EIT 2013, TKP4850 Biofuels - a good solution?

Project report

From Seaweed to transport fuel:

A business perspective on the fermentation of brown macro algae to bioethanol in Norway.

Group 6, Bond Breakers

"It's up to you. You can do whatever you want"

- Edd A. Blekkan

Preface

This report was written as a part of the course "Experts in Teamwork" at NTNU in the village "Biofuels- A good solution?". The report is titled "From Seaweed to transport fuel: A business perspective on the fermentation of brown macro algae to bioethanol in Norway."

The reader of this report is expected to be a businessman or company executive not necessarily well versed in chemistry, but with a good business sense and a good sense of numbers. The report does not delve into the finer points of microorganism genetic manipulation, but focuses on current and realistic technologies.

The goal of this report is to investigate and describe the economics around seaweed fermentation in such a way that a person of good business skills should be adequately informed of the opportunities in algae fermentation, even with a mere casual knowledge of the subject.

The people involved in the project were two chemical engineers, a biotechnologist, an electrical engineer, a mathematician and a marine biologist.

The project is relevant both to Norway and to the world. With the prospect of climate change ever looming, the prospect of a carbon neutral source of liquid biofuels is very attractive indeed. The use of algae also allows the production of biofuels from biomass without using precious farmland or labour intensive forestry. The development of an algae industry promises new employment opportunities new centres of competence.

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Original project description

Bond Breakers.

Feasibility study on the production of bioethanol from brown macroalgae.

Type of report

Feasibility study. Aimed at a businessperson.

Project

The project involves the creation of a feasibility study on the production of bioethanol from brown macroalgea in a Norwegian setting. Our hypothesis is that such a process can be done effectively and profitably in Norway and the project will endeavor to test this hypothesis to its fullest extent. We believe that working off Norwegian feedstock makes for a local anchoring of the project and makes it more interesting to local businesses and people.

The project involves

- Studying feedstock availability
- Studying feedstock treatment
- Studying fermentation process
- Studying the market for the product

This will be done with a focus on the economics of the process. In the end, the report should be able to be used as the basis for further study, or as the basis of a proper business plan.

Project goal

A report enabling the curious businessman to create a viable business plan or that can at least be used as a basis for further study.

Introduction

Can you make a business out of making fuel from seaweed in Norway? This is a question very relevant to environmentally minded investors and businessmen. The answer can be complex, and there are many factors regarding supply, demand and available technology that he or she must know. This project aims to give the curious businessman the knowledge he or she need to make a decision regarding the feasibility of brown macro algae fermentation to ethanol. This is done by assessing the current and potential supply of algae, the market of the ethanol produced and the processes themselves in order to give a good overview of the potential economics of macro algae fermentation. The main focus of the project is the potential for the use of existing opportunities, mainly the fermentation of currently unused parts of the feedstock used in the alginate industry. A secondary focus is the potential for future sources such as domestic aqua-cultured algae.

Norway has a limited amount of farmland and high labour cost. This makes it non-feasible to produce first generation biofuels such as maize bioethanol or biodiesel from rape in Norway. Second generation technologies are therefore currently being tested as to their feasibility. One source of such biomass is lignocellulose, but the harvest of large amount of trees is labour intensive and therefore expensive. The use of seaborne resources is of great interest to Norway as a nation with a large coastal area and brown macro algae is therefore a very promising resource.

