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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 trade-able 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 (Berndes 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 biorefinery products.

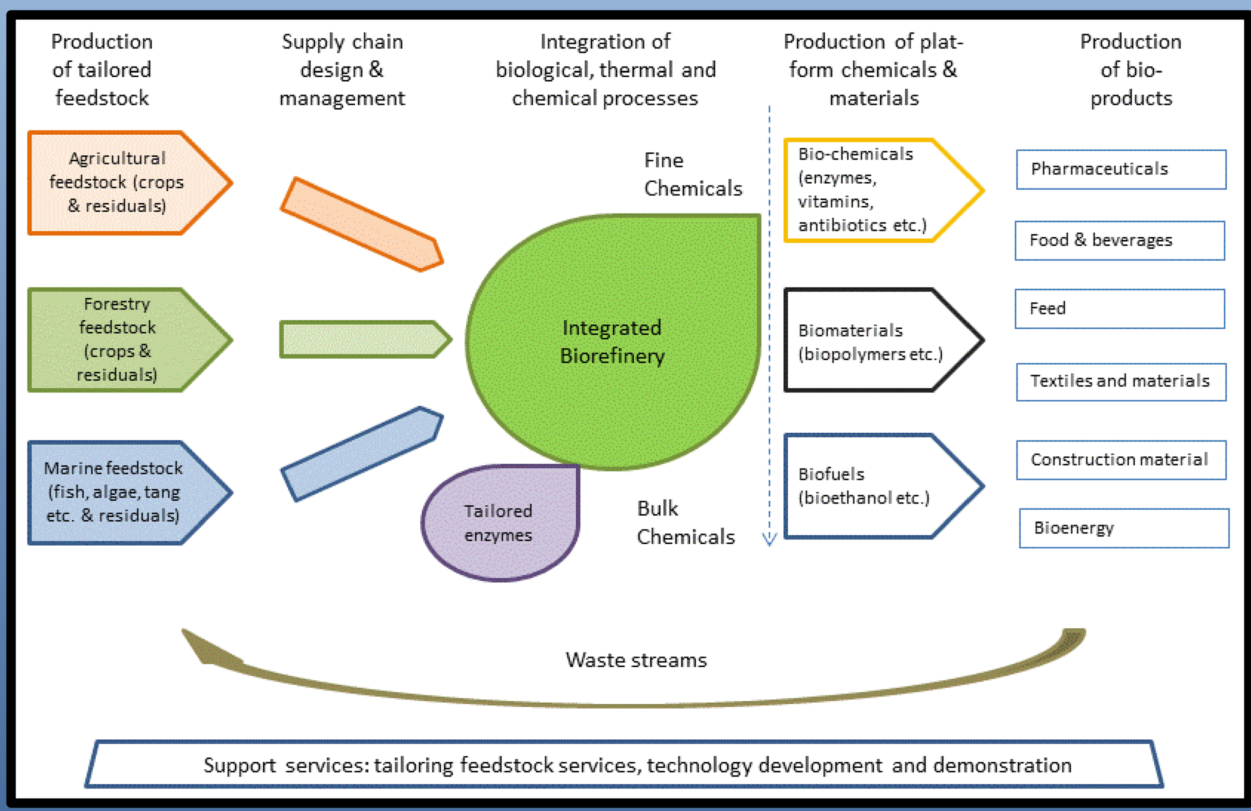

Figure 1. Integrated biorefinery value chain

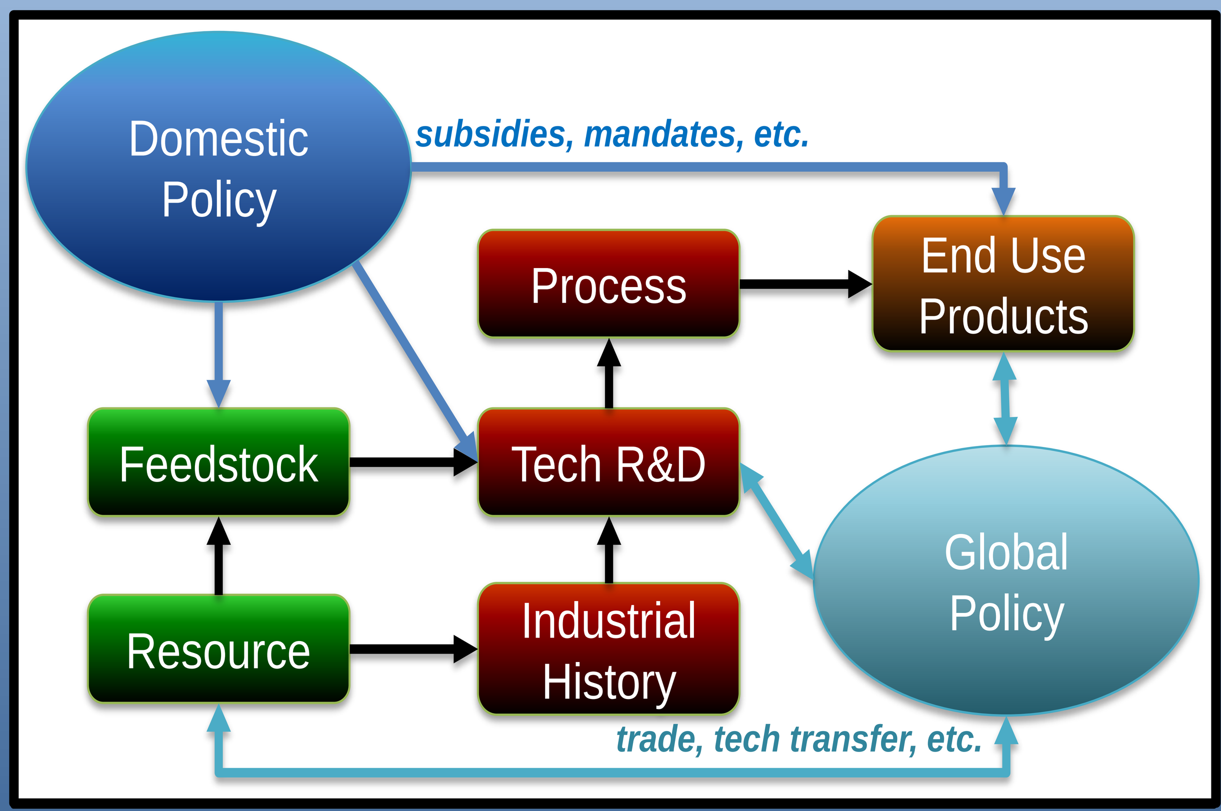

Figure 2. Structure for value chain analysis

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

Firm: 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/t 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).

Finland

Firms: UPM & VAPO
Feedstock: Tall oil (from black liquor sope), wood and black liquor
Processing: Hydrogen process (UPM), gasification and Fischer-Tropsch (Biomass-to-Liquid BtL) (UPM and VAPO)
Output: Biodiesel
Path Dependencies: Limited feedstock, Hydrogen process plant purely market-oriented and non-subsidied investment, which however is EU policy driven by getting benefit from the EU renewable energy policy, BtL investment start-up with EU NER 300 support.
Firm: St1
Feedstock: Biowaste from food industry (Ethanolix-concept); Municipal and industrial bio waste (Bionolix); material including cellulose, e.g. sawdust (Cellunolix)
Processing: 1st generation fermentation
Output: ethanol, animal feed, biomethane based heat and electricity
Path Dependencies: distributed in St1 own stations, fuel sold to North European Oil Trade. Ltd. Finland set a 20% RE target in transportation. Waste-based fuel has a low level of excise tax.

Sweden

Firm: Örnsköldsvik; R&D conducted in an 'industrial ecology' setting around Processum, including SEKAB, MoRe (a dedicated bioresource R&D firm originating from various paper and pulp firms), Domsjö, SP (applied research organization) and various universities (Luleå, Umeå).
Feedstock: Softwood and pulp from Domsjö Fabriker
Processing: Physical pre-treatment, bleaching, enzymatic digestion
Output: Specialty cellulose (hygiene and cosmetics), lignin for concrete, solid fuel, biogas
Path Dependencies: Development of technology and a research park. Linkages to the textile and concrete industries. Old paper mill that has been transformed to a biorefinery; industry struggling to break out of the traditional paper and pulp business model (bulk, commodity production, economies of scale and price competition) while a fully integrated biorefinery would more lean on specialized products, economies of scope and quality competition.

Norway

Firms: Weyland & Borregaard
Feedstock: Ag & forestry residue, paper waste (Weyland); pulpling 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 CE 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 fuels. 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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