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BIOREFINERIES: PULP INDUSTRY 2.0

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ABSTRACT

The biorefinery concept ushers in radical change in the chemical pulp industry. Instead of being part of one value chain, the adoption of the biorefining will make the traditional chemical pulp industry part of several value chains and a facilitator in a wide range of business ecosystems. The raw material used in biorefineries allows for the development and production of numerous biochemicals and biomaterials. For the transformation from chemical pulping to biorefining, revolutionary process and product innovations are necessary. To make it happen, absorptive capacity is needed among the actors. Production operations and management become more complex creating the potential for conflict of interests in and between business ecosystems. As the transformation towards biorefining is based on innovation, there is also a need to obtain intellectual property rights. The contribution of this paper is that it identifies the challenges and business potential in the transformation from chemical pulping to biorefining. As the transformation process is at an early stage, scenarios for the future are constructed from the experiences of a few frontline operations. They give indications regarding future value added products-based business models, in addition to the traditional pulp business, and about becoming a core actor in many multi-sector research and business ecosystems.

Keywords: Biorefining; Industry Transformation; Micro- and Nanocellulose; Innovation; Intellectual Property

INTRODUCTION

The biorefinery concept ushers in radical change in the chemical pulp industry. The change from chemical pulping to biorefining gives the industry a new lease of life as the demand for print media declines in several markets. While bleached softwood kraft pulp producers are in a position to offset at least a part of the falling demand from printing and writing paper producers by selling reinforcing pulp to the board producers, bleached hardwood kraft pulp producers are in a more serious situation. Currently, this is not a major concern for the Brazilian and Uruguayan bleached eucalyptus kraft pulp producers due to the excellent product properties and quality of the Brazilian and Uruguayan bleached eucalyptus kraft pulp, in addition to their relatively low production costs.

The dependence of the paper production and its downstream value chains on the chemical pulp industry has not been conducive for the chemical pulp industry to develop offerings outside of paper production. However, the diminishing demand for printing and writing paper has given an impetus to search for new production processes, products and markets. Wood as a renewable material provides hitherto unused opportunities. The innovative biorefinery concept - labelled Pulp Industry 2.0 - provides a platform for new processes, chemicals and materials. The wood material delivered to a mill site can be valorised to new end uses that meet customer requirements also in high-end market niches.

The production volumes of specialty products produced in a biorefinery are significantly smaller than the 1,300,000 tonnes per year produced in a modern bleached eucalyptus kraft pulp mill. Wood-based specialty products can be used in a wide range of value chains in the chemical, textile, construction, pharmacy, cosmetics and electronics industries. A special twist comes from the micro- and nano-scale materials that are in the innovation pipeline.

In some instances, wood-based chemicals and materials may enjoy a regulatory advantage vis-à-vis competing chemicals and materials based on hydrocarbons. For instance, the regulations that require a certain percentage of biofuels in gasoline and diesel used in cars, promote clearly the production of biofuels. The possible end of the internal combustion engine means and their relatively low level of value added means that biochemicals and biomaterials make strategically more sense. When the investments in capital intensive biorefinery processes are considered, it is necessary to keep in mind that a regulatory advantage may end rapidly as the result of changing regulations and political priorities (cf. Jernström et al. 2017: 8). The goal must be that biochemicals and biomaterials are cost competitive with competing chemicals and materials.

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Of particular concern is the potential competition from hydrocarbon-based chemicals and materials, because the ongoing energy transition will probably force hydrocarbon extractors to look for alternative uses for hydrocarbons. It is also likely that the hydrocarbon sector will attempt to defend its current position against biochemicals and biomaterials. For chemical reasons, the competition would mostly affect lignin-based chemicals and materials. At the same time, lignin-based chemicals and materials are of significant interest in biorefining (Bujanovic et al., 2012). Biochemicals and biomaterials based on the physical structures of wood, and carbohydrates and extractives would be less impacted.

