of feedstock chosen in the previous question 6? Please, choose the three most important ones.
Accessibility and competition for raw material
Unstable markets and volatility of raw material costs
Harvesting equipment and costs
Logistics and transportation economics
Storage of biomass
Quality of feedstock (e.g. dirt, moisture, density)
Infrastructure and new equipment designs for feedstock utilization
Public perceptions and environmental debate
Regulatory hurdles
Other, please specify
No opinion
8. In your opinion, which of the following forest biorefinery products will have the greatest market potential in the future? Please, choose the three most important products.
FT-diesel
Methanol for fuel
Hydrogen
Synthetic natural gas
Dimethyl ether (DME)
Ethanol for fuel
Butanol for fuel
Bio-oil by pyrolysis
Biodiesel by hydrotreatment
Biodiesel by tranesterification
Polymers
Resins
Lubricants
Solvents (e.g. acetone, ethanol, butanol, methanol)
Organic acids (e.g. lactic acid)
Other, please specify
No opinion

Module 4/5 Scenarios
It will take around 5 minutes to answer to this module.

1. In your opinion, what role will the production of biofuels in biorefineries play on the forest cluster's competitiveness in your country? (very insignificant, somewhat insignificant, neutral, somewhat significant, very significant)
In 5 years
In 10 years
In 20 years
In 30 years
In 40 years
2. In your opinion, which of the following views of the future describes best the future development of the forest cluster in your country? (Source, modified from Häyrynen et al. 2007)
1 Business as usual. There are no radical changes in the development of the forest cluster in the future. Production efficiency is further optimized. Raw material availability in the market is a crucial factor in future success. Production costs and demand determine locations for production facilities. Biorefineries and related new bioenergy products will not play a significant role in the forest cluster.

2 Restructuring the business. Competitiveness of the national, traditional forest cluster disappears. Staying with old production structures contains high risk. Investments are aimed towards new markets and new business concepts. There is a strong interest and increasing amount of projects towards forest biorefinery concepts and new bioenergy products.
3 Sustainability. Sustainability is the key issue also in the financial decision making. The forest cluster is successful in a society, which respects ecological values and sustainable forest utilization. Production will be further developed towards energy and raw material efficiency. Biorefineries and related new energy products guarantee the forest cluster's success in a sustainable way.
4 Domestic competencies. Globalization increases the risks related to international business, thus making domestic investments more stable and appealing. The national security of fuel supply and independence of imported oil will be seen as important issues. The forest industry core competencies are sustained in domestically and competitiveness of domestic companies are maintained**.** Combination of skills in biorefineries creates a core competence, which cannot be easily copied, thus making them a valuable competitive national advantage for the forest cluster.

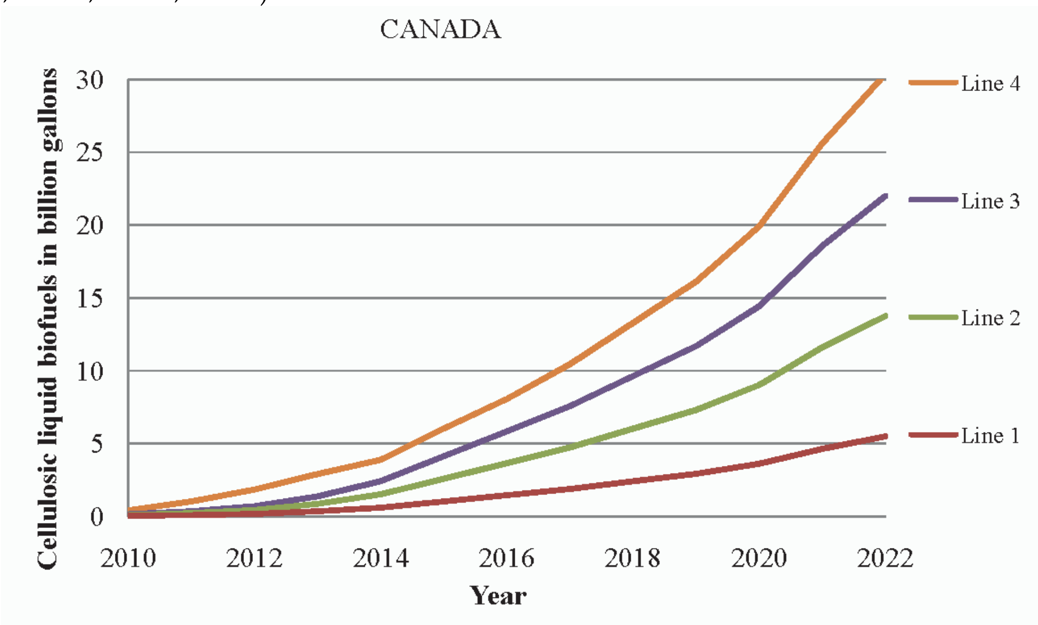
3. In order to get the right figure for the next question, please choose your own area.
(U.S., Canada, Finland, Sweden, Latin America)
3a. In the case that there will be no radical changes in the business environment, which pathway describes best the CELLULOSIC liquid biofuel production in the U.S.? Please, choose one alternative.
Line 3 indicates the goal for the production of cellulosic biofuels according to the Renewable Fuel Standard.
(Line 1, Line 2, Line 3, Line 4)



