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ENABLING THE TRANSITION TO A BIO-ECONOMY: INNOVATION SYSTEM DYNAMICS AND POLICY

Summary report from a project within the collaborative research program Renewable transportation fuels and systems

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PREFACE

This project is financed and carried out within the f3 and Swedish Energy Agency collaborative research program *Renewable transportation fuels and systems* (Förnybara drivmedel och system).

f3 Swedish Knowledge Centre for Renewable Transportation Fuels is a networking organization which focuses on development of environmentally, economically and socially sustainable renewable fuels, and

- Provides a broad, scientifically based and trustworthy source of knowledge for industry, governments and public authorities
- Carries through system oriented research related to the entire renewable fuels value chain
- Acts as national platform stimulating interaction nationally and internationally.

f3 partners include Sweden's most active universities and research institutes within the field, as well as a broad range of industry companies with high relevance. f3 has no political agenda and does not conduct lobbying activities for specific fuels or systems, nor for the f3 partners' respective areas of interest.

The f3 centre is financed jointly by the centre partners and the region of Västra Götaland. f3 also receives funding from Vinnova (Sweden's innovation agency) as a Swedish advocacy platform towards Horizon 2020. Chalmers Industriteknik (CIT) functions as the host of the f3 organization (see www.f3centre.se).

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1 INTRODUCTION

1.1 BACKGROUND

A key factor in the realisation of a successful bioeconomy is the development of biorefinery systems that are well-integrated into the existing infrastructure (OECD 2009). IEA (2009: 2) defines biorefineries as "the sustainable processing of biomass into a spectrum of marketable products (food, feed, materials and chemicals) and energy (fuels, power and heat)." In short, biorefineries aims to provide high versatility in the utilisation of biomass, and minimise and recycle waste streams. A main goal is to produce both high-value low-volume and low-value high-volume products. Current biorefineries in Europe are mostly based on a single conversion technology and a limited amount of products produced but a combination of several, utilizing existing industrial infrastructure, can reduce overall costs and increase flexibility in product possibilities and power generation. This is known as the integrated biorefinery and is a key step towards the advanced bioeconomy (McCormick & Kautto 2013).

The principal products of the bioeconomy are biobased products and bioenergy, while the fundamental technology, introduced to replace petroleumbased refineries, is biorefineries. Thus, biorefineries underpin the future of many biobased products such as liquid biofuels for transport. Even though biorefinery ideas are increasingly discussed on paper, the adoption by Swedish industry and integration in existing infrastructures is limited. Existing fossil fuel based systems are stabilized by lock-in processes leading to path dependent developments which constrain the deployment of innovative biorefining alternatives (Grin et al 2010). A transition between technological systems consists of co-evolutionary processes that include changes in governing institutions, regulation, markets, user practices and industrial structure (Geels et al 2008). Moreover, transitions do not follow a one-size-fits-all model but are shaped by contextual factors (Truffer & Coenen 2012). Thus, some regions and actors leap ahead while others lag behind.

1.2 AIM AND RESEARCH QUESTIONS

The project aims to assess opportunities, challenges and steering options to expedite development and deployment of Swedish integrated biorefineries. The central research question is: What promotes and hinders transition pathways to the development and deployment of integrated biorefineries in Sweden?

To accommodate the multi-faceted character of transition pathways, the project seeks to answer the following research sub-questions:

1. How do different Swedish firms and industries (incumbent and emergent) react to the opportunities and threats posed by a biorefinery transition?

2. How is the development and deployment of integrated Swedish biorefineries shaped by framework conditions and policy regulations and to what extent is there a need for change to facilitate a transition?

3. To what extent are Swedish biorefinery transition pathways influenced by different regional contexts?

2 OUTPUT OF THE PROJECT

The project has resulted in 7 published papers, 1 submitted paper currently (December 2017) under review in academic journals as well as 1 database. Below we briefly summarize the papers and thesis and elaborate on the content of the database.

2.1 SUMMARIES OF PAPERS

1. Hansen, T., & Coenen, L. forthcoming. Unpacking resource mobilisation by incumbents for biorefineries: the role of micro-level factors for technological innovation system weaknesses. Technology Analysis & Strategic Management.

This paper unpacks resource mobilisation for biorefineries by studying investment decisions of incumbent pulp and paper firms in Sweden and Finland. The analysis highlights that the limited adoption of biorefinery technologies can be attributed to both insufficient abilities (lack of needed competencies and partnerships) and interests (preference for improving existing technologies) by pulp and paper incumbents. Drawing on the technological innovation system perspective complemented with insights from the management literature on the role of incumbents in technological change, four issues are empirically identified as important for improving resource mobilisation for biorefinery technologies: establishing loosely coupled divisions in pulp and paper firms; creating internal markets for new bioproducts aimed at further technological development; entering purchasing agreements with downstream actors; and investing in new managerial competencies.

