Why is biofuel seaweed preferable environmental sciences essay

Our pivotal goals in this study are: we try to make people aware that seaweed is an excellent candidate for next generation green fuel, at the same time help more people form the awareness that it is time to reduce dependency on fossil fuel and to find new type of biofuel, and hopefully, this would be some contribution to our whole society's sustainable development. We decided our topic-seaweed-after great discussion, because all of us thought seaweed best suit our team's interdisciplinarity. We retrieved information mainly from literatures, government websites, economic websites, via libirary, google scholar, lecture notes, database, resources. Besides, we consulted Professor Edd and Associate Professor Størker Moe about standard written formats and fermentation process, respectively. For each of the five chapters, we divided it into six tasks and assigned each to everyone. We took turns to combine everyone's task before the following Wednesday session. On the next Wednesday, everyone would give commnents and modification on the combination so as to make it coherently combined. Likewise, we combined the whole report in the same way, which was revised in a repeated way. In order to share useful information effectively and save other's retrieving time, everyone uploaded his or her literatures that were considered useful for other's task on Itslearning. We uploaded the drafts on Facebook and posted the revised version on Itslearning. In the very technical part-feasibility study in Norway, the calculations and analysis were conducted together by Anh Phan Hung, Reza Farzad, Adnan Ul Haque Syed, while the biogas and bioethanol was carried out by Jianhai and Junu, due to their most relevant expertise. As for the specific calculation numbers, we performed in a general way, and the final profit was gross, which was based on available data we could get.

1. 2. Background

1. 2. 3 Why is biofuel/seaweed preferable?

It is believed that the environmental issues above are mainly caused by human's significant dependence on fossil fuel. Meanwhile, it is manifest that the remaining amount of natural rock oil is limited. Therefore, novel fuels are badly needed, which are environmentally friendly as well as thought to take over the role of conventional fuel. Biofuels are considered more desirable than other alternative fuels, due to that they have low emission profile and utilize renewable resources. The first-generation biofuels are extracted from sugars, and vegetable oils originated from arable crops such as maize, potato, sugar cane, wheat, rapeseed oil, etc., while the second generation biofuels are derived from lignocellulosic biomass or woody crops, agricultural residues or waste (https://en. wikipedia. org/, 7 April, 2013). They have brought bright future for exploration of green fuels. Nevertheless, some demerits prevent them from acting as the pivotal energy source in the world: First, these crops occupy large area of arable land that can be produced food. Considering there is a large population that is suffering from starvation, growing crop plant for fuels is not practical. Second, those plants require much fresh water and fertilizer, however water scarcity happens often in many regioand fertilizer; however, ertilizer may contribute to environmental problems, such as eutrophication (Rant, 20 March, 2013). Third, fuels from food crops are far less than the demand for traditional fuels by our daily life, hence it seems that such biofuels are not realistic. Fourth, according to FAO's report 2008, rapid extensive production of biofuels from edible crops can drive up commodity prices, and subsequently impacts people's benefits especially in developing countries (Sahoo et al., 2012)With the disadvantages of the first generation fuels emerging, seaweed is a promising source forfirst-generation fuel, and this is recognized by more and more instnext-generationiearchers. The main advantages of seaweed are as follows: first of all, macroalgae is able to assimilate an average of 0. 26 x 106 tonnes cmacro algae can ming that seaweed is a potential candidate for CO2 sequestration (Sahoo et al., 2012). Secondly, not only does seaweed need less water than terrestrial crops, but it can be grown in sea water. And even though herbicide and pesticide ar also not used in seaweed cultivation, it grows in a high speed. Thirdly, seaweed is rich in fatty acid, thus its oil yield exceeds other oilseed crops. Fourthly, after oil extraction from seaweed, the residual biomass can be used as feed, or for fermentation. On top of all, we can control the chemical composition of seaweed by altering the growth environment, making it rich in chemical components of interest (Chung et al., 2011).