Summary

The economic feasibility of producing ethanol from seaweed was investigated. It was found that a standalone plant producing ethanol was not economically viable at current prices. If the plant is integrated with existing industry, however, it can exploit an existing source of raw material essentially free, allowing profitability. The varying content of fermentable sugars throughout the year presents a challenge and production should use raw material from periods of high carbohydrate content. The price of product is very important to the profitability, with the price for fuel ethanol being relatively low. An eight month per year operation based on transport fuel would have a return of around 34 %, while an operation being able to sell its product as heating fuel for fireplaces would have a return in excess of 98 %. If one were thinking about starting ethanol production, it would be prudent to do additional market research into the possibility of marketing the bioethanol for uses such as fireplace fuel and not just as transport fuel. The market for alternate uses is not as big though, and carries risks such as regulation and from fashion trends. While fuel ethanol does not pay as well, it does have an essentially unlimited market. As of current time, the cultivation of seaweed is merely at the pilot stage, but promises to be a source of raw material in the future, and further work should be carried out in the field. The field of ethanol production is definitely an interesting one in a commercial setting, and will become more important in the future as the spectre of global warming looms.

Seaweed

Seaweed, also referred to as macro-algae, is a term used for a variety of marine flora that comes in a variety of shapes and sizes. They have little of the tough cellulose and lignin of terrestrial flora and instead contain three interesting carbohydrates[1]. The first two are laminaran and mannitol. These are storage carbohydrates that the seaweed accumulates during the spring and summer. These are used during the low light winters of the north to survive and it is these two carbohydrates that are interesting when it comes to fermentation. Laminaran is a glucose polymer that not very soluble, but is fairly easy to break down. Mannitol is a sugar alcohol that is soluble, but has a redox imbalance when it comes to anaerobic fermentation. Alginate is an important structural component in algae and has a curious ability to exist either freely, or as a cross-linked matrix, depending on the charge of the cations present. Alginate in a solution with sodium (Na^+) will be relatively free flowing, but if calcium (Ca^{2+}) is used, the alginate will form a solid gel. This ability to go from a liquid to a solid, together with its other properties makes it very useful in the medical industry and for uses like immobilization of enzymes. An example of the seaweed *Laminaria hyperborean* (Stortare in Norwegian) can be seen in Figure 1.

Figure 1: ***Laminaria hyperborean[2].***

Sourcing the algae

A realistic source of adequate quality and quantity of raw material is obviously critical in order to make a plant work. For the algae to ethanol plant, a steady supply of seaweed will be necessary to ensure operation. For a Norwegian based supply, the options are wild caught and grown seaweed. A challenge with using seaweed is that its content is highly variable throughout the year. The total dry matter content varies between 10 and 27 per cent with laminaran and mannitol content varying massively between winter and summer as seen in Figure 2[3].

