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Value chain analysis of biofuels: Borregaard in Norway

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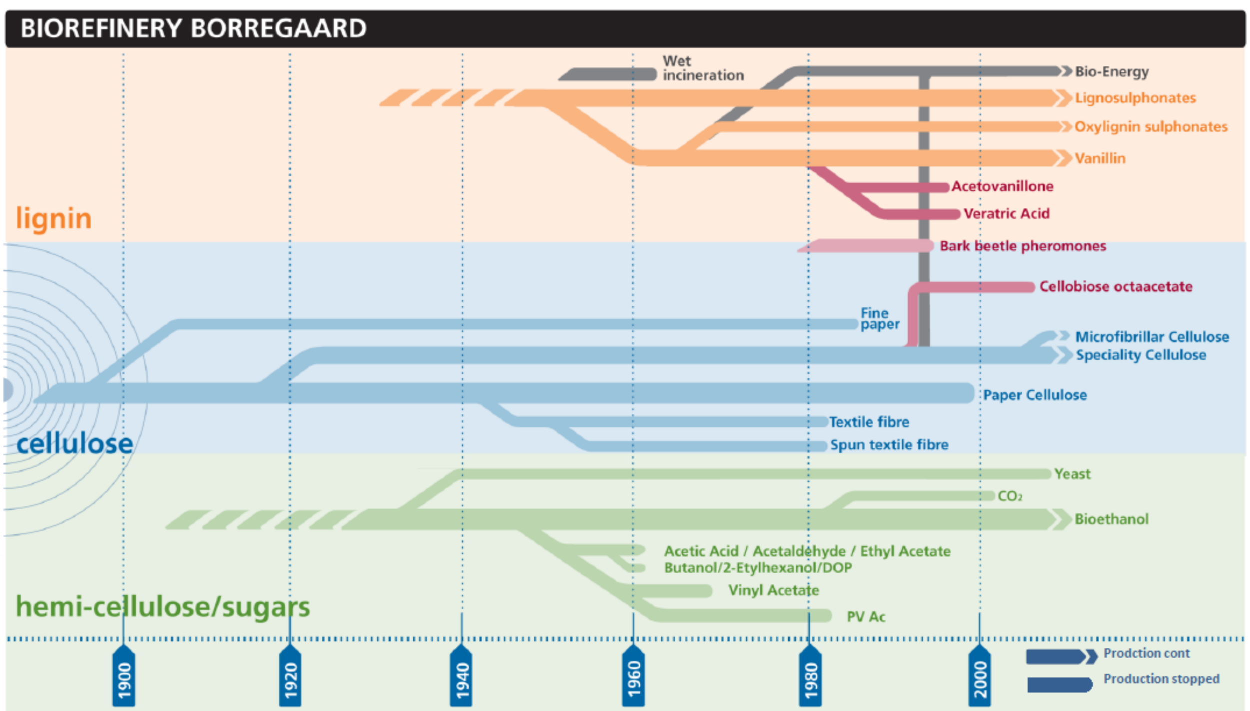
Borregaard is a Norwegian company, established in 1889 in Sarpsborg in the Østfold County. Traditionally, Borregaard has been engaged in pulp and paper processing. At the end of the 1930s the company started producing chemicals based on timber (spruce) as a raw material exploiting the hemi-cellulose in the feedstock. Since the 1950s Borregaard used also the lignin components of the feedstock for producing chemicals (Figure 1).

Borregaard has a strategy directed towards the production of value added products from renewable raw materials and advanced bioethanol is just a complementary product in that product portfolio. Borregaard has no ambition to become a leading producer of advanced biofuels. The rationale behind this strategy is that Borregaard sees advanced biofuels just as another commodity and Borregaard has tried to uncommodify the company and to become a specialised company regarding their product portfolio. This strategy has paid off today and conventional pulp and paper plants cannot compete with Borregaard because of high labour and feedstock costs and low value added products.

Figure 1: The timeline of Borregaard: transformation from a conventional paper plant to a biorefinery (Source: Borregaard)



After a takeover in 1986, Borregaard became part of the chemical division of the Orkla Group. Orkla is a Norwegian industrial conglomerate operating globally. Orkla has not been a driver for Borregaard's biorefinery strategy, but for Borregaard it was positive that Orkla had a focus on value added products and allowed large comprehensive innovation and R&D activities at Borregaard. The strategic decisions on innovative and R&D strategies have been made by Borregaard and not by Orkla. This was quite similar to the R&D intensive Orkla subsidiary Elkem Solar. Now, Orkla has more strategic focus on branded consumer goods operations and companies like Borregaard do not fit into Orkla's strategy.

