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Review Article

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A Review of UAE Native Seaweed as Potential Bio-Refinery Feedstock for Jet Fuel and High Value Chemicals

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Abstract
The UAE government has hosted several initiatives to produce sustainable jet fuel from locally available feedstock to support its sustainable energy strategy and vision. With more than 2000 km of coastline UAE is home to a large variety of aquatic biomass, such as seaweed. The local seaweed strains can act as ultimate candidate feedstock for not only bioenergy (jet fuel) but also a source for high value chemicals. Seaweed contains high carbohydrates and rapid growth rates and low lignin content. Several seaweed biomasses strains have been identified along the shores of the Emirate of Abu Dhabi amongst which one strain Ulva Sp. was the most dominant in terms of occurrence and availability. A bio refinery utilizing the local UAE seaweed strains could provide many advantages for the commercial viability the due to the fact that seaweed has potential to other high value product such as active components for pharmaceutical products as their market value is much higher that sustainable jet fuel. The preliminary chemical characterization showed significant glucan contents which indicate fermentable sugar content in these biomass samples. This make the local aquatic biomass an interesting research project both to fulfill the sustainable jet fuel initiative and establish further knowledge in the local aquatic biomass bio-refinery capabilities.

Keywords: Seaweed, Bio-refinery, Jet fuel, Sustainable, High-value chemicals.

Introduction
Commercial airlines are these days facing significant pressure to reduce their greenhouse gases emissions because of using jet fuel sourced from fossil fuel. While there are intensive amount of research in field of sustainable energy and specially those designed to run on ground vehicles and energy production, the aviation sector had fewer attention due to the fact that airplane engines require more complex fuel characteristic. This prompts the need for engaging in research for promoting the alternative fuels and development of recently found energy sources which are both sustainable and inexhaustible for jet engines. The International Air Transport Association (IATA) have urged the aviation industry to use sustainable fuels which include SAF (Sustainable Aviation Fuel) notation [1]. The concept of SAF is derived from sustainable biomass such as wood, waste biomass or algae which can reduce the carbon footprint and provide a more sustainable source for energy. The issues associated with the current fossil jet fuel is that it incurs lots of resources during the process of production which is not recommended by IATA which results in high production cost and carbon footprint [2]. Researchers and R&D centers around the world have put great efforts in developing sustainable processes for production of jet fuel based on different biomass. However, most of the research has shown high product costs when compared to fossil fuel derived jet fuel thus requiring government incentive to be commercially viable. Seaweed, which also called Macro Algae, has the potential to be significant feedstock source for bio-refinery since it can be utilized to produce jet fuel as well as high value chemicals such as pharmaceutical components and proteins in which their market value surpass the bio- jet fuel value . In the context of the UAE, the best methods to utilise local aquatic biomass for bioenergy and biochemical production is not well understood yet. A study to develop this understanding could establish a fundamental knowledge for the native aquatic biomass in UAE as well as the opportunity to take part in the government sustainable jet fuel initiatives.

UAE Jet fuel Requirement
UAE has surpassed Saudi Arabia in terms of jet fuel consumption with nearly 170,000 b/d (Barrel per Day) of jet fuel consumed in 2016 and become the largest aviation fuel consumer in the Arab region (see figure 1) [3, 4]. In 2016 the jet fuel consumption in UAE increased by 44 % percent in just 4 years from about 100,000 b/d in 2012 (figure 1) mostly due to the continuous expansion in the airplane fleets and massive increase in airport operations in the country. In the context of UAE, which aspires to be a more sustainable and eco-friendly country, the government joined the KYOTO framework in 2005 taking an international promise is reducing its carbon emissions which resulted initiating several projects in clean energy under umbrella of Clean Development Mechanism and which has an upcoming goal in producing 27% of its energy from clean and sustainable sources in 2021 [5]. Abu Dhabi National Oil Company (ADNOC) is responsible for aviation

fuel supplies in the country. ADNOC supplies its jet fuel to several UAE's international airports including both Abu Dhabi International Airport and Dubai International Airport as well as Sharjah, Ras Al Khaimah, Fujairah Airports in additions to its refueling facilities in other small local airports in the country [6]. ADNOC's owned refinery TAKREER which is located 240km west of Abu Dhabi is the main jet fuel refinery in the country and currently has invested US $10 bn refinery upgrade project.

