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 spectre 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 macro algae.

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.

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, which still lost money, but significantly less. 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 -27,4 %, while a twelve month operation being able to sell its product as heating fuel for fireplaces would have a of -4,25 %. 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.

Contents

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. The goal of this project is 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 process itself in order to give a good overview of the potential economics of macro algae fermentation. A cost overview is also done by investigating the cost building and running a plant co-located with an alginate plant. This is done to give as complete an overview as possible in order to allow for decisions to be made on a fair basis. 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 project enabling less waste, while creating a fuel with low carbon intensity is clearly a highly relevant project not just to the business man and Norway, but to the entire world.

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 oil-seeds 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.

Note: This report uses the Norwegian standard of using , as the decimal separator and . to separate thousands

1. 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. They 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].***

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 seaweed 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].

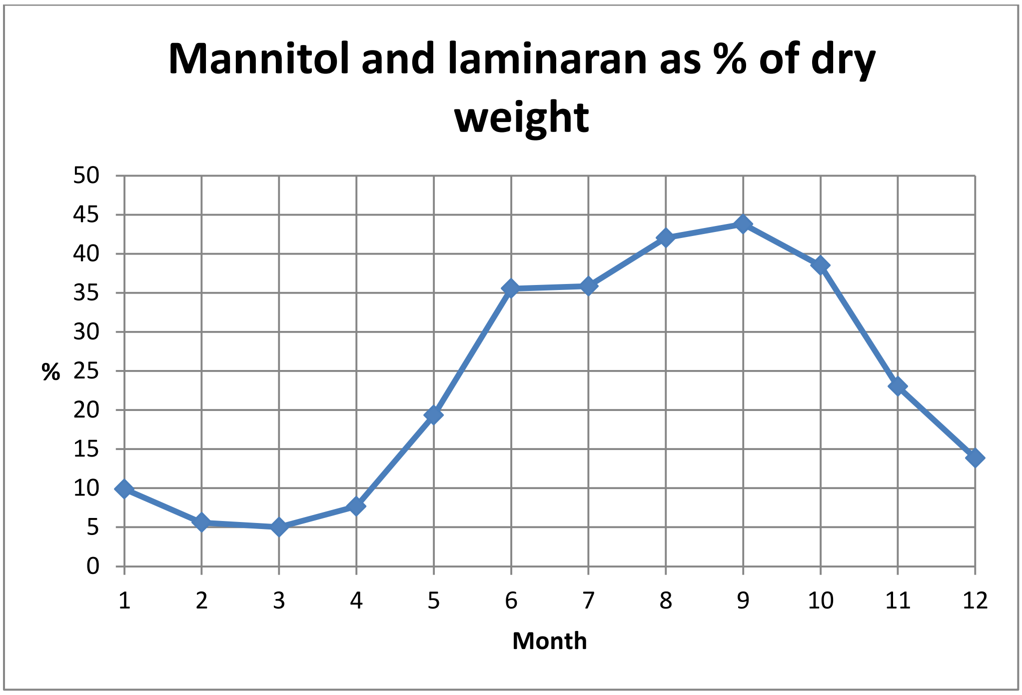

Figure 2: Content of laminaran and mannitol as % of total dry weight throughout the year[4].

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], as well as producing some synergies in other parts of investment and running costs. 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 seaweed than wild harvested, though this is not used for energy production, but for
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. The cost of cultivating the seaweed *L.Hyberborean* is at around 660 NOK/dry ton for a rope farm in the United States.

3. 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.

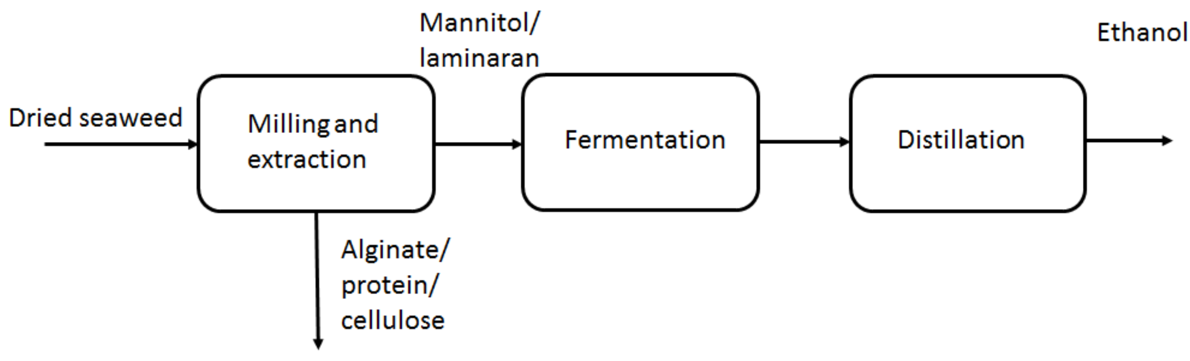

Figure 3: Process diagram for the process.