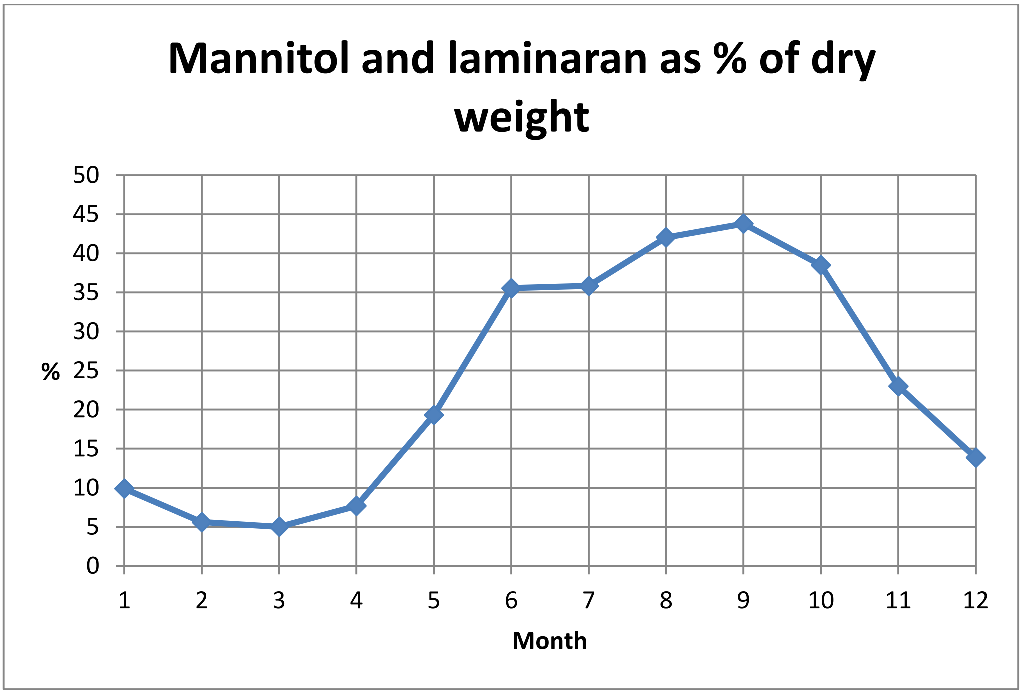

Figure 2: Content of laminaran and mannitol as % of total dry weight throughout the year[4].

As can be seen in this graph, fermentable sugars are most available in the period between June and October, and it drops off dramatically before and after this period.

Wild algae of Norway

Norway has a long and twisty coast line, with an environment well suited for seaweed growth[5, p.200]. The standing stock of algae in Norway has been estimated in excess of fifteen million tons, with a fresh growth of around five million tons. The seaweed *Laminaria hyperborean* (stortare) accounts for around 80 % of the seaweed in the so-called sub-littoral zone, which is the area below the low tide mark. Another seaweed is *Ascophyllum nodosum* (grisetare), which grows in the littoral zone and makes up around 60 % of the seaweed in this zone[1, p. 14]. The littoral zone stock is only around 10% of the sub-littoral stock though. Given the reasonably abundant seaweed resources of Norway, wild caught algae are very much a possibility as a feedstock.   Norwegian harvest of macro algae is currently around 150.000 metric tons per year of *L. hyperborean* and 20.000 metric tons per year of *A. nodosum* [4, p. 10]. *L. hyperborean* is harvested along the coast from Rogaland in the south, to Sør-Trøndelag in the north throughout the year in four year cycles[5, 6]. The problem with using wild algae is that all of the harvest of *L.Hyberborean* is sold to FMC Biopolymer, which is an alginate plant located in Haugesund. Alginate is a much more valuable product than ethanol and the plant would not be able to stand in competition with the alginate industry[5, p.202].

Co-location with alginate plant

One interesting thing about the alginate industry is that is only uses the alginate part of the seaweed and it would therefore be possible to co-locate the plant with an alginate plant, allowing use of the other carbohydrates for ethanol fermentation[1, p. 68]. The only large Norwegian alginate plant is operated by FMC biopolymer in Haugesund. This plant produces around 5000 dry tons of alginate per year[6].

Grown algae

Worldwide, aquaculture of seaweed is a much larger source of algae
Seaweed energy solutions is among the actors working on cultivation of seaweed for combined .
Worldwide, the most grown algae is the Saccharina japonica. Norway has a similar species Saccharina latissima, which is the one being used for pilot cultivation.

Processing algae

In order for a usable product to be created, the seaweed must be processed. The processing consists of several steps. The seaweed starts out as dried seaweed from which the interesting parts are extracted after milling[1, p. 68]. After this, there is a fermentation step to convert the carbohydrates to ethanol. Finally, the ethanol must be distilled up to the required specifications. A process diagram is seen in Figure 3.

