POLICY PAPER

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EXECUTIVE SUMMARY

By analyzing the abundant microorganisms in the naturally occurring mangroves of Ras Al Khaimah in the United Arab Emirates (UAE), this policy paper discusses the feasibility of a future where the emirate invests in biofuels sourced from its mangroves as opposed to using conventional methods of fuel production and usage, which can have negative impacts on the environment and economy. It explores the successes and challenges of each phase of biofuel technology innovation, so that the previous trials and errors can help decision makers critically assess the potentials of utilizing biofuels in current technology as well as in future projects. This paper finds that currently it is possible to use the existing mangroves as a source of fungi for biofuel production, but more investment is needed to support industrial-level production. It concludes with policy recommendations for supporting future research, implementing long-term energy solutions that address the UAE's environmental and economic concerns, and encouraging future leaders and innovators to think local in addressing global problems.

Alternative Energy in the UAE: The Potential of Biofuels Sourced from Ras Al Khaimah Mangroves

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Introduction

Research on biofuels is a field currently of growing interest to scientists and policy makers alike due to the expansion in worldwide energy demand by developing economies as well as the recent increments in global oil costs. According to the 2013 Intergovernmental Panel on Climate Change (IPCC), the increasing demand for energy is expected to reach 37,000 tons globally by 2035, and the reserves of oil and gas alone will not likely be able to sustain this demand (IPCC, 2013).

In addition to the diminishing quantities of these fossil fuels, another grave concern is the environmental consequences of their production and usage. IPCC's research found that as of 2011, concentrations of the extremely harmful greenhouse gases, such as carbon dioxide, nitrous oxide, and methane, had exceeded their pre-industrial levels by about 40%, 20%, and 150%, respectively. Carbon dioxide emissions in particular increased directly from fossil fuel combustion and cement production (IPCC, 2013). Also, the continued use of fossil fuels to drive humankind's need for fuel-driven technology have been found to have a negative impact on climatic changes, such as the warming of the atmosphere and oceans, the decrease of snow and ice, and the rise of sea levels (IPCC, 2013). To tackle these issues, an increasing number of concerned governments and countries have adopted measures to reduce fossil fuel production while increasing the use of renewable sources of energy.

Currently, an estimated 13% of the world's energy is known to be generated from renewable sources (IEA, 2013) and a sizable majority of that comes from biological sources in the form of biofuels. This paper makes a case for biofuels being a strong energy-source contender for the United Arab Emirates (UAE), which aims to increase its production of clean and renewable energy, such as nuclear, solar, wind, and waste-to-energy to 27% of its total energy consumption by 2021 (Abdul Kader, 2016). Mangrove forests, stretching along thousands of square meters of UAE coastlines, are a unique ecosystem that harbors a diverse group of photosynthetic organisms for which there is evidence for, and growing potential of, becoming a viable source of biofuel (Amin, 2009). This is because they contain organic matter known as lipids, which are essential to the production of biofuels.

Use of microorganisms is particularly advantageous when making biofuels for three main reasons: (1) the microbes have short life cycles unlike other sources of lipids, which reduces the amount of time needed for them to achieve full maturity, (2) the microbes can easily multiply into mass amounts in a very short amount of time, unlike other sources of lipids, and (3) the microbes require minimal care and maintenance, in turn needing very little labor and upkeep.

This policy paper discusses the potential that microbes hold for making the emirate of Ras Al Khaimah a producer of biofuel. It first provides an overview of the different generations of biofuel innovations and advancements, analyzing both their successes and challenges. The paper then introduces the next generation of biofuel research, which utilizes microorganisms for the production of biofuels, before contextualizing the potential of this research to Ras Al Khaimah and the greater UAE. It outlines the findings and implications of a recent study that analyzed fungal content of soil samples from the Ras Al Khaimah mangroves in order to assess their potential for biofuel production. The paper concludes with policy recommendations for supporting future research, implementing long-term energy solutions that address the UAE's environmental and economic concerns, and encouraging future leaders and innovators to think local in addressing global problems.