3b. In the case that there will be no radical changes in the business environment, which pathway describes best the CELLULOSIC liquid biofuel production in Canada? Please, choose one alternative.

The Renewable Fuels Standard requires 5 % renewable content in gasoline (app. 0,55 billion gallons) by 2010.

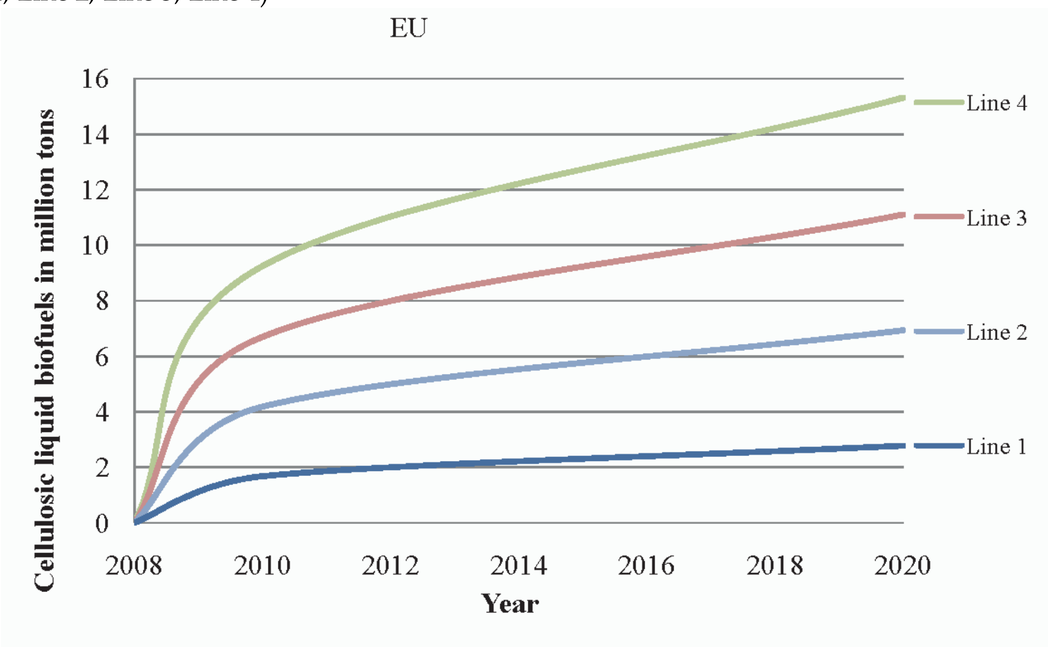
(Line 1, Line 2, Line 3, Line 4)



3c. In the case that there will be no radical changes in the business environment, which pathway describes best the CELLULOSIC liquid biofuel production in the EU? Please, choose one alternative.