Expanding from commodities like bleached chemical pulp to R&D-intensive value-added chemicals and materials will require a different mentality in the chemical pulp industry. The absorptive capacity (Cohen and Levinthal, 1990; Nooteboom, 2000; Tortoriello, 2015) for multidisciplinary knowledge and new modes of business activities needs to be broader than is currently the case in the chemical pulp industry. In parallel, competences for marketing and branding of new products made from wood have to be multiplied (Näyhä and Pesonen 2014). Wood as a renewable raw material and the ways it is valorised to new end uses provide solutions to global challenges, like climate change and the need to replace non-renewable materials. This means that sustainability can be integrated into the business models of the companies linked to the biorefinery business ecosystems. Because of the complexity of the comparative production systems, product features and user experiences, it is not easy to build the socially defined legitimacy aspect into the competitive arena and by so doing provide a stimulation for the use of wood-based products (Suchman, 1995; Bitektine and Haack, 2015; Santos and Silva, 2016). The transformation towards biorefineries also raises the issue of intellectual property rights – an issue the pulp industry has little experience with historically – as value added biochemicals and biomaterials can be invented and produced only after significant investments in R&D.

The objective of this paper is to set the scene for relevant moves by companies in the pulp industry with experience in a commodities-based business model, essentially producing one main product (pulp). A scene for the future is to adopt a special products-based business model, in addition to the traditional pulp business, producing numerous products and taking on an orchestrator role in several multi-sector research and business ecosystems (Wallin, 2006; Lilja and Moen, 2017).

The Next Generation of Chemical Pulping: The Biorefinery

In the chemical industry, joint production is common (Müller-Fürstenberger, 1995). This situation is no different in chemical pulping, and it will be more complex in much of biorefining. Joint production adds complexity to operations management. In a bleached kraft pulp mill, the focus on one product – pulp for board- and/or papermaking – has rendered the target of the production optimization relatively straightforward. The advent of biorefineries will increase the number of products based on a wide scope of side streams that so far have not been valorised to the best potential end uses.

The complexity of production optimization has been different in various regions of the world. Major issues have been the availability and price of the wood raw material. The logistical chain from the buying and harvesting of wood to the transportation of the wood to the mill site is rather complex in countries where the wood is not growing on plantations, fully owned by the firms. When forestry sites are owned by private persons, it is not easy to convince the owners that some areas of their forest should be put to final or light selection felling, and put up the harvesting operation and the sale of the wood raw material for tender. Moreover, availability and the future price of wood is a major issue also in Brazil when many biorefinary projects are entering the full production stage and the demand for wood is growing. Some biorefinery projects are owned by foreign companies as shown by the Lençóis Paulista operation owned by Royal Golden Eagle International from Singapore. The demands of landless people also pose challenges to the wood supply.

The transformation towards biorefining will change the meaning of integration. At the mill sites, the integration of pulp and paper/board production was a major transformation, leading to reduced costs and increases in the productivity of integrated pulp and paper/board mills in the Nordic countries in the past. The transformation will mean that the focal part of an integrated operation is the pulp mill instead of the paper/board mill. This will reopen the debate on integration also in Brazil.

Biorefining is based on extensive valorisation of the chemical and physical components of the wood to the most value-added end-uses in the market. The higher value added paves the way for breaking the commoditization of Nature (Goven and Pavone, 2015), thus setting the stage of improved environmental and health performance as chemical pulping transforms into biorefining.