Biofuels: First, Second, and Third Generations

Biofuels refer to fuel derived from the processing of biomasses such as carcasses and metabolic byproducts of living organisms, plant residues, and domestic waste. Several countries have invested in biofuel production successfully, with the United States leading with 3.5 million metric tons of oil produced in 2016 (see Figure 1). There have been three previous generations of biofuel production, which are still in use. However, each generation builds upon the successes and limitations of the innovations of the previous iterations, allowing for the current advancements of the next generation of biofuels.

The first generation of biofuels produced bioethanol, which is also one of the most well known biofuels. Bioethanol is an alcohol derived from corn, sugar cane, wheat, and vegetable waste, and it can be produced using a sugar fermentation process or from a chemical procedure reacting ethylene with steam. The primary sources of bioethanol are corn and sugarcane plantations (Pogaku & Sarbatly, 2014).

Ethanol or ethyl alcohol is a colorless fluid, biodegradable, low in harmfulness and toxicity, which causes minimal ecological contamination if accidentally spilt. Ethanol releases one third as much energy as gasoline; however, it burns more efficiently, generating less carbon dioxide. It can be used in combination with gasoline in order to reduce greenhouse gas emissions and lower the reliance on fossil fuels. Other processes, such as catalytic transesterification and distillation of vegetable oils, can be used to produce biodiesel to run diesel engines. That said, first generation biofuels suffer from environmental and economic disadvantages. They threaten the food chain, lower soil quality, reduce water availability for agriculture, drive up the prices of agricultural products, and are generally costlier to produce compared to fossil fuels (Gasparatos et al., 2013).

The second generation of biofuels also involved the production of bioethanol but with focus on treating the biomass prior to production and separating the dry plant

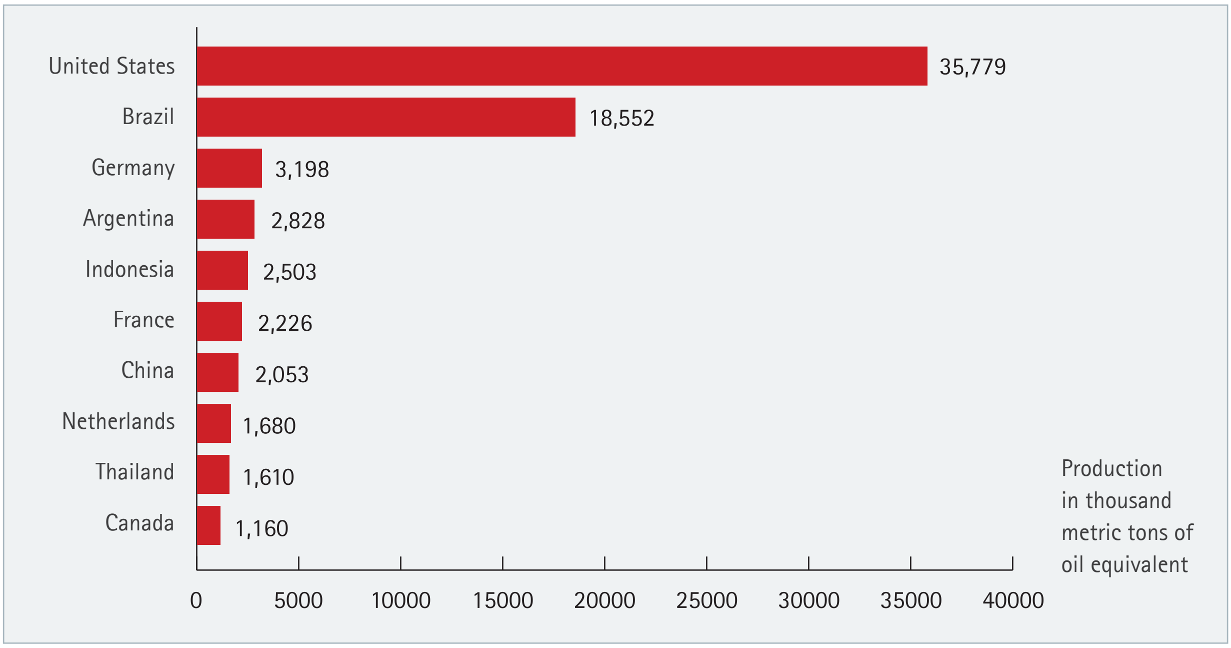

Figure 1. Statistics on the leading countries in biofuel production in 2016

Note. Statistics on leading countries' 2016 biofuel production. From *Statista*. Retrieved from https://www.statista.com/statistics/274168/biofuel-production-in-leading-countries-in-oil-equivalent/. Copyright 2018 by Statista.

matter (lignocellulosic biomass). Biomass sources range from food waste, forest residue and ash, to industrial solid wastes (Sims et al., 2010). Second generation biofuels have some advantages, such as being less costly than their first-generation counterparts to produce, not having negative effects on food supply, and not requiring high quality land.