The European Union has 5,75 % minimum biofuel target in total transport use by 2010 and 10 % target by 2020. The assumption is that one third of the biofuel production will be cellulose-based. Line 3 indicates this assumption.

(Line 1, Line 2, Line 3, Line 4)



3d. How much CELLULOSIC biofuels will be produced in your country in the year 2020 in the case that there will be no radical changes in the business environment? Please, choose one alternative.
Less than 1 million tonnes
1-5 million tonnes
6-15 million tonnes
16-25 million tonnes
More than 25 million tonnes
4. In your opinion, what are the prerequisites for actualizing the political goals concerning production of liquid biofuels in your country? Please, define the most important factor(s) which would make this pathway possible.
Open
No opinion
5. In your view, which of the following renewable traffic fuels have the greatest potential when compensating fossil fuels in the future? Please, choose one alternative.
Conventional agri-based biofuels
Cellulosic agri-based biofuels
Wood-based biofuels
Municipal waste-based biofuels
Green electricity
Hydrogen
Other, please specify

Module 5/5 Business models
It will take 5-10 minutes to answer to this module.

1. What is your opinion about the following statements concerning reactions and foresight of the forest cluster to the changing business environment (strongly disagree, somewhat disagree, neutral, somewhat agree, strongly agree).
1. There is a need for a comprehensive re-evaluation of wood utilization and the wood-refining chain from a fresh perspective.
2. Large companies in the forest cluster concentrate on the optimization of the whole organization's business operations and the possibilities of single production units are not adequately recognized.
3. Forest industry companies concentrate on growth in new market areas and do not consider new possibilities in their existing markets.
2. What is your opinion about the following statements concerning the biorefinery concept and new wood-based products (strongly disagree, somewhat disagree, neutral, somewhat agree, strongly agree).
1. Existing infrastructure and permits in the forest cluster create significant competitive advantages for the forest cluster compared to other actors in the biorefinery business.
2. Wood-based biofuel production is considered as a serious business opportunity in the forest cluster.
3. Wood-based chemicals production is considered as a serious business opportunity in the forest cluster.
4. Capitalizing on biorefinery opportunities will be the only way to avoid massive shutdown and loss of pulp and paper facilities.
5. Forest biorefinery consortia offer small companies a possibility to enter new, larger markets.
6. Forest companies in our country have a chance to be leading actors in forest biorefinery business worldwide.
7. Flexibility in production according to the market situation (possibility to vary raw material mix and adjust processes) increases profitability of forest biorefineries.
8. Forest biorefineries are sensitive to changes in the business environment.
9. Wood-based biofuels produced in biorefineries will have a positive public response.

10. Wood-based biofuels produced in biorefineries will be mainly used in the domestic market.
11. In the future (2020), wood-based liquid biofuels will be produced on a commercial scale.

3. In your view, what kind of skills and business competencies will be needed in the future for the forest cluster/forest biorefineries? Please, estimate the significance of the following issues. (very insignificant, somewhat insignificant, neutral, somewhat significant, very significant)

Business know-how
Financial expertise
Risk management skills
Product and technological innovation
Business model innovation
Process expertise
Ability to interact with and actively shape the environment
Management of change
Recognition of new core competencies and applying new information
Understanding of new markets
Consideration of long time perspective
Creation and management of networks
Management of wood supply chain

4. In your view, what are the most important strengths of the forest cluster related to the development of forest biorefineries in your country?

Open
No opinion

5. In your view, what are the most important weaknesses of the forest cluster related to the development of forest biorefineries in your country?

Open
No opinion

6. In your opinion, what part of the forest biorefinery supply chain will be the most challenging to manage? Please, choose the most important one.

Forest management
Harvesting/collection of raw-material
Storage of raw materials
Pre-processing
Transportation to conversion
Production
Distribution
Marketing & branding
End use

7. In your opinion, how significant are the following partners in forest biorefinery consortia? (very insignificant, somewhat insignificant, neutral, somewhat significant, very significant)

Forest industry
Technology providers in the forest cluster
Energy industry
Car industry
Oil industry
Chemical industry
Biotech industry

8. In your view, which one of the following industries will be the dominant actor in the forest biorefinery consortium? Please, choose one alternative.