In Finland, the first next generation chemical pulp mill of Metsä Group, which started its operation in August 2017 at the Äänekoski site and was named a ´Bioproduct mill´, has become a model for what biorefining is and what kinds of opportunities are embedded in it. As less than 50 per cent of the wood raw material brought to the mill site is turned into the main product pulp, there are abundant opportunities for additional businesses based on especially the side streams. As a starting point for the transformation towards biorefining, Metsä Group itself already produced at the mill site, in addition to pulp and board, also turpentine, tall oil, bioelectricity, steam, district heat and solid biofuel (bark). Linked to the start-up of the Bioproduct mill, Metsä Group itself entered full-scale production of two novel concepts, namely upgrading of bark by means of gasification and conversion of the odorous gases into sulphuric acid. In addition to these investments by Metsä Group, a partner, EcoEnergy SF, has started up a first-of-its-kind biogas production plant that utilises the sludge of the Bioproduct mill as its raw material. Moreover, Metsä Group's innovation pipeline is expected to bring forward several additional concepts. These include the use of pulp for the production of biocomposites and textile fibres, new bioproducts from lignin and bark, as well as fertilizers and earth work material from dregs and ashes (von Weymarn 2017; Lilja and Loukola-Ruskeeniemi 2017: 20-21).

Partnerships, in both the R&D phase as well as in the business phase are central to the biorefinery concept implemented by Metsä Group (Metsä Group 2016). Even before the start-up of the new Bioproduct mill, several other companies already had their operations at the Äänekoski mill site. These include a cheese factory that can make use of the excess energy from the pulp mill for the drying of its cheese products, a factory making pulp-based chemicals (CMC), a factory making pigments out of CO2 and an energy company of the municipality making bioenergy and buying district heat produced from the wood raw material. In the coming years, the Äänekoski industrial ecosystem is expected to grow further as established companies and start-ups are needed to fully implement the biorefinery vision of Metsä Group. The name of the producer of biocomposites has already been made public, but the names for the bark-based products, lignin-based products and for the textile fibre have not been revealed. In addition, the Group itself will start the production of veneer at the Äänekoski site.

Commercially, the production of 1.3 million tonnes of long and short fibre chemical pulp will have a stabilizing effect on the Äänekoski biorefinery. This will provide a long-term perspective for the business ecosystem to evolve and thus facilitate the use of the opportunities available. The new pulp production will also replace the old chemical pulp mill that has come to the end of its life cycle.

In the Finnish innovation system, the availability of R&D and pilot facility services is not a bottleneck. The challenges are related to the absorptive capacity in the management of traditional pulp and paper companies, in the availability of evidence needed for the legitimation of investments in order to enter into full-scale production and in the competences for marketing the products developed for new value chains and consumers (cf. Näyhä and Pesonen 2014). The research programme of the Technical Research Centre of Finland (VTT 2016) suggests that the Äänekoski Bioproduct mill is only the first step. Innovative processes and products being studied by VTT (2016) include:

- Bio-based polyamides and polyesters (competing with hydrocarbon-based polyamides and polyesters);
- Bio-based feedstock for chemicals based on fast pyrolysis;
- Cellulose nanofibrils-based pastes for 3D printing;
- Hemicellulose-based lactic acid and glycolic acid;
- Lignin-based emulsifiers in food applications;
- Lignin-based phenolic resins;
- Nanocellulose-based materials; and
- Thermoplastic lignin-based composite materials.

One of the aims of the R&D work at VTT (2016) is the development of flexible product portfolios for biorefineries. Increased flexibility will be valuable when a biorefinery strives to maximize its profitability in the face of demand and price fluctuations for different products. The meaning of "flexibility" is still poorly elaborated in the context of biorefineries. The term may refer to operational flexibility, i.e., a biorefinery may be able to ride out operational problems by taking advantage of operational redundancies. The term may also refer to business flexibility, e.g., a biorefinery may be able to take advantage of business opportunities quickly.

Another issue will be the degree of flexibility. At this stage, the volume-related flexibility is limited, because the volume-related focus is still in the board- and papermaking fibre. From the standpoint of business flexibility, biorefining offers a significantly higher degree of flexibility, because some of the chemicals and products being developed are expected to have clearly higher prices and profit margins (in absolute terms) than board- and papermaking fibre. Thus, a small operational flexibility to shift a relatively small part of the production from board- and papermaking fibre to chemicals and materials may entail a significant business flexibility.