Therefore, in 2011 silicon production for wafers at Elkem Solar, another former subsidiary of Orkla, was sold to a Chinese company (BlueStar), and in October 2012, Orkla initiated a stock market floatation of Borregaard. Borregaard's core business is based on the concept of a biorefinery that processes chemical products based on different types of lignocellulosic feedstock.

1. Value chain characteristics

1a. Main activities/segments

Feedstock provisioning

Borregaard has used lignocellulosic feedstock, sulfite spent liquor (SSL, 33% dry content) from spruce wood pulping as feedstock for bio-ethanol production over many years. The feedstock has been provided by the regional forestry industry and is relatively expensive compared to other countries. Borregaard has consumed annually about 1 million sm3 spruce (400.000 tons) (Johansen, 2009). Borregaard is paying close to 1.000 NOK for 1 ton of dry wood and 30% of this is related to logistics (300 NOK). There are also many restrictions on the import of biomass related to diseases, insects etc.

In the most recent pilot demonstration plant, the BALI facility, built near Sarpsborg, The Pilot started in 2012. The BALI pilot can use very different types of lignocellulosic feedstock, such as bagasse, spruce, eucalyptus and wheat straw. However also the usage of other feedstock will be explored, such as corn stover, bamboo and switch grass (Gargulak, 2010, p. 17; Rødsrud, Frölander, Sjøde, & Lersch, 2010). Bagasse comes from the sugar cane production and Borregaard considers building a large biorefinery, near the feedstock, for avoiding high transportation costs.

Processing (primary and secondary)

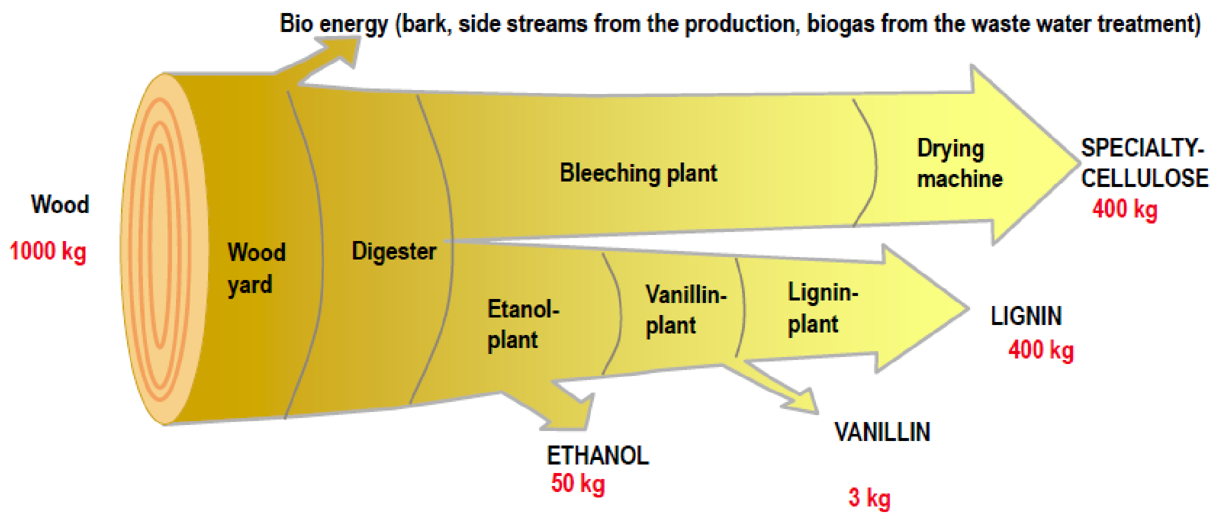
The bioethanol that is produced in Borregaard's biorefinery is based on extracting sugar from wood (spruce), which is then fermented to make ethanol. The biorefinery started already in 1938. This means that Borregaard has never been engaged in producing first generation biofuels but only second generation bio-ethanol or more precise 'advanced bioethanol'. The bio-ethanol process in the commercial operation is technically almost the same as it was from the start in 1938. The commercial biorefinery produces annually:

- 160.000 ton speciality cellulose;
- 170.000 ton speciality lignin;
- 20 million litres 2. generation bio-ethanol;
- 1.300 ton bio-vanillin;
- 200 GWh bioenergy
- 30 GWh biogas (anaerobic digestion) (Johansen, 2009, p. 4).

There exists just a very small production volume of first generation biofuels in Norway which is based on potatoes or cereals for producing alcohol for drinking but not for fuels. Because of the high costs in the Norwegian agriculture using agricultural crops for producing bioethanol or biodiesel has never been an option and will never happen.

Figure 2 illustrates the processing of biomass in Borregaard. Ethanol is just a by-product of the total process, produced in the commercial ethanol plant. The pulp for a paper mill is produced by cooking spruce chips with acidic calcium bisulfite cooking liquor. Hemicellulose is hydrolysed to various sugars during the cooking process. After concentration of the sulfite spent liquor, the sugars are fermented and ethanol is distilled off in several steps. A part of the 96% ethanol is dehydrated to get absolute ethanol. Much more focus is on the production of valuable specialty cellulose and lignin. Also vanillin is a valuable end product of the biorefinery, produced in smaller volume but higher value than ethanol.

