Papers in Innovation Studies

Paper no. 2015/34

# Unpacking investment decisions in biorefineries

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This is an early version of a paper to appear in Technology Analysis & Strategic Management with the title "Unpacking resource mobilisation by incumbents for biorefineries: The role of micro-level factors for technological innovation system weaknesses".

This version: September 2015

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**WP 2015/34**

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Examining investment decision in Swedish and Finnish pulp and paper firms, this paper highlights the importance of considering decision-making processes within companies in order to understand the limited diffusion of biorefinery technologies. Further, the paper identifies organisational innovations in the form of new divisions, forward vertical integration, and creation of new value chain relations as central to commercialisation of biorefinery technologies. Theoretically, it argues that the technological innovation systems framework should be complemented with insights on decision-making processes within companies in order to understand the development of emerging technologies.

**JEL codes:** L73, O31, O33, Q55

**Keywords:** Biorefineries; investment decisions; organisational innovation; pulp and paper industry

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# Unpacking investment decisions in biorefineries

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Abstract

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# 1. Introduction

Fostering a viable bio-based economy is considered to be a crucial element in the transition to a low carbon society (European Commission 2012). A bio-based economy can be understood as an economy where the basic building blocks for materials, chemicals and energy are derived from renewable biological resources, such as plant and animal sources rather than fossil resources (McCormick and Kautto 2013). Today, bio-based goods replace just 0.2% of petroleum-based goods but alternatives exist for over 90% of them (Richardson 2012).

A key enabling factor in the realisation of a transition to bio-based economies concerns the development and diffusion of biorefinery systems (OECD 2009). We follow the IEA (2009, 2) in defining biorefineries as *'the sustainable processing of biomass into a spectrum of marketable products (food, feed, materials and chemicals) and energy (fuels, power and heat).'* Various studies have pointed out that biorefining is of particular relevance and interest to the pulp and paper industry in its strategic efforts to seek new, alternative ways to extract and appropriate greater value from biomass (Stuart 2006; Pu et al. 2008). Instead of using the forest biomass exclusively for the production of pulp and paper, biorefining allows for its conversion into additional or substitute products such as low-carbon fuels (e.g. 2$^{nd}$ generation bio-ethanol, DME and biodiesel), green chemicals, substances used in the construction industry, viscose for clothing, or ingredients for the food and pharmaceutical industry; while making more efficient use of the heat in the production process. As such, biorefining allows for the production of both high-value low-volume and low-value high-volume products.

Many observers thus consider biorefining as a promising strategy for forest industries to increase their efficiency and diversify into different markets. Essentially, it holds the potential for improving the pulp and paper industry's competitiveness, while at the same time improving its energy-efficiency, carbon emission impact and overall environmental performance (Karltorp and Sandén 2012; Novotny and Laestadius 2014; Näyhä and Pesonen 2014). At the same time, these studies find that the adoption of biorefinery technologies in pulp and paper industry in practice is limited. Potential explanations for the notably slow adoption are lack of competencies and absorptive capacity, the high capital intensity of the industry and difficulties in establishing strategic partnerships with actors from related industries along the value-chain.

An important and, among policy-makers, popular instrument to increase the rate of diffusion of biorefinery technologies is through trial and demonstration projects (Klitkou et al. 2013; Karltorp 2014). An important rationale for such publicly funded trial and demonstration projects is to help reduce technological uncertainties and learn about the acceptance, desirability and adaptation of new technologies. Ultimately the aim of these trial and demonstration projects is to upscale and overcome the well-known 'valley of death' between research, development and demonstration (RD&D) and market introduction. By upscaling, we refer to the application of biorefinery technologies, which have been developed and tested in demonstration projects, into commercially operating plants. This requires, however, that actors in industry are willing to undertake significant investment at a relatively early stage.

So far, most previous studies have approached the adoption of biorefinery technologies at the meso-level, taking an (technological) innovation system perspective (Negro and Hekkert 2008; Hellsmark and Jacobsson 2012)). This approach foregrounds the role of networks of actors and institutions in the development and diffusion of novel technology. While an innovation system perspective has yielded important insights regarding the slow diffusion of biorefinery technologies, it suffers from a tendency to black-box processes within firms (Farla et al. 2012). This paper complements existing

studies by looking specifically at investment decision at the level of the firm. Such investment decisions seem to constitute a critical bottle-beck for the limited upscaling of biorefinery technologies and its wider adoption in pulp and paper industries.