2. Hansen, T.; Klitkou, A.; Borup, M.; Scordato, L. & Wessberg, N. forthcoming. Path creation in Nordic energy and road transport systems – the role of technological characteristics. Renewable & Sustainable Energy Reviews

This paper reviews path-creation processes in road transport systems in the Nordic countries: e-mobility in Denmark, hydrogen and fuel-cell electrical vehicles in Norway, and advanced biofuels in Finland and Sweden. The study builds on the path creation literature, which seeks to explain the emergence of new technological pathways. Drawing on recent insights concerning the differences between design- and manufacturing-intensive technologies, the paper analyses the influence of technological characteristics on path creation processes. The case comparison indicates that technological characteristics seem to have greater influence on the content of activities in the later phase rather than the early phase of path creation processes. The analysis also emphasises that barriers to path creation processes differ depending on technological characteristics. This highlights the importance of considering technological characteristics in energy and transport policies.

3. Hellsmark, H. et al., 2016. The role of pilot and demonstration plants in technology development and innovation policy. Research Policy, 45(9), pp.1743–1761.

Pilot- and demonstration plants (PDPs) represent bridges between generating basic knowledge and tech-nological breakthroughs on the one hand, and industrial applications and commercial adoption on theother. This paper reports on a longitudinal study of how two technological fields that received significantpublic funding evolved—biochemical conversion of biomass and thermal conversion of black liquor. Indoing so, this study makes two contributions. First, it provides a framework for analyzing the roles ofvarious types of PDPs in developing new technology. The framework highlights the learning processestaking place at and around these plants and how they contribute to

reducing different types of risks.It also elaborates on the importance of actor networks and institutional preconditions, and how bothnetwork performance and institutions can be influenced through various strategies. Second, the articlecontributes with new insights into the challenges of innovation policy in a PDP context. A policy mix isoften required because policy cannot be considered meaningfully at a single level of government and willtherefore be influenced heavily by limited foresight and politics (both nationally and locally). Therefore, policy must address both the need for parallel and iterative public funding of R&D and different types ofplants, as well as attempts to directly influence collaborative processes in actor networks.

4. Hellsmark, H. et al., 2016. Innovation system strengths and weaknesses in progressing sustainable technology: the case of Swedish biorefinery development. Journal of Cleaner Production, 131, pp.702–715.

Based on the combination of economic challenges and uncertain policy conditions in the United States, European Union, and elsewhere, the development of advanced biorefineries has progressed slower than anticipated. This has delayed the transition to a more sustainable and less carbon-intensive economy. In this article, we adopt the technological innovation system (TIS) approach to analyze advanced biorefinery development in Sweden, a front-runner country in current development. The analysis highlights a number of system strengths (e.g., long-term research funding; significant research infrastructure; strong actor networks) that have contributed to developing the Swedish TIS, but also important system weaknesses (e.g., weak coordination among ministries; lack of industrial absorptive capacity; unclear roles) inhibiting it. The article highlights a combination of four policy measures that build on the system strengths to address the system weaknesses: (a) the implementation of a deployment policy for creating domestic niche markets; (b) improved policy timing and more structured coordination among different governmental agencies; (c) the provision of stronger incentives for mature industries to invest in R&D and improve their absorptive capacity; and (d) improved organization and financing of existing research infrastructure. In addition to the empirical contribution, the article contributes with novel insights into the TIS framework by highlighting the dynamics between system strengths and weaknesses, and suggests that system strengths should be better emphasized in future TIS studies.

5. Hellsmark, H. & Söderholm, P., 2016. Innovation Policies for Advanced Biorefinery Development: Key Considerations and Lessons from Sweden. Biofuels, Bioproducts and Biorefining, Accepted for publication

This paper provides an innovation systems perspective on the combination of policy instruments that will be required to stimulate technological development in the advanced biorefinery field. We first consult the established innovation policy literature, and provide a general framework that can be used to identify the type of policy instruments needed to develop new sustainable technology. In a second step, we illustrate how these general principles can be applied in the context of future biorefineries based on either the thermochemical or biochemical conversion of lignocellulosic biomass feedstocks. We draw heavily on the experiences of biorefinery development in Sweden. A central conclusion is that in Sweden, and elsewhere, there are few niche markets for advanced biorefineries and a lack of long-term policy instruments for the more established renewable fuels. For this reason, there is a need for innovation policy instruments that create markets for renewable fuels and green chemicals, thus supporting technology development during a niche market phase and allowing for the first commercial-scale plants to be built. The aim of such a policy would be to stimulate learning, form value chains, and experiment with various design options on a larger scale; this

complements the use of technology-neutral policy instruments such as carbon pricing, which primarily promotes the diffusion of mature technologies. The policy instruments that are candidates for the niche market phase include, for example, public procurement and various types of price guarantees.