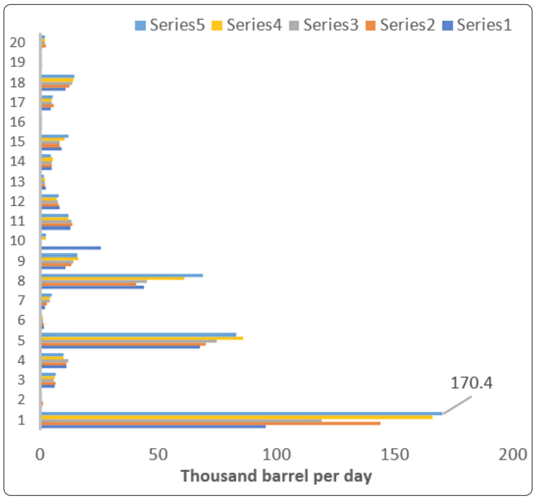

Figure 1: Arab nation's consumptions of Jet fuel [4]

UAE Local Aquatic Biomass

Though there is no official detailed report of type of local seaweed strains in UAE, previous research on aquatic biomass screening was carried and several seaweed strains was recorded off the coast of the Abu Dhabi Islands (Table 1 & Figure 2) . Seaweed such as Ulva sp (figure 3) , Padina boergesenii and Colpomenia sinuosa (figure 4) were found in several offshore sampling location. Ulva sp was most predominant species in terms of occurrence on the shoreline of Abu Dhabi.

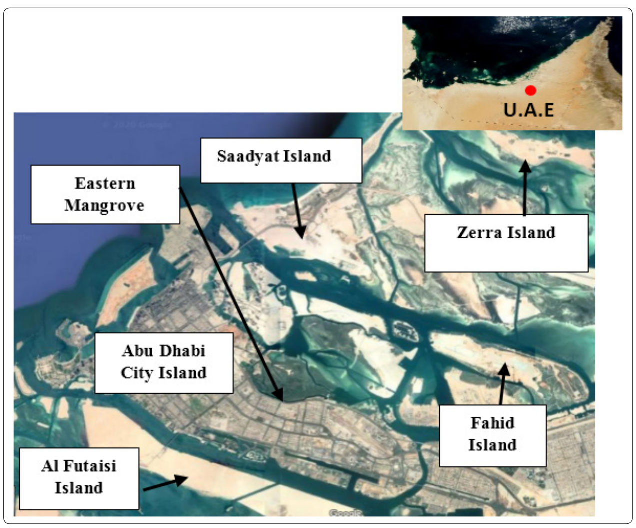

Figure 2: Some of sampling locations around the Island of Abu Dhabi

Figure 3: Samples of Ulva sp. near Eastern Mangrove Cornich Abu Dhabi Island

Collection of the Ulva sp. sample from different sites (Table 1) was recorded throughout the year with most dense biomass blooms being seen during relatively cold times of the year between October to July. Phaeophyta (Brown algae) were recorded included Padina boergesenii, and Colpomenia sinuosa in deep water around the Island of Abu Dhabi. Padina boergesenii for instance grows in spring and then dies off in late autumn when specimens are frequently covered in epiphytes organism. They are found in the infra littoral zone on hard substrates at surf-exposed coasts. During the winter (October – March) large areas of sublitoral reef flats are covered by Colpomenia sinuosa before they die off in spring. In spring Colpomenia sinuosa is broken down and often visible floating on the water surface and by the summer C. Sinuosa is usually completely broken down.

Table 1: Sampling details around the coastline and Islands of Abu Dhabi

Water conditions	Location/GPS coordinates	Depth (m)	Main type of flora present
pH=8.02, TDS=25.9 ppt, Temp=22.8°C	Eastern mangroves, 24.455285, 54.405102	0-1	Ulva sp.
No recording	Eastern mangroves, 24.455285, 54.405102	0-1	Ulva sp.
pH=8.02, Temp=23.5°C	Eastern mangroves, 24.455285, 54.405102		Ulva sp.
No recording	Mussafah channels	0-1	Ulva sp.
No recording	Al Sammaliah Island, 24°27'36.70"N, 54°32'13.23"E	No recording	Padina boergesenii
No recording	Eastern mangroves, 24.453088, 54.445839	1-2	Ulva sp.
No recording	Ghurab and Bel Ghailam, 24.582977 54.503442, 24.537859 54.461500, 24.586603 24.586756 54.484726, 54.521969	1-3.4	Padina boergesenii, Sargassum., Colpomenia sinuosa
No recording	Eastern mangroves, 24.453088, 54.445839	1-2	Ulva sp.
No recording	Al Futaisi Island, 24.397079, 54.300863	1-2	Padina boergesenii

