Commercialization potential aspects of microalgae for biofuel production: An overview

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Abstract  Biofuels are particularly important as an alternative fuel option for transportation. The sustainability of biofuels will depend on the development of viable, sustainable technologies that do not appear to be yet commercially viable. Successful development of algae-based biofuels and co-products industry requires the optimum combination of technical innovations in systems and processes, coupled with economic feasibility in the practical implementation and integrated scale-up for commercial production and marketing.

This article discusses the importance of algae-based biofuels together with the different opinions regarding its future. Advantages and disadvantages of these types of biofuels are presented. Algal growth drives around the world with special emphasis to Egypt are outlined. The article includes a brief description of the concept of algal biorefineries. It also declares the five key strategies to help producers to reduce costs and accelerate the commercialization of algal biodiesel. The internal strengths and weaknesses, and external opportunities, and threats are manifested through the SWOT analysis for micro-algae. Strategies for enhancing algae based-fuels are outlined. New process innovations and the role of genetic engineering in meeting these strategies are briefly discussed. To improve the economics of algal biofuels the concept of employing algae for wastewater treatment is presented.

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1. Introduction

Innovative technologies and sources of energy must be developed to replace fossil fuels and contribute to the reduction of emissions of greenhouse gases associated with their use. Biofuels are particularly important as an alternative option for transportation fuels. However, biofuels derived from terrestrial crops such as sugarcane, soybeans, maize, rapeseed, among others, impose pressure on food markets, contribute to water scarcity and precipitate forest devastation. In this way, the sustainability of biofuels will depend on the development of viable, sustainable, second-generation technologies that do not appear to be yet commercially viable. In this perspective, algal biofuels are generating substantial awareness in many countries. As of today, it has been shown that it is scientifically and technically possible to derive the desired energy products from algae in the laboratory. The question lies, however, in
whether it is a technology that merits the support and development to overcome existing scalability challenges and makes it economically feasible [1].

Successful development of an algae-based biofuels and co-products industry requires the optimum combination of technical innovations in systems and processes, coupled with economic feasibility in the practical implementation and integrated scale-up for commercial production and marketing. Enabling successful advancement and commercialization of the still relatively immature field of algal biofuels also requires the confidence and engagement of key public and private stakeholders so they can make necessary investments over time to reduce technical risks and overcome challenges to developing an algal biofuels industry [2].

A critical evaluation of the available information suggests that the economic viability of the process in terms of minimizing the operational and maintenance cost along with maximization of oil-rich microalgae production is the key factor, for successful commercialization of microalgae-based fuels [3].

Regarding the future trends of algal biofuels there are different opinions. Benemann [4] has a rather pessimistic opinion in his article of opportunities and challenges in algal biofuel production. He stated that the cultivation of microalgae for biofuels in general and oil production in particular is not yet a commercial reality and, outside some niche, but significant, applications in wastewater treatment, still requires relatively long-term R&D, with emphasis currently more on the R rather than the D. This is due in part to the high costs of even simple algae production systems (e.g. open, unlined ponds), and in even larger part to the undeveloped nature of the required algal mass culture technology, from the selection and maintenance of algal strains in the cultivation systems, to the achievement of high productivities of biomass with a high content of vegetable oils, or other biofuel precursors. One short-cut to the goal of algal biofuel development would be to co-produce algal biofuels, specifically, vegetable oils, with higher value products, or in wastewater treatment. This pathway of development would allow this technology to develop and mature to the point where the algal biofuels could become an important component of such processes, and eventually even the main output. However microalgae are already used in wastewater treatment where they provide O2 for bacterial breakdown of the organic component in the wastes [4].

Recently Benemann [5] reported that algal biofuels are possible in principle; but more long-term (~10 years) R&D is needed to achieve the high productivities required. Moreover in an interview Benemann [6] stated that algal biofuel is still an open problem as regards its economics. He added that only open ponds would be able to achieve the low-cost required for biofuels. The fundamentals and economic projections, as well as LCAs (Life Cycle Assessments), are promising in costs and applications, but achieving the assumpions on which these are based and translating these into practical applications still require considerable research and development work.