Figure 2: Process diagram for Borregaard Industries - overview

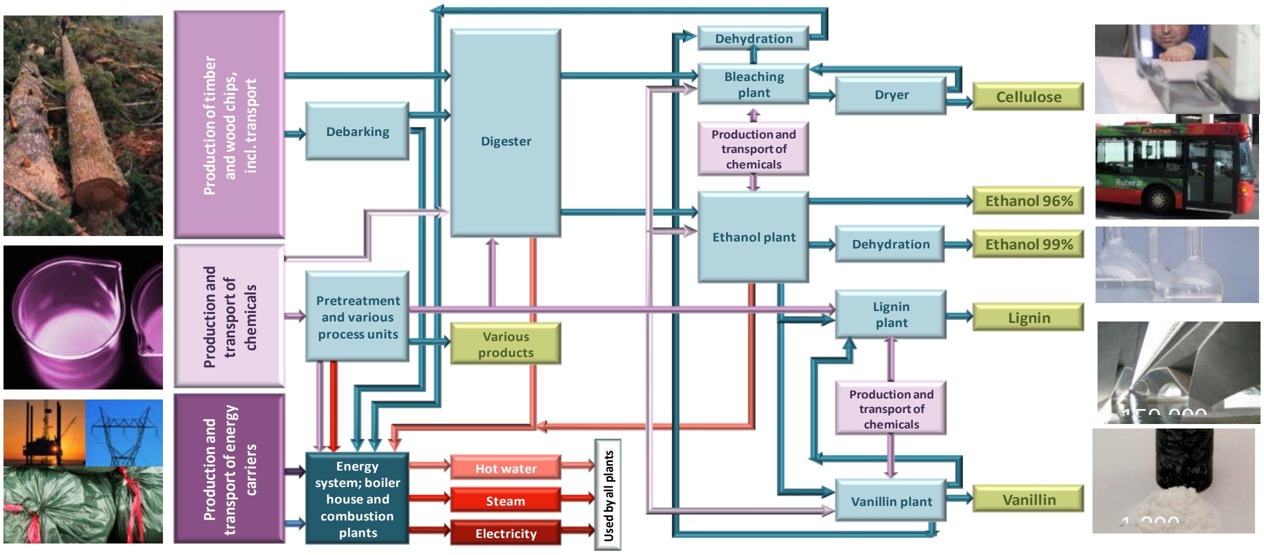


Applications (end products)

Cellulose	Lignin	Vanillin	Ethanol
Construction materials	Concrete additives	Food	Car care
Cosmetics	Animal feed	Perfumes	Paint/ varnish
Food	Dyestuff	Pharmaceuticals	Pharmaceutical industry
Tablets	Batteries		Bio Fuel
Textiles	Briquetting		
Filters	Mining		
Paint / varnish			

Source: Johansen (2009), Bacovsky, Dallos and Wörgetter (2010)

Figure 3: Process diagram for Borregaard Sarpsborg



Source: Brekke and Modahl (2012, p. 24)

Figure 3 gives a schematic overview over the flows of raw material and energy through the different processing steps towards the end products. Borregaard has been interested in optimizing these processes over the last decades. The most recent development has been the BALI Pilot plant, where the pre-treatment of the feedstock is central.

Borregaard has an additional 6 production plants around the world, and they do not produce bio-ethanol but only lignin speciality chemicals. For bio-ethanol production Borregaard has only two plants and both located in Norway, the commercial plant producing between 20 and 25 million litres advanced bio-ethanol per year and the BALI pilot plant.

The BALI pilot plant is a research plant and does not produce ethanol to the market. The strategic goal for the BALI Pilot is that Borregaard wants to continue to be the World leading supplier of lignin-based chemicals and to improve this, with bio-ethanol as an important - by-product. The strategic goal is to build and operate plants in Europe or other places in the World and not to become a technology supplier.

