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A Value Chain Analysis of Nordic Cellulosic Ethanol Production

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Introduction

Cellulosic ethanol (CE) is produced from lignocellulosic feedstocks such as agricultural and forestry residues, energy crops, and municipal waste. From a simplistic view, the CE (production) process takes an easily tradeable low value product (biomass) and converts it into a high value product in high demand (transport fuel) while contributing to reduced GHG emissions. Yet, the production of CE remains limited, despite numerous demonstration plants and small scale pilot studies (Limayem and Ricke 2012), and substantial technical potential given the resource availability (Bernides et al. 2003).

Method

We conducted interviews of all the firms that produce 2nd generation bioethanol within the Nordic countries: Denmark, Sweden, Norway, and Finland. The case studies identified the feedstock, the supply chain, the technology and industrial process, production materials and output (Figure 1). In addition, we noted the institutional history, funding, and national policy landscape. Using these case studies, we examine the innovation and industrial dynamics from a value chain approach (Ponte and Sturgeon 2013; Bolwig et al. 2010) highlighting the important linkages and characteristics of the pathway structures (Figure 2) combined with technological innovation system theory (Hekkert et al. 2007). We find that the three dominant structures (and subsequent limiting factors) in the CE production chain are local resource availability (which sets an institutional legacy), local industrial knowledge base, and domestic policy landscape (which establishes priorities, feedstock subsidies, research, and end use products). Furthermore, the viability of CE production depends on its integration with higher value bioproducts.

Hypothesis

Production of 2nd generation bioethanol is more than just a technical issue; resource availability, institutional structures, and the policy landscape have a substantial effect on whether or not 2nd generation bioethanol is produced at any significant scale.

Denmark

Firms: Inbicon, which markets to Statoil. Inbicon is a subsidiary of DONG, the state-owned energy company. Processing supported by Novozymes, Danisco, BioGasol

Resource: Wheat straw (most abundant biomass resource in Denmark)

Processing: Hydrothermal pre-treatment, enzymatic hydrolysis, fermentation Output: 5% ethanol blend for petrol, lignin pellets, C5 molasses (animal feed).

Path Dependencies: Conflicting capital investments, policy (700 kr/l for incinerated straw subsidy; 2050 goal to be fossil fuel free; EU req for blended fuel-req. 99% alcohol), dominant enzyme technology. Variable feedstock costs. Further policy and market incentives necessary before industrial scale plants are constructed (Larsen et al. 2012).

Sweden

Firms: Weyland & Borregaard

Processing: Ag & forestry residue, paper waste (Weyland); pulping liquor (Borregaard commercial plant): various lignocellulosic feedstock (Borregaard’s BALI pilot plant)

Processing: Acid hydrolysis, saccharification with commercial enzymes, conventional fermentation of hexoses, aerobic fermentation or chemical conversion of pentoses and chemical modification of lignin

Output: ethanol (Weyland); speciality cellulose, ethanol, lignin and vanillin/ high value chemicals (Borregaard)

Path Dependencies: Norwegian tax structure is generally confusing - does not distinguish between 1st and 2nd generation ethanol as a gasoline additive. Biodiesel was dropped. Norway biofuel policy is unpredictable and lacks incentives for advanced bio-ethanol. There are restrictions on importing biomass due to sustainability regulations. High forestry feedstock costs. Forestry industry has historically been oriented towards pulp and paper and construction. Substantial fossil fuel exploration and hydropower. Changes in 2010 RD&D funding have led to more demo-projects. Weyland more interested in licensing the technology abroad; Borregaard in integrated bio-refineries, producing CE and high value specialty products.

Conclusions

We find that the technology itself is an important output that is incentivized (through licensing and consulting), which contributes to the low actual capacity, since only a demonstration plant is needed. This is specifically the case in Norway and is also a factor in Denmark. Nevertheless, Denmark is able to produce 2nd generation ethanol and sell it commercially, due to a favourable tax structure. In Sweden, it is more lucrative to produce specialty high value products rather than ethanol. Finland has the most incremental technological development, producing fuels using 1st generation technology from waste products, and now moving to 2nd generation technology for wood pulp. However feedstock prices are high throughout the Nordic countries. We conclude that international (e.g. EU) policies should account for national resource availability, industrial structure and strategy, institutional context, and political goals.

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