1. 2. 4 Biomass production of seaweeds

The use of seaweed as a source to produce bioethanol or biofuel have been researched and developed in recent years. One of the most important thing need to be considered is biomass production of seaweed. Actually, harvesting seaweed biomass from natural stock in Europe and cultivating seaweed intensively or integrated with other species like fin fish and shellfish in Asian regions are the two main ways to get seaweed stock in order to produce bioethanol (Burton et al., 2009). In Europe, Norway and France are the two major harvesters of seaweed. For example, the annual amount harvested seaweed, mainly Laminaria species, is around 120, 000 tonnes and about 50, 000 – 70, 000 tonnes, in Norway and France respectively (Burton et al., 2009). Besides Norway and France, Ireland has also harvested a large number of macro algae, about 29000 wet tonnes (Table 1. 4. 1), mainly Ascophyllum species. The Irish Seaweed Industry Organisation (ISIO) cited in ((Burton et al., 2009) reported that about 75000 tonnes of Ascophyllum nodosum could be sustainably harvested every year, so lower than a half of the amount of Ascophyllum is being exploited. However, the development for seaweed industry in order to maintain the sustainable stock from wild harvesting has been well-managed in Europe, especially Norway, France and Ireland. The estimation of exploiting a natural stock globally is shown in Table 1. 4. 1

Table 1. 4. 1: Seaweed Wild Harvest Estimates for Selected Countries (FAO, 2006)

The other important source supplying a large number biomass production of seaweed has probably come from aquaculture cultivation. In fact, the seaweed species like Laminaria saccharina and S. japonica are the two main cultivated seaweeds in Northern of China, Korea and Japan with the harvested fresh weight biomass nearly 4. 0, 0. 3 and 0. 05 million tonnes respectively (Ohno and Largo, 1998, Wu, 1998). On the past two decades, some different systems of seaweed cultivation have been applied and strengthened from intertidal fixed and floating bottom farms for Eucheuma and Gracilaria (e. g. Philippines, Vietnam, Thailand) to designed floating net structures for Porphyra and long-line systems for macro-algae in China, Korea, and Japan (Critchley and Ohno, 1998). These cultivation systems are possibly a potential development for the industrial scale of seaweed cultivation in a coastal and offshore region. However, it is necessary to optimize the harvesting technology and current cultivation systems in order to decrease the cost, energy demand and labor-intensive process. (Roesijadi et al., 2008, Troell et al., 2009).

1. 1. 5 Possibility to popularize seaweed culture

Initially, it is worthy of mentioning that previous parts answer one pivotal question about considering possibilities of popularizing seaweed for biofuel production: why we should popularize it? Nowadays, seaweed is produced in thousands tonnes but to be able to meet market expectations for fuel; it would have to be grown in billion's tonnes. The possibility to grow seaweed in the oceans is quite realistic when one would take into account that oceans make up about 70% of the earth. In China, seaweed is already cultivated on a large scale. Besides Asia, there is a big potential for growing this plant along Atlantic coastal waters. There are possibilities for growing algae, but some processes in the production chain have to be overcome challenges with growing, harvesting, processing and transport of seaweed. The possibilities for growth of seaweed depend on the type of algae. Kelps, for example, can grow at extreme low water levels or in very deep water (depending on how clear water there is). Algae can grow in very various types of environment, do not have so many requirements for growth (nutrients, sunlight), and they can be cultivated in the open sea (it leaves the coastal area for other purposes) (Kraan, 2013). Among marine macro algae, species of the brown macroalgae order Laminaria (so-called kelp species) are among the fastest growing plants in the world. These large algae prefer and thrive in temperate waters, which in the case of Europe stretch from northern Portugal to Northern Norway, in the northern hemisphere kelp grows from Mexico to Alaska and in the southern hemisphere from Peru down to the tip of Chile (Kraan, 2013). If we harvested seaweed from two farms of the size of Luxemburg localized in the North Sea, we would be able to meet 50% of the ethanol expectation for European needs (Kraan, 2013). That is not much of the sea area to meet 2-3% of world demand for ethanol if we produced biofuels (Kraan, 2013). Considering how large oceans are, area taken from it for biofuel production would be negligible. There are of course environmental impacts, which cannot be neglected, which would be discussed below. Popularization of seaweed farm on the large scale is not recommended, but smaller farms (up to 10km2) are in favor due to impacts and changes to the environment that large farm can cause.