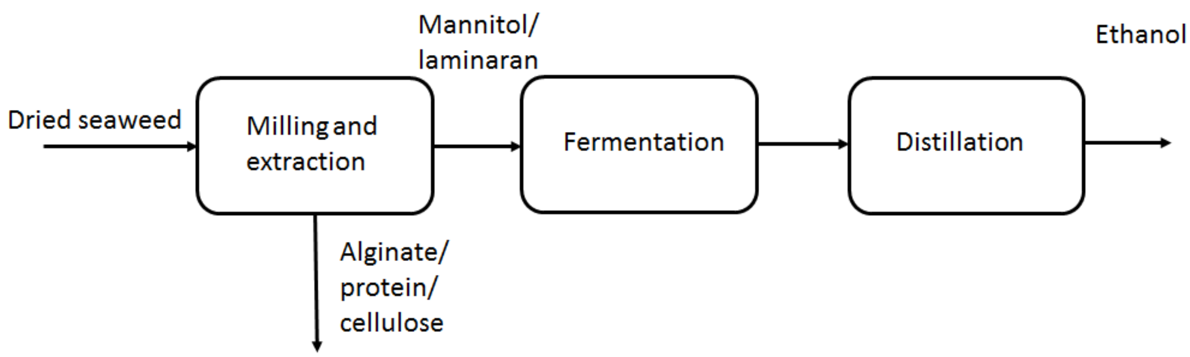

Figure 3: Process diagram for the process

Pre-processing

The seaweed needs to be prepared before it can be used in the fermentation. The pre-processing amounts to grinding the seaweed into slurry to make the carbohydrates more available to the microorganisms. The mannitol and laminaran is separated out in this step and sent to fermentation. The rest of the mixture can be sent to the alginate plant.

Fermentation

The fermentation process itself varies regarding what parts of the seaweed is fermented. When both laminaran and mannitol is to be fermented, a mix of microorganisms is required.

Separation and distillation

The ethanol needs to be distilled up to standard. If ethanol is to be used as a small blended part of gasoline, it will need to be distilled close to 100%, as water in the ethanol creates problems with corrosion and phase separation.

Selling the product

Once the seaweed is converted, the ethanol produced need to be sold in order for any money to be made. Ethanol is a versatile product that can have uses as varied as drinking, as a solvent or liquid fuel for heating or transport. Ethanol for drinking is rather heavily regulated and taxed in Norway and is not a viable path, though as denatured ethanol is not taxed as much it is well suited for either heating or transport.

Transportation fuel

Bioethanol can be used as a transport fuel, either blended with ethanol as a small component such as E5, or major component as E85. It can also be used alone as a transport fuel. Norwegian authorities mandates that fuel sold in Norway have a 3,5% content of biofuels, with discussions on raising this to 5 % on-going[7]. Norway as a country uses a fair amount of diesel engines, where ethanol cannot be blended in, but it retains a sizeable amount of gasoline vehicles, which again means a decent market for bioethanol in Norway, though gasoline sales have been declining for several years. In 2012, the market for vehicle gasoline was 1,4 billion litres[8], implying a market for blended ethanol in excess of 48 million litres per year. In fact, the market has been described as basically unlimited, and the danger of oversaturation is low[4].

Heating

Selling the bioethanol as a fuel for heating presents an attractive option. A major advantage of an ethanol fireplace is that a chimney is not needed, due to a much cleaner burn[9]. This allows for more freedom in design and use of the fireplace. Figure 1 shows an ethanol fireplace from Vauni, a Swedish company

Figure 1: An ethanol fireplace[10]

As of January 2013, between 30.000 and 50.000 ethanol driven fireplaces have been sold in Norway[11]. If one assumes a use of one litre of ethanol per use and fifty uses per year, the total market for fireplace ethanol would be around two million litres of bioethanol per year.

This market is too small to absorb all the production alone, especially given that a one hundred per cent market share cannot be assumed, though clever use of “made in Norway” should increase sales somewhat. A possible market is Sweden and the rest of Scandinavia, with Sweden having its own producer of ethanol fireplaces. Another benefit of seeking a market outside Norway is that bioethanol is sold for as low as 25 NOK in Norway for four litre cans, but 33 SEK (29,44 NOK) per litre for 60 litre packages in Sweden[12].

The ethanol driven fireplaces have some health and safety issues, due to the fact that refilling the fireplace with ethanol presents a fire hazard. This is due to the fact that the presence of a small flame and residual heat may be hard to detect. The health and safety issues have led to calls for a ban on ethanol driven fireplaces and there therefore exists a risk of being unable to sell ethanol for heating fuel at the elevated price[11].