6. de Besi, M. & McCormick, K. 2015. Towards a Bioeconomy in Europe: National, Regional and Industrial Strategies. Sustainability, 7(8): 10461-10478.

Establishing an advanced European bioeconomy is an important step in achieving the transition towards sustainable development and away from fossil fuels. The bioeconomy can be defined as an economy based on the sustainable production and conversion of renewable biomass into a range of bio-based products, chemicals, and energy. Several strategies have been produced in Europe from different perspectives that outline visions, intentions, and recommendations for the transition to a bioeconomy. An analysis of twelve of these strategies was conducted using a meta-analytical framework. This paper outlines the results of this study covering national, regional, and industrial perspectives on the bio-based economy in Europe. The analysis shows that a common direction for the bioeconomy, based on research and technological innovation in the various applications of biotechnology, is developing in Europe. It highlights the important role that the regional level will play in facilitating collaborations between industries and research institutions needed to foster innovation and optimize the use of biomass. The analysis also identifies that the development of European bio-based product markets are needed for bioeconomy expansion. However, the transition needs to have a lifecycle perspective in order to ensure that an economy founded on biomass is sustainable and equitable.

7. Voytenko Palgan, Y. & McCormick, K. 2016. Biorefineries in Sweden: Perspectives on the opportunities, challenges and future. Biofuels, Biorpoducts and Biorefining 10 (5): 523–33.

A growing political interest in the development of biorefineries is being shaped by climate change and a need to develop economically viable substitutes (i.e., fuels, products and chemicals) to those produced in traditional oil refineries. The pulp and paper industry in Sweden has been stagnating and it is therefore potentially promising to integrate biorefining into its activities as one way of diversifying its business. Sweden has good prerequisites for a transition to a bioeconomy due to its natural geographic conditions, industry, and infrastructure. It has developed a bioeconomy strategy and piloted several biorefinery projects. At the same time, the deployment of biorefineries has been slow, and they have not reached commercial scale. The aim of this paper is to provide an overview of the current and future development of biorefineries in the context of the emerging bioeconomy in Sweden. It is based on a literature review, policy analysis, and ten interviews with bioeconomy experts. It maps key political and legal aspects, economic and raw material aspects, social and cognitive aspects, and technology and infrastructure aspects that facilitate and hinder the development and deployment of biorefineries in Sweden. This paper identifies four action points important to the development of biorefineries and the bioeconomy: (i) commitments – establish targets and policies that drive the transition; (ii) contradictions – improve alignment on visions, goals, and activities; (iii) capacity – build up infrastructure and competences to harness the potential; and (iv) collaboration – develop cooperation across sectors and between actors.

8. Bauer, F.; Coenen, L.; Hansen, T.; McCormick, K. & Palgan, Y.V. (submitted): Technological innovation systems for biorefineries – A review of the literature

The concept of a bioeconomy can be understood as an economy where the basic building blocks for materials, chemicals and energy are derived from renewable biological resources. Biorefineries are considered an integral part of the development towards a future sustainable bioeconomy. The purpose of this literature review is to synthesize current knowledge about how biorefinery technologies are being developed, deployed, and diffused, and to identify actors, networks and institutions relevant for these processes. A number of key findings can be obtained from the literature. First, investing more resources in R&D will not help to enable biorefineries to cross the 'valley of death' towards greater commercial investments. Second, while the importance and need for entrepreneurship and the engagement of small and medium-sized enterprises (SMEs) is generally acknowledged, there is no agreement how to facilitate conditions for entrepreneurs and SMEs to enter into the field of biorefineries. Third, visions for biorefinery technologies and products have focused very much on biofuels and bioenergy with legislation and regulation playing an instrumental role in creating a market for these products. But there is a clear need to incentivize non-energy products to encourage investments in biorefineries. Finally, policy support for biorefinery developments and products are heavily intertwined with wider discussions around legitimacy and social acceptance.