This paper aims to provide a better understanding of investment decisions in upscaling of biorefinery technologies. With a focus on Sweden and Finland, we specifically direct our attention to retrofitting of existing production facilities in the pulp and paper industry (Cohen et al. 2010), and asses how these decisions are conditioned by, one the one hand, different organisational characteristics (Hill and Rothaermel 2003) and, on the other hand, different investment logics (Bergek, Mignon, and Sundberg 2013; Mignon and Bergek 2012).

The remainder of the paper is organised as follows. The following section presents the conceptual framework, and section 3 describes the methodology. Section 4 contains the analysis of biorefinery investment decisions by pulp and paper firms, while the final section concludes and discusses implications for policy and theory.

# 2. Conceptual framework

The Technological Innovation System (TIS) perspective has become a popular analytical tool to explain the success and failure of the development and diffusion of renewable technologies and their contribution to low-carbon transitions. The focus on analysing emergent technological fields distinguishes TIS from related frameworks (Coenen and López 2010) like the sectoral (Malerba 2002) and regional innovation systems (Cooke 2001). The TIS perspective emerged in the early nineties from a quickly expanding innovation system literature, which is rooted in evolutionary economics and industrial dynamics (Freeman 1987; Lundvall 1992; Nelson 1993). A TIS is defined as *'a dynamic network of agents interacting in a specific economic/industrial area under a particular institutional infrastructure and involved in the generation, diffusion, and utilisation of technology'* (Carlsson and Stankiewicz 1991, 93). These actors, networks, institutions and technology constitute the structural components of the TIS following the more general systems of innovation framework (Edquist 1997). A novel and quintessential aspect of the TIS perspective concerns its attention for the functional performance of the innovation system's components, conceptualised through a set of functions, as defined in two programmatic papers by Bergek et al. (2008) and Hekkert et al. (2007). This set of functions distinguishes between the ability of innovation systems to support entrepreneurial activities, knowledge development and diffusion, guidance of the search, market formation, resource mobilisation and finally creation of legitimacy around technologies.

Apart from analysing the built up of systemic support for innovation in an emerging technological field, the set of functions has also been applied to inform policy-making and formulate rationales for policy action (Negro, Hekkert, and Smits 2007). Here, the TIS framework follows the more general approach to policy legitimation found in the innovation systems literature concerning systemic failures or problems (Klein Woolthuis, Lankhuizen, and Gilsing 2005; Laranja, Uyarra, and Flanagan 2008; Wieczorek and Hekkert 2012; Smith 2000). The underlying idea is that innovation systems are a problem oriented heuristic: resources and capabilities are mobilised and coordinated in order to find a solution to a problem (Gee and McMeekin 2011; Metcalfe and Ramlogan 2008). Once the TIS framework delivers an analytical output of how well the functions are fulfilled, this is followed by a definition of process goals in terms of a desired functional pattern (Bergek et al. 2008). Since weak functions signal the need for policy intervention, the identification of inducement and blocking mechanisms leads to specifying key policy issues – which are subsequently transformed into policy recommendations.

Drawing on the TIS perspective, a recent study conducted by the Swedish Energy Agency offers a set of important insights for the development and diffusion of biorefinery technologies in Sweden (Swedish Energy Agency 2014). This report provides an overview of system strengths and weaknesses for a range of renewable energy technologies, including biorefining. Here, it is found that knowledge development and diffusion in the area of biorefining is relatively strong. Research and development in biorefinery technologies have received substantial financial support in Sweden and have created a strong research infrastructure across Swedish universities and research institutes in the field. As a consequence, Sweden has acquired a key position globally in many platform technologies in the area of biorefining. Other innovation system functions are, on the other hand, much less developed. Notably, resource mobilisation and market formation are considered to be weak aspects of the innovation system around biorefineries.

More specifically the report mentions that publicly funded financial support has been primarily given to early stages in the innovation process, whereas support for upscaling is only marginal. At the same time, co-financing from industry has been lagging behind. As a result, it is argued, few resources have been mobilised to offset the market uncertainties that are associated with biorefineries. It is therefore not surprising that another system function, market formation, is equally poorly developed. Only small amounts of biofuels and biochemical are produced, often for research purposes rather than on a viable commercial basis. Likewise, policy instruments and changes in regulatory requirements have not been deployed to such an extent that it has created a market for bio-based products.