The biorefinery approach is of particular interest to the Brazilian and Uruguayan industry, because the demand for bleached hardwood kraft pulp, including bleached eucalyptus kraft pulp, is confronted with more severe challenges than the demand for bleached softwood kraft pulp. Although the demand from tissue producers for bleached eucalyptus kraft pulp will probably remain strong at least in the medium-term, the challenges associated with the demand from printing and writing paper producers will probably continue. In the past decades, it was possible to import existing kraft pulping-related knowledge into Brazil (Figueiredo, 2014). At the present moment, the Brazilian and Uruguayan industry cannot rely on importing European and North American knowhow, because biorefinery-related knowledge is embryonic everywhere.

Considering the relatively low production costs at Brazilian and Uruguayan bleached eucalyptus kraft pulp mills, Brazilian and Uruguayan producers are probably not in immediate danger of becoming unprofitable. However, a deterioration of profitability is likely. The biorefinery approach offers potential solutions to future challenges in the bleached eucalyptus kraft pulp market. To build competences needed in the biorefinery approach, several issues have to be brought onto the agenda.

Firstly, what kinds of R&D avenues are chosen for distinct products and in what kinds of research-based ecosystems? Secondly, what can be learned from the past related to radical innovations of the chemical pulp industry? Thirdly, how to involve potential customers to the step-wise innovation process needed in the formation of new value chains and finally, how to tackle the issue of intellectual property rights that comes into play when significant investments are made into R&D?

Choosing R&D Avenues

The shift from contemporary bleached kraft pulp mills to biorefineries is associated with major R&D efforts. Firms wishing to operate wood-based chemical operations can choose from a wide range of alternative and/or complementary approaches in R&D. They may decide to conduct the R&D activities by themselves, to help spin-offs and start-ups from research institutes and universities to do the research and patenting, or to enter into open innovation platforms with multiple actors from various industries and research institutes.

Firms in the pulp industry need to develop competences for making difficult choices between many of the potential R&D avenues. Until quite recently, they have relied on the R&D achievements accumulated by firms engaged in mechanical and process engineering, and automation. These suppliers have acted in close cooperation with their buyers. Leaps in the productivity of the pulp production processes have created an engineering culture in which the major emphasis has for decades been on incremental innovations, after a major new generation production concept has been established.

Exploration-related R&D projects, particularly, exhibit significant uncertainty. As in the interrelationship between the pharmaceutical industry and biotechs, the firms in the chemical pulp industry could attempt to reduce uncertainty they are exposed to by letting start-ups, research institutes and universities perform particularly the front-end of the R&D projects. The firms in the chemical pulp industry could then identify the most successful R&D projects, make equity investments in start-ups at various funding rounds, and finally acquire those start-ups that have come up with interesting pilot and demonstration results, and are about to move to full-scale production but are in need of significant external funding. This would be analogous to pharmaceutical firms acquiring biotechs.

Irrespective whether a firm in the pulp industry decides to start an R&D project itself (or with partners), or buys a licence for a technology from a research institute which has patented it, or acquires a start-up, the firm needs competences in identifying the R&D projects. The challenge is significant, because there are numerous value chains in which biochemicals and biomaterials from biorefineries can be used. Solving this challenge requires a broad understanding of chemical engineering and the industries based on chemical engineering.

The Äänekoski biorefinery project shows that a significant part of the R&D activities may be carried out by partners. This does not free the biorefinery operator from acquiring significant scientific and engineering knowledge about the chemicals and materials to be produced from the intermediate products supplied by the platform operation in the biorefinery. This is because changes in the operations of the biorefinery may be necessary to improve the partner's operational and product performance and by so doing contribute to the sustainability of the partner's business. Thus, a critical issue in a multi-actor biorefinery context is: Do contemporary bleached kraft pulp producers have sufficient knowledge to collaborate with partners?

The focus on production costs has led the pulp industry to reduce complexity in its production processes. Although the production of some chemicals and materials may not have any impact on the current configuration of the fibre line and recovery cycle, the production of chemicals and materials may lead to increased production process complexity in some instances in the future.