Economics

Major factors in the profitability of macro algae fermentation are the following.

- Cost of macro algae
- Cost of processing
- Cost of investment
- Yield of ethanol from the algae
- Price of ethanol product

The landing cost of algae was 23 euro per wet ton in 2012, corresponding to roughly 175 NOK [6]. With an average solid content of 18,5 %, this implies a cost of around 930 NOK/dry ton. This is a rather high cost by itself, though if the plant can be co-located with an alginate plant this cost is essentially eliminated. Further calculations are based on a co-located plant

Since the content of the algae is so highly variable, continuous production throughout the year may not be economical. During winter, the fermentable sugars may constitute as little as five per cent of the solid content, and the solid content itself may be as low as ten per cent. An eight month cycle from May to December would give an average fermentable sugar percentage of 31,5 % of solids compared to 23,3 % for a twelve month cycle. For a standalone plant this would be problematic, as seasonal production still requires payment of loans, employees etc. A standalone plant could solve this by storing dried algae from periods of high carbohydrate content, to be used all year round. For an integrated plant, the employees could be used for other tasks and essential maintenance could be done in the downtime.

Calculations for ethanol production per wet ton seaweed can be seen in table 1

Table 1: Ethanol produced per wet ton

Cycle	Fermentable sugars [kg per wet ton]	Ethanol [litres per wet ton]
8 months	58,3	37,2
12 months	43,2	27,6

The eight month cycle has a significantly higher yield of ethanol. The use of an average solid content of 18,5 % in the calculations mean than in reality this difference is even greater, as the solid content would be higher in the eight month cycle and lower in the twelve month cycle.

The harvesting of seaweed is continuous throughout the year, amounting to 150.000 wet tons. The twelve month cycle would see all of this, while the eight month cycle would see less. Total production for the cycles are seen in table 2.

Table 2: Ethanol production

Cycle	Seaweed [wet tons]	Ethanol produced [mill litres]
8 months	150.000	4,14
12 months	100.000	3,72

Unsurprisingly a twelve month cycle would produce more total ethanol, but a lot less per ton of seaweed. The cost of processing the algae can be estimated at around half the landing cost, e.g. around 88 NOK per wet ton of algae processed[1, p. 69]. The net income of the project would depend on the price achieved for the product. An overview of cost and income is seen in table 3. A price of 3,7 NOK/litre for transport fuel and 6,25 NOK/litre for heating fuel was assumed.

Table 3: Economical calculations

Cycle and type	Income [mill NOK]	Cost [mill NOK]	Net income [mill NOK]
8 months, transport fuel	13,77	8,60	5,17
12 months, transport fuel	15,31	12,89	2,42
8 months, heating fuel	23,26	8,60	14,66
12 months, heating fuel	25,86	12,89	12,97

By comparison, buying the algae wholesale would give a production cost of 263 NOK/litre and even the most favourable case would lose 2,5 million NOK per year. Clearly, a standalone plant producing just ethanol from wild caught seaweed is not viable in the current climate. All cases using free raw material from the alginate industry shows positive net income. Especially interesting is how being able to sell the bioethanol at an elevated price vastly increases the profits.

The investment cost of the plant would be around 15 million NOK. Return on investment is seen in table 4.

Table 4: Returns on investment

Cycle and type	Return on investment
8 months, transport fuel	34 %
12 months, transport fuel	16 %
8 months, heating fuel	98 %
12 months, heating fuel	86 %

The eight month cycles give the highest return on investment under the approximations used, where cost is based on per ton wet algae processed. Nevertheless, all cases show profits. The profit is especially large when the ethanol is sold for a higher price. This implies a high sensitivity to product price. Since the raw material approximated as free, the cost of algae has a smaller effect on profits, since it is used as basis for processing costs.