These observations have been primarily made at the system level and point to a general reluctance by industry to make investments that would allow biorefining to move from a RD&D-focused formative phase towards a growth phase, characterised by commercial activities and the emergence of markets for bio-based products. To better understand the reluctance of industry to scale-up and move towards commercial exploitation of biorefineries, it is therefore important to take a closer look at the decision-making processes within companies vis-à-vis the large scale and commercial implementation.

The importance of investment decisions for the deployment of renewable energy has already been addressed in previous studies (Bergek, Mignon, and Sundberg 2013; Mignon and Bergek 2012). These studies did not focus on biorefining specifically but have examined renewable electricity production across-the-board, including biomass, wind power, hydro and solar. These studies found that motives to invest in renewable energy can be quite diverse and certainly range beyond what is traditionally considered the prime rationale, namely generation of economic value. Rather, non-economic motives played an equally, if not more important role for deciding to invest in renewable energy production. Here, a distinction was made between motives related to sustainability, interest in the technology and problem-solving. On the basis of these different motives, five types of entrepreneurs are identified with different aims and strategies to invest in renewable energy.

(1) Investment-driven entrepreneurs are driven exclusively by the profit that they expect to gain from investing. Their decision-making process is largely based on an economic rationality where a portfolio of investment opportunities are evaluated and assessed, often based on a comprehensive technological investigation and investment calculation, in order to pick the most profitable one. For these kinds of entrepreneurs, investing in renewable energy is one among many options. (2) Diffusion-driven entrepreneurs are also driven by economic incentives, however, counter to investment-driven entrepreneurs, with a particular stake in specific new products or services related to renewable energy. They identify a need in the market and decide to mobilise resources to address this gap. (3) Technology-driven entrepreneurs do not consider the investment as economically driven

but rather recognise and pursue an opportunity derived from technological knowledge and commitment. Being rather unconcerned with profits or markets, these aficionados invest primarily due to their passion for a specific technology. This passion can to a large extent be fuelled by a belief that this specific technology will contribute substantially in terms of contributing to sustainable development. (4) Solution-driven entrepreneurs are largely driven by a problem that they want to solve, which could relate to technological, environmental or business performance. As such, the dominant logic is not profit-maximisation but rather the ability to solve a problem while keeping the costs of the solution low. Finally, (5) efficiency-driven entrepreneurs are primarily concerned with resource efficiency and sustainability rather than profit generation. They do not like to see valuable natural resources go to waste.

Of course, the above studies have not been carried out specifically with biorefining in mind even though Mignon and Bergek (2012) note that pulp and paper companies are particularly likely to invest in biomass based renewable energy primarily with a problem-solving motive in mind. Nonetheless, moving beyond an investment-driven rationale, this typology is helpful to start questioning why pulp and paper companies are or are not investing in the implementation of biorefinery technologies. It also raises the question whether different investment logics may coexist within firms. Thus, while these investment rationales arguably play an important role, the organisational context of the firm also needs to be taken into consideration.

Following the work by Leonard-Barton (1992), the management literature has emphasised that core capabilities may turn into core rigidities, which inhibit new developments in incumbent firms. Established knowledge, values and technical systems facilitate innovation in existing products and processes, but also hinder innovation beyond the current focus of incumbents.

However, it should be acknowledged that incumbents can under certain condition avoid getting trapped in core rigidities. Hill and Rothaermel (2003) question the sometimes taken-for-granted Schumpeterian notion that incumbent firms have great difficulties in responding to disruptive technologies and, thus, go into decline while new entrants rise to market dominance by exploiting this novel technology. They assert a number of propositions that would allow incumbent firms to neutralise the incumbents' inflexibility when facing disruptive technological change (see also Christensen 1997).