The BALI Pilot in Sarpsborg is based on biochemical conversion of lignocellulosics (input: 1 ton/day). The pilot will produce ethanol; lignin, specialty chemicals; single cell protein and sugar derivatives (output: 110 tons/annually). The experience gained over years in the commercial plant has been a valuable knowledge input into the pilot project. The main difference to the commercial plant is that Borregaard will use all of the cellulosic fibre for ethanol production, not just the hemi-cellulose as in the commercial plant, but also the cellulose; and both are broken down to sugars with enzymes. The yield is therefore much bigger and the production process is more simplified – there are only two products, bio-ethanol and lignin chemicals. The BALI process is based on chemical pre-treatment, saccharification with commercial enzymes, conventional fermentation of hexoses, aerobic fermentation or chemical conversion of pentoses and chemical modification of lignin. The project has the aim to “develop a biorefinery concept for production of marketable products and cost efficient processes for production of such from biomass. The partners aim at developing a complete train of process steps starting with a new and innovative pre-treatment process that will enable other solutions for downstream processing and manufacturing of other (and more valuable) products than state of the art. A palette of profitable and carefully selected products branching out from the specific pre-treatment process where all the three main components of biomass are used for marketable products is essential in the project. In addition, the know-how developed in the project will be crucial for running biorefineries efficiently and profitably over time, since the demand for products will change and the availability and cost of feedstock will change. More specifically, a combined production of 2nd generation bioethanol, specialty chemicals and other bio products will be developed. Reduced cost of saccharification by either reduced enzyme consumption or by reduced inhibitor production from acidic saccharification are expected results" (Lersch, 2009).

Over time there is a trend towards bio-based products in replacement of the fossil based economy. Borregaard has been working with a biorefinery for 50 years, long time before this became so popular. And the company sees that there is an increasing demand for bio-based products.

Use of waste products

For the BALI process different waste products can be used: Bagasse is a residual from the sugar and ethanol production from sugar cane and wheat straw is a residual from agriculture in Europe.

The production of industrial steam and electricity for the biorefinery is based on residual products from the processes of the biorefinery, such as bark and wood chips.

Integration with other energy production technologies

Already in 2000, Borregaard integrated a reactor built by Cambi, based on thermal hydrolysis for processing Waste activated sludge from the pulp factory and producing biogas. To reduce energy costs in its biorefinery, two municipal waste incineration plants are operating at Borregaard`s site in Sarpsborg. The first one was originally built and operated by Energos (since 2003), but is now owned and operated by Borregaard. The second one was built and is operated by Hafslund (since 2010). The Hafslund plant was built with public support from Enova, a public enterprise owned by the Ministry of Petroleum and Energy and the government's main tool in its focus on environmentally friendly restructuring of energy consumption and production. The facility extracts energy from approx. 90-120.000 tonnes of sorted municipal waste per year. Total annual supply is approx. 350 GWh industrial steam.

End use

The ethanol is used in different areas, such as car care, paint, vanish, the pharmaceutical industry and as a biofuel. The biofuel is used in busses and as an addition to petrol (5%). For lignin products there is a reasonable growth of market potential. The lignin chemicals have the performance as petroleum-based products; even they are not chemically identical. Borregaard is also working with micro fibres which have a different and improved functionality compared to petroleum-based products. There is not enough value in producing bio-ethanol as a stand-alone product in Norway. Therefore, in Norway, Borregaard is focussing on the lignin chemicals and other value added products.

In other countries, where feed-in tariffs for renewable electricity are in place, it could be an option to burn the lignin and produce heat and electricity in cogeneration power plants.

If the framework conditions become favourable for bio-ethanol because of too high fossil carbon prices then there is also an option for market growth of advanced bio-ethanol in replacement of conventional (sugar- and starch-based) bio-ethanol.

Distribution, marketing and sales

Borregaard is today the world's largest manufacturer of advanced bio-ethanol, with a production of around 20 million litres per year. 1 million litres of the annual 20 million litres is sold to the public transport company Ruter and its 20 bio-ethanol busses in Oslo. In late 2011 Borregaard started to supply Statoil with advanced bio-ethanol for adding to petrol (5%). The bio-ethanol sold to Statoil is sold in eastern Norway. Now Borregaard supplies Statoil with 1 million litres per year. Borregaard requires a premium on their ethanol because they can sell the bio-ethanol to other customers. Statoil's bio-ethanol blends are mainly based on imports of conventional bio-ethanol from other countries. In 2012 there were used 16 million litres of bio-ethanol in Norway (SSB), and only 1 million litres is advanced bio-ethanol.

1b. Main supporting activities

Borregaard has developed in the last period its knowledge base on advanced bio-ethanol:

- In 2008 the firm received funding from the BIA-programme of the RCN for a 2-years project on combined chemical and microbiological fermentation processes.
- In 2009 Borregaard conducted together with Østfold Research a Life cycle assessment study on cellulose, ethanol, lignin and vanillin.
- In 2009 Borregaard received 19 million NOK funding from the Research Council of Norway for its 5-years project Biomass2Products; research partners from the Norwegian University of Science and Technology, Sintef and the Norwegian University of Life Sciences are involved.
- The BALI Biorefinery Pilot in Sarpsborg is partly financed by the Norwegian Government through Innovation Norway and the Research Council of Norway. The total investment was about 135 million NOK, while public funding from Miljøteknologiordningen (Innovation Norway) was 58 million NOK.
- In the same year Borregaard received for 2010–2014 35 million NOK EU FP7 funding for two project proposals sent to the Joint Biorefinery Call. Borregaard has used parts of the funding for building a pilot facility, the BALI-plant. These two projects are EuroBioRef[1] and Suprabio[2]. In the same year Borregaard received also funding for another project under the EU FP7, Sunlibb[3].