However, as their production involves the pretreatment of the biomass, it ends up being a more complex process than that of producing first generation biofuels. The breakdown of resistant substances in the biomass using mechanical, thermochemical, and/or biochemical processes presents an additional logistical, technological, and financial burden on biofuel production (Ho et al., 2014). Moreover, there are concerns surrounding the quality standards for refining these biofuels as they can reduce engine life if not properly refined.

The third generation of biofuels is derived from rapidly growing, photosynthetic microorganisms called algae. Algae are a suitable source of biofuel due to their high lipid content and high productivity. Other advantages of algae include, but are not limited to, high photosynthetic efficiency, rapid growth, ability to adapt to different environments, and high carbohydrate content. Pretreatment is required, much like the biomasses of the second generation, and methods to treat algae prior to fermentation include processes such as mechanical commination, irradiation, steam explosion, and alkaline treatment, among others (Li et al., 2014). However, the pretreatment of algal biomass is less expensive than that of crops in the previous generations of biofuel due to the algae's high moisture content and soft structure.

Despite the abundance of algae and the relatively lower costs involved in its pretreatment, there are setbacks that make it hard to commercialize third generation biofuels on a large scale. First, growing algae requires large quantities of nitrogen, phosphorous, and water. This is of concern as the production of fertilizers for growing algae generates greenhouse gases that may exceed the amounts saved via the use of biofuels. Second, the cost of pretreatment and enzymes renders the production of third generation biofuels economically less viable than other sources of fuel. The pretreatment is still expensive, involving steps with high-energy demands and use of expensive chemicals, which need to be curtailed in order to reduce the cost (Demirbas, 2009; Lee & Lavoie, 2013). If algae are to be used as a source of biofuel, then efforts need to be made to maximize the efficiency of the process (Amin, 2009).

Next-Generation Biofuels

The use of microorganisms for the production of biofuels is currently being explored as they present a number of advantages and viable solutions to the problems that the other generations of biofuels encountered. As previously mentioned, lipids are one of the primary ingredients for the production of biofuel, and microorganisms such as bacteria, fungi, and micro-algae are able to produce and accumulate over 20 – 30% of their cell mass as lipids (Ratledge, 2001). Among these microorganisms, fungi such as yeasts and molds are known to be capable of accumulating the most lipids.

Fungi are a sensible choice for the production of biofuel for a number of reasons. Firs, fungal growth can occur very quickly, sustained by such affordable sources of nutrients such as waste, byproducts, and raw materials. Fungal growth is not impeded by seasonal, climatic, and spatial variations like the growth of plants and animals. Another promising aspect of using fungi for biofuel is that the amount of lipids present in fungi can be modified, so that the optimization of growth conditions and/or the mutation of enzymes involved in lipid synthesis can maximize the amount of lipids obtained from each fungal cell.

However, in addition to the quantity of biofuel produced, one needs to verify the suitability of fungal single cell oils (SCOs)[1] as feedstock for biofuel. The quality of next-generation biofuels depends on the fatty acid composition (i.e. monounsaturated and/or saturated fatty acids of various sizes) of the lipid feedstock. The fatty acid composition of fungal SCOs is a species-specific trait that is under the influence of extrinsic conditions including temperature, pH, the carbon to nitrogen ratio, oxygen concentration, and mineral supplies, among others (Khot et al., 2012). Extensive research conducted by Amaretti et al. (2010) demonstrated that temperature had positive effects on the growth rate and volumetric productivity of oleaginous (oily) yeast such as *Rhodotorula glacialis*, while changing the media that the fungus was being grown in could increase the content of essential fatty acids as much as 68%. Many other studies have shown the influence of environmental factors on growth and lipid synthesis in oleaginous (oily) fungi (Santamauro et al., 2014; Brown et al., 1990; Dey et al., 2014), making it a strong contender as a source of next generation biofuels.