II. Scope and Methodology

2. 1 Brown seaweed, red seaweed, and green seaweed

Brown seaweeds are rich in alginate, which is responsible for more than 80% of organic substance, and serve as the skeletal component in an intercellular matrix. In Norway, the most abundant brown seaweed species are Laminaria hyperborea and Ascophyllum nodosum and they are already commercially utilized. The content of mannitol and laminaran is about 10% of dry weight in the two Norwegian species. Furthermore, brown seaweeds contain sulphatedfucose, proteins (low), cellulose, fucoidan and polyphenols. In comparison with land plants, brown seaweeds lack lignin and have low cellulose content, making it easier to be biodegraded. Ethanol production from storage carbohydrate's mannitol and laminaran is much more favorable, since they can be more easily extracted (Horn, 2000). However, the more complex composition of seaweed requires specific bacteria with a broad substrate range for fermentation (Horn, 2000). Like brown seaweeds, red seaweeds also have no lignin, rich in carbohydrates. One kind of red seaweeds, Gelidiumamansii, can be degraded to produce monosugars: it contains fibrin and agar. The former is composed of cellulose, which can be degraded into glucose. The latter is made up of galactan, which can be converted to galactose. Glucose and galactose can be used as sources of ethanol production through fermentation (Yoon et al., 2010). In terms of green seaweeds, its cultivation is not as prevalent as brown and red seaweeds, but they are preferred in some regions. For instance, in India, conversion from green seaweeds to biofuel is flourishing, such as Sea6 Energy Private Ltd. has raised $655, 500 to develop green algae biofuel (http://www. biofuelsdigest. com, April 2013).

2. 2 Natural vs commercial seaweed farms

There is a difference between natural and commercial, large-scale mariculture. The focus of the latter is set up on maximizing yields within the shortest possible time period. It is aimed mostly on the result, and can cause the different kind of problems linked to the environmental issues like: reduction of fouling alga and epiphyte growth, control of grazing animals, low level of planting stock. On top of that industrial scale of cultivation of the seaweed can cause irreparable damage to natural aquatic and terrestrial ecosystems and in the end also some social problems (Titlyanov and Titlyanova, 2010). The large-scale production is concentrated mostly in the East-Asia and South America countries. In China and Korea Saccharina japonica is the most common grown type of brown algae (Titlyanov and Titlyanova, 2010). Seaweed is used mostly for human consumption. In 2012, the total production of aquaculture in China was 11315000 tonnes and brown algae yielded for half of it. Less was produced respectively in Philippines (100000 tonnes) and in Chile (also 100000 tonnes) (Titlyanov and Titlyanova, 2010). The difference between seaweed grown naturally and commercially is that values for maximum productivity in the natural environment are 10 times higher than those in cultivating environment (Lüning and Pang, 2003). That is possible due to high developed natural multi-layered systems, which are difficult to build in artificially by humans.

2. 3 Seaweed harvesting

There are two main ways of harvesting seaweeds that are manual harvesting, which is used for the intertidal zone on the shore and mechanical harvesting which is applied widely in industrial scale. The hand harvesting is used in the past but now the mechanical system is preferred to improve the harvesting efficiency and reduce the cost. In Norway, the trawlers were used to tear the mature seaweed and leave the small size attached to the rock for regrowth. The trawl can take one tonne of seaweed for every drag and increase to 150 tonnes daily. After harvesting, the kelp is transferred into transporting ship and then to collecting stations or factory for the first biomass pretreatment before putting to the main process of fermentation (Meland and Rebours, 2012). With this harvesting method, the kelp forest in Norway is remaining stable level even in some locations with high harvesting pressure. In France, another system, so-called Scoubidou, is managed by using a hook to twist, break and put the seaweeds into the boat. Using the

Scoubidou can improve the harvesting efficiency of seaweeds, because only one man in a boat can collect many tonnes of seaweed per day (Burton et al., 2009). There are also other examples of harvesting seaweeds such as using a boat to collect drift seaweed in beach tidal zones in Italian (Burton et al., 2009). In Chile, the best method of preserving the seaweed resource for future production is to take half of the fronds from each individual in one population so that they can regrow on the harvested individual rapidly, stimulate the new frond and lower the densities through the scratch (Borras-Chavez et al., 2012).

2. 4 Biomass Pretreatment

Usually, stones collected with the holdfast (A holdfast is a root-like structure that anchors aquatic sessile organisms, such as seaweed, other sessile algae, stalked crinoids, benthic cnidarians, and sponges (Burton et al., 2009) of Laminaria (Laminaria is a genus of 31 species of brown algae (http://en. wikipedia. org/, April 2013)) and snails are removed as a first step in pretreatment. Plastic bags and other rubbish may also be found. Foreign objects screening is carried out before chopping and milling. Sometimes the larger pieces of seaweeds may be used instead of smaller ones, so chopping and milling may be carried out in different ways. Sand levels can be minimized by using waste collection vehicles. Life span of brown seaweeds is longer when compared to Green seaweeds. These seaweeds can be kept at an ambient temperature for several hours. Owing to presence of polyphenol, they survive against degradation. Harvesting of brown seaweeds is usually carried out on weekend but they reach to factory on the coming wekday, which cause some natural dewatering of the seaweed (Burton et al., 2009).