Firstly, Hill and Rothaermel (2003) argue that incumbent firms must overcome internal forces of inertia and resistance of change based on routine systems that produce predictability and reliability. As noted by Francis, Bessant, and Hobday (2003) radical organisational transformations are, fundamentally, political processes. Mechanisms to overcome resistance to change are the creation of legitimacy within the firm for autonomous action, e.g. through organisational procedures specifically designed to encourage and fund the initiation as well as provide regular evaluation of new products and services. In other words, a strategy of institutionalised product and service innovation. Here, they stress the importance of loosely coupled, stand-alone divisions to commercialise new technology. Secondly, incumbent firms must counteract the tendency to engage in limited search; *'to over-value the feedback from their existing customers, to ignore small, out-of-the-way market niches, and to let existing strategic commitments drive attempts at pioneering new technology to the margins of the organization'* (Hill and Rothaermel 2003, 262). This calls attention for the strategic advantage of possessing downstream complementary assets that are critical to the commercialisation of the new technology or the need to engage in strategic alliances to access these complementary assets. Moreover, it stresses the importance of organisational slack understood as *'the cushion of actual or potential resources which allows an organization to adapt successfully to […]*

*external pressures for change in policy, as well as to initiate changes in strategy with respect to the external environment'* (Bourgeois 1981, 30).

# 3. Methodology

The material for this analysis of investment decisions in upscaling of biorefinery technologies has been collected using a mixed methods approach. Sources include academic papers, grey literature, secondary data such as yearly reports by firms and interviews covering various aspects of the transformation of the Swedish and Finnish pulp and paper industry since 2012. Additionally, 21 interviews were carried out with a specific focus on investment decisions in the period March-September 2014. Due to the sensitivity of the interview topic, informants and the organisations they represent were promised anonymity, however, table 1 provides an overview of the profiles of the interviewees.

**Table 1. Profile of interviewees**

| *Organisation type* | *Interviewees* |
|---|---|
| Pulp and paper firms | I7, I8, I19, I20, I21 |
| Research institutes | I1, I17, I18 |
| Universities | I2, I5, I11, I13, I14, I16 |
| Technology suppliers | I3, I12 |
| Intermediaries and other actors | I4, I6, I9, I10, I15 |

# 4. Biorefinery investment decisions by pulp and paper firms

A rapid increase in research on biorefineries is evident at the global level, as well as in Sweden and Finland (see table 2). Naturally, this increase is primarily driven by university research, but it is clear from the interviews that Swedish and Finnish pulp and paper firms are significantly involved in research activities. Partly, this is driven by a considerable research push within the biorefinery area from the public sector, where patient research funding from public sources has been available for some time (I10). But it is also driven by constantly increasing efforts from Swedish and Finnish pulp and paper firms, from early-stage research to testing and establishment of pilot plants where for instance the processing of new products based on pulp side streams are tested (I10; I18; I20). Data from Sweden highlights that investments in such pilot and demonstration plants linked to biorefinery technologies have increased significantly over the last 10-15 years (Hellsmark 2015). Thus, policies have in particular focused on supporting the development of new technologies which could be implemented in existing pulp and paper mills.

**Table 2. Development in published scientific articles on biorefineries**

| | *2005* | *2006* | *2007* | *2008* | *2009* | *2010* | *2011* | *2012* | *2013* | *2014* |
|---|---|---|---|---|---|---|---|---|---|---|
| World | 19 | 35 | 71 | 93 | 165 | 225 | 271 | 354 | 444 | 561 |
| Sweden and Finland | 0 | 0 | 2 | 4 | 10 | 24 | 35 | 38 | 45 | 60 |
| Swedish and Finnish share | 0% | 0% | 3% | 4% | 6% | 11% | 13% | 11% | 10% | 11% |

*Based on number of articles on the topic of 'biorefinery' in Web of Science Core Collection*

However, it is equally clear that research efforts have – with very few exceptions – not resulted in the implementation of biorefineries. As highlighted by the report by the Swedish Energy Agency, resource mobilisation and market formation are particularly weakly developed functions in the biorefining innovation system (Swedish Energy Agency 2014). Swedish and Finnish examples of investments in biorefinery technologies are the retrofitting of the mill in Örnsköldsvik (Domsjö Fabriker, now Aditya Birla), a gas generating plant at Joutseno Mill (Metsä Fibre), a lignin extraction system at Sunila Mill (Stora Enso) and a biodiesel production facility at Kaukas Mill (UPM). In other cases, planned investments have been cancelled such as the investment by Södra in a lignin extraction system at the Mörrum Mill. In other words, Swedish and Finnish pulp and paper firms have so far invested in very few commercial applications of biorefinery technologies.