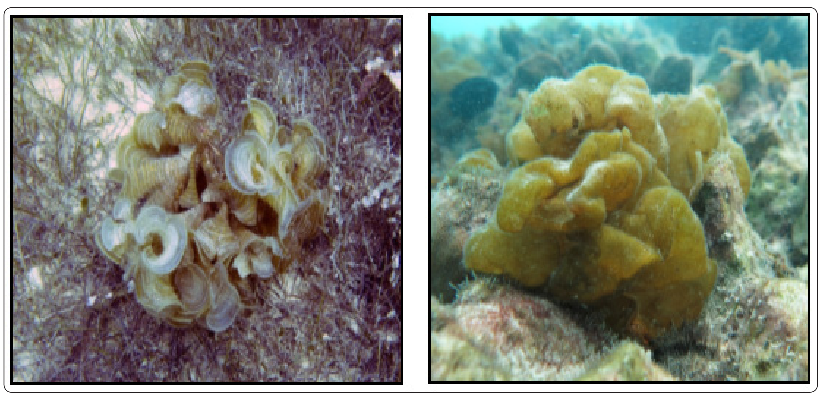

Figure 4: Padina boergesenii (left) and Colpomenia sinuosa (Right) screened offshore of Abu Dhabi's Island

The previous screening of seaweed around the Island of Abu Dhabi showed various aquatic biomass and some especially interesting seaweed grown in water temperature reaches 16 °C in the winter and cross 34 °C during the summer with water salinity ranging from 50 ppt to 70 ppt [7].

The structural carbohydrate content and acid insoluble residues were measured (Table 2) using NREL laboratory analytical procedure for all three seaweed samples (Ulva.Sp., Colpomenia sinuosa and Padina boergesenii) [8].

Table 2: Structural carbohydrates and acid insoluble residue content in three types of seaweed (w/w %, all per dry matter basis, average +/- standard deviation)

Material	Glucan [%]	Xylan [%]	Arabinan [%]	Acid insoluble residue [%]	Starch [%]
Ulva Sp.	7.34 +/- 0.15	3.08 +/-0.05	7.69 +/-0.11	15.84 +/- 0.38	1.52 +/- 0.03
Padina boergesenii	8.05 +/-0.01	3.66 +/-0.01	0.47 +/-0.02	13.05 +/- 0.54	0.31 +/- 0.01
Colpomenia sinuosa	9.47 +/-0.09	3.31 +/-0.06	0.25 +/-0.02	18.94 +/- 1.73	0.24 +/-0.01

The glucan contents in the 3 seaweed species showed good indications for biofuel production although other seaweed carbohydrates (not yet reported for above local samples) such as alginate, carrageenan, agarose, mannitol and agaropectin are important factor in seaweed biofuel production as well for production of high value chemicals.

Seaweed to Jet fuel

For jet fuel production, several conversion technologies are currently been developed. These conversion technologies are mainly based on two conversion pathway, Chemical and Biochemical pathway. The most common chemical conversion pathways include thermochemical routes such as Gasification, Pyrolysis, Fischer Tropch (F-T), High Thermal liquefaction (HTL) and High Thermal Upgrading (HTU) [9-13]. The biochemical pathways include Fermentation and Anaerobic Digestions (AD). Sugar to Jet Fuel (STJ) and Alcohol to Jet Fuel (ATJ) are conversion routes that are partially based on biochemical conversion pathway [14, 15]. The selectivity of these conversion pathways is mostly depending on type of biomass used as feedstock. Table (3) summarizes the different conversion pathways in respect to the feedstock that can be used for each process and jet fuel production cost [16-20].

Table 3: Comparison of some common jet fuel conversion pathway

Conver-sion Pathways	Feedstock	Final Product Cost		Comments	Ref.
Gasification , Fischer Tropch	MSW, Wood , Biomass (algae , residual biomass)	$2.2–$2.6/gal Jet fuel based on residual feedstock	Conventional Jet Fuel Cost $ 1.39/gal [20].	FT route is approved by ASTM for Jet fuel	10
Pyrolysis	MSW, Wood , Straw, Seedcake , residual biomass	$1.73 /gal Bio-oil based on rice husk feedstock		High oxygen content product	12, 10, 16
HTL , HTU	Wet biomass	$0.92/l Jet fuel based on lignocullolosic feedstock		High energy value and low oxygen content product	11, 17 ,9
STJ	Sugary , Starchy , Linocullolosic biomass	$1– $1.54/l Jet fuel based on sugar biomass		Further R&D required	18,10
ATJ	Sugary, Starchy, and Lignocellulosic biomass	$0.96/l – $1.38/l Jet fuel Depending on type of feedstock		Further R&D required	19, 15

The current jet fuel production cost from biomass based on the above conversion technologies is relatively high and does not favor any large-scale industrial plant. This is due to the fact that the majority of sustainable jet fuel projects are based on a single product (jet fuel) and do not consider utilization of biomass within the refinery process to produce other high value products.