Green seaweeds with high water content and being sensitive to microbial degradation need to be processed immediately. Dewatering of seaweeds is carried out using pressing conveyors. (Burton et al., 2009).

2. 5 Bioethanol and biogas from seaweeds

2. 5. 1. Biogas

Seaweed has a great potential as an energy crop because it contains easily hydrolysable sugars with a low lignin content. The lignin content reported for sugar beets, maize and seaweed Ulva lactuca was about 4. 5 g/g, 15. 1 g/g and 0. 03 g/g dry matter respectively. Anaerobic digestion not only solves the problem of disposal, but also provides renewable energy in the form of methane. However, the anaerobic digestion of seaweed is not straightforward, with problems about high concentrations of SO42−, NaCl and heavy metals encountered. If these heavy metals could be removed, the digestate could be used as a fertilizer. Nevertheless, the problem with the high concentration of SO42−and hence sulphide in the digester would be increased when removing heavy metals that are expected to precipitate with H2S in the digester. The subject of the study was thus the removal of heavy metals from the seaweed leachate and subsequent biogas production. Two-stage anaerobic digestion of seaweed allows the removal of heavy metals from seaweed prior to biogas production. The removal of heavy metals is performed with Iminodiacetic Acid (IDA) cryogel carriers (efficient in removing Cd2+, Cu2+, Ni2+ and Zn2+ ions from seaweed leachate). The removal efficiency ranges from 41 to 79%, depended on the type of heavy metal. However, the mobilization of heavy metals from seaweed is low. The removal of heavy metals from the seaweed leachate has a significant effect and reduces the methane yield with about 17% in batch tests and about 15% in experiments with the up flow anaerobic sludge reactor (UASB) reactors compared to non-treated leachate. Therefore, post-treatment with heavy-metal removal might be a more suitable option to avoid the loss of methane potential. Comparable methane yields are obtained in the anaerobic digestion of seaweed and its leachate; however, 14 days is required to produce 90% of the methane from seaweed compared to only nine days with seaweed leachate, thus, shorter treatment time is required in a two-stage digestion system. Efficient treatment of seaweed leachate is achieved in a UASB reactor with a high gas production rate (GPR) of 3. 0 N l CH4/l/day at a short hydraulic retention time (HRT) of 12 h. Hence; a smaller reactor volume is required in reducing the cost of a treatment system. The study demonstrated that two-stage anaerobic digestion is promising as a waste handling method for seaweed (Nkemka and Murto, 2010).

2. 5. 2. Bioethanol

Seaweeds contain some types of glucans that are polysaccharides composed of glucose. These glucans are able to hydrolyze by saccharification enzymes, and ethanol can be produced from hydrolysates. Since the content of glucans presented in seaweed is low, then approach to high concentration of ethanol has been difficult but for increasing concentration of the ethanol that is produced from seaweed, we can use two methods. First, we can use continuous saccharifications, in which the hydrolysate of primary saccharification is used, after removing the residue, as a hydrolyzing liquid for secondary saccharification. The second method is combined saccharification, where the acid hydrolysis of other polysaccharides is followed by the enzymatic hydrolysis of other polysaccharides for the production of high concentration of fermentable sugars. Extracts from Laminaria hyperborea could possibly be fermented to ethanol commercially. In particular, seaweed harvested in the autumn is rich in easily extractable laminaran and mannitol. Four microorganisms are tested to carry out this fermentation, one bacterium and three yeasts. Only Pichia angophorae can utilise both laminaran and mannitol for ethanol production, and its substrate preferences are investigated in batch and continuous cultures. Laminaran and mannitol are consumed simultaneously, but with different relative rates. In batch fermentations, mannitol is the preferred substrate. Its share of the total laminaran and mannitol consumption rate increases with oxygen transfer rate (OTR) and pH. In continuous fermentations, laminaran is the preferred substrate at low OTR, whereas at higher OTR, laminaran and mannitol are consumed at similar rates. Optimization of ethanol yield requires a low OTR, and the best yield of 0. 43 g ethanol per g substrate is achieved in batch culture at 4. 5 pH and 5. 8 mmol O_2 l^{-1} h^{-1}. However, industrial production of ethanol from seaweed would require an optimization of the extraction process to yield a higher ethanol concentration (Horn et al., 2000).