2.2 DATABASE

A large part of the work in the project was to construct a database with information about innovation projects related to biorefineries and biorefinery platform technologies in Sweden. Measuring innovation has been one of the main challenges for innovation studies over the last decades. Although several indicators are now available, including input oriented ones such as R&D spending and output oriented ones such as patents, they each have difficulties in capturing the actual innovation process – R&D is not the same as innovation and many innovations are not patented. Recent attempts at trying to map innovations in more detail include the SWINNO database (Sjöö et al. 2014) which looks at innovations in several industrial sectors in Sweden during recent decades, with the usual focus on completed innovations, rather than the innovation process. The database developed in this project instead captures the process of innovation through its focus on innovation projects, not the final product.

The projects included in the database are projects which are co-financed by private firms and two public funding organizations namely Vinnova (the Swedish innovation agency) or Energimyndigheten (the Swedish energy agency), the two main governmental agencies supporting applied research and innovation projects in energy related fields. The projects were identified in the project database of each of these agencies by searching for terms relating to biorefineries and the platform technologies (gasification, biochemical processing, torrefaction, and pyrolysis). The decision letter and application, describing the project, were requested from the agencies and read by the researchers and it is based on this information that the database was developed. The database is thus based on planned work, rather than outcomes. The database includes information about 120 projects, 24 of which were financed by Vinnova and 96 by the Swedish energy agency, running from 2001 to 2015. Each project is described with a short overview and then with more detailed information according to the categories described in Table 1.

Table 1. Overview of information in the database.

Category	Variable
Overview	Description of project fundamentals, e.g. start and end date, main applicant, funding.
Budget	Information about total budget, share of the total budget funded by the agency and budget per year that the project is running.
Organisation role	Information about the roles of organisations affiliated with the project, e.g. as participants, cofinancers, or consultants.
Organisation type	Information about the organisations affiliated with the project, e.g. type, sector, location and size.
Persons	Information about individuals affiliated with the project and the organisations they represent.
Raw materials	Information about raw materials related to the project, e.g. agricultural, forest, or process residues.
Products	Information about products related to the project, e.g. transportation fuels, intermediates, or chemicals.
Platform technologies	Information about platform technologies related to the project, e.g. torrefaction, entrained flow gasification, or biochemical conversion.
Infrastructure	Information about research and demonstration infrastructures related to the project, e.g. the LTU Green Fuels facility.

The new database complements existing resources as a source of information about biorefinery innovation and its role in the transition to a bioeconomy. The database can be used after the end of the current project for several types of studies. The database has initially been used in one study, which is to be concluded early 2017, that focuses on the ways that organisations engage in collaborations for biorefinery technologies. The study uses the database to map the dynamics of the network of organisations participating in the projects and how this unfolds over the period of 2004-2014. Future work could focus on collaboration around specific technologies, spatial patterns of collaboration or the participation of certain types of organisations in this kind of collaborative projects.

3 FINDINGS

‘**How do different Swedish firms and industries (incumbent and emergent) react to the opportunities and threats posed by a biorefinery transition?’**

This study has identified a number of significant strengths in the innovation system for Swedish biorefinery development (Hellsmark et al., 2016a). In international comparison, there is a significant and large-scale research infrastructure, consisting of prominent research actors, strong research networks (both nationally and internationally) and access to substantial long-term research funding.

Even though these strengths are undoubtedly important components for large-scale adoption of biorefineries they are not sufficient. Hellmark et al. (2016a) point to critical bottlenecks in the innovation system when it comes to the deployment of biorefineries. Among others, the study has identified weak industrial participation and a lack of industrial absorptive capacity, weak collaboration across knowledge and organizational boundaries as well as a lack of appropriate policies that explicitly facilitate market adoption and commercialization and weak coordination among government ministries and agencies (resulting in partial innovation support that mainly targets R&D).

Specifically for incumbent firms in the paper and pulp industry Hansen and Coenen (forthcoming) found that these face difficulties to mobilize both the financial as well as human resources to scale up biorefinery technologies due to limited absorptive capacity. Internal R&D investments in biorefining by incumbents are reportedly low, and a lot of research is left instead to sectoral research institutes (Bauer et al., 2016). As a consequence there is little absorptive capacity in industry to actually exploit new knowledge on biorefineries. An important explanation for this is that the knowledge and competence base of such firms is closely tied to existing production systems. Moreover, most incumbents continue to channel investments to improvements of existing technologies responsible for main profit streams in the short run based on established and mature product groups. To summarize, incumbents in paper and pulp are constrained by limited abilities and interest in biorefineries leading to path dependency in existing technologies and markets.