High Value Chemicals from Seaweed

Marine seaweed includes chemical substances which are markedly different from terrestrial biomass. Organic chemicals, including carbohydrates or secondary metabolites, are typically special and vary depending on the marine seaweed diversity. Seaweed was used commercially as food and/or for the processing of their polysaccharides (e.g., carrageenans, alginates, agars), comprising 83-90 percent of their global market value [21]. However, they are also considered to possess numerous primary or secondary metabolites with great potential applications in the pharmaceutical, nutraceutical, and cosmetic industries. Those features significant opportunities for producing different marketable goods of greater economic value than fuels. The incorporation of their useful non-energy bio-products will also provide an opportunity to offset the cost of bioenergy production from seaweed. Polysaccharides with sulphated groups for instance extracted from Phaeophyta (brown algae), Rhodophyta (red algae), and Chlorophyta (green algae) have been discovered to be active against pathogens [22]. In general, when processed for medical purposes, polysaccharides have high values as it ranges from $13/kg to $15/kg [23, 24]. Phenolics and polyphenolic compounds, are found in a variety of marine and terrestrial plants and especially in seaweeds [25]. Due to their antioxidant properties, polyphenols show a wide range of biological effects. The relatively high concentrations of phenolic compounds in species of marine algae leads to their antioxidant properties which can be useful in reducing deleterious oxidative reactions to health, such as oxidative stress related disease ; cataract , ageing and autoimmune disorder [26]. The antibacterial activity of bromophenols was isolated and examined from red alga Rhodomela confervoides [27]. The extraction value of Phenolics compounds depends on methods of extraction ranging from $0.83/kg to $4.58/kg [28]. Carotenoids that are originally from marine pigment sources found to be different in terms of structure when compared to those found on land [29]. Seaweeds carotenoids, including fucoxanthin, neoxanthin, canthaxanthin, and peridinin tempt apoptosis in cancer cells [30, 31]. The market value of the pigments relies on the types of extractive components from the pigments. The price range of carotenoids components is between $300/kg and $1500/kg based on the applications and industry that uses the component while the price range of phycobiliproteins components is between $500/kg and $50,000/kg [23]. Seaweeds are excellent sources of rare sugars, since their polysaccharides are typically composed of various types of sugars with special chemical structures [21]. Rare sugars in the pharmaceutical and nutraceutical industries have high market prices due to their large potential biological activity and low-calorie properties (1-2 kcal g-1). For instance, Mannitol is a form of six-carbon sugar alcohol with a heavy-market value of $7.3/kg with 15,000 tons per year on the global market [21].

Discussions

As world is putting efforts in cutting its carbon footprint and providing alternative fuel sources for its ground and air vehicles. The United Arab Emirates has kept its promise as one of Kyoto protocol signees to diversify its energy sources away from fossil fuel. Recently the local government is shown interest in producing sustainable jet fuel for its official national fleets, Etihad airline. While most of attention was on Municipal Solid Waste (MSW) and halophytes (Salicornia) as a local biomass feedstock for sustainable jet fuel production [6,32] , the UAE aquatic biomass was not considered mainly due to lack of data available on local seaweed biomass.

The research in the field of sustainable jet fuel is progressing and many biomasses has been studied for feedstock to produce jet fuel. The conversion pathways in the other hand has been developed at certain point although the need for process optimizations is still required to overcome some technical issues. The final product (jet fuel) in most of conversion pathways will require further processing in order to achieve the fuel specification for aircraft engines. Overall, the jet fuel produced from sustainable biomass is currently more expensive compared to the jet fuel produced from crude oil refineries. Seaweed biomass, as discussed earlier, has been studied for decades for its food and health benefits while it has only recently gained interest as an energy crop. Developing a bio-refinery concept based on local seaweed strains to produce energy (jet fuel) and extracting a valuable product will unlocks the UAE aquatic biomass potential.

Conclusion

Seaweed in general are less investigated for energy production in all round the world that due to utilization of such biomass in many country especially East Asian region for food production. However recent interesting in utilization of seaweed for biofuels and high value chemicals production are rising. The UAE which has long sea coast line with shallow water and extreme weather condition will play an important role in discovering aquatic biomass for bio-refinery concept and nerveless such aquatic biomass can act as potential feedstock for sustainable jet fuel initiative.

UAE native seaweed biomass showed significant value of these biomasses for energy production. The preliminary chemical characterization showed significant glucan contents which indicate fermentable sugar content in these biomass samples. This make the local aquatic biomass an interesting research project both to fulfill the sustainable jet fuel initiative and establish further knowledge in the local aquatic biomass bio-refinery capabilities.

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