Forest industry
Technology providers in the forest cluster
Energy industry
Car industry
Oil industry

Chemical industry
Biotech industry
Other, please specify
9. What is your opinion about the following statements concerning forest biorefinery consortia (strongly disagree, somewhat disagree, neutral, somewhat agree, strongly agree).
1. The forest biorefinery consortia will lead to a growing dependence on co-operation within the biorefinery value chain.
2. There are business opportunities for new actors in the forest biorefinery value chain.
3. The forest biorefinery consortia will lead to new division of tasks within the biorefinery value chain.
4. The forest biorefinery consortia will need new processes for strategy making.
5. The forest biorefinery consortia will need strong leadership.
6. The forest biorefinery consortia will lead to new division of power within the biorefinery value chain.
7. The dominant companies in the forest cluster are responsible for introducing and putting into practice new business ideas.
8. Sharing responsibilities between the biorefinery value chain actors will be problematic.
9. Sharing revenues between the biorefinery value chain actors will be problematic.
10. Sharing synergy benefits between the biorefinery value chain actors will be problematic.
10. In your view, what level of ROI (return of investment) would be acceptable for the forest biorefineries? Please, choose one alternative.
5 % ROI
10 % ROI
15 % ROI
11. This is the last question of the questionnaire. If you have any additional comment(s) concerning forest biorefineries, please add them here.

APPENDIX 2 THE INTERVIEW THEMES OF THE THIRD DELPHI ROUND

Interview themes

Evaluation and processing of the results from the 1st and 2nd rounds
Part 1 Key Diffusion Factors Promoting Forest Biorefineries & Future Scenarios

1. **Key factors** (according to my previous research) **promoting** faster development of **forest biorefineries** are summarized in the following figure.
Choose
-the most relevant macro-scale factors
-the most relevant sector-/industry-specific factors
-the most relevant strategic level factors that promote biorefinery diffusion

-Which issues do you consider the most relevant? Why?
-What are the critical success factors in the forest biorefinery business?
-Are there issues that are not mentioned in the previous list?
-What are the most important external/internal sources of national (respondent's own country) competitive advantage?
-What are the current threats & barriers to forest biorefinery development?

2. What is your opinion of the **cellulosic biofuel production volumes** presented in the following scenarios (particularly the respondent's own country)? Are they realistic?[13]

3. What is your opinion of the **technological options** presented in the following figures (particularly the respondent's own country)? Do they correspond to your view about the issue?

Finding new aspects
Part 2 Forest Industry Corporate & Business Strategies

1. How would you describe the forest industry's past and current situation and strategic actions (in general)?

2. How would you describe the **forest industry's past and current strategic actions in developing biorefineries?**

-How competitive advantage has been pursued in the forest industry?
i.e. What kinds of competitive strategies have been used in order to gain a competitive advantage? What kinds of methods have been used in pursuing a competitive strategy?
-'What business are we in?', is this clear for the forest industry?(corporate str)
-'How should we compete?' is this clear for the forest industry?(business str)
-Innovativeness
-Future-oriented actions?
-Mistakes/successes?
-Customers' needs, competition, capabilities & resources – how are they met?
-What is missing – knowledge, skills, vision, courage, will, financial resources?

---

[13] The scenarios and the technological options that were evaluated by the respondents in the third research round are presented in the manuscript 1.

3. How would you describe the **change** that is currently happening in the forest industry?

-Nature, time, scope

-Capability, capacity and readiness for change

-Need for dual strategies and separate organizational units?

4. How does the **future** of the forest industry look?

-Location/amount of production facilities?

-Share of traditional products/new products (biofuels, biochemicals, product diversity, future star products?)

-What are the future core competences and unique resources (key success factors, strategies to attain them)?

-Opportunities & threats? Strengths and weaknesses? (SWOT)

-What kinds of actions would be needed most at the moment in the forest industry?