Pre-processing

The seaweed needs to be prepared before it can be used in the fermentation. There are several reasons for pre-treating the seaweed. Firstly, the seaweed contains polyphenols, which can interfere with the fermentation[1, p. 31]. By milling the seaweed, the carbohydrates themselves also become more available in the fermentation process. The pre-processing amounts to grinding the seaweed to a slurry. 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. This is the potential process described by Horn[1]. The alginate can also be extracted as a solid by first using a mild hydrolysis followed by the addition of calcium carbonate. This solidifies the alginate, allowing it to be removed as calcium alginate. In this process, the protein and other elements follow the carbohydrate stream[7].

Fermentation

Fermenting the carbohydrates is a critical step in the process and the yield achieved here is very important to the overall economy of process. The fermentation works by breaking down the sugar into ethanol and carbon dioxide. This is a rather standard process and is used widely in among others the brewery industry. The fermentation of glucose is seen in Figure 4[8].

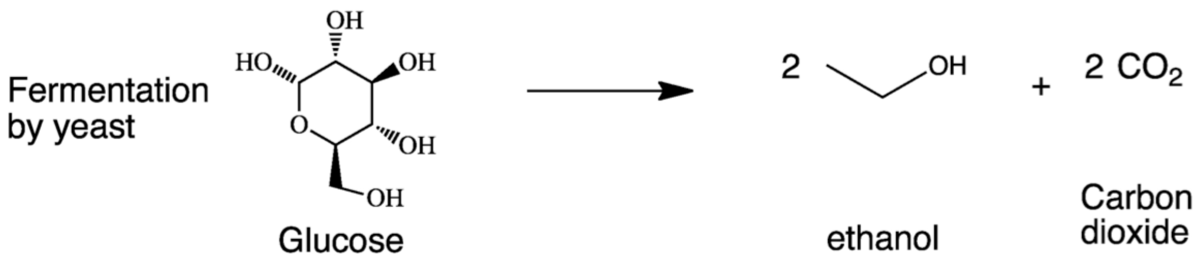

Figure 4: Glucose fermentation by yeast

There are several different microorganisms that can be used for the fermentation. One option is to use a mixture of *Saccharomyces cerevisiae* and *Zymobacter palmae*. The *S cerevisiae* would consume the laminaran, perhaps aided by the enzyme laminarinase added separately to help break the laminaran chain down to more easily fermentable glucose. The *Z. palmae* would deal with the mannitol. Another option is to use the yeast *Pichia angophorae*, which is able to ferment both the laminaran and the mannitol. The yield of ethanol using *P.angophorae* would be around 0,43 grams of ethanol per gram of carbohydrate feed in a batch process and 0,27 grams of ethanol per gram of carbohydrate feed in a continuous process [1, p.64]. The choice between a batch process and continuous process is an open question, with the continuous process having the obvious advantage of be continuous and allowing a steady rate of production. The problem with a continuous process in the case of seaweed fermentation using *P.angophorae* is the lower yield of ethanol.

The standard yeast *saccharomyces cerevisiae* has an ethanol tolerance of around 15 % and has been known to produce ethanol up to at least 12,3 % from a glucose concentration of around 20 %[9]. A practical batch industrial process can have a concentration of around 10,8 weight %. A continuous fermentation process can have a practical ethanol concentration of 6-7 volume %. The pH of the system needs to be in a narrow range of 4,5-5. The fermentation of mannitol also requires a small supply of oxygen to allow a proper redox balance[1, p.64]. The combination of these factors creates some challenges in maintaining optimal conditions.

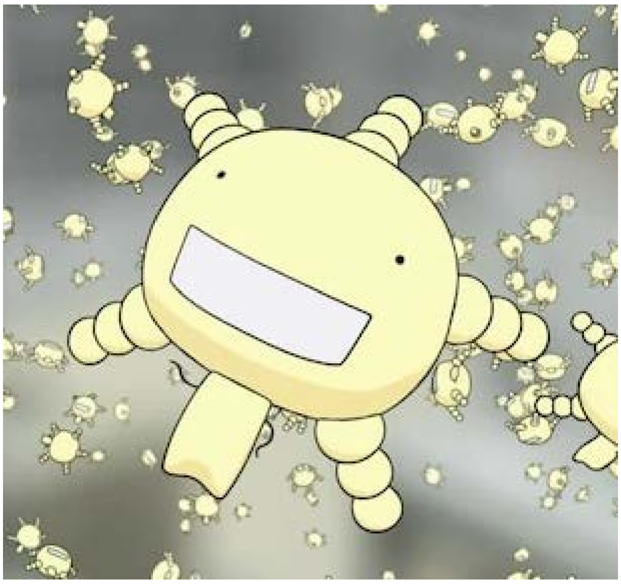

Figure 5: Animated version of the yeast *S. cerevisiae* (from Moyashimon).