Our analysis suggests four ways by which the ability and interest of paper and pulp incumbents can be increased (Hansen and Coenen, forthcoming):

1. Establish loosely-coupled new divisions focused on biorefinery business development
2. Make more use internally of new biorefinery products to support competence development in non-traditional bioproducts and processes
3. Develop more knowledge on new bioproducts markets and users (in addition to knowledge about technology)
4. Develop new business-models and managerial competences beyond business-as-usual in paper and pulp

Although there is considerable publicly funded R&D, as well as R&D carried out in private-public cooperation, on biorefinery processes, designs and configurations, most of this research is carried out to develop technological knowledge. Efforts by entrepreneurs or other new entrants to commercialize such technologies and develop new technology-based business seems largely absent. A key

barrier towards such entrepreneurial experimentation is the large investments needed to fully test the viability and feasibility of different biorefinery concepts and designs (Bauer et al., 2016).

Development activities in pilot- and demonstration plants provide are key elements to address challenges related to deployment exactly because they focus not only on 'pure' technical challenges but also help reduce the organizational-, market-, and institutional risks and uncertainties that actors face in advancing biorefineries. Based on biorefinery related case studies in Sweden, Hellsmark et al. (2016b) show that pilot- and demonstration plants indeed serve different purposes, namely (1) creating awareness and legitimacy for a specific application, product, process or service (high profile pilot and demonstration plants), (2) testing, evaluating and characterizing different technological options for a certain application (verification pilot and demonstration plants), (3) market deployment and introduction or (4) acting as permanent test centers to make continuous improvements and test new technological options. Even though individual pilot- and demonstration plants may primarily be geared to specific purposes the study found that technology deployment would require comprehensive activities that cut across all purposes. This poses a challenge to policy-makers how to design support for pilot-and demonstration plants that achieves systematic progress from technology to market.

'How is the development and deployment of integrated Swedish biorefineries shaped by framework conditions and policy regulations and to what extent is there a need for change to facilitate a transition?'

Based on a review of twelve bioeconomy strategies in Europe covering national, regional and industrial perspectives de Besi and McCormick (2015) conclude that there is a strong push towards a European bioeconomy founded on supporting scientific research and technological innovation with a central role for the development and demonstration of biorefineries. These strategies acknowledge that the EU and national governments are important in providing the necessary funding programmes and a coherent policy framework. The latter is still an unresolved challenge as there are policies and regulation that support and incentivize the use of biomass and biorefineries as an energy source while there is almost no political or financial support for the industrial material use of biomass. Furthermore it is noted that policies and regulative frameworks that support the development of new markets and the uptake of bio-based products are acknowledged at the regional level but largely underprioritized in national strategies (see also Hellsmark et al. 2016a).

Specifically for Sweden Voytenko and McCormick (2016) identify four action points important to the development of biorefineries and the bioeconomy.

1. Commitment: there is a need to develop long-term and more ambitious policies (i.e. rules, advanced biofuel targets, and quota obligations for at least 15-20 years)

2. Contradictions: support for rather than conflict between fuels and non-fuel biobased products in visions, goals and activities tied to the bioeconomy

3. Capacity: development of bioeconomy sectors and industries encompassing and combining fuesl, chemicals and materials

4. Collaboration: closer involvement of users and consumers with universities, research institutes and industry in prioritizing knowledge gaps and new problem areas

Similarly Hellsmark and Söderholm (2016) emphasize that innovation policies for biorefinery development should be attentive to synergies between concurrent production of biofuels, bio-based chemicals and bio-energy. Moreover, there is a strong need to support (niche) market-creation for fuels, chemicals and materials produced in biorefineries through for example public procurement and various types of price guarantees.

'To what extent are Swedish biorefinery transition pathways influenced by different regional contexts?'

The study emphasizes the importance of pilot –and demonstration plants as instruments that help to address concurrently supply-side and demand-side challenges facing biorefineries. Typically such plants are localized in specific regions, e.g. around Örnsköldsvik, Göteborg and Piteå (Hellsmark et al., 2016a) bringing together different actors from academia, research institutes and across different industries. It seems that regions indeed provide for fruitful arenas for learning and experimentation with the formation of value chains for bio-based products, processes and services. Moreover, policy mixes that target the development and deployment of biorefineries in a more comprehensive and systemic way seem to be more prevalent at the regional level. It may seem that regions located in the periphery profit from a larger scope for experimentation and to 'learn-from-failing' yet actors face difficulties when upscaling biorefineries to large-scale and commercially-viable plants. Core regions, on the other hand, may provide greater critical mass in terms of industry activity, resources and policy support and capacity but may at the same time be more susceptible for processes of path-dependency and inertia. Our findings in this respect are however preliminary and would warrant further empirical research.

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