A production facility producing numerous chemicals and materials side-by-side will face both engineering and business-related optimization challenges. So far, energy generation for external sale and by-products have played a relatively minor role in the chemical pulp industry. This has allowed for a relatively simple production process optimization – one focussed on fibre production demonstrating high strength and optical properties, and a uniform product (high quality). In the industry's quest for solutions, the literature on industrial engineering and management is of limited assistance in this context, because it has overwhelmingly focussed on the production of discrete products.

The concepts developed in the context of the production of discrete products are of limited or no use in the context of complex production processes with producing several products side-by-side. Comprehensive concepts, needed in the management of complex production processes with numerous products being produced side-by-side, need to be developed in the chemical pulp industry when it transforms into the biorefining industry in the coming years. The optimization function will be time-dependent, reflecting demand and price fluctuations across several chemicals and materials. Considering the high price of some innovative chemicals and materials, the production of the most plentiful products, electricity and fibre, may become of secondary importance in production process optimization.

For Brazil and Uruguay, the advent of biorefineries creates a source for chemicals and materials to be produced outside of the traditional paper industry value chains. Some of the large Brazilian firms in the pulp industry are already making moves towards this direction. For instance, Fibria Celulose S.A. made several investments in R&D based start-ups in Canada and a five million euros investment in Spinnova Ltd, a start-up based in Finland, developing a new technology for the spinning of yarn from wood-fibre. After the merger of Suzano and Fibria, the knowhow from these investments can be put to use at an accelerated speed due to the strong balance sheet. In the case of Spinnova, the R&D experts from (former) Fibria are continuing as board members while now representing Suzano. This facilitates the implementation of the strategic plan of Spinnova according to the road map set before the merger of Suzano and Fibria. In addition, international firms are planning to make investments for full production facilities for products outside the traditional pulp production. The Brazilian and Uruguayan governments are alerted to the new opportunities related to the wood-based bioeconomy and in Brazil the industrial strategy programme is implemented with the help of BNDES and the universities.

Learning from earlier phases of development

There is a cultural issue with the chemical pulp industry: On the scale of exploitation and exploration (March, 1991), the pulp industry has predominantly focussed on the exploitation of existing engineering competences instead of exploring novel processes, chemicals and materials. From a chemical engineering standpoint, kraft pulping has experienced significant evolutionary innovation but no revolutionary innovation since 1879, i.e., the invention of kraft pulping by Carl F. Dahl. There certainly have been changes over the years, e.g., the advent of continuous digesters, pressure diffusers, oxygen delignification and totally chlorine free bleaching, but all these changes have occurred within the confines of kraft pulping and have thus been evolutionary.

The other major approach to industrial chemical pulping, sulphite pulping, has seen more exploratory development and commercialization of processes, chemicals and materials over the years. The cause has been that the strength properties of sulphite pulp were not competitive with kraft pulp, and this crisis triggered innovation. In spite of innovation, sulphite pulping has almost disappeared. Another issue has been that the innovation happened in relation with chemicals and materials that could be produced at lower cost by using other raw materials, e.g., hydrocarbons and non-wood plants.

The fate of sulphite pulping is both an inspiration and a warning to biorefining. It is an inspiration, because it shows that wood is a potential raw material for numerous chemicals and materials. It is a warning, because it shows that the potential of wood raw material does not necessarily result in chemicals and materials that are cost competitive with the same or similar chemicals and materials based on other raw materials.

Innovation is a difficult path. The success rate – from a research and development project to a commercially successful new chemical or material – is low, probably as low as ten percent. When investment resources are allocated to competing projects internally, the high failure rate in explorative innovation projects makes it easy for proponents of capital investments in the exploitation of incumbent engineering to outflank proponents of exploration. To tackle the controversy between the exploration- and exploitation-related innovation modes from an organizational learning point of view, a new organizational culture needs to be developed.

