INDUSTRY TRANSFORMATION FROM CHEMICAL PULPING TO BIOREFINING

ABSTRACT

The purpose of this paper is to analyse the transformation of the chemical pulp industry into the biorefinery industry. The contributions of this paper are threefold. First, the *status quo* of the transformation in Brazil, Canada and Finland have been assessed with interviews. Second, the competition between hydrocarbon-based chemicals and materials on the one hand, and biochemicals and biomaterials on the other hand, and its implications for the transformation, have been assessed. Third, the transformation has been assessed using the concepts of absorptive capacity and legitimation. The results show that all major Finnish firms in the chemical pulp industry engage in biorefining-related research and development, and that the Finnish government plays a significant role in the research and development activities through VTT Technical Research Centre of Finland, a wholly owned government entity. In Brazil, the firms are in different stages – ranging from very little activity to actively pursuing opportunities in biorefining. Canada occupies a middle ground between Brazil and Finland.

Keywords: Absorptive Capacity, Biorefinery, Bioengineering, Innovation, Legitimation, Sustainable Development

INTRODUCTION

The purpose of this paper is to study the transformation of the chemical pulp industry into the biorefinery industry in a comparative multi-country study. The chemical pulp industry faces a challenge because of the decline of print media in Europe and North America in particular. Although board and tissue manufacturing have not been affected by this decline, the decline in printing and writing paper manufacturing is forcing the chemical pulp industry to look for other businesses. At first, the production of biofuels was considered an alternative for diversification, but possible future limitations in the use of the internal combustion engine (Handelsblatt, 2016) for environmental and health reasons would also severely impact the demand for biofuels. Transforming chemical pulping into biorefining for the production of biochemicals and biomaterials is considered a promising path forward, e.g., bio-based technology platforms to substitute petrochemicals (Bioamber, 2017), and nanocrystalline materials improve the flexural strength of cement (Celluforce, 2017). Blair et al. (2017) have defined biorefining as "*the production of some combination of materials, chemicals, fuels, and energy from biomass feedstocks*" (p. 528). It must be kept in mind that biomass may also be other than wood (Salles-Filho et al., 2017).

The success of the transformation from chemical pulping to biorefining depends on the competitiveness of biochemicals and biomaterials produced in biorefineries vis-à-vis similar products. A challenge for biorefining is that biomass-based outputs from the biorefineries compete with hydrocarbons (Bünger, 2010), which may limit its competitiveness. An example of this happened when a segment of the chemical pulp industry – the sulphite pulp industry – attempted to compete with hydrocarbon-based chemicals and materials.

Biorefineries have the potential of producing products ranging from low to high value-added chemicals and materials (Stuart, 2006; Wield, 2013; Hansen and Coenen, 2017). The competitive situation is

complicated by a likely decline in hydrocarbon demand as the result of government action to protect the environment and health – e.g., the Canadian National Energy Board has estimated that the fossil fuels consumption will peak in 2019 (CBC, 2017). A business and institutional assessment of the prospects of biorefining is required. The development of biorefining is happening with different focus and speed in the various locations around the globe.

The paper contains a comparison between Brazil, Canada and Finland based on interviews. As costs of raw materials of the chemical pulp industry are much higher in the two northern countries – thus decreasing the industry profitability – it is expected that Canadian and Finnish firms are under more pressure to make the transition than the Brazilians.

Even with this pressure, it is evident that there is a slow development toward the biorefining, and already some attention in extant research has been devoted to the identification of reasons for its slow adoption. The listing of reasons covers such challenges as capital costs, feedstock supply, financing, human resources, industry leadership, market access, partnerships, and technology (Janssen and Stuart, 2010; Näyhä and Pesonen, 2012; 2014; Novotny and Laestadius, 2014; Blair et al., 2017). In this paper, a different view has been adopted. Based on the empirical material it is argued that at the core of the slow transformation toward biorefining in Finland and Canada is the lack of absorptive capacity (Zahra and George, 2002) in the traditional chemical pulp industry due to its decades old subordination into a supplier role for the paper and board value chains. According to the framing of the concept by Cohen and Levinthal (1990), absorptive capacity contains epistemic and cognitive structures that make the exploitation of external knowledge possible and open up exploration processes for new knowledge.

Absorptive capacity is also needed for legitimizing (Suchman, 1995; Bitektine and Haack, 2015) the investments needed for the R&D work at various stages, for the move toward full-scale production and for integrating the sustainability argument into the business model of each of the products produced within the business ecosystem of a biorefinery (Leonardi, 2011). In the case of Brazil, although the lack of absorptive capacity also exists, firms are still in early stages of the development of biorefinary due to the high profitability of pulp and paper business, especially in the aspects related to the forest yield and productions costs, which causes a lack of investments in the transition. Firms are hesitant to take the risk of investing in a not mature segment, which makes them behave as followers, instead of leaders in the technology development.

This paper is divided into four sections. In the Research Design and Methodology, the methodological choices are explained. In the Background, the developments in chemical pulping over the last two decades and challenges associated with the transformation from chemical pulping to biorefining are considered historically and conceptually. In the Empirical Material, the interview results are presented and assessed. In the Discussion, the empirical material is assessed from the standpoint of absorptive capacity and legitimation.

This paper adds to the understanding of industry transformation particularly in a capital intensive industry in the context of the bioeconomy. The empirical evidence illustrates how absorptive capacity can the improved, e.g. by facilitating the formation of spin-offs and start-ups and including them into a biorefinery business ecosystem. The empirical evidence also illustrates how sustainability is included in the business models of distinct products, providing thus legitimation for the transformation towards a wood-based biorefinery industry. This improvement in the absorptive capacity may bring lessons not

only to Canada and Finland, but also to Brazil, since decline of the pulp and paper business seems to be irreversible and the movement toward biorefineries will happen sooner or later.