On the other side Chisti and Yan [7] were optimistic as they reported that algal fuels are not yet commercial, but their economic outlook is promising. Dozens of startup companies are attempting to commercialize algal fuels. Displacing petroleum derived transport fuels with fuels from algae could potentially reduce the emission of carbon dioxide by roughly 30% in the United States. A major impediment to investment in fuels-from-algal technologies is the susceptibility of petroleum price to large and unpredictable fluctuations. Oil from algae is likely to be financially viable in a scenario with crude petroleum sell for > $100 per barrel [7]. It is foreseen by the US industry that full commercialization of algal oil will begin to take place in the US in roughly 4–5 years. Recently, some companies in the US have been working toward bringing down the price of photobioreactors (PBRs) to almost the same cost as open ponds [3].

Ribeiro and da Silva [1] reported a rise of companies’ strategies of entering new markets. For instance, during March and April 2011, news was published, both in Europe and the US, reporting new activities of algae-based companies. They added that these are signs that the uncertainties around the commercialization of this still not mature technology are not sufficient to hinder investment decisions.

2. Algae-based biofuels credibility

Compared to other types of biofuels, algae-based biofuels present several advantages. These advantages comprise:

1. Capability of producing oil all year long, therefore the oil productivity of microalgae is greater compared to the most efficient crops.
2. Algae grow in brackish water and on not arable land; not affecting food supply or the use of soil for other purposes.
3. They can couple CO2-neutral fuel production with CO2 sequestration.
4. Algae produce nontoxic and highly biodegradable biofuels.
5. Possess a fast growing potential as they can complete an entire growing cycle every few days. Approximately 46 tons of oil/ha/year can be produced from diatom algae. Several species have 20-50% of oil content by weight of dry biomass.
6. Regarding air quality, production of microalgae biomass can fix carbon dioxide (1 kg of algal biomass fixes roughly 1.83 kg of CO2). This CO2 is often available at little or no cost. However, the fixation of the waste CO2 of other sorts of business could represent another source of income to the algae industry. Some species are capable of using the flue gas as nutrients, there are few species that survive at high concentrations of NOx and SOx present in these gases.
7. The nutrients for the cultivation of microalgae (mainly nitrogen and phosphorus) can be obtained from liquid effluent wastewater (sewer); therefore, besides providing its growth environment, there is the potential possibility of waste effluent treatment. This could be explored by microalgae farms as a source of income in a way that they could provide the treatment of public wastewater, and obtain the nutrients the algae need.
8. Growing algae do not require the use of herbicides or pesticides.
9. Algae can also produce valuable co-products, as proteins and biomass after oil extraction that can be used as animal feed, medicines or fertilizers, or fermented to produce ethanol or methane.
10. Biochemical composition of algal biomass can be modulated by different growth conditions, so the oil yield can be significantly improved.
11. Capability of performing the photobiological production of biohydrogen.

3. Claims against algae-based biofuels

Despite its vocation as a potential source of biofuels, many challenges have hindered the development of biofuel technology from microalgae to become commercially viable [1]. Among them are:

1. The selection of species must balance the requirements for biofuel production and extraction of valuable byproducts.
2. Must achieve greater photosynthetic efficiency through the continuous development of photobioreactors.
3. There is a need to develop techniques for growing a single species, reducing evaporation losses and increasing the utilization of CO2.
4. There exists few commercial cultivating “farms”, so there is a lack of data on large-scale cultivation.
5. Difficulty of introducing flue gas at high concentrations, due to the presence of toxic compounds such as NOx and SOx.
6. Choosing algae strains that require fresh water to grow can be unsustainable for operations on a large scale and exacerbate fresh water scarcity.

7. Cultivation issues for both open and closed systems, such as reactor construction materials, mixing, optimal cultivation scale, heating/cooling, evaporation, O2 build-up, and CO2 administration, have been considered and explored to some degree, but more definitive answers await detailed and expansive scale-up evaluations.
8. To minimize operational costs, commercial farms often recycle the growth medium following algal harvest. However, growth medium re-use has been implicated with reduced algal productivity due to increased contamination by algal pathogens and/or the accumulation of inhibitory secondary metabolites.
9. One difficulty in culturing algae is that the algae shade one another and thus there are different levels of light saturation in the cultures. This influences the rate of growth of the algae. In addition, wild strains of algae invade and dominate algal culture strains, and oil production by the algae is reduced.
10. Another major problem with the culture of algae in ponds or tanks is the harvesting of the algae. Harvesting algae from tanks and separating the oil from the algae is a difficult and energy-intensive process.
11. Cultivating microorganisms for prolonged time in near saturated cultures generates cell debris with a propensity to stick to and pollute the walls of the vessel. Such contamination requires scrubbing for removal; however after a few years of use the scrubbing damages the surface, thus affecting the optical properties of even the highest grade glass. Another possible contaminant in Green Fuel’s case may be soot particles from the flue gases.