5. What kind of **role** does the forest industry play **in the biorefinery consortium**?

-Dominant? (elaborate on the earlier results)

-Challenges? (elaborate on the earlier results)

-Needed capabilities, resources and competencies (tangible, intangible)? Elaborate on the earlier results

6. How do **biorefineries fit in** with the forest industry's

-History and organizational culture (strategic drift, path dependency)

-Visions, values and goals

-Capabilities (tangible, intangible)

-Structure and systems (the ways in which people can be organized for success)

Finding new aspects

Part 3 Environmental and Economic Sustainability in Forest Biorefinery Value Chain Companies

1. Is **environmental sustainability** an important **driver** in the forest biorefinery business?

2. According to my previous study, environmental sustainability was emphasized more in Scandinavia than in North America. Could you elaborate on the issue – why was environmental sustainability in your view more significant in Scandinavia than in North America?

3. Is **production of biofuels** in the forest biorefineries **sustainable**?

-Environmentally/Economically?

-Why? Why not?

4. What are the **greatest environmental challenges** related to the biorefinery value chain (raw material/production/use)?

5. How has the environmental sustainability of the business been measured/should be **evaluated/measured** in the forest biorefinery value chain companies?

Examples from KLD's database:

Strengths

Environmentally beneficially products and services

Pollution prevention

Recycling

Clean energy (as a resource)

Communications (internal & external communication, high transparency)

Property plant and equipment (above-average environmental performance)

Management systems (e.g. ISO 14001, other voluntary programs)
Other strengths

Concerns
Hazardous waste
Regulatory problems (substantial fines for violations of environmental regulations)
Ozone-depleting chemicals (manufacturer)
Substantial emissions
Agricultural chemicals
Climate change (use and sale fossil fuels)
Other concerns

6. How does **environmental sustainability relate to the strategic purpose** of biorefinery value chain companies?

-Is the purpose determined in response to the shareholders only, or to other stakeholders? Is the whole society or are common goods (like environmental issues) taken into an account?

APPENDIX 3 PROMOTING FACTORS FOR THE FOREST BIOREFINERY DIFFUSION BASED ON FIRST AND SECOND DEPHI ROUNDS

-High price of oil
-Climate change
-National security of fuel supply
-Long-term and consistent federal and state energy and environmental policies
-Realistic evaluation of national competence and skills
-Political pressure towards non-agricultural biofuels
-Demand of liquid biofuels
-Sustainability criteria for biomass use and sustainable energy production goals between society and industry
-Knowledge of politicians and public about various energy production pathways

-Capability to collect, transport and utilise existing wood biomass resources
-Private and public financing, reduction of financial risk by means of subsidies, tax incentives and loan guarantees in forest biorefinery projects
-Joint effort of research institutes, forest industry, oil industry, energy industry and technology providers in the forest cluster in the biorefinery business
-R&D for demonstration and pilot plants, and consultancy in the forest cluster in biorefinery development
-Political and public knowledge of the forest sector, forest management and environmental impacts of wood biomass use
-Improvements in forest management
-Short rotation energy crops with high yield
-Mobilisation of private forest owners in order to increase feedstock availability
-Maintenance of infrastructure in the forest cluster
-Focused joint efforts by industries and governments towards forest biorefineries
-Increased collaboration between forest industry companies and other companies within the same industry
-Increased collaboration between Nordic countries in biorefinery development
-Exploring the local and micro-scale opportunities for forest biorefineries

-Increased product and technological innovation and process expertise in the forest cluster
-Understanding of new markets and management of change
-Active participation of forest industry and business know-how about new possibilities
-Reassessment of the situation and re-evaluation of the wood-refining chain in forest industry
-Recognition of the possibilities of single production units by large companies in the forest cluster
-Utilisation of existing infrastructure and permits in the forest cluster in biorefinery business
-Development of economic wood fractionation and conversion technologies
-Integrated use of non-wood biomass sources along with wood-based biomass in biorefineries
-Support for small and medium-sized companies in biorefinery value chain
-Successful collaboration and division of tasks within the biorefinery consortium
-Strong leadership in biorefinery consortium
-New processes for strategy-making in biorefinery consortium
-Flexibility in biorefinery production in accordance with the market situation

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