Previous studies have pointed towards a number of challenges faced by the Swedish and Finnish pulp and paper industry, which partially explains the absence of a transition towards biorefining (Karltorp and Sandén 2012; Näyhä and Pesonen 2014; Novotny and Laestadius 2014; Novotny and Nuur 2013). Firstly, pulp and paper firms have focused on building capabilities around core activities and thus lack competencies in areas outside pulp and paper. Even pulp and paper firms which have committed to significant investments in biorefineries continue to have an overwhelming focus on mature product groups in their competence development (I21). Secondly, the pulp and paper industry is highly capital intensive and very large investments have been made in existing machinery. Thirdly, pulp and paper firms face significant difficulties in establishing strategic partnerships with actors from related industries. Combined, these characteristics imply that the ability to innovate outside existing products and processes is limited, thus, pulp and paper firms clearly appear to be in a situation where core competencies have become core rigidities. As expressed by an informant explaining the potential for moving into bio-based chemicals (I8): *'Our core competence is the processing of biomass. We know how to purchase wood, how to transport it, how to process it further. But our knowledge on chemicals is very limited.'*

However, as pointed out by Hill and Rothaermel (2003) these core competencies – or rigidities – are not necessarily pervasive and uncontested within the firms. Reflecting this, across our interviews it was evident that the R&D departments at the pulp and paper firms would often repeatedly make calls for investments in biorefinery technologies. These calls would be based on technology-driven motives, where the R&D managers would emphasise the opportunities arising from the new technologies; however, they have rarely had an audience in the firms' top-level management.

### *4.1. Preference for investments in proven technologies*

The core activities of pulp and paper firms are characterised by economies of scale, bulk production of commodities and price-based competition. Contrary to this, biorefineries require a focus on economies of scope and a competitive strategy based on product differentiation and quality (Coenen, Moodysson, and Martin 2014; Novotny and Laestadius 2014). Thus, the difference is striking and it is therefore perhaps not surprising that the management of pulp and paper firms are hesitant to move into the field. An informant (I20) explains that while the top-level management is interested in the biorefinery technologies presented to them *'…they don't really understand the field. They might have a vague idea that it is something worth betting on.'* Consequently, investments are concentrated in traditional pulp and paper activities and the standard feedback to the R&D departments is to continue developmental work on biorefinery technologies (I20): *'We are told: 'You need to further-develop the business model, look more at how the technology functions, and then we*

*can consider it again' It is a very, very long process.'* Thus, referring to the taxonomy of Mignon and Bergek (2012), while technology-driven motives are dominant among decision makers in R&D departments, such motives are much less important among top-level managers. Here, investments are rather motivated by problem-solving, in particular related to technological problems in existing production facilities.

This focus reflects an inability to more beyond limited search (Hill and Rothaermel 2003) and invest in products and processes that are not closely relating to the existing portfolio. Interestingly, a representative of a pulp and paper firm, which has undergone a significant transformation during the last decade through divestments, conversions and closures of paper mills, and increasing investment in biorefinery technologies, note that this process has only been possible due to a significant change of staff at multiple levels in the firm (I21): *'Many people had to leave the company on the way.'* However, such a change is the exception rather than the norm. A non-corporate researcher (I2) explains that it is very difficult to convince the management of Swedish pulp and paper firms. Again, the management of Swedish pulp and paper firms are found to be interested when new technologies are presented to them, but *'then they go back and change nothing'*. This is contrasted to Brazilian firms, which are found to be much more receptive: *'They are younger firms, so they are not so locked in their way of thinking, their grandparents didn't work in the same mill as themselves.'*

The conservatism of top-level management concerning choices of investments is also reflected in the account of another informant (I18): *'I really cannot say that [top-level management] is good at [investing in biorefinery technologies rather than traditional pulp and paper technologies].'* This informant proposes that pulp and paper firms may not be the right to take biorefinery technologies to the commercial stage due to the significant associated changes in business models. Thus, in the competition for investment funds internally in pulp and paper firms between biorefinery technologies and traditional pulp and paper technologies involved in the production of e.g. paper or packaging, the latter continues to be the front-runner. As explained by an informant (I8): *'Traditional business areas and business activities are considered the major business for the foreseeable future. They will always be the biggest business areas […] biorefinery activities are still small and will take decades to get bigger.'* Thus, while it was emphasised by an informant (I18) that there are individuals in the top-level managements of pulp and paper firms, which are positive towards investments in biorefineries, this informants also noted that the members of top-level managements with responsibilities for operations are not receptive to such ideas. And currently, the latter group appears to have the greater influence on investment decisions.