[1] EuroBioRef: EUROpean multilevel integrated BIOREFinery design for sustainable biomass processing http://cordis.europa.eu/projects/rcn/93922_en.html

Capital expenditure (CAPEX) is considered as very important for Borregaard. It is necessary to have a CAPEX at the same level as the competing technologies. For bio-ethanol the company is at the same level as the competing technologies. Most of the competitors apply a similar procedure for producing bio-ethanol quite as Borregaard, starting from raw material, pre-treatment and hydrolysis of the hemi-cellulose. For enabling bio-ethanol companies to compete with companies producing fossil fuels the government needs to implement either higher carbon taxes in general or has to differentiate taxes between different types of fuels.

1c. Type of companies involved in each segment

Feedstock provisioning

The most important issue is to be close to the biomass used in the process. At Borregaard feedstock is provided by the local forestry industry, but the price for Norwegian wood is very high. For providing large volumes of wooden biomass Norway needs to upgrade its whole forestry value chain in a sustainable way. Import of biomass from other countries as a feedstock is not seen as a sustainable option (Johansen, 2013).

Enzymes have been bought from international leading firms, such as Novozymes in Denmark. Enzymes can be stored or produced on site, and Borregaard is investigating recycling of the enzymes. For a huge facility based on the BALI process located for instance in South America then the enzyme provider would probably build a production facility in the region.

Processing (biorefinery)

Borregaard is processing the feedstock and produces bio-ethanol in two facilities, one commercial plant and one pilot plant.

1.d. Lead firms

Borregaard has the one and only existing commercial biorefinery for producing bio-ethanol worldwide which is based on the biochemical pathway and which is operational (compare IEA Bioenergy Task 39 database on commercialisation of 1st and 2nd generation liquid biofuels from biomass)[4].

Borregaard supplies bio-ethanol to Statoil, the leading Norwegian producer of oil and natural gas products, and owner of a retail chain for petrol and diesel. All of the bio-ethanol that Statoil Norway uses complies with the European standard for ethanol used as a petrol additive, and all vehicles that can drive on Bensin95 can use Bensin95 containing five per cent bio-ethanol.

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[2] Suprabio: Sustainable products from economic processing of biomass in highly integrated biorefinerieshttp://cordis.europa.eu/projects/rcn/94178_en.html

[3] Sunlibb: Sustainable Liquid Biofuels from Biomass Biorefining http://cordis.europa.eu/projects/rcn/95909_en.html

[4] http://demoplants.bioenergy2020.eu/projects/mapindex

1.e. Value chain governance structure

For Borregaard's advanced bio-ethanol production the *market* governance structure is probably the dominant governance structure. Borregaard has at least three main costumers, Statoil, ASKO and Ruter in Oslo.

2. Key technologies characteristics

2.a. Technologies for main and supporting activities and assessment of their development stage

There are two processes to be considered: the traditional biorefinery and the BALI pilot.

The main technologies applied in the traditional biorefinery, which started already in 1938 to produce is based on cooking spruce chips with acidic calcium bisulfite cooking liquor. Hemicellulose is hydrolysed to various sugars during the cooking process. After concentration of the sulfite spent liquor, the sugars are fermented and ethanol is distilled off in several steps. This technology is rather energy intensive. Fossil fuels have been gradually replaced by renewable energy sources.

The BALI pilot is based on biochemical conversion of lignocellulosics. The pilot will produce ethanol; lignin, specialty chemicals; single cell protein and sugar derivatives. The process is based on chemical pre-treatment, saccharification with commercial enzymes, conventional fermentation of hexoses, aerobic fermentation or chemical conversion of pentoses and chemical modification of lignin. This technology is still in an early stage due to the status of the pilot project (start in 2012), but the technical performance is high.

2.c. Is the technology disruptive or path-following/incremental?

The BALI pilot is disruptive, since it combines chemical pre-treatment, the special competence field of Borregaard, with enzymes and different types of fermentation. Borregaard has patented its pretreatment process worldwide (Sjøde, Frölander, Lersch, & Rødsrud, 2008). This complex process enables the production of products from all components of the biomass, cellulose, hemicellulose and lignin. It allows the hydrolysis of cellulose at low costs. The enzymes are much less consumed than in other processes and can be recirculated. The products of the BALI process can be integrated into existing value chains and new value chains can be built up. However, the lignin market will be a possible limitation. Therefore, the BALI process will not become a dominant design for biorefineries for the next years. If the market conditions should change and bio-ethanol becomes profitable because of too high costs for fossil carbon, than the BALI process could become a dominant design for producing advanced bio-ethanol. However, this will probably not happen in the next three years (Johansen, 2013).