Table 1  A SWOT analysis for micro-algae.

<table>
<thead>
<tr>
<th>Internal Strengths</th>
<th>Weaknesses</th>
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<tbody>
<tr>
<td>Positive</td>
<td>Negative</td>
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<tr>
<td>- Algal-oil processes into biodiesel as easily as oil derived from land-based crops.</td>
<td>- Difficult to find an algal strain with a high lipid content and fast growth rate that is not too difficult to harvest, cost-effective and that is best suited to region where it is going to be produced (Genetic modified species could be a solution, but it causes another threat).</td>
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<tr>
<td>- Algae are the fastest-growing plants in the world. The per unit area yield of oil from algae is estimated to be 7–31 times greater than the next best crop, palm oil.</td>
<td>- Not the same species for different regions.</td>
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<tr>
<td>- Algae consume carbon dioxide as they grow.</td>
<td>- Still commercially immature technology – not many large-scale companies in production.</td>
</tr>
<tr>
<td>- Algae are very important as a biomass source.</td>
<td>- Environmental sustainability of algae-based biofuel still uncertain due to insufficient data and not many Life Cycle Assessment (LCAs) been made.</td>
</tr>
<tr>
<td>- Algae can be grown almost anywhere, even on sewage or salt water, and does not require fertile land or food crops.</td>
<td>- Extraction and processing still expensive compared to other biofuels.</td>
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<th>External Opportunities</th>
<th>Threats</th>
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<td>Positive</td>
<td>Negative</td>
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<td>- Possibility of production of other higher value products for commercialization (Singh and Gu, 2010) and access other markets.</td>
<td>- If future demand for biofuels falls radically this industry could face bankruptcy.</td>
</tr>
<tr>
<td>- Subsidies and policies could turn this technology economically feasible.</td>
<td>- Market and societal acceptance still unclear.</td>
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<tr>
<td>- As algae consume carbon dioxide as they grow, they could be used to capture CO2 from power stations and other industrial plants that would otherwise go into the atmosphere.</td>
<td>- If genetically modified, it could generate regulatory limitations and societal disavowal.</td>
</tr>
<tr>
<td>- Integrated algae-based biorefinary model could be adopted.</td>
<td>- Diffusion difficulties: the large number of competing fuels could delay algal biofuels to achieve high growth on the basis of cost.</td>
</tr>
<tr>
<td>- Algae-based fuel properties allow the use in jet fuels.</td>
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gas, which could be particularly troublesome due to their high absorptivity. Maintaining the optical clarity of the inner surface will severely limit the economic life of the plant [8].

12. Algae can grow on brackish water from saline aquifers or in sea water. While this may solve some of the water availability problems, it will result in other undesirable side effects: salt precipitation on the bioreactor walls; precipitates on pumps and valves leading to reduced lifecycle; presence of salts in the final biomass, which will likely have to be purged with steam[8].

4. SWOT analysis

With the purpose of clearing all the possibilities and threats of this technology, a SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis has been developed [1] and is shown in Table 1. A SWOT analysis is a common tool used to plan and understand the four major categories involved in a project, business or technology. For using such a tool, it is needed to specify the objective of the project and identify the internal and external factors that are supportive or unfavourable to achieving that objective. A SWOT analysis is often used as part of a strategic planning process. The objective here would be the increased use of algal biofuels over the next 30 years.

5. Algae growth drives around the world

The countries with a coastline on the Mediterranean Sea (roughly between 45 and 30 N), are suitable locations for algae farms, in particular in those countries south of the Mediterranean that experience warmer climates and whose temperature do not go too much below 15°C throughout the year. This sort of warm climate of the Mediterranean region can facilitate the algal growth in the open or closed pond system. The southern countries that border the Mediterranean Sea, e.g. Morocco, Algeria, Tunisia and Egypt, are particularly attractive because of high temperatures and enormous unused desert land. Even if some of these countries do not have plenty of water resources that is also not a constraint. It is well established now that algae do not require freshwater, rather they can grow with recycled brackish or salty water. Besides, these countries are developing countries and could strongly benefit from such an industry. Algal farming can provide jobs for locals and the transfer of technologies to developing countries can also be beneficial for the country concerned [3].