In summary, upscaling of biorefinery technologies appears to be impeded by a preference among most top-level managers for investments focusing on solving technological problems in existing production facilities. This questions the emphasis in policy making on support for the development of new technologies, which seems to implicitly assume that technologies will more or less automatically be taken up by firms and commercialised once they are sufficiently developed (see also O'Connell and Haritos 2010), however, this ignores the so-called 'valley of death' between RD&D and commercialisation. Conversely, in our analysis, we identified the need for organisational innovations as central to the commercialisation of biorefinery technologies. In the following, we analyse the role of new divisions (section 4.2), forward vertical integration (section 4.3), and creation of new value chain relations (section 4.4).

### *4.2. New divisions*

As emphasised by Hill and Rothaermel (2003), stand-alone divisions in charge of commercialising new technologies may be an important step for incumbents to embrace radical new technologies. Some Swedish and Finnish pulp and paper firms have recently established designated biorefinery

business units, e.g. UPM Biorefining and Stora Enso Biomaterials, and informants highlighted this as an important step towards further commercialisation of biorefinery technologies. To exemplify, an informant (I3) representing a technology supplier to the pulp and paper industry notes that *'You need to have designated divisions within the company. The people from the traditional departments will not take decisions to invest in biorefining technologies, these processes step on their own feet.'* Similarly, when describing a potential biorefinery investment, a representative (I21) from a pulp and paper firm notes that *'it must also impact the investment budgets of the other business areas […] they are not fully happy.'*

While it was generally agreed that such organisational changes strengthen the position of biorefining within the firms, they are not sufficient by themselves. For instance, while Holmen established Holmen Biorefinery Center in 2009, the firm is yet to make its first major biorefinery investment (Novotny and Laestadius 2014), and describes itself as *'people committed to paper'* (Matthis 2014, no page) who, thus, continue to concentrate investment on product development of paper. This also reflects that the size of biorefinery investments necessitates decision taking at by top-level management. To exemplify, while decisions by two pulp and paper firms to support the development of a biorefinery technology could initially be taken by the head of R&D groups, follow-up decisions to support investments in a demo-plant had to be taken by the divisional management, and decisions to invest in full commercialisation (which did not materialise) by top-level management (I8; I17; I18). Similarly, an informant (I20) representing another pulp and paper firm explains that investments in improvements of existing technologies such as the manufacturing of packaging can often be taken at the divisional level, while investments in commercialisation of biorefinery technologies needs to be decided by top-level management. Thus, it is simply easier to take decisions to invest in incumbent technologies, than to move across the 'valley of death' from RD&D to full-scale commercial investments for new technologies.

In summary, establishment of biorefinery divisions within pulp and paper firms are an important step towards further commercialisation of biorefinery technologies, but they do not by themselves guarantee increasing investments in commercialisation of biorefinery technologies, as these investment decisions are taken by the top-level management due to their size. As stated by an informant (I7) commenting on a recently released strategy by the biorefining division of the firm he represents: *'Top management probably looks differently at things'*. Thus, while new divisions will create room for middle-level managers with technology- or diffusion-driven investment motives (Mignon and Bergek 2012), the final investment decisions regarding commercialisation of new biorefinery technologies will still reside with top-level managers where investments are often motivated by the search for solutions to technological problems in existing production facilities.