RESEARCH DESIGN AND METHODOLOGY

The analysis of the on-going transformation process from the traditional pulp industry to biorefining is based on a comparative cross-national multi-level case study design. As units of analysis, we have specified, firstly, the dominant large forest industry firms with roots in three countries: Brazil, Canada and Finland. The second unit of analysis consists of features in the national innovation system in each of the country, including the connectivity of different actors to transnational epistemic communities. For categorising the features in the national innovation systems, we have used a grounded theory approach (Strauss and Corbin, 1998) by focusing on activities, actors and institutional practices that help to increase the absorptive capacity needed in the transformation process towards the biorefining industry. Thus,the distinctive features in the national innovation system can be conceptualised as explanatory mechanisms for the differences found in the steps taken in the innovation pipeline towards the biorefining industry among the traditional forest industry firms.

As to the collection of information of the research object, we have used multiple methods. Firstly, we have conducted in-depth interviews, over a period of four years, with key interviewees from research institutes, universities and firms, focusing on the initiatives taken towards developing new products, processes and being engaged with new customers and value chains. Information received from these interviews has been complemented by using media releases of the firms, available in their home sites. Besides the more focused information collection, we have conducted field-level ethnography (see Zilber (2014). This has occured by doing parallel studies in forest industry firms, by participating in conferences that have had their focus in the transformation towards the biorefinery approach and by being employed in universities and research institutes that have made major structural changes in order to become in tune with signals set by transnational epistemic communities related to the business potential in new wood-based products. The complementary information collected has helped us to triangulate the information received from the person-based interviews and thus facilitated the specification of the comparative outcome at the firm level in each of the country and by identifying features in the national innovation system that have contributed to the formation of the comparative configuration at the level of the firms.

12 interviews were conducted in Brazil, five in Canada, and 26 in Finland. The interviews exhibited a mix of open and specific questions.

Methodologically, this paper is based on a qualitative comparative multiple case study approach, making use of in-depth interviews with firms' executives and industry experts. The chosen methodology is conducive to gaining in-depth insights of the study object, but there are limitations in reproducibility (Blanchet et al., 2005). The empirical material is based on interviews conducted among Brazilian, Canadian and Finnish industry managers, consultants and researchers from 2014 to 2017.

BACKGROUND

The production of printing and writing papers started to decline in Europe in the aftermath of the Great Recession that commenced in 2007 and in North America it had started to decline already prior to that, as shown in Figure 1. These declines have had direct implications for the chemical pulp industry,

because it is a major supplier of fibre to the printing and writing paper producers. In spite of this, the chemical pulp industry's transformation into the biorefinery industry is still nascent more than a decade later.

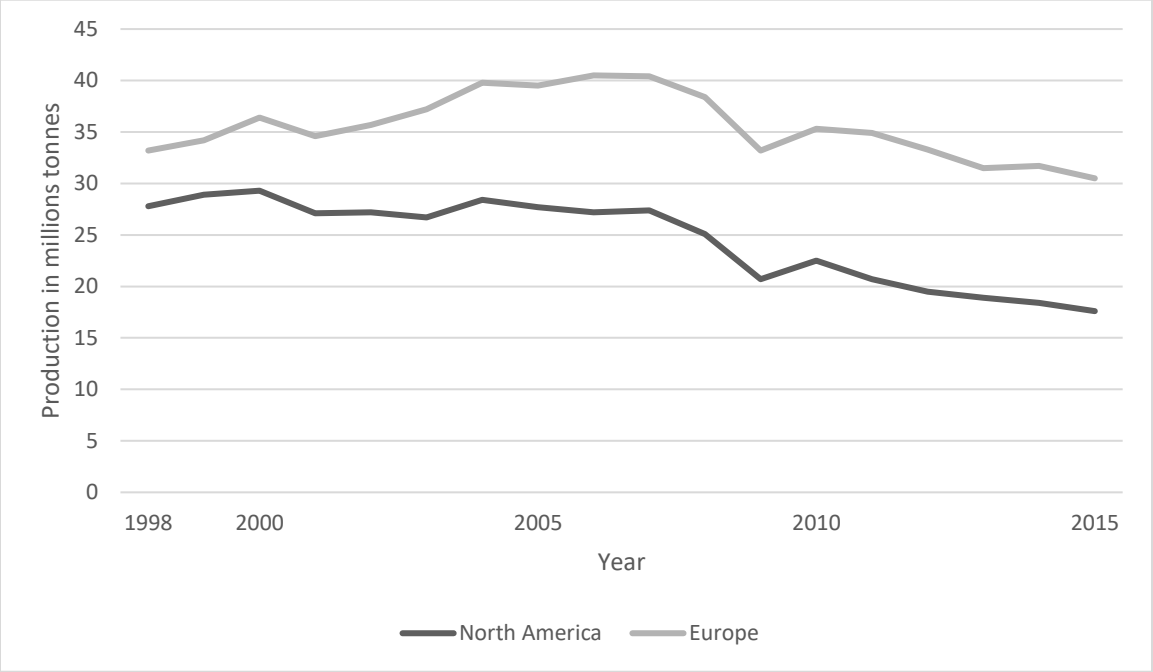

Figure 1: Production of printing and writing paper 1998-2015 (million tonnes) (data source: FAOSTAT).

The transformation from chemical pulping to biorefining is radically changing the structure of the value chains the industry is part of. As Figure 2 shows, chemical pulping has been a part of the paper- and boardmaking value chain with relatively minor external sales of energy and tall oil. Ventures into other value chains, like into the textile value chain with the production of viscose and into the construction value chain with the production of lignocellulose, have remained small.