Despite the fact that the production of algal biofuels is not yet on commercial scale, there are many companies engaged in this business. Figure 1 shows a pie chart representing the percentage distribution of algal biofuel producing companies around the world in different regions.

Figure 1 Region-wise percentage of companies around the world producing algal fuels[3].

Figure 2 Worldwide technologies being used for algal biofuel production companies[3].

6. Algal biorefineries concept

The main components of a typical algal feedstock are proteins, carbohydrates, lipids, and other valuable components, e.g. pigment, anti-oxidants, fatty acids, vitamins etc. [3]. Figure 3 shows a flowchart listing the main components of microalgae. The protein and carbohydrate contents in various strains of microalgae are high, up to 50% of its dry weight. The maximum lipid content in microalgae is also around 40% on wt. basis, which is reasonably good. A wide array of products can be formed from the algae. These products range from the food supplements and nutrients for human, livestock feed, fine organic chemicals for pharmaceuticals, pigments and various other applications, e.g. chlorophyll, biobutanol and acetone etc., along with energy fuels, e.g. biodiesel, bioethanol, and biomethane [3].

6.1. Non-fuel products from microalgae

6.1.1. Food supplements and fine chemicals of medicinal importance

Microalgae are a potential source of various food supplements and biomaterials used in pharmaceutical industry. Some of
these are omega-3 fatty acids, eicosapentanoic acid (EPA), docosahexaenoic acid (DHA) and chlorophyll. The practical sources of omega-3 in microalgae are normally EPA and DHA. EPA also finds its medicinal use in the treatment of heart and inflammatory diseases: asthma, arthritis, migraine headache and psoriasis [10].

6.1.2. Livestock feed
The livestock feed is another useful product which may be obtained from the algae. Comprehensive nutritional and toxicological evaluations have demonstrated the suitability of algae biomass as a valuable feed supplement or substitute for conventional animal feed sources [11].

6.2. Biofuels products from algae

6.2.1. Biodiesel
The primary advantages of biodiesel are that it is one of the most renewable fuels and also non-toxic and biodegradable. Any biofuel production process, which can successfully
replace an equivalent conventional fuel, needs to fulfill three basic requirements. First, a sufficient feedstock to produce fuel at commercial scale should be produced, secondly it should cost less than conventional fossil fuel, and it should match standard specifications of fuel quality [3].

6.2.2. Bioethanol
In general, two methods are normally adopted for the production of bioethanol from biomass. The first one is a biochemical process, i.e. fermentation and the other is by thermo-chemical process or gasification. The fermentation process produces ethanol and CO2 in addition to methane by the anaerobic digestion of the remaining algal biomass slurry left after fermentation, which can further be converted to produce electricity. A number of advantages have been reported in the production of bioethanol from algae. Fermentation process involves less intake of energy and the process is much simpler in comparison to the biodiesel production system. In addition, CO2 produced as a by-product from the fermentation process can be recycled as carbon sources for microalgae cultivation, thus reducing greenhouse gas emissions as well. However, the technology for the commercial production of bioethanol from microalgae is yet under the development stage and is being further investigated. A recent work on bioethanol production by fermentation has been reported by Harun et al. [12].

6.2.3. Biomethane
Biogas produced from anaerobic microorganisms by anaerobic digestion mainly consists of a mixture of methane (55–75%) and CO2 (25–45%). Methane from anaerobic digestion can be used as fuel gas and also be converted to generate electricity. Residual biomass from anaerobic digestion can also further be reprocessed to make fertilizers. Due to the absence of lignin and lower cellulose, microalgae exhibit good process stability and high conversion efficiency for anaerobic digestion. Although microalgae offer a good potential for biogas production, commercial productions have still not been implemented [13].

6.3. The ideal configuration of an algal biorefinery
There is a question raised on how to go for a product-based or energy-oriented biorefinery. But at the same time a hybrid refinery may be a more profitable venture, rather than exclusively a product-based or energy-based biorefinery. It has been pointed out that as feedstock, algae could fit into most of the integrated biorefinery designs that are on the drawing board as its primary components might be optimized to produce more oils, carbohydrates or proteins. The challenge lies in the identification of better species and reducing the costs of production, which are currently an order of magnitude above other biofuel systems. As with other biorefinery ideas, the use of algae presents numerous routes to the future integration of raw materials, processes and products to create a hybrid biorefinery. Singh and Gu [3] proposed a schematic flow sheet for a hybrid algae bio-refinery as presented in Figure 4.