### *4.3. Forward vertical integration*

There are several examples of investments in biorefinery technologies by Swedish and Finnish pulp and paper firms where the possibility of identifying an internal use has been central to carrying through the investment decision (I7; I8; I10; I18). This allows the firms to start experimenting with the processes at full scale. As described by a firm representative (I7), talking on such an investment: *'It is actually an R&D investment. Many other investments would have been much more profitable.'* Thus, many development activities take place at these plants, which function as platforms for demonstration projects at the industry scale (I10). The signalling effect towards potential customers is of particular importance. To exemplify, (I7) *'[this investment] gives access to lignin; we did not have this so far and therefore we were not taken seriously by downstream lignin product developers. Now we have cards to play… We will use the lignin to develop new products.'* Similarly, describing the background for an investment in a similar technology by another firm, an informant explains (I18): *'If*

*you want the customers to buy lignin, you first have to show that you can produce it – otherwise you are not trustworthy […] you have to show that you are serious with biorefining, and that you have a product which you can offer to collaborators every day, not just once in a while.'* In this way, investing in full-scale biorefinery technologies may be motivated by an internal use of the products, which allows the firms to experiment with developing different value chains (see below), potentially adding new products with higher value added to their product portfolios.

Summarising, this forward vertical integration creates a new internal market for the products, which are used as input to R&D activities. In essence, these are examples of R&D investments, which are easier investment cases to argue, since there are no immediate commercial requirements, thus, investment rationales are modified. Consequently, the challenge of eventually securing an external market for the products remains, however, as expressed by an informant (I10): *'It may sound conservative as a first step, but when you are putting tens-of-millions of euros into it, you have to be careful.'*

### *4.4. New value chain relations*

As suggested by Hill and Rothaermel (2003), a second very important facilitator for investments in commercial scale biorefinery technologies is involvement of downstream actors, in particular commitment to purchasing agreements. This is important as the firms enter markets that are significantly different from current product portfolios and they are therefore uncertain whether there is a market or not. This challenge is expressed in the following way by an informant (I19): *'It is very difficult. We have people that can sell 100,000 tons of paper but no chemicals. We don't have the competencies. Before we can make these investments, we need to secure demand. And we don't know these customers […] But it is not just about knowing them, it is also about creating trust, because these are very large investments.'* Another informant (I8) expresses a similar view, arguing that pulp and paper firms' knowledge on the chemical industry is insufficient while, conversely, *'…it is the opposite for chemical industry. They have higher competence in processing of different organic molecules and they know the rules of the game in chemical markets […] but they have very limited knowledge about handling of biomass.'* Thus, across the interviews, partnerships with firms from industries such as chemicals, gas, oil, automotive and textile were considered key to investment decisions in biorefinery technologies as they can open doors to new markets outside traditional forestry products. To exemplify, one informant (I10) explains how a purchasing agreement with a gas company helped the investment decision in the commercialisation of a gasification technology by a pulp and paper firm. In fact, due to the capital intensity of biorefinery developments, such agreements may even be necessary for demonstration plants. In one case, the construction of a demonstration plant for a lignin technology was only feasible due to the commitment of a customer to purchase the produced lignin for a period of three years (I18).

In light of this, it is an important challenge that pulp and paper firms often find it difficult to initiate cooperative relations with partners from downstream industries (Näyhä and Pesonen 2014). In our interviews, we also came across such issues, which appear to reflect a concern for becoming locked into value chain relationships where the pulp and paper firms are considered as mere suppliers of raw material with little value added. For instance, a representative of a pulp and paper firm (I20) explains that collaboration with a composite producer was terminated due to disagreements concerning who should be responsible for the various steps in the processing of the wood: *'It is difficult to reach an agreement on the responsibility for the processing. The business model is crucial.'* This informant notes that the chemicals industry has so far mostly considered pulp and paper firms as suppliers of raw material, but that there are some signs that this is changing, acknowledging that pulp and paper firms should be responsible for more steps in the production process.

In summary, the importance of downstream purchasing agreements is evident from the interviews, as a number of informants (I7; I8; I20; I21) put it very simply: top-level management will not decide to invest in full-scale biorefinery technologies before agreements with downstream producers are signed. If such agreements are absent, top-level management will be likely to reject such investments or postpone the investment decisions. This highlights the importance of reducing the risk associated with biorefinery investments, in light of a preference among top-level managers for investments in solutions to technological problems in existing production facilities.

# 5. Conclusions and implications for policymakers and managers

Biorefining is frequently highlighted as a promising development pathway for pulp and paper firms, as it allows them to diversify into high-value products, while at the same time improving energy efficiency and reducing carbon emissions. This is particularly the case in developed countries, where pulp and paper firms face increasing competition from South American and Asian firms. Consequently, both policy and research in Sweden and Finland have increasingly given attention towards biorefinery technologies, however, only few examples of commercialisations have followed in Swedish and Finnish pulp and paper firms. This is the apparent paradox that this paper has analysed.