Another strategic challenge for firms in the chemical pulp industry is to develop chemicals and materials that cannot be produced from hydrocarbons, cannot be produced from hydrocarbons without property and quality disadvantages, or cannot be produced from hydrocarbons without cost disadvantages. Potential cost disadvantages are aggravated with the historical price volatility of hydrocarbon prices. If this continues in the future, then this will translate into periods of unprofitability for wood-based chemicals and materials competing with hydrocarbon-based chemicals and products.

From the point of view of Brazil and Uruguay, the more than 1600 wood species that exist on the continent provide plenty of opportunities. *Eucalyptus spp*. may offer opportunities not available for *Pinus silvestris*-based production. Additionally, the Brazilian industry has also significant expertise in creating genetically modified trees (Fibria, 2014) which may offer particular advantages in biorefining.

New value chains

The challenges related to biorefining do not only relate to the early phase of the innovation pipeline. They are also very much related to the downstream of the value chains. Representatives of other industries, not well informed of the potentials of wood-based chemicals and materials, have to be convinced of new opportunities. One approach for achieving this goal is to invite potential customers early on to the common projects used to develop the laboratory findings towards pilot and demonstration stages. For the management culture of pulp firms this may require a radical change as it has been enough to meet the requirements set by the paper, board and tissue producers in the past. In this new context, biorefinery operators need to develop a different and proactive mentality vis-à-vis their customers' business.

For creating new value chains, it might also be relevant to form cross-sectoral ecosystems, going far beyond dyadic relations between the buyer and the seller. Cross-sectoral ecosystems conducive for innovation have been found to include a wide array of actors (Bellamy et al, 2014; Spring et al., 2017), including besides firms in various value chains also financial institutions, governmental organizations, research institutes and start-ups. Because innovation involves recombination of existing knowledge, broadening the knowledge foundation increases the likelihood of innovation. Too specific knowledge may impede collaboration with partners from other industries and thus innovation.

There are some generic roles that firms in the pulp industry may adopt. The companies may choose to be suppliers to producers of innovative chemicals and materials – this would correspond with the position of chemical pulp producers in the paper value chain – or developing new businesses around innovative processes, chemicals and materials themselves. Particularly bleached kraft pulp mills belonging to vertically integrated paper producers have been and are little more than extensions of paper production. The emergence of innovative processes, chemicals and materials is an opportunity for firms in the pulp industry to take on the orchestrator role (cf. Wallin 2006; Lilja and Moen, 2017) in a wide scope of research and business ecosystems at the heart of different value chains.

The capacity to mobilize a proper organizational set-up of research and development in the context of innovative processes, chemicals and materials poses challenges for the pulp industry. The fault line runs between exploration and exploitation. It is necessary to shield exploration activities from exploitation activities. At least a separate organizational unit is needed for the explorative activities done within the firm (cf. Näyhä and Pesonen 2014). Analogously with the interplay between the biotech and pharmaceutical industries, another approach would be that large pulp firms direct funding and support to start-ups engaged in research and development. Then, at a certain stage of the innovation pipeline, the large pulp firm would acquire the most promising start-ups. Either way, professionals in the pulp industry will require sufficient competences in the identification, acquisition and integration of innovative engineering based on the R&D done by start-ups.

Even after innovative processes, chemicals and materials have reached a sufficient level of maturity, it may be necessary to take steps to protect the innovative processes, chemicals and materials within the firm. Units focussing on exploitation and exploration are culturally so different that combining them will almost inevitably result in conflict, and it is likely that teams in charge of the innovative processes, chemicals and materials will lose in such a conflict.

As Brazilian university programmes in engineering are not industry specific, the competences internalised from them are conducive to innovation. Industry-specificity in Master's Programmes contains the danger of reducing absorptive capacity of the professionals and thus the competence to legitimate by research based evidence chemicals and materials that could be produced as part of the emerging biorefinery concepts.