Mangroves: A Treasure Trove

Fungi are naturally abundant in the UAE's mangroves. Mangrove forests are coastal ecosystems created by trees and shrubs growing in the harsh area between land and sand inundated by tidal water (Spalding et al., 2010). They are commonly found elsewhere in tropical regions, and harbor a wide spectrum of species adapted to the unique environment of mangroves, which entails high salinity, anaerobic soil, and extreme tides.

The most diverse and abundant mangroves are located in estuaries, lagoons, marshes and deltaic areas, and they are reported to have higher biomass productivity levels compared to other tropical forests (De Lacerda, 2002).

[1] Single cell oil is also referred to as microbial lipid content.

Fungi are involved in the final stages of decomposition of detritus including wood and leaf litter, thereby assisting in critical ecological processes such as nitrogen fixation and nutrient cycling. They play a key role in supplying mangrove plants with nutrients and sustaining the growth of the mangroves, which means they exist in abundance already.

The diversity of mangrove fungi is both influenced by and a result of the diversity of each component of a mangrove, such as the mangrove's range of plantation, age, and habitat characteristics (i.e. temperature and salinity). The most prominent types of fungi found in mangrove forests include basidiomycetes, oomycetes, ascomycetes, and thraustochytrids (Satyanarayana & Johri, 2005). Despite being the second largest group of marine fungi, mangrove fungi have not significantly been studied for their microbial lipid content.

The Future of UAE Fuel: Are Biofuels the Way Forward?

In order to better understand the potential of the mangroves in Ras Al Khaimah and the UAE, a team of scientists and lab technicians from the American University of Ras Al Khaimah (AURAK) collected soil samples from the mangroves in the emirate. The team analyzed soil samples, specifically assessing the content of oleaginous fungal species that could be used in the production of biofuels.[2]

Results

Upon inspection of the lipids in the fungi obtained from the Ras Al Khaimah mangrove soil samples, it was evident that they could be used in the production of biofuels. One of the fungi that were identified, *A. versicolor*, was estimated to accumulate 24.2% weight for weight (w/w, meaning percent of mass) of their cell mass as lipids, while another, *A. nidulans*, accumulated 23.03% (w/w). The lipid contents observed were both greater than 20%, and therefore, within the average range for oleaginous (oily) fungi. Another fungi found present in the Ras Al Khaimah mangroves, *A. terreus*, has been shown in separate studies, to accumulate up to 51% (w/w) of their cell mass as lipids if their composition is optimized by adjusting the initial pH of the lipid fermentation media and cultivation time. This demonstrated the promising potential of the fungal species under study for biofuel production.

Implications for the Adoption of Biofuel Production in the UAE

In light of the promising results of this study, biofuels are a natural choice for energy production and usage in the UAE as it transitions its energy consumption to clean and renewable sources. However, for a change of policy, consideration must be given to the sustainability of changes along with the costs of implementing them in the first place. In the field of energy sources, biofuels supply energy security and nurture the natural resources already present in the communities wishing to use them. Essentially, biofuels are also a perfect substitute to conventional sources of fuel as they can provide a much longer-term solution and can also be utilized across a broader spectrum at very low cost.

Another reasons biofuels are a natural energy choice for the UAE is that they can be adapted and implemented into existing engines with little or no modification to the engine or its fuel system, reducing any potentially high costs that would come from having to completely switch out engines (SGBioFuels, 2016). Biofuels can also be consumed and stored in the same way as petroleum diesel fuel, and they emit much lower amounts of greenhouse gases than is currently being emitted from the burning of fossil fuels. The large amounts of fossil fuel based emanations are the cause of a numerous health problems, such as respiratory diseases and cancers. Biofuels release much lower levels of toxins into the air than the normal fossil fuels (Perritano, 2016), and would therefore be a much more favorable option than the fossil fuels currently being used.