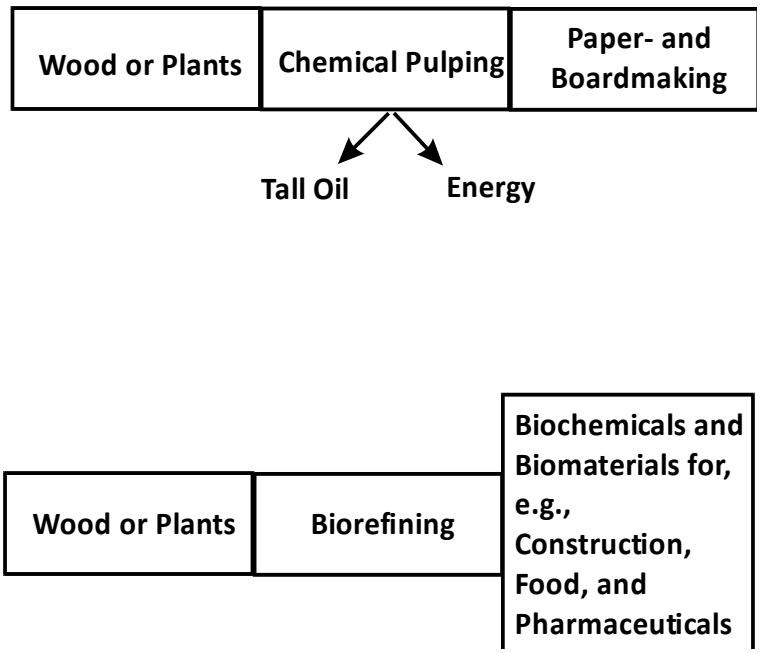

Figure 2: Increase in the number of value chains in the paper- and boardmaking industry due to the transformation from chemical pulping to biorefining.

In biorefining, the industry may be part of numerous value chains. The potential products range from strength increasing additives in building materials to feedstock in the production of pharmaceuticals. Generally speaking, the Canadian interviewees noted that there is an inverse relationship between expected production volume and expected unit price, see Figure 3. Whereas biorefining – as many other processes in the chemical industry – is characterized by joint production, the transformation from chemical pulping to biorefining is adding complexity to the industry's operations management. In biorefining, it is imperative to continuously optimize the combination of products to maximize profitability. This may require some redundancy in the process design that increases capital intensity in an already capital intensive industry.

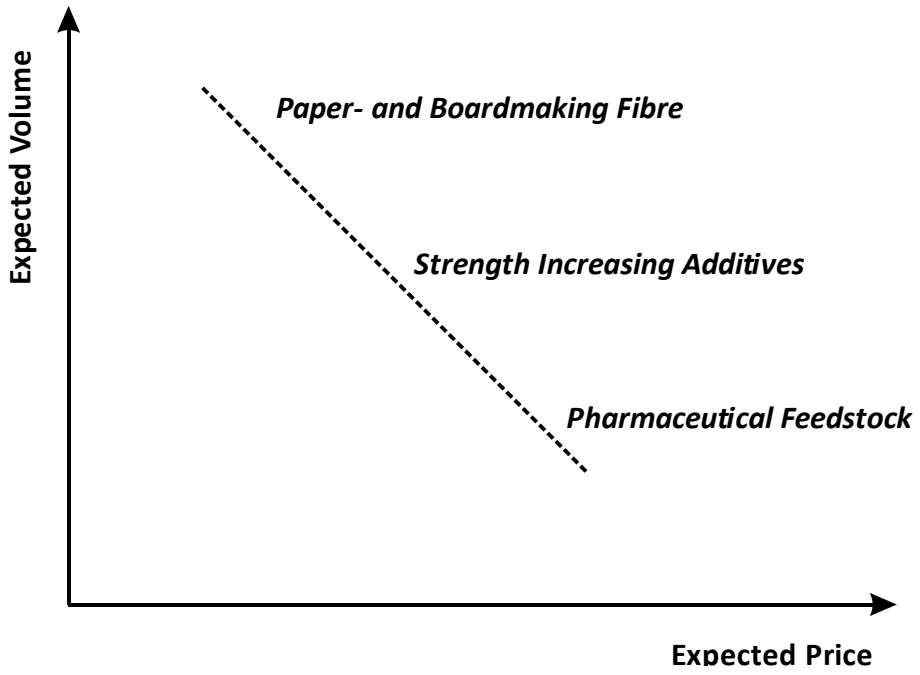

Figure 3: The expected production volume versus the expected price

A challenge in the transformation from chemical pulping to biorefining is that the chemical pulp industry has scant experience in dealing with the new value chains. The customers of, e.g., strength increasing additives and pharmaceutical feedstock may have product-related requirements which are new to the companies operating biorefineries. A successful partnership with the customers requires that the parties understand each other, and this is currently not guaranteed. Finding a common language is one of the first and most serious obstacles.

The transformation from chemical pulping to biorefining coincides with a fundamental shift in energy strategy globally. The era of hydrocarbons is ending as a result of energy transition necessitated by environmental and health concerns. In order to effectuate the change, governments have already adopted regulations to combat climate change, and hazardous nitrous oxides and particulate emissions, e.g., Directive 2008/50/EC on ambient air quality and cleaner air for Europe. A ban of the internal combustion engine in road transportation can be expected in the foreseeable future in many jurisdictions. The regulatory (institutional) change should have unfavourable effects on demand for biofuels and particularly hydrocarbons, as shown in Figure 4. The impact of regulatory (institutional) change is expected to be more severe for hydrocarbons than biofuels, because biofuels will probably substitute them to a more significant degree, e.g., in aviation.