7. Strategies for algae biofuels commercialization
Thurmond [14] in his study on the algae biofuels and biomass market, stated five key strategies as approaches to help producers to reduce costs and accelerate the commercialization of algal biodiesel, biocrude, and drop in fuels: They are faster, fatter, cheaper, easier, and fractionation marketing strategies.

7.1. Faster
A primary strategy for most algal biofuel producers is to identify the algal species that have a high oil content, that will also grow quickly to produce biodiesel, biocrude and drop-in fuels. Algae with high oil content such as *Botryococcus braunii* (Bb)
growth slowly and can be harvested only a few times a week, whereas algae with lower oil content such as Dunaliella or Nannochloropsis (in the 20–40% range) will grow more quickly and can be harvested daily or a few times a day. For this reason, most algal R&D projects and pre-commercial projects are using algae strains with 20–40% content.

7.2. Fatter

Algal producers are especially interested in utilizing algal species with a high triglyceride (TAG) oil content for biodiesel and biocrude production. Most algae systems today can generate from 2500 gallons up to 5000 gallons of oil per acre annually using 30% oil content. If algal producers can utilize fatter algae with 60% oil content, they can reduce the size and footprint of algal biofuel production system by as much as half, resulting in significant capital and operating costs savings.

7.3. Cheaper

Based on the examination of several algal business and economic models, the Algae 2020 study finds the estimated costs to produce algal oils and algal biodiesel today ranges from $9 to $25 per gallon in ponds, and from $15 to $40 in photo-bioreactors (PBRs). Reducing these costs is critical for commercial success. An outstanding, significant economic challenge for algal producers is identifying low cost oil extraction and harvesting methods used for algae.

This study also revealed that a dozen or so companies are now coming up with breakthrough and innovative methods to bring costs down below for extraction and harvesting. Extraction systems can be expensive with estimates up to $15 per gallon of oil produced depending on the extraction method. One company, Algae to Energy uses a patented system from Missing Link Technology that can extract algae for less than $.25 per gallon. Another example is a harvesting technology from Algae Venture Systems that costs less than $.30 per gallon of oil produced compared to traditional centrifuge technologies which can cost upwards of $1 or more per gallon of algal oil. Origin Oil Co. [15] has announced its process for a single step extraction of algal oil. Initial testing indicates that the new algae oil extraction process is simpler and more efficient than current systems, without requiring chemicals or significant capital expenditure for heavy machinery. With single-step extraction, the amount of energy used to crack the algae can be significantly less than other extraction technologies and results in the separation of oil, water, and biomass (see Figure 5).

In order to reduce the cost of production further, OriginOil [15] has lately announced a new company study indicating a potential production cost as low as $2.28/gallon ($0.60/Liter or $ 95.76/bbl) for gasoline or diesel using a blend of algal and waste feedstocks, using the latest growth, harvesting and fuel conversion technologies from Origin Oil and other innovators.

7.4. Easier/better

The Algae 2020 study has identified that reducing the number of steps for algal biofuels production is essential to provide easier, better, and lower-cost systems. An example is to employ a method that utilizes algal species and cells as mini-processors and refiners in a process referred to as “milking the algae” that will excrete hydrocarbon fuels directly such as Arizona State’s blue-green algae that excretes a kerosene type of jet fuel or Algenol’s blue-green algae that consumes and excretes ethanol fuel directly. By ‘milking the algae,’ these algal micro-refineries help to bypass the harvesting, extraction and refining systems all together by excreting forms of biofuels directly from the cells. These methods lead to significant cost reductions, and help to simplify complex processes for emerging algal producers and customers of new algal biofuel production systems.

7.5. Co-product fraction marketing strategies

These are critical to success. Even with algal species with up to 50% oil content, an additional 50% biomass remains. This biomass fraction contains valuable proteins for livestock, poultry and fish feed additives valued from $800 up to $2500 per ton.