Policy Recommendations

As promising as the findings of the fungi in the mangroves of Ras Al Khaimah are for the emirate's future in biofuel, further analysis is still required to determine quality and efficiency of the biofuel to be produced. Future studies conducted by the Biotechnology Team at AURAK will focus on the fatty acid profiles of the fungal oils in order to validate and compare their potential as biodiesel feedstock as well as serve to potentially indicate the quality of the fungal-based biofuel. The experiments conducted on these fungi will also provide invaluable research on lignin-degrading enzymes, biodegradation, and other industrial applications of mangrove microbes.

[2] Upon collection of soil samples using sterilized equipment, the samples were introduced to a liquid mixture known as a culture media broth to encourage the microorganisms in the soil samples to flourish. The mixture was then transported to the Biotechnology Laboratories at AURAK, where it was added to another growth medium called lipid fermentation agar. This growth medium was used because it is known to induce lipids. Once fungal colonies had grown from the soil sample and agar mixtures, they were each filtered, washed with distilled-water, and freeze-dried with liquid nitrogen. The freeze-dried fungi cell mass was then further crushed in with methanol in order for the lipid content of the cells to be released. After adding chloroform to the methanol and fungi mixture, it was filtered and put in a centrifuge machine. The final step involved putting the mixture into a rotary evaporator at 55 degrees Celsius, which finally separated the fungal lipids from the solvents (methanol and chloroform). Additionally, the isolated fungi were analyzed through morphological identification, and the oil content assessed through fluorescence microscopy and gravimetric analysis.

In addition, efforts need to be made to reduce the overall cost of producing biofuel from fungi. The largest cost component of this process is growth media for fungi, which is a specially developed substance that provides the necessary nutrients for each individual microorganism's growth. This can be overcome by replacing commercial growth media with inexpensive media derived from various types of organic waste. Some of the organic substrates that have been shown to support microbial growth for lipid production include, but are not limited to, corncob waste liquor, orange peel extract, municipal wastewater, waste molasses, urea, waste rice straw, fertilizer effluent, and agro-industrial byproducts (Subhash & Mohan, 2011; Subramaniam et al., 2010).

In order to facilitate the UAE's transition to clean and renewable energy usage through utilizing its natural resources in the form of biofuel production, we therefore recommend the following:

For Biofuel Producers

While making use of the natural occurring microorganisms in mangroves around Ras Al Khaimah, the production of biofuel may require fungi to be grown in mass quantities in other media. One inexpensive method of growing fungi, rather than using commercial growth media, is to make use of organic waste. Waste collection, disposal, and recycling entities can be approached to put in procedures that facilitate the sanitary and controlled production and transport of fungi for the use of biofuel production.

For Funding Agencies

There is a need for more funding agencies that support bioenergy research. In order to encourage researchers, faculty, and students alike in the universities around the UAE to partake in studies which could unlock reserves of biofuel sources in the local habitat, a lack of funding is oftentimes a barrier that can be easily removed. Research in bioenergy requires state of the art laboratory equipment and storage conditions to best extract high quality results from organic materials.

For Educators

To nurture a generation of future leaders and innovators, educators in the UAE could provide opportunities to students that would increase their awareness of the potential that the biomass around them have in providing bioenergy. Conducting campaigns and workshops at schools, and holding competitions for innovative energy ideas can instill a culture that values the importance of environment conservation and appreciates the natural resources in Ras Al Khaimah. These campaigns can invite collaborations between individual innovators and organizations that would enable research to be possible.

For Empowering Community Members

Community members need to be encouraged to dispose of their rubbish in a way that facilitates the potential biofuel industry and supports the UAE's transition to clean and renewable energy usage. Public campaigns and workshops can be organized to help community members understand how to selectively dispose of rubbish in a way where household waste is left in waste containers or recycling bins prior to collection by waste collectors. This can facilitate the recycling process. Additionally, this supports our previous recommendation to produce biofuel from fungi by replacing commercial growth media with inexpensive media derived from organic waste.

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References

Abdul Kader, B. (2016). UAE raises clean energy target to 27% by 2021. *Gulf News.* Retrieved from https://gulfnews.com/news/uae/environment/uae-raises-clean-energy-target-to-27-by-2021-1.1917569

Amaretti, A., Raimondi, S., Sala, M., Roncaglia, L., De Lucia, M., Leonardi,A., & Rossi, M. (2010). Single cell oils of the cold-adapted oleaginous yeast Rhodotorula glacialis DBVPG 4785. *Microbial cell factories, 9*(1), 73.