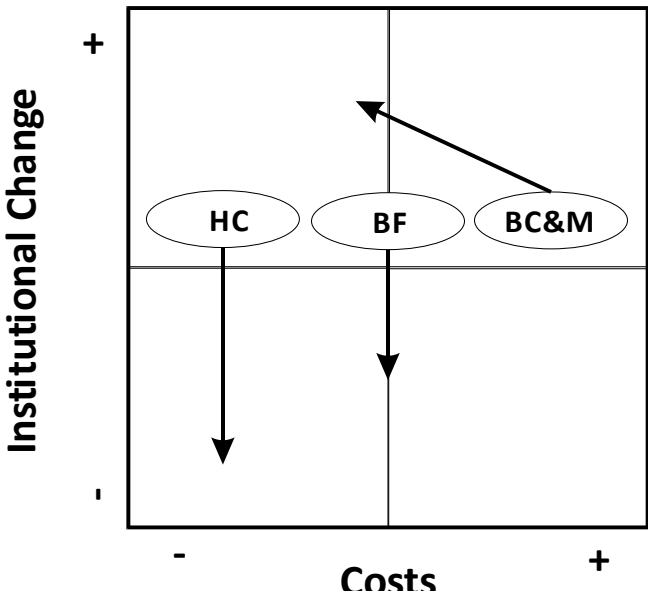

Figure 4: Dynamics in the competition between hydrocarbons (HC), biofuels (BF), and biochemicals and biomaterials (BC&M) expected by the authors

The unknown is the impact of energy transition on the costs of hydrocarbon-based chemicals and materials. On the one hand, the shutdown of the highest cost hydrocarbon extraction operations would put downward pressure on hydrocarbon prices. On the other hand, much of the hydrocarbon value chain is based on joint production – e.g., there might not be a market for some fractions thus unfavourably affecting the overall financial performance of hydrocarbon refineries – and economies of scale – e.g., hydrocarbon pipelines, would put an upward pressure on hydrocarbon prices. The net effect cannot be reliably forecast.

Within the chemical pulp industry, the kraft – or sulphate – process proved superior to the sulphite process in the 1950s. The resulting crisis in the sulphite pulp industry gave rise to significant inventiveness, e.g., a hybrid of chemical and mechanical pulping called BCTMP (Bleached Chemi-thermomechanical Pulp), and modifications to existing sulphite pulp mills to produce chemicals and materials, e.g., rayon and viscose. These attempts were ultimately unsuccessful. Part of the problem has been that kraft pulp mills have expanded into dissolving pulp grades as demonstrated by the conversion of the Thurso Mill in Québec (Specialty Cellulose, 2012). The fundamental problem has been that hydrocarbon-based chemicals and materials competed with the sulphite pulp industry particularly when crude prices have been low. This will be no different in the case of biorefineries. The effects of decarbonisation and energy transition on the cost competitiveness of biorefineries are thus to be considered cautiously in face ofthe emerging situation in the hydrocarbon sector.

Historically, dissolving pulp can be considered an approximation of the chemical pulping-based materials competing with hydrocarbon-based materials. Considering the capital intensity of chemical pulping operations, they will take advantage of market opportunities created by high oil prices with a lag. Figure 5 also shows that a decline in oil prices does not immediately result in a decline in dissolving pulp production.

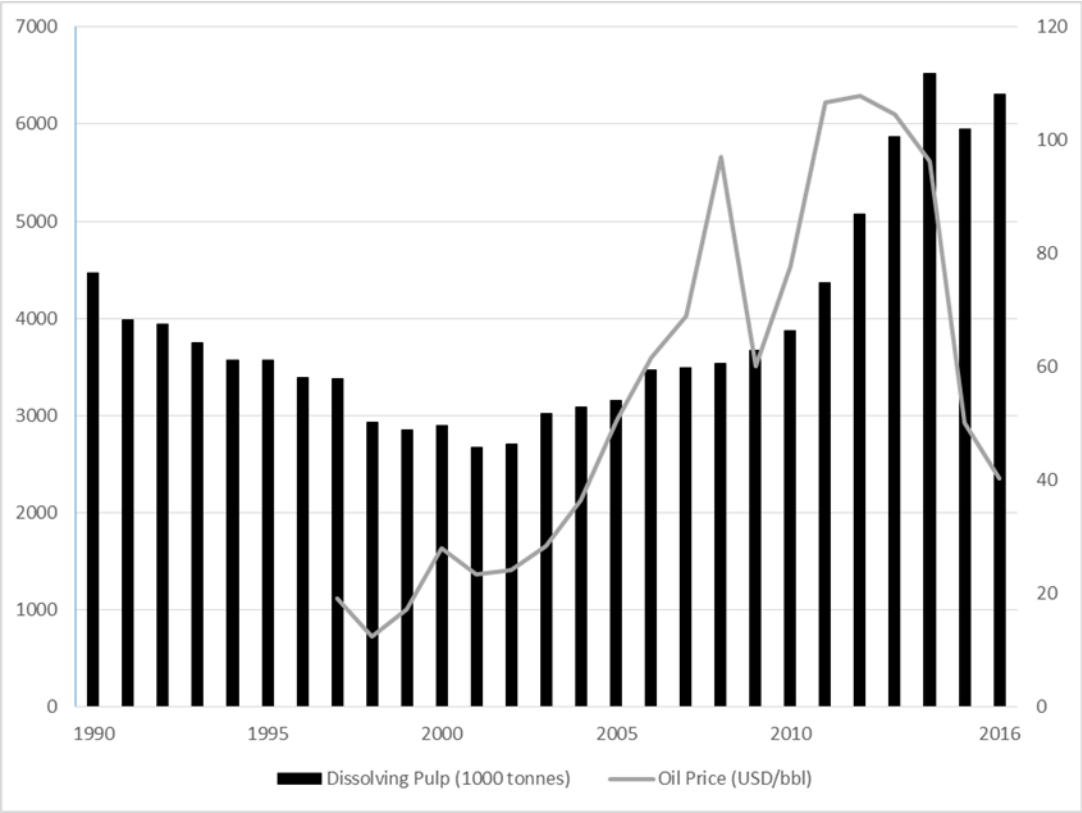

Figure 5: Production of dissolving pulp (FAOSTAT, 2017) and world oil import prices (IEA, 2017).