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 to around 99,5 %, as water in the ethanol creates problems with corrosion and phase separation. The distillation is an important part of the overall cost of production. If the product is to be used for other purposes, it needs only be distilled to around 96 %. This is highly convenient, as there exists an azeotrope at this point. This means that distilling above this point requires equipment such as a vacuum distillation tower.

4. 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 a drink, 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[10]. 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[11], 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[12]. 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[13]

As of January 2013, between 30.000 and 50.000 ethanol driven fireplaces have been sold in Norway[14]. 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[15].
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[14].

5. 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

All calculation were done using a value of 5,92 NOK/$ and 7,475 NOK/EUR.

Total ethanol production

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. The calculations are based on an average solid content of 18,5 % and a yield of 0,43 grams of ethanol per gram of carbohydrate feed.

Table 1: Ethanol produced per wet ton

Cycle	Fermentable sugars [kg per wet ton]	Ethanol [litres per wet ton]
8 months	58,3	31,75
12 months	43,2	23,53

The eight month cycle has a significantly higher yield of ethanol per ton of algae. 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	100.000	3,17
12 months	150.000	3,53

Unsurprisingly a twelve month cycle would produce more total ethanol, but a lot less per ton of seaweed.

Capital costs

The process would be a batch process where around 76 tons of dry seaweed, corresponding to around 410 tons wet weight would be processed per day. The ethanol production itself would vary throughout the year due to carbohydrate content. The use of already dried seaweed means that no drying is needed, and the first major unit is the extractor/pre-processing step. The seaweed would be milled and acidified with an acid such as sulphuric or hydrochloric acid at pH 4. Following this, sodium carbonate would be added to convert cross-linked calcium alginate into sodium alginate. The sodium alginate would then be removed from the solution either by adding lye to make the alginate into an acid foam[7], or adding calcium carbonate to precipitate it out of the solution in solid form. The solution minus the alginate would be sent into a holding tank awaiting fermentation. This process would be able to run continuous or batch. A batch with a two hour residence time would need a volume of around 100.000 litres for four batches per day based on one litre of water per 200 grams of dry seaweed. The holding tank would need to hold around 400.000 litres. Some water would be removed to increase the concentration of carbohydrates before fermentation, as the fermentable carbohydrates are only a part of the dry mass. A heavier solid to liquid ratio could also be used to increase concentration of carbohydrates.

After pH is adjusted to 4,5-5, the next step would be fermentation in a fermenter with a residence time of 24 hours, necessitating two fermenters for one batch per day. Each fermenter would have a volume of 400.000 litres. If the large volumes prove impractical, it is of course very much possible to increase the number of tanks and reactor, though this would increase investment costs somewhat. After fermentation, the solution now containing around 8,6 weight % ethanol is moved to a second holding tank to prepare for distillation. Distillation is done in a low energy distillation system, processing 3,17-3,53 million litres EtOH/year. After distillation, the resulting ethanol is stored in a tank and sold on.
An overview of equipment costs are seen in table 3.

Table 3: Equipment purchase costs

Equipment[16]	**Cost [Thousand NOK]**
Acidification tank	480
Extraction reactor	730
Holding tank for fermentation	480
Fermenter x2	2.500
Holding tank for distillation	480
Distillation equipment[17]	1.500
Ethanol tank	90
Random other equipment (grinder etc.)	940
Total cost	7.200
Physical plant cost	18.900
Fixed capital	35.500
Total investment (including working capital)	40.000

Cost for equipment was calculated using Sinnot with a factor of 1,3 to adjust for inflation, except the distillation setup, which was extrapolated from Katzen by first doing a linear scaling, adjusting for an average inflation of 2,5 % over 30 years and adding another 50 % to account for base costs. A plant will require a fair amount of other equipment such as pumps. This was assumed to be around 15 % of other investment. To get the total investment cost accounting for factor such as installation, buildings, contractor fees etc, a factor of 3,4 for physical plant cost and 1,45 for contingency and contractor feed was taken from Sinnot[16, p.252]. The cost is likely an overestimation, as integration of the plant with the alginate plant would remove several factor increasing costs and the investment could be as low as 24 million NOK with a physical cost factor of 2,4 and contingency/contractor factor of 1,4. However, to be as conservative as possible, the higher investment is used.

Operating costs

The cost of processing the seaweed depends on a host of factors including wages, fermentation costs and utilities. An overview of the costs can be seen in table 4. The costs are taken from Kwiatkowski [18] and Sinnot [16] and increased by a factor of 1,3 to account for changes to the PPI (producer price index)[19, 20].