Amin, S. (2009). Review on biofuel oil and gas production processes from microalgae. *Energy Conversion and Management, 50*(7), 1834-1840.

Brown, D., Hasan, M., Lape-Casillas, M., & Thornton, A. (1990). Effect of temperature and pH on lipid accumulation by Trichoderma reesei. *Applied Microbiology and Biotechnology, 34*(3), 335-339.

De Lacerda, L. D. (2002). *Mangrove ecosystems: function and management.* Springer Science & Business Media.

Demirbas, A. (2009). Political, economic and environmental impacts of biofuels: a review. *Applied Energy, 86*, S108-S117.

Dey, P., Mall, N., Chattopadhyay, A., Chakraborty, M., & Maiti, M. (2014). Enhancement of lipid productivity in oleaginous colletotrichum fungus through genetic transformation using the yeast CtDGAT2b gene under model-optimized growth condition. *PloS one, 9*(11), e111253.

Gasparatos, A., Stromberg, P., & Takeuchi, K. (2013). Sustainability impacts of first-generation biofuels. *Animal Frontiers, 3*(2), 12-26.

Ho, D., Ngo, H., & Guo, W. (2014). A mini review on renewable sources for biofuel. *Bioresource technology,* 169, 742-749.

IEA. (2013) IEA, *International Energy Agency World Energy Outlook 2013*. International Energy Agency IEA/OECD. Paris.

IPCC. (2013). IPCC, *Intergovernmental panel on climate change, Climate Change 2013*. The Physical Science Basis.

Khot, M., Kamat, S., Zinjarde, S., Pant, A., Chopade, B., & RaviKumar, A. (2012). Single cell oil of oleaginous fungi from the tropical mangrove wetlands as a potential feedstock for biodiesel. *Microbial Cell Factories, 11*(1), 71.

Lee, R. A., & Lavoie, J. M. (2013). From first-to third-generation biofuels: Challenges of producing a commodity from a biomass of increasing complexity. *Animal Frontiers, 3*(2), 6-11.

Li, K., Liu, S., & Liu, X. (2014). An overview of algae bioethanol production. *International Journal of Energy Research, 38*(8), 965-977.

Perritano, J. (2016) Top 10 Advantages of Biofuels. Retrieved from https://auto.howstuffworks.com/fuel-efficiency/biofuels/10-advantages-of-biofuels.htm

Pogaku, R., & Sarbatly, R. H. (2013). *Advances in biofuels.* New York, NY, USA: Spring

Ratledge, C. (2001). *Microorganisms as sources of polyunsaturated fatty acids. Structured and modified lipids*, 351-399.

Santamauro, F., Whiffin, F., Scott, R., & Chuck, C. (2014). Low-cost lipid production by an oleaginous yeast cultured in non-sterile conditions using model waste resources. *Biotechnology for biofuels, 7*(1), 34.

Satyanarayana, T., & Johri, B. N. (2005). *Microbial diversity: current perspectives and potential applications.* IK International Pvt Ltd.

SGBioFuels, (2016). 6 Reasons Why We Need Biofuels. Retrieved from www.sgbiofuels.com/6-reasons-why-we-need-biofuels/

Sims, R., Mabee, W., Saddler, J., & Taylor M. (2010). An overview of second generation biofuel technologies. *Bioresource technology, 101*(6), 1570-1580.

Spalding, M., Kainuma, M., & Collins, L. (2010). *World Atlas of Mangroves.* Earthscan, London, UK.

Subhash, G. V., & Mohan, S. V. (2011). Biodiesel production from isolated oleaginous fungi Aspergillus sp. using corncob waste liquor as a substrate. *Bioresource technology, 102*(19), 9286-9290.

Subramaniam, R., Dufreche, S., Zappi, M., & Bajpai, R. (2010). Microbial lipids from renewable resources: production and characterization. *Journal of industrial microbiology & biotechnology, 37*(12), 1271-1287.

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