Biorefining raises the spectre of a novel business model – one that has been almost completely alien to the pulp and paper industry. This is a business model based on acquiring, exclusively using, licencing and selling intellectual property in biorefining-related processes and products. A challenge for firms from all three countries is that they have no significant experience and competences in such a business model. Consideration about industries which have been intellectual property-intensive for a longer time suggests that intellectual property rights can become a major revenue generator, and an obstacle for innovation. The biorefinery industry will probably be more intellectual property law-driven than chemical pulping industry. This will require from managers additional competences and different mentalities.

EMPIRICAL MATERIAL

The interviews exhibited some significant differences between the interviewees from the three countries, Brazil, Canada and Finland, and between the organizations. The results are summarized in table 1. There was a difference of opinion among the Canadian interviewees what the **optimal target market** is for biorefineries. The Canadian interviewees supported the view expressed in Figure 3 that the expected prices of the products are inversely related to the expected production volume. The position around the middle of the curve in Figure 3 was favoured by most with some support for the

highest priced products. A reason given for the majority opinion was that the production of the highest priced intermediate products would adversely affect the production of other biochemicals and biomaterials. Whereas biorefineries – like many operations in the chemical industry – are characterized by joint production, biorefineries will need to dynamically optimize their profit by adjusting the products and volumes being produced.

	Brazil	Canada	Finland
Optimal Target Market	Different firm strategies	Middle price and volume position	The whole scope of products based on wood
Regulatory (Institutional) Changes	Environmental regulations have an impact (but the impact will come later)	Environmental regulations have an impact	Environmental regulations have an impact
Pace of Transformation	Slow	Slow	Slow
Cost Competitiveness	No improvement vis-à-vis hydrocarbon-based chemicals and materials	No improvement vis-à-vis hydrocarbon-based chemicals and materials	New niche products based on wood in the pipeline outcompeting hydrocarbon-based products (e.g. Paptic Ltd. and Spinnova Ltd.)
Transformation Strategy	Follower	Leader	Leader
National Innovation Strategy	Weak	Weak	Strong
Licensing and Selling Intellectual Property Rights	Yes	Yes	Yes
Other Legal and Regulatory Drivers	None	None	Many initiatives in the public political discussion
University Education	No specialization in chemical pulping technology, considered a weakness	Specialization in chemical pulping technology	Specialization in chemical pulping technology

Table 1: Summary of results interviews with biorefinery industry experts in Canada, Brazil and Finland

The interviewees effectively identified the same product opportunities in biorefining in Brazil, Canada and Finland. This can be interpreted as a result of scientific conferences and publications, and probably also the contacts with and use of the same consultants and research institutes. It is noteworthy that the

equipment and machinery suppliers were not mentioned as drivers of the transformation from chemical pulping to biorefining. In the *status quo ante*, the equipment and machinery suppliers held a key position in technological change in chemical pulping.

The empirical evidence – in contradiction to the Background assessment above – is inconclusive in regard to the impact of **regulatory (institutional) changes** affecting the hydrocarbon sector on the competitive position of biofuels, and biochemicals and biomaterials. It is noteworthy that several Brazilian and the Canadian interviewees saw the production of biofuels as a feasible business strategy. One reason is that many countries will impose a minimum percentage of biofuel in all the oil to be processed in the refineries in a short-term (reference), which will increase drastically the demand. Brazil can be an example for this process considering the addition of bioethanol to oil and development of hybrid engines. Another reason is that biofuel is starting to substitute oil and gas in several applications, e.g. aviation and heating systems. The issue of the relatively calorific value in addition the potential of wood as a source of biodegradable chemicals and materials was raised by one Finnish interviewee. Several interviewees mentioned the potential of biochemicals and biomaterials. These results were surprising for two reasons related to the environment and health. First, the impact of the likely ban of the internal combustion engine on biofuels in the long-term has not been fully recognized yet. A ban of them will not only reduce the demand for hydrocarbon-based fuels, but it will also reduce the demand for biofuels used in internal combustion engines. Second, the accumulated waste problem in, e.g., the Pacific Ocean focusses the attention on the biodegradability of chemicals and particularly materials.

The interviewees did not envision a rapid **pace of transformation** from chemical pulping to biorefining. The cautiousness of the interviewees may be rooted in a combination of a myriad of reasons. In the literature, challenges with capital costs, feedstock supply, financing, human resources, industry leadership, market access, partnerships, and technology (Janssen and Stuart, 2010; Näyhä and Pesonen, 2012; 2014; Novotny and Laestadius, 2014; Blair et al., 2017) have been identified. To these reasons can be added the historical experience of the chemical pulp industry, particularly the experience in the sulphite pulp industry.

An improvement in the **cost competitiveness** of biochemicals and biomaterials vis-à-vis competing chemicals and materials – often hydrocarbon-based – was not expected by the interviewees. They were cautious on this score. This result was not expected by the authors, because evolutionary innovation has a tendency of reducing production costs over time. If the production costs of biochemicals and biomaterials did not sink below those of equivalent hydrocarbon-based chemicals and materials, then the commercial success of biochemicals and biomaterials would depend on their superior properties and/or regulations favouring their use.

There were significant differences between firms and countries in regard to the **transformation strategy** from chemical pulping to biorefining. The interviews showed that among the three countries studied, Canada and Finland have adopted a leadership strategy, and Brazil has adopted a follower strategy. There is a difference in degree between Canada – particularly the province of Québec – and Finland. Whereas the future importance of biorefining has been recognized as a key industry in Canada and Finland, biorefining receives less government attention and support in Canada than in Finland. In Brazil there has been a common understanding that biorefineries are the future for the pulp and paper industry, but the modern pulp and paper producers are focusing more on its thermoelectric potential,

which hinders the leadership in the use of biochemical and thermochemical routes in biorefineries (CGEE, 2013).