Innovation and Intellectual Property Rights

Institutions, including legal systems, have a strong impact on business strategy (Grewal and Dharwadkar, 2002; Wang et al., 2016). In industries in which innovation is an important factor in competition, the protection of inventions with (legal) intellectual property rights (IPR) is of strategic interest. The pulp industry has historically little experience with IPR. On the equipment side, IPR has usually been in the domain of equipment suppliers like Andritz and Valmet. On the process side, a considerable part of the IPR has been in the domain of the chemicals and equipment suppliers with pulp producers playing a small part. In the chemical pulp markets, IPR has played a minimal role. The foundation of competition has been based on product properties, product quality, and price. Whereas these three have been based on process controls and stability, and raw material, IPR has played a limited commercial and strategic role so far.

In the still embryonic biorefining, IPR will offer new strategic opportunities: Firms may become included in R&D-related ecosystems by providing co-funding for early stage research and later on make equity investments in firms that have made progress in the stages of the innovation pipeline, like Fibria did over many years. At a later stage, the firms acting as venture capitalists may choose to enter into biorefining, and/or create cash flows from selling or licensing the biorefining-related knowhow. Such financialization processes of R&D investments turned into IPRs have been experienced in the life sciences industry very widely (Birch, 2017).

The transformation into biorefining contains a new legal landscape as innovative processes, chemicals and materials will require close attention to IPR. Strategically, IPR plays a multitude of roles. IPR establishes a legally protected monopoly for a limited time, and during this time the IPR holder can recoup the R&D costs and potentially significant profits. However, IPR can also be used strategically to block potential competitors even if the IPR holder does not use the IPR rights.

Because of national differences, in addition to IPR-related contents in international trade agreements, navigating the landscape of the Intellectual Property Law is a complex task. Companies in the bleached kraft pulp industry will need to gain competences in Intellectual Property Law on their way to biorefining. By so doing, they can secure that at least part of their investments in the R&D is turned into assets that can be used as a source of income.

CONCLUSION

Wood-based innovative chemicals and materials produced in biorefineries offer new business opportunities for the chemical pulp industry. The diminishing demand for printing and writing paper will make it necessary for the pulp industry to look for new customers, chemicals and materials.

The contribution of this paper is that it outlines the challenges of the pulp industry when it moves from a commodities-based business model to a specialty products-based business model as part of the transformation towards a biorefinery approach. The key issues are not only related to engineering and science, but also to mentality. Most notably, this paper identifies (i) the incompatibility of an exploitation-focussed mentality in the present pulp industry with an exploration-focussed mentality conducive to value added products in biorefining, (ii) the need to broaden the competences into areas of chemical engineering that are outside of traditional kraft pulp engineering, and (iii) the need to gain competences in intellectual property-based competition.

Biorefineries offer the prospect of a greater process and product – chemicals and materials – flexibility. This flexibility coincides with a greater process complexity. Whereas the chemical pulp industry has striven to reduce production process complexity particularly in order to reduce costs, increasing process complexity represents a turning point. The move towards biorefining also means a greater business complexity as the number of value chains, of which the industry is part of, increases.

An aspect of the transformation to biorefining is the identification, acquisition and integration of innovative engineering. A significant part of the R&D activities occurs in small start-ups – this is an analogy with the relationship between the pharmaceutical industry and the biotech sector. The pulp industry has relatively little experience in the identification, acquisition and integration of innovative engineering, and all of them are challenging.

A key challenge for the pulp industry will be competition from hydrocarbon-based chemicals and materials. Because of the chemical similarities of hydrocarbons and wood, these two raw materials will be competing in many instances. It will be necessary for the biorefinery industry to develop products which cannot be copied by using hydrocarbon and by so doing enter the market with lower costs. The ongoing and accelerating global energy transition from fossil fuels to renewables will force hydrocarbon-based value chains to seek new business opportunities in chemicals and materials – and these will, in many instances, compete with wood-based chemicals and materials.

The pulp industry transforming into biorefinery industry is on the threshold of an exciting future characterized by innovation. This is a future where the pulp industry is not a mere supplier of fibre to paper producers, but it is an industry that is participating in and co-shaping numerous value chains in the chemical industry in its widest meaning. ■

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