2.d. Market characteristics

Bio-ethanol is provided for a nursing market – bio-ethanol driven busses and bio-ethanol has to be added to petrol for a mass market.

Borregaard is a market leader in global niche markets with a strong specialized product portfolio. In 2011 Borregaard had a turnover of 4 billion NOK (Johansen, 2011). The company has achieved market shares in following product groups (Neumann, 2008, p. 7):

Specialty Cellulose	• #1 European and leading global producer • Market leader in selected applications
Lignin	• #1 and only global supplier of lignin-based products • Unique technical and application expertise
Fine chemicals, Pharmaceuticals	• Leading supplier of x-ray contrast media intermediates • Supplier of intermediates, APIs to major pharmaceutical companies
Ingredients	• Leading supplier of vanilla flavour
Bioenergy	• Bio-ethanol

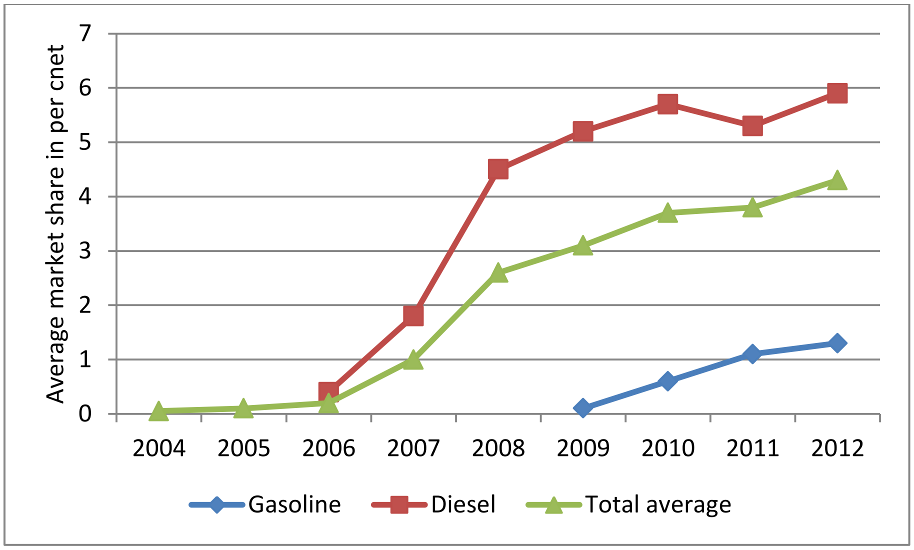
Source: Neumann (2008)

The development of the market for biofuels over the last years can be seen in the following table. Here it is distinguished between conventional bio-ethanol and advanced bioethanol and conventional biodiesel. In 2012, 1.7 million litres advanced bio-ethanol, 18 million conventional bio-ethanol and 160 million conventional biodiesel (based on rape seed) (Johansen & Guell, 2013:4). That means that biofuels are still dominated by conventional biodiesel. In addition to the 4.3% renewable share achieved by biofuels on average (figure 4) come 0.7% from the deployment of electrical cars.

Table 1: Biofuel market development 2004-1012 (million liters) (Johansen & Guell, 2013:4)

	Biodiesel (rape seed)	Bioetanol (starch/sugar)	Bioethanol (lignocellulosic)
2004	2		
2005	4		
2006	7	0,1	
2007	39	0,1	
2008	104	1,5	0,7
2009	122	1,4	0,9
2010	144	9,6	1,1
2011	139	16	1,3
2012	160	18	1,7

Figure 4: Biofuel market shares in per cent. 2004-2012 (Johansen & Guell, 2013:4)



2.e. Energy and environmental performance

For 2013 Borregaard has the vision to use only renewable feedstock and energy resources. The BALI pretreatment process allows two alternatives for producing ethanol: (1) modified acidic sulfite cook or (2) modified neutral sulfite cook. The output of ethanol is almost at the same level: (1) 15% and (2) 16% of incoming biomass and added chemicals. Borregaard has provided a comparison of its performance based on three different types of feedstock, both energy efficiency and GHG reduction, with the process developed by DONG Inbicon and three standard gasification processes (Rødsrud, et al., 2010). The comparison shows that the BALI process based on bagasse has very high energy efficiency and also reasonable high reduction of GHG, while he results for wheat straw are also good.