In Finland, the transformation is a prominent part of government policy – both at the national and the European Union levels. The disappearance of Nokia's former mobile business and the associated business infrastructure have lent urgency to national government actions. The foreseeable decline of the hydrocarbon sector in Canada – particularly in the provinces of Alberta and Saskatchewan – as a result of the likely ban of the internal combustion engine and energy transition in major markets – has not given the impetus to similar government involvement in Canada so far.

The similarities in the corporate strategies of the major Finnish pulp and paper firms observed in the interviews reflect the existence of a **national innovation strategy** favouring the transformation into biorefining. VTT (VTT Technical Research Centre of Finland) plays a major role in the research and development activities, but the firms are active as well (cf. Lilja and Moen 2017; Lilja and Loukola-Ruskeeniemi 2017). All Finnish firms have actively pursued research, development and commercialization of products emanating from biorefining. Unlike the industry-owned Canadian FPInnovations, the VTT Technical Research Centre of Finland is wholly owned by government.

In Canada, the pulp and paper-owned research institute FPInnovations occupies a central place in the biorefining innovation ecosystem in Canada. Major pulp and paper firms like Domtar and Kruger have financed and acquired intellectual property from FPInnovations. Several Canadian interviewees pointed out that a difference between Canada and Finland is that Canadian firms have only limited in-house research and development resources which can be used for biorefining-related work. As a consequence, government-supported activities have been limited to research done at universities, networking initiatives connecting firms and universities, and support for start-ups and SMEs – administered by, e.g., CRIBIQ in Québec. Among the major Canadian pulp and paper firms, different strategies vis-à-vis biorefining can be observed. Whereas the Domtar and Kruger embraced the transformation to biorefining early on, Resolute has been slower.

In Brazil, there are significant differences between firms. On the one hand, it shows an incipient national innovation strategy focusing on biorefineries, although with well stablished knowledge and technology base related to sugar cane bioethanol, which allows for utilization of related expertise and infrastructure to advance the development of biorefineries . On the other hand, major Brazilian pulp and paper firms have shown different paces in biorefining-related activities. The most active has been Fibria that has acquired Canadian and Finnish firms from different technological paths (Lignol, focused on lignin; Ensyn, focused on pyrolysis; and CelluForce, focused on cellulose nanocrystals) or minority stakes in them thus giving Fibria access to biorefining-related intellectual property and technology of different areas. Suzano has chosen a different path by having been slower and choosing to engage in in-house research and development, focusing only in lignin.

Although the majority of the interviewees in Brazil, Canada and Finland saw a business model based on **licencing and selling intellectual property rights** feasible, some interviewees voiced different views. A Canadian interviewee emphasized the right to use instead of intellectual property rights basing the argument on the rapid pace of innovation in biorefining. A Finnish interviewee presented a fundamental argument against intellectual property rights by maintaining that intellectual property rights slow down innovation in biorefining by discouraging fundamental research in favour of easily and quickly patentable inventions. A Brazilian interviewee presented a point-of-view that patents have

more psychological than economic value, which would justify a not very big focus on it at the moment. This affirmative illustrates the Brazilian firms' role of followers.

The interviewees expressed less certainty about **other legal and regulatory drivers** and obstacles relating to the transformation into biorefining. Although this can partially be ascribed to the complexity associated with the diversity of processes and products, this result was surprising to the authors. The authors expected to find here some discussion about, e.g., the ramifications of the transformation from chemical pulping to biorefining on the renewable energy targets. The use of lignin as a raw material will remove it from the primary energy mix, and it may have to be replaced by another primary energy source – particularly in the generation of process heat – that has higher greenhouse gas emissions than the zero assigned to wood.

All interviewees shared the view that a transformation from chemical pulping to biorefining needs to happen in the chemical pulp industry. In spite of the potential profession-based bias, the need for this transformation was agreed upon bythe interviewees. The need for this transformation has been driven by the crisis in printing and writing paper industry in Canada and Finland. The majority of the Canadian interviewees considered that this crisis has reduced the reluctance to change in the chemical pulp industry. Whereas the Brazilian chemical pulp producers have some of the lowest production costs in the world, there is not the same urgency for the transformation into biorefining in Brazil. This may be a contributing reason to the different pace in the transformation observed in the Brazilian chemical pulp industry.

The **university education** in Canada and Finland on the one hand and Brazil on the other hand are different in the degree of specialization at the master level. Whereas specialized pulp and paper programmes which have moved toward bioengineering in Finland, the Brazilian Universities do not yet offer such focused programmes. The interviewees from Brazil saw in this difference one of the reasons for the lower level of exploration in biorefining in Brazil. One interviewee told that one Brazilian firm had hired a manager graduated in Finland to explore opportunities in biorefining.

DISCUSSION

The slow pace of the transformation from chemical pulping to biorefining raises the issue of its fundamental reasons. Whereas forecasts in conjunction with discontinuous change – and the transformation is a discontinuous change for chemical pulping – are dependent on subjective assessments of future developments. This subjectivism brings into focus the absorptive capacity and views on legitimacy of the decision-makers.

Cohen and Levinthal (1990) maintain that absorptive capacity "*confers an ability to recognize the value of new information, assimilate it, and apply it to commercial ends*" (p. 128). The slow pace in the transformation from chemical pulping to biorefining suggests that it took a crisis in one of the major customer industries, the printing and writing paper industry, for the chemical pulp industry to recognize the value of and assimilate new information, i.e., technology related to biorefining. The assimilation process is still ongoing, and the commercialization of biorefining is still embryonic.

The transformation from chemical pulping to biorefining also requires the ability to recognize new ways of operations management and new business models, including new legal foundations for business. On the one hand, the joint production of multiple products renders the optimization of operations more

complex. On the other hand, competition based on intellectual property requires in-depth legal capabilities in addition to making continuous research and development necessary as competitors use research and development to achieve competitive advantages. In the *status quo ante*, equipment and machinery suppliers performed much of the research and development. The transformation means a partial internalization of innovation with acquisition and licencing of intellectual property making up much of the rest.