2. 5. 3. Application of biotechnology

In biofuel production from brown seaweeds, some challenges have emerged. First of all, the presence of polyphenols in seaweed tissues can inhibit biodegradation. Secondly, due to complicated composition of seaweed, ethanol has to be produced from various intermediates, which means versatile microbes utilizing all the intermediates are required. Alternatively, a combination of microbes can be considered. On top of all, the most abundant constituent, alginate, is difficult to directly be converted to ethanol (Horn, 2000), there is no industrial microbe to break down alginate and convert it into fuels and chemical compounds (Biello, 2012). However, synthetic biologist Yasuo Yoshikuni, a co-founder of Bio Architecture Lab, Inc. (BAL), and his colleagues genetically modified Escherichia coli, a gut bacterium that has made headlines for food contanimination, since it is capable to metabolize mannitol and glucose. The genetic modification conferred it the ability to convert sugars in an edible seaweed called kombu into fuel. Their finding was reported in the January 20 issue of the journal Science (Biello, 2012). The research team found a 30 kbp section of DNA from the bacterium Vibrio splendidus 12B01 that was expected to contein all the genes for alginate degradation, transport, and metabolism. To transform E. coli with the 30 kbp DNA correctly, the they built a library of random DNA fragments from the V. splendidus genome, which were ligated with a carrier called fosmid respectively. After tramsferring these DNA fragments into E. coli, they identified the desired colonies by using alginate as the only food source in culture medium. Finally they obtained colonies that had a particular fosmid designated pALG1 . Then the team determined the protein coding section of pALG1 and analysed the alginate transport system. After this, they engineered E. coli strain by transforming the required genes, introducing ethonal production pathways from other bacteria and deleting some byproduct pathways. After this stage, they tested the ethonal-producing property of their engineered E. coli strain in a medium that conteined five percent sugar mixture comprising alginate, mannitol, and glucose at a ratio of 5: 8: 1, which stands for the typical ratio in brown seaweeds. The ethanol production was about 20 g/L (Wargacki et al., 2012). In the final demonstration, they used Saccharina japonica known as an edible seaweed to test their engineered E. coli. Ethanol was produced at a yield of 0. 281 grams per gram algae, more than 80 percent of the hypothesis yield, and about 83 percent of the ethanol was produced within 48 hours. And the experiment temperature is between 25 and 30 ℃. This brings a promising future for the application of engineered E. coli. in biofuel production from seaweed (Wargacki et al., 2012). And according to Yoshikuni , there is no need to worry about evasion of the engineered microbe, which might be detrimental to the ocean ecosystem, since this species of E. coli. only survives in human gut rather than ocean. Additionally, if we introduce other pathways instead of ethanol, this engineered microbe is expected to produce more products, such as isobutanol, green plastic (Biello, 2012, Niemeyer, 27 April, 2013). In terms of future application of this technology, it is bright. BAL has big-name partnerships spanning three continents, which include Norwegian oil giant Statoil. Statoil sponsors the technology for converting Norwegian seaweed to ethanol. By 2012, BAL had raised $37. 5 million, including $12 million in venture capital to develop this technology, and Mr. Trunfio said, if everything goes well, the commercial renewable chemicals would be available by 2014 and biofuel within five years. The pilot facility for application was being constructed by BAL in Chile, where the whole process from harvesting to production would be displayed (Korosec, January 20, 2012). Once this technology is implemented on commercial scale, seaweed would bring 1, 500 gallons of ethanol per acre if its biomass production is 18 to 22 dry tons per acre, which is 50 percent more ethanol per acre than sugar cane and triple the ethanol per acre of corn (GARTHWAITE, January 23, 2012).