Table 2: Comparison of performance indicators: energy efficiency and GHG reduction

Process	Feedstock	Effective mass conversion		Effective energy conversion		Reduction of GHG
		tons TS product / tons TS feedstock	1 ton fuel / ton feedstock input	energy output for sale / energy input (HHV)	fuel energy / energy input (HHV)	
Gasification MeOH (Methanol)	Wood	22 %	22 %	50 %	50 %	91 %
Gasification DME (Dimethyl ether)	Wood	16 %	16 %	50 %	50 %	92 %
Gasification FT (Fischer–Tropsch)	Wood	20 %	20 %	44 %	44 %	91-92%
Dong Inbicon	Wheat straw	57 %	17 %	71 %	28 %	85 %
BALI	Bagasse	68 %	21 %	95 %	42 %	84 %
BALI	Wheat straw	68 %	21 %	84 %	37 %	78 %
BALI	Spruce	58 %	31 %	67 %	41 %	81 %

Source: Rødsrud, Frölander, Sjøde & Lersch (2010, p. 23)

In 2011 Borregaard received an independent verification of data and environmental information of its ethanol 96% product. This has been carried out by Østfold Research in accordance with ISO14025, § 8.1.3.[5] The Norwegian EPD Foundation was established in 2002 by the Confederation of Norwegian Enterprise and the Federation of Norwegian Building Industries. The rational for EPD Norway was the need for standardized and internationally valid Environmental Product Declarations for products and services. Borregaard has registered six of its products at EPD Norway.

3. Geographic scope

The production of bio-ethanol is concentrated in Sarpsborg, in South-East Norway. Borregaard provides 20 million litres advanced bio-ethanol to the South-East of Norway. Borregaard is operating globally, has subsidiaries in 20 countries and has it's headquarter in Sarpsborg, in South-East Norway. From 1990 to 2006 Borregaard established subsidiaries by acquisition of or joint venture with chemical companies in Europe, such as England, Sweden, Germany, Spain, Finland, Italy, Switzerland and Czech Republic. Globally such processes succeeded in the USA, China, South-Africa, India and Brazil.

Borregaard plans to build in the next ten years several plants in regions where there is a market for Borregaard's lignin products and biomass is readily available. The main regions are Brazil and other countries in South-America, the USA and Canada, Europe and South-East Asia.

4. Institutional context

For Borregaard, Norway is a very challenging place to produce biofuels. This is caused by mainly two challenges: (1) too expensive biomass material with the globally highest wood prices, and (2) an unpredictable biofuel policy by the Norwegian government, lacking incentives for producing advanced bio-ethanol at the moment. In Norway, it is impossible to compete with the fossil fuels because of a too low carbon tax on fossil fuels and too high costs of biomass. And even if there would be temporal incentives it would be not a good option on the long run to concentrate just on producing bio-ethanol. A higher profit can be achieved in lignin chemicals and other value added products.

The government has several instruments to support a vague "technology-push" strategy for advanced biofuels. Beside the Research Council of Norway with its different programmes there is Innovation Norway, the largest innovation policy instrument in Norway, owned jointly by the Ministry of Trade and Industry and the county administrations, is also allocating funds to renewable energy technology. Since 2010 Innovation Norway has in place a programme for environmental technology, where Borregaard was funded with 58 million NOK in 2010. In the field of transport the government agency Transnova under the Ministry of Transport and Communications gives funding to projects on non-fossil fuels for transport.

[5] http://www.epd-norge.no/getfile.php/PDF/EPD/Kjemikalier/NEPD183Eethanol%2096%20%25.pdf

There are several important research organisations which are active in this field, such as the Norwegian University of Science and Technology, Sintef, the Norwegian University of Life Sciences, the Paper and Fibre Research Institute and Østfold Research.

The history of Norwegian climate policy shows some hesitating trends regarding advanced biofuels. The White Paper on Climate (St.meld. nr. 34, 2006–2007) stated the ambition for target oriented and coordinated policy measures for an increased use and expansion of bioenergy up to 14 TWh by 2020 and that the target of an increase of 14 TWh before 2020 is maintained. The White Paper highlighted the need for advanced biofuels in Norway.

The Norwegian government has agreed to the EU-target for 2020 to achieve 10% renewable fuels in transportation. That means that the government has to comply with these targets. This could be achieved by mandatory targets or differentiated taxes.

First about the *mandatory target*: Since 2010 there exists a mandatory target of 3.5% of all biofuel in Norway, an increase from 2.5% in 2009. In the most recent White Paper on Climate Policy (St.meld. nr. 21, 2011–2012) the government stated that it would introduce a 5% mandatory target as soon as the sustainability criteria are assessed as sufficient. After gaining experiences with these criteria the target the government has the aim to increase the target towards 10%. In the beginning of 2013 the government agency KLIF supported the introduction of a 5% mandatory target by January 2014, but the government does not see the sustainability criteria as sufficient and has therefore decided to keep the 3.5% target and not to introduce the 5% target (Solhjell, 2013). In 2012, Norway has achieved 4.3%, 0.8% above the 3.5% mandatory target, but far from the 10% target for 2020. This means a rather unpredictable situation for any company engaged in advanced biofuel production in Norway.