A prerequisite for absorptive capacity is the existence of a common language according to Cohen and Levinthal (1990). Whereas the transformation from chemical pulping to biorefining entails contacts and cooperation with new customers and partners, the existence of a common language is not guaranteed. E.g., it cannot be assumed that an engineer with a background in chemical pulping speaks the same (scientific) language as a scientist in the pharmaceutical industry. This may prove an impediment to or at least a factor that slows down the transformation from chemical pulping to biorefining.

The seminal and widely used definition of legitimacy by Suchman (1995) means that legitimation is a social phenomenon, and the argument made by Bitektine and Haack (2015) means that legitimation occurs at multiple levels. The start of the transformation from chemical pulping to biorefining coincided with a growing crisis in the printing and writing paper industry. This suggests that the change in legitimacy has been tied to a crisis that has forced actors in the chemical pulp industry to change their views on what is legitimate.

It is open to question to which degree the failure of the sulphite pulp industry to survive after adopting biorefinery-like business and operational models has delayed the legitimation of biorefining in the sulphate, or kraft, pulp industry. The crisis in the printing and writing paper industry has been enough to overcome any such potential obstacle, but the legitimation of biorefining might have been faster under other circumstances.

The results of this study suggest that there are differences in the multilevel approach to legitimacy in the three countries. In the case of Canada and Finland, the major pulp and paper firms have adopted the view of the need to embrace biorefining signifying that there is a multilevel concurrence – the industry and the individual firms. In the case of Brazil, the heterogeneous biorefining-related strategies of the firms suggest that the legitimacy has existed only at the firm-level, but as more firms start biorefining-related activities this has started to change of late.

Considering the results from the perspective of national innovation systems, there are some differences between Brazil, Canada and Finland. Canada and Finland have similar national innovation systems in the biorefineries field in terms of having research institutes with significant research and development capabilities, FPInnovations and VTT, respectively. In Brazil, some universities pursue a biorefinery-related research agenda. Additionally, there are a number of start-ups engaging in research and development in Canada and Finland, and incumbent chemical pulp producers participate in their financing in different ways. The national innovation systems of Canada and Finland differ in the role incumbent chemical pulp producers play in biorefining-related research and development: Whereas the incumbent chemical pulp producers have practically no in-house research and development resources in Canada, the incumbent chemical pulp producers actively pursue research and development in Finland (Lilja and Loukola-Ruskeeniemi 2017: 8-61). In Brazil, there is an incipient national innovation system, which means there are new activities in terms of coordination of policies targeting the sector and the fact that individual incumbent chemical pulp producers pursue different strategies. In terms of research

base there is already a significant level of consolidation, there are 28 advanced research groups focusing on biorefineries and forest-based biomass (CGEE, 2013).

The authors make three recommendations to the industry. First, in all three countries it is necessary to build capabilities for dealing with customers and partners in other value chains than the customary paper and board industry value chain. Second, in Brazil and Canada the creation of in-house biorefining-related research and development capabilities should be pursued. Third, in Brazil a biorefining-related national innovation strategy should be adopted.

CONCLUSION

The purpose of this paper was to analyse the transformation of the chemical pulp industry into the biorefinery industry. For this, three issues have been assessed. First, the impact of the diminishing demand for the printing and writing paper products on the pulp and paper firms and for their transformation is assessed. Second, the failure of the sulphite pulp industry to survive by establishing a biorefinery-like business model. Lastly, differences and similarities in the transformation in Brazil, Canada and Finland are compared.

This paper contributes to the literature in three ways. First, the current status of the transformation from chemical pulping to biorefining is established with a comparison between Brazil, Canada and Finland based on interviews with industry managers, consultants and researchers. The interviews allow for the identification of different intellectual property strategies, business strategies in the beginning of the transformation, firm and national innovation strategies in different countries and firms. In spite of the chemical pulp industry being global, differences were observed. Contrary to the Finnish chemical pulp industry, the Brazilian industry does not have a uniform strategy for the transformation. The result is that all Finnish major firms in the chemical pulp industry have extensive research and development activities relating to biorefining, and in Brazil there are substantial differences between the firms. In this respect, the Canadian is between Brazil and Finland, albeit closer to Finland.

Second, the competition between biochemicals and biomaterials on the one hand, and hydrocarbon-based chemicals and materials on the other hand has received scant attention in the literature. This issue is of significant importance, because hydrocarbon-based chemicals and materials usually compete with biorefining-based biochemicals and biomaterials. Looking forward, the commencing energy transition will destabilize the hydrocarbon sector, and this will probably impact the competitive dynamic between hydrocarbon-based chemicals and materials on the one, and biorefining-based biochemicals and biomaterials on the other hand. The assessment in this paper contributes to closing this gap in the literature.

Third, the transformation from chemical pulping to biorefining has been assessed using the concepts of absorptive capacity and legitimation. The use of these two concepts in the assessment of the pulp and paper industry is not a novel approach *per se*, but the three-country comparison lends it a different dimension. Limited absorptive capacity and limited legitimacy of alternative processes and products among the decision-makers in the chemical pulp industry even in the face of industry crisis has been some of the main obstacles for the transformation of chemical pulping industry into biorefinery, mainly in Canada and in Finland. In Brazil, the transition is so embryonic that these two factors could not arise, as the rhythm of the transformation is held back by the lack of interest in investing in biorefinery because of the high profits of the pulp and paper business. As northern countries are still making the

transition at a slow pace, if Brazil solve the problems of absorptive capacity and legitimacy in the short term, it may catch-up to the world-leaders level easier than it usually happens in other industries, turning this global competition more interesting.