2. 6 Biorefineries

Biorefineries are facilities that convert biomass materials from living or recently living organisms into fuels. Basically, biofuels are manufactured by a biorefinery which integrates the biomass conversion processes. The biorefinery concept is thus analogous to today's petroleum refineries that produce multiple fuels, power and chemical products from petroleum. Biorefinery systems generally work by processing a bio-based feedstock input to create fuel (King et al., 2010). There are some conversion methods to convert biomass feedstock to fuel. Since in this project seaweed is introduced as feedstock, we can put seaweed in sugar-based feedstock category then fermentation method is chosen. The fermentation of sugar solutions originating from either starch crops or lignocellulosic material requires pretreatment of the feedstock to liberate the sugars from the plant material. Starch is usually hydrolyzed enzymatically to deliver sugar solutions, followed by the microbial fermentation stage to produce bioethanol. Sugar crops such as sugar cane can be directly fermented to produce ethanol (King et al., 2010)The Biochemical Platform is currently based on biochemical conversion processes and focuses on the fermentation of sugars extracted from biomass feedstocks. The production of bioethanol requires three main steps: fermentation of the sugars, distillation to remove the bulk of the water and dehydration to further remove water from the remaining azeotropic water/ethanol mixture (King et al., 2010)Figure 2. 6. 1:

Biofuel Flow. The multiple synthetic conversions routes of major biofuels (King et al., 2010)

2. 7 Process Description of conversion from seaweed to ethanol

There are three main steps in process, pretreatment, saccharification & fermentation, purification. In other words, if these four steps are working together, then seaweed will change to bioethanol. Here we will introduce each step briefly as below: Pretreatment: In pretreatment step, most of the carbohydrates in the feed change to soluble sugars with thermal acid hydrolysis. For thermal acid hydrolysis, steam is used to prepare the required heat also to dilute H2SO4 is added as a catalyst in this step. Saccharification & Fermentation: In this step, incoming flow from previous step (pretreatment) is saccharified and fermented to ethanol. First, incoming flow is neutralized with ammonia due to a considerable amount of sugar loss in liquor by side reaction at high pH. Saccharification enzymes are used in incoming flow to produce sugars for fermentation. In fermentation section, sugar is converted to ethanol by enzymes. Also, CO2 is released into atmosphere (Fasahati and Liu, 2012). C6H12O6è 2 C2H5OH+ 2 CO2Purification: First, liquid phase that contains water and ethanol is sent to the distillation column. Furthermore, 2 packed-bed columns are linked to distillation column for purification. To be specific, distillate ethanol from top of the distillation column contains a little amount of moisture, so in order to get high concentration ethanol, we should remove moisture from ethanol, thus 1 absorber (1 packed-bed column) is used to get rid of moisture. After that, a small amount of pure ethanol is sent to the regenerator (2 packed-bed column) and ethanol desorbs water in the particle and again recycles it back to distillation column, so if 1 packed-bed column gets occupied by water, we can switch it with second packed-bed column, by this action we have continuous process (Figure 2. 6. 1) (Moe, 2013)Figure 2. 6. 2: Short process description from seaweed to bioethanol (Moe, 2013)BIELLO, D. 2012. Genetically Engineered Stomach Microbe Converts Seaweed into Ethanol. Scientific American. BORRAS-CHAVEZ, R., EDWARDS, M. & VÁSQUEZ, J. A. 2012. Testing sustainable management in Northern Chile: harvesting Macrocystis pyrifera (Phaeophyceae, Laminariales). A case study. Journal of Applied Phycology, 24, 1655-1665. BURTON, T., LYONS, H., LERAT, Y., STANLEY, M. & RASMUSSEN, M. B. 2009. A review of the potential of marine algae as a source of biofuel in Ireland. Dublin: Sustainable Energy Ireland-SEI. CHUNG, I. K., BEARDALL, J., MEHTA, S., SAHOO, D. & STOJKOVIC, S. 2011. Using marine macroalgae for carbon sequestration: a critical appraisal. Journal of Applied Phycology, 23, 877-886. CRITCHLEY, A. T. & OHNO, M. 1998. Seaweed resources of the world, Kanagawa International Fisheries Training Centre, Japan International Cooperation Agency. FAO, F. 2006. Statistical Yearbook 2005–2006. FAO, Rome, 190. FASAHATI, P. & LIU, J. J. 2012. Process simulation of bioethanol production from brown algae. Cellulose, 6, 6. GARTHWAITE, J. January 23, 2012. Bioengineering e. coli to turn seaweed into fuel [Online]. Available: http://green. blogs. nytimes. com/2012/01/23/unlocking-seaweeds-next-gen-crude-sugar/. HORN, S., AASEN, I. & ØSTGAARD, K. 2000. Ethanol production from seaweed extract. Journal of Industrial Microbiology and Biotechnology, 25, 249-254. HORN, S. J. 2000. Bioenergy from brown seaweeds. Norwegian University of Science and Technology. HTTP://EN. WIKIPEDIA. ORG/. April 2013. Laminaria [Online].

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