Conclusions and recommendations

The economic feasibility of producing ethanol from seaweed was investigated. It was found that a standalone plant producing ethanol was not economically viable at current prices. If the plant is integrated with existing industry, however, it can exploit an existing source of raw material essentially free, allowing profitability. The varying content of fermentable sugars throughout the year presents a challenge and production should use raw material from periods of high carbohydrate content. The price of product is very important to the profitability, with the price for fuel ethanol being relatively low. An eight month per year operation based on transport fuel would have a return of around 34 %, while an operation being able to sell its product as heating fuel for fireplaces would have a return in excess of 98 %. If one were thinking about starting ethanol production, it would be prudent to do additional market research into the possibility of marketing the bioethanol for uses such as fireplace fuel and not just as transport fuel. The market for alternate uses is not as big though, and carries risks such as regulation and from fashion trends. While fuel ethanol does not pay as well, it does have an essentially unlimited market. As of current time, the cultivation of seaweed is merely at the pilot stage, but promises to be a source of raw material in the future, and further work should be carried out in the field.

References

1. Svein Jarle Horn, *Bioenergy from brown seaweeds*, 2000, NTNU.
2. Dukachev, S.S. *Small laminaria hyperborea*. 2007 [cited 2013 01.05]; Available from: http://en.wikipedia.org/wiki/File:Laminaria_hyperborea.jpg.
3. Haug, A. and A. Jensen, *Seasonal variations in the chemical composition of Alaria esculenta, Laminaria saccharina, Laminaria hyperborea and Laminaria digitata from Northern Norway*. Rapport / Norsk institutt for tang- og tareforskning. Vol. 4. 1954, Oslo: Akademisk trykningssentral. 14 s., 20 diagr., ill.
4. Aleksander Handå, S.F., Ole Jacob Broch, Roger Richardsen, Jorunn Skjermo, Kjell Inge Reitan, *Dyrking og anvendelse av tare, med spesiell fokus på bioenergi i nordområdene.* SINTEF Fiskeri og havbruk, 2009.
5. Alan T. Critchley, M.O., *Seaweed Resources of the World*. 1998: Japan International Cooperation Agency.
6. M. Meland, C.R. *THE NORWEGIAN SEAWEED INDUSTRY, WORK PACKAGE 1&2*. 2012 [cited 2013 13.03]; Available from: http://www.netalgae.eu/uploadedfiles/Norwegian_seaweed_industry_WP12.pdf.
7. Miljøverndepartementet. *Påbud om økt omsetning av biodrivstoff*. 2010 [cited 2013 01.05]; Available from: http://www.regjeringen.no/nb/dep/md/aktuelt/nyheter/2010/Pabud-om-okt-omsetning-av-biodrivstoff.html?id=599548.
8. Statistisk sentralbyrå. *Sal av petroleumsprodukt, 2012, endelege tal*. 2013 [cited 2013 01.05]; Available from: http://www.ssb.no/energi-og-industri/statistikker/petroleumsalg/aar/2013-04-05.
9. Vauni. *About the Vauni Fireplace*. 2013 [cited 2013 27.01]; Available from: http://www.vauni.com/en-gb/information/faq.
10. Vauni. *Picture of an ethanol fireplace*. [cited 2013 01.05]; Available from: http://www.vauni.com/images/stories/slideshow/globe/globe02.jpg.
11. Rune Thomas Ege, M.B. *Krever forbud mot biopeiser*. 2013 25.01.2013 [cited 2013 27.04.2013]; Available from: http://www.vg.no/nyheter/innenriks/artikkel.php?artid=10106856.
12. Vauni. *Bioetanol/spisbränsle av hög kvalitet till ett oslagbart pris*. 2013 [cited 2013 01.05]; Available from: http://www.vauni.com/en-gb/fuel/spisbransle-eco-flame-billig-bioetanol-till-skorstensfria-spisar.