Table 4: Operating costs

Expense	**Cost 8 month cycle [thousand NOK]**	**Cost 12 month cycle [thousand NOK]**
Variable costs		
Yeast	61	110
Electricity	132	147
Steam	640	710
Cooling water	115	128
Other chemical etc.	100	100
Total variable	1.048	1.195
Fixed costs		
Maintenance	3.500	3,500
Operating labour	7.000	7.000
Lab costs	1.400	1,400
Supervision	2.000	2.000
Plant overhead	3.500	3.500
Capital charges	4.000	4.000
Insurance	400	400
Local taxes	400	400
Royalties	400	400
Total fixed	22.600	22.600
Total running costs	23.700	23.800

The need for steam is based on a low energy distillation system by Katz et al.[17], using the figures for anhydrous motor ethanol with a steam requirement of 2,2 kg/litre EtOH produced.

Costs for the chemicals used for alginate extraction was assumed to be borne by the alginate plant. This also covers water needed in the process. Cost of steam was set to 92 NOK/ton steam by taking the steam cost from Sinnot, converting to NOK and adjusting by 1,3. Cooling water and electricity costs were extrapolated from Kwiatkowski. The fixed costs were all taken from Sinnot. To account for any other needed chemicals, an additional 100.000 NOK was added. An integrated plant could share employees and other with the alginate plant. The plant would operate and need employees mainly during the day, but some supervision might be needed at night in order to make sure the fermentation is in order and around 1,5 shifts would therefore be needed. The plant would use two engineers and ten members of the proletariat as active labour. An engineer would have a cost of roughly one million NOK per year, while a member of the proletariat would have half that. Two supervisors would be used at a cost of one million each.

The major costs are the fixed costs, with labour costs being the major expense. A lot of the variable costs have been assumed negligible due to colocation with the alginate plant. Buying seaweed at 171 NOK/ton would add an additional cost of 25 million NOK to variable costs. From these calculations, it can easily be seen that a standalone plant would be wholly unfeasible.

Gross and net income

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 5. A price of 4 NOK/litre for transport fuel and 6,25 NOK/litre for heating fuel was assumed. The number for the heating fuel is based on being able to sell the product at one quarter of retail price. Transport fuel price is from the U.S Energy information administration[21]. From earlier calculations it can also be seen that distilling to 96 % instead of 99,5 % has a low impact on total costs.

Table 5: Economical calculations

Cycle and type	Income [mill NOK]	Cost [mill NOK]	Net income [mill NOK]
8 months, transport fuel	12,7	23,7	-11
12 months, transport fuel	14,1	23,8	-9,7
8 months, heating fuel	19,8	23,7	-3,85
12 months, heating fuel	22,1	23,8	-1,7

The project is unprofitable at prices that can be expected in the current business climate. This is partly due to an overstatement of investment costs and labour, as the plant would be able to share a lot of expenses with the alginate plant. At any rate, the price of bioethanol is too low compared to the cheap black gold. If the plant was given some subsidies reflecting its contribution to the environment and the price ethanol was higher it might be viable. Breakeven is at around 6,74 NOK/litre, and in order to have a respectable return on investment of 10 %, it would need an ethanol price of around 7,93 NOK/litre. If the alternate investment of 24 million is used and the fixed costs are scaled to this, cost would be reduced to 14,7 million NOK/year and the plant would have this return at 4,84 NOK/litre and a breakeven at 4,16 NOK/litre. Table 6 shows the returns on investment using a simplistic net income over total investment formula.

Table 6: Returns on investment

Cycle and type	Return on investment
8 months, transport fuel	-27,5 %
12 months, transport fuel	-24,3%
8 months, heating fuel	-9,6 %
12 months, heating fuel	-4,25 %
Optimistic investment, heating fuel	30,8 %

It is clear from this that the project is risky and liable to lose money. There is a glimmer of hope in that the lower investment number shows a profitable return assuming a good synergy between the ethanol plant and the alginate plant. It is also clear from these numbers just how important the ethanol price is for profitability. If it should rise to a higher level due to increased demand in the future, the project might yet be a viable one.

6. Conclusions and recommendations

The economic feasibility of producing ethanol from seaweed was investigated. It was found that a standalone plant producing ethanol was not at all 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, which still loses money, but significantly less. 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 -27,4 %, while a twelve month operation being able to sell its product as heating fuel for fireplaces would have a of -4,25 %. 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. Further study should also be done regarding the possibility of harvesting more of the algae when the content of carbohydrates is high. Genetic manipulation of microorganisms should also be able to increase the yield of ethanol more towards the theoretical yield of 56,8 weight %. Finally, this project did not deal with biogas production as a part of the plant, and the possibility of a fully integrated plant producing biogas, ethanol, and alginate should be investigated. In the end, it is up to the market to take the chance and implement this plant.

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