Further research is needed on three issues. First, an assessment and development of proactive strategies for increasing absorptive capacity and legitimacy in the context of discontinuous and transformational change. The increase in absorptive capacity and legitimation has been a reactive response to a crisis in the transformation from chemical pulping to biorefining. Second, an assessment of the dynamics of an industry transformation from a situation with commercially available open innovation to a situation where intellectual property strategies and the financialization of intellectual property plays a major strategic role. Third, bioeconomy-based service strategies are currently embryonic and warrant attention.

The transformation of chemical pulping to biorefining is a case of firms and an industry breaking out from incremental change within the confines of effectively one value chain to radical change that make them actors in numerous value chains. It is also a case of a global industry experiencing radical change while participating in opportunities arising from sustainable development.

REFERENCES

Bioamber, (2017), Products. https://www.bio-amber.com/bioamber/en/products (accessed 29 October 2017).

Bitektine, A., and Haack, P., (2015), The “macro” and the “micro” of legitimacy: Toward a multilevel theory of the legitimacy process. Academy of Management Review, 40(1), 49–75.

Blair, M.J., Cabral, L., and Mabee, W.E., (2017), Biorefinery strategies: exploring approaches to developing forest-based biorefinery activities in British Columbia and Ontario, Canada. Technology Analysis & Strategic Management, 29(5), 528-541.

Blanchet, A., Ghiglione, R., Massonnat, J., and Trognon, A., (2005), Les techniques d’enquête en sciences sociales. Paris: Dunod.

Bünger, M., (2010), Biofuels: Putting pressure on petrol. Renewable Energy World, 13(12), 5–25.

CBC, (2017), Canada's fossil fuel use to peak in 2019, National Energy Board now projects. http://www.cbc.ca/news/canada/calgary/neb-fossil-fuel-demand-2017-report-canada-energy-future-1.4372967 (accessed 27 October 2017).

Celluforce, (2017), Applications. http://www.celluforce.com/en/applications/ (accessed 29 October 2017).

CGEE, (2013), Eficiência energética: recomendações de ações de CT&I em segmentos da indústria selecionados – celulose e papel. Série documentos técnicos, 20. Brasília (DF): Centro de Gestão e Estudos Estratégicos.

Coenen, L., Moodysson, J., and Martin, H., (2015), Path renewal in old industrial regions: Possibilities and limitations for regional innovation policy. Regional Studies, 49(5), 850–865.

Cohen, W.M., and Levinthal, D.A., (1990), Absorptive capacity: a new perspective on learning and innovation. Administrative Science Quarterly, 35(1), 1128-1152.

Faostat, (2017), Forestry production and trade. http://www.fao.org/faostat/en/#data/FO (accessed 07 October 2017).

Handelsblatt, (2016), Warum ein Verbrenner-Verbot überflüssig ist. http://www.handelsblatt.com/unternehmen/industrie/autoindustrie-warum-ein-verbrenner-verbot-ueberfluessig-ist/13421934.html (accessed 27 October 2017).

Hansen, T., and Coenen, L. (2017), Unpacking resource mobilisation by incumbents for biorefineries: the role of micro-level factors for technological innovation system weaknesses. Technology Analysis & Strategic Management, 29(5), 500-513.

IEA, (2017), Monthly oil price statistics. http://www.iea.org/statistics/monthlystatistics/monthlyoilprices/ (accessed 28 October 2017).

Janssen, M., and Stuart, P., (2010), Drivers and barriers for implementation of the biorefinery. Pulp & Paper Canada, 111(3), 13–17.

Leonardi, L. (2011), Bio refinery and its development in Brazil. Revista O Papel, 72 (3), 04-05.

Lilja, K., and Loukola-Ruskeeniemi, K., (eds.) (2017), Wood-Based Bioeconomy Solving Global Challenges. Helsinki: Ministry of Economic Affairs and Employment in Finland (MEAE guidelines and other publications 2/2017).

Lilja, K., and Moen, E., (2017), Orchestrating a new industrial field: The case of the Finnish wood-based bioeconomy. International Journal of Business Environment, 9(3), 266-278.

Näyhä, A., and Pesonen, H.-L., (2012), Diffusion of forest biorefineries in Scandinavia and North America. Technological Forecasting and Social Change, 79(6), 1111–1120.

Näyhä, A., and Pesonen, H.-L. (2014), Strategic change in the forest industry towards the biorefining business. Technological Forecasting and Social Change, 81, 259–271.

Novotny, M., and Laestadius, S., (2014), Beyond papermaking: Technology and market shifts for wood-based biomass industries – management implications for large-scale industries. Technology Analysis & Strategic Management, 26(8), 875–891.

Salles-Filho, S.L.M., Drummond de Castro, P.F., Bin, A., Edquist, C., Ferroa, A.F.P., and Cordera, S., (2017), Perspectives for the Brazilian bioethanol sector: The innovation driver. Energy Policy, 108, 70-77.

Specialty Cellulose (2012), Lenzing signs deal to increase dissolving pulp cooperation. http://specialtycellulose.com/tag/lenzing-ag (accessed 28 October 2017).

Strauss, A., and Corbin, J., (1998). Basics of qualitative research techniques and procedures for developing grounded theory (2nd edition). London: Sage Publications.

Stuart, P., (2006), The forest biorefinery: Survival strategy for Canada's pulp and paper sector? Pulp & Paper Canada, 107(6), 13–16.

Suchman, M.C., (1995), Managing legitimacy: Strategic and institutional approaches. Academy of Management Review, 20(3), 571–610.

Wield, D. (2013), Bioeconomy and the global economy: industrial policies and bio-innovation. Technology Analysis & Strategic Management, 25(10), 1209-1221.

Zahra, S.A., and George, G., (2002), Absorptive capacity: A review, reconceptualization, and extension. Academy of Management Review, 27(2), 185-203.

Zilber, T.B., (2014), Beyond a single organization: challenges and opportunities in doing field level ethnography. Journal of Organizational Ethnography, 3(1), 96–112.