The analysis highlights the importance of different investment motives within the pulp and paper firms for explaining this paradox. While decision makers in R&D departments will argue for investments in biorefineries due to technological commitment and the expected contribution of these technologies to long-term sustainable development, top-level managers prefer to prioritise investment funds for problem-solving in relation to current technological problems in existing production facilities. While top-level managers are frequently funding R&D activities around biorefinery technologies, they hesitate to invest in the commercialisation of these technologies. This finding is supported by the analysis of Björkdahl and Börjesson (2011) who indicate that while Swedish pulp and paper firms do support new idea development, there is an acute lack of risk-taking at the management level, which inhibits investments beyond established products. In effect this reproduces an internal 'valley of death' where new technologies developed in R&D departments never make it to the commercial scale. This questions the focus in policy making on development rather than diffusion of new technologies.

We argue that this conclusion highlights the need of moving beyond the firm as a black box in the TIS literature (Markard, Hekkert, and Jacobsson in press). Our analysis highlights that in some cases, it is only certain parts of firms (e.g. R&D departments) that contribute positively to the development of a specific emerging technology, while the management of these firms may in fact hamper the development of emerging TISs. This does not question the relevance of a systemic perspective on innovation processes, but it highlights the need for complementing it with theories on decision-making processes within organisations, such as contributions on investment motives (Mignon and Bergek 2012) and incumbent organisational characteristics (Hill and Rothaermel 2003).

The analysis pointed to the central role of organisational innovations in the form of new divisions, forward vertical integration, and creation of new value chain relations for the commercialisation of biorefinery technologies. Thus, policies aimed at upscaling of biorefinery technologies should consider the possibilities for supporting such organisational innovations in pulp and paper firms (Coenen, Moodysson, and Martin 2014). Firstly, regarding new divisions, we suggest that it is important that policymakers are aware of potential conflicts within firms in order to optimise the pay-off from public investments in RD&D. Employees from R&D departments may often write applications for support to public research and innovation programs, and more generally be the main

point of contact in the firms to policymakers. However, if top-level management has limited interest in commercialisation of emerging technologies, then it is questionable if the public resources allocated to knowledge and technology generation in R&D department are sufficiently exploited by these firms. This highlights the need for involving top-level management as a target for learning processes.

Secondly, regarding new value chain relations, the analysis suggests that facilitation of contact to downstream actors is very important for the commercialisation of biorefinery technologies, especially in light of the emphasis on product diversification. Thus, policy can potentially play an important role by facilitating arenas for interaction between pulp and paper firms and potential downstream actors. While such venues are often organised according to single industry platforms, this suggests that it might be more important to take prospective value chains as a starting point.

Finally, in terms of management implications, we do not suggest that top-level managers should necessarily adapt the same perspectives on evaluation of potential investments as R&D employees – it is natural that employees with different function and responsibilities consider investment options from different angles. Still, we argue that some alignment is needed across the different functions in a firm; in a short-medium term perspective it makes little sense for a risk adverse management to delegate significant resources to RD&D in biorefinery technologies, if it will anyway not consider commercial applications.[1] However, more importantly, securing long-term profitability will most likely require that the top-level managements open up to diversification through investments in biorefinery technologies. This requires expanding the competence-base of the firms through recruitments and further education of employees, and managerial attention to organisational innovations in the form of new divisions, forward vertical integration, and creation of new value chain relations.

## Acknowledgements

The authors would like to thank Fredric Bauer and Antje Klitkou for helpful comments. This research was funded by the Swedish Energy Agency and the Swedish Knowledge Centre for Renewable Transportation Fuels through the project *Enabling the transition to a bio-economy: innovation system dynamics and policy*, and by Nordic Energy Research through the project *Technology Opportunities in Nordic Energy System* Transitions. Additional financial support was provided by the Swedish Research Council (Linnaeus Grant No. 349200680) and the Swedish Governmental Agency for Innovation Systems (Grant agreement 2010-07370). Finally, the authors thank the interview persons for their time.

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[1] Of course, following an open innovation logic, firms could also capitalise such RD&D investments externally. However, this does not seem to be a frequent business model in the pulp and paper industry.

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