Secondly on the *taxes*: there exist a rather confusing tax system for bio-ethanol and biodiesel. The Norwegian government introduced in 2006 a tax exemption for bio-ethanol if this bio-ethanol would constitute the main part of gasoline. In response to that, in May 2006 Statoil launched a new gasoline including 85% bio-ethanol, the so-called E85. However, this was not necessary advanced bio-ethanol: in a specification Statoil admitted that it is based on corn from Europe and sugar cane from Brazil. In 2007, ethanol or flexi-fuel cars (that is E85 cars) were allowed a reduction in the Vehicle Import Duty, equalling NOK 10 000.

Since 1999 biodiesel was exempt from fuel tax (NOK 3.02 per litre) and CO_2 charges (NOK 0.54 per litre). At the end of 2009 the removal of parts of the tax exemption for bio-diesel led to a high debate on framework conditions for the development of biofuels in Norway. However, some financial incentives are still in place, such as high blends of biodiesel (B7, B30) have exemption from CO_2-tax and 50% reduction of road-use tax. Pure biodiesel (B100) requires only half road-use tax. Gasoline mixes containing more than 50 % bio-ethanol (E85 and ED95) have full exemption from road-use taxes (Johansen & Guell, 2013), but most of the bio-ethanol is used in low blends which allows no tax exemption.

5. Path dependencies

In all countries the future development of biorefineries and advanced bio-ethanol will dependent on the specific circumstances of the different countries, such as access to biomass, the existing preferences in the fuel mix and institutional framework conditions. Over the next ten years companies will try to experiment with biorefineries and bio-ethanol. There have to be started a lot of different companies with different technological approaches to allow the appearance of a new technological regime for producing advanced bio-ethanol. If the bio-ethanol becomes very successful and a dominant design for advanced bio-ethanol could be established then industry will invest in such technology and also large incumbent oil companies like Shell or BP will engage in this field and will scale-up the production significantly.

In a Norwegian context there exist several path dependencies with relevance for bio-ethanol and biorefineries. These path dependencies are related to the following: (1) the Norwegian economy and policy is oriented towards the exploitation of fossil fuels, (2) electricity production is dominated by hydropower and feed-in tariffs for electricity do not exist, (3) the forest sector is traditionally oriented towards pulp and paper industry, and (4) there is plenty of unused forest biomass but the price for this biomass is the highest in the World.

As long as the Norwegian economy is based on fossil fuels and the income of the state is based on this economy the government is hesitant giving better institutional framework conditions for advanced biofuels. Large capital investments for necessary advanced biofuel infrastructure will not come as long as the Norwegian economy is based on petroleum and natural gas. This is despite the fact that Norway has a huge amount of biomass available in unused forest resources, both in form of logs and forest residuals, the latter are at the same price level as the logs. The crisis of the global pulp and paper industry has also hit the Norwegian pulp and paper industry. The closure of a number of the important industrial actors (i.e. Norske skog, Viken skog) has contributed to a down-size of the Norwegian forest-based value chain. A better integration of the whole value chain and an orientation towards more value added products of this sector away from pulp and paper could contribute to a revival of the Norwegian forest-based industry and a step forward to the bio-based economy.

It is more probable that the development of new biorefineries will happen in Sweden and Finland rather than in Norway because the forest industry is ten times bigger than in Norway, the crisis of the pulp and paper industry has therefore a bigger impact on employability and export revenues in those countries and this again allows and requires new business possibilities.

6. Conclusions

In Norway, the emergence of a technological innovation system for advanced biofuels is supported by a somehow favourable context with the long-standing presence of key resources, actors, institutions, networks and organisations involved in bioenergy. An important driving force for advanced biofuels is the search for alternative, non-fossil fuels. However, the niche for advanced bio-ethanol is still characterised by high costs and technological risks. The business model of a biorefinery as Borregaard has developed over the last decades is based on exploiting the whole bio-resource for value added products with advanced bio-ethanol as an important by-product.

Alongside improvements in knowledge development and the demonstration of the possibilities of this new knowledge, the expectations for these technologies have grown, and this in turn has triggered policy makers to set targets for sustainable biofuel use and to step up RD&D funding. However, the biofuel target is still at 3.5% and has not been stepped up as expected, which may cause a failure to fulfil the 10% renewable fuels target in 2020.

Major system challenges for advanced biofuels in Norway are the import of first generation biofuels, especially conventional biodiesel, the high costs for biomass and the presence of the predominant fossil fuel regime which is favoured by the institutional context. Challenging this regime will require a combination of incentives, such as regulations, development of new standards for advanced biofuels, increased mandatory turnover of advanced biofuels, and favourable taxes.

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