Part of the oil fraction, the Free Fatty Acids (FFAs) can produce DHA (fish oil equivalents), Omega 3 and Omega 6 heart healthy oils, as well as valuable products such as Beta Carotene and other supplements from carotenoids. Other fractions of the algae contain valuable chemicals or molecular compounds that can be used to produce green plastics, green detergents, cleaners, etc. that are bio-degradable, non-toxic, and can be sold at a premium price over traditional petroleum based products. The biomass co-product marketing strategies will be critical to the success for aspiring algal biodiesel and drop-in fuel producers.

8. Role of genetic engineering

A number of companies are working on genetically modifying algae to speed growth, increasing lipid content and favorably changing the economics of fuel production [16]. But some critics fear that gains in algal productivity could come at the expense of ecological health. Creating genetically modified algae, which are almost guaranteed to get out of the lab and into the natural environment, without much insight into the consequences is a scary idea. But with the right protection in place, a system of bio-containment, can offer the requested safety, examples are:

![Figure 6 Schematic diagram of Joule's process [17]](image)
• **Sapphire Energy**, with the **GM-giant Monsanto** designed algae that will be unequipped to live outside a controlled environment.
• **Synthetic Genomics**, funded heavily by **Exxon**, have alluded to the creation of a “suicide” gene that will kill an alga if it escapes into the lab.
• **TransAlgae** is creating algae with traits that paralyzed them in the wild – like taking away their ability to swim or absorb **CO₂** in certain environments. The company also says it is developing a self-destructing gene.

Early outcome examples of genetic engineering contribution to the progress of biodiesel are by **Joule Co.** [17] and **Synthetic Genomics**. Joule Unlimited Co. engineered microbes directly and continuously converts sunlight and waste **CO₂** to diesel, ethanol or commodity chemicals with no dependence on downstream processing or precious natural resources (see Figure 6). These photosynthetic organisms can produce 15,000 gallons of diesel or 25,000 gallons of ethanol per acre per year. The company estimates to produce diesel fuel at a cost as low as $30 per barrel and ethanol at $50, which would make its fuels immediately competitive in the marketplace. After testing its new process on the pilot scale, the company began construction of its first production facility, a 10-acre demo plant that will eventually scale up to commercial production. It has later been announced that Fluor Corp. was awarded an engineering, procurement and construction management (EPCM) contract by Joule Unlimited, Inc. to design and build a biofuel demonstration facility in New Mexico.

The company expects to face competition from other developing microbes that excrete biofuels, including **Synthetic Genomics**. ExxonMobil investigated microorganisms excreting diesel. **Exxon** developed bacteria that metabolize cellulose and excrete diesel. ExxonMobil invested US$ 600 million in the synthetic biology firm for the development of algal fuels using genetic engineering methodologies (*Oligae* [18]).

Researchers at the Iowa State University say they have unlocked a genetic pathway in algae that can dramatically increase the amount of **CO₂** consumed by the organisms, thus helping to recycle more of the greenhouse gas and increasing oil yields for non-food based biofuels by as much as 50% [19].

### 9. Algae for wastewater treatment

While research and development of algal biofuels are currently receiving much interest and funding, they are still not commercially viable at today’s fossil fuel prices. However, a niche opportunity may exist where algae are grown as a by-product of **high rate algal ponds (HRAPs)** operated for wastewater treatment [20]. HRAPs are shallow, open raceway ponds and have been used for the treatment of municipal, industrial and agricultural wastewaters. The algal biomass produced and harvested from these wastewater treatment systems could be converted through various pathways to biofuels, for example anaerobic digestion to biogas, transesterification of lipids to biodiesel, fermentation of carbohydrate to bioethanol and high temperature conversion to bio-crude oil [21].

In a comparison between commercial algal production and wastewater treatment via HRAPs Park et al. found that the capital costs, operation and maintenance costs, Land use and the most costly parameters are covered by wastewater treatment.

In addition to significantly better economics for plant capital and operation costs, algal biofuel production from wastewater treatment has a significantly less environmental impact in terms of water footprint, energy and fertilizer use, and residual nutrient removal from spent growth medium compared to commercial algal production which consume freshwater and fertilizers.

Also in this trend Lundquist et al. [22] performed an assessment of the algal oil production also employing HRAPs. They found that the oil production cost varies between $28/bbl (produced as a secondary product in case of waste water treatment) and $405/bbl (in the case of no waste water treatment) depending on the mode of the process.

### 10. Concluding remarks

Giant cargo boats and US navy warships have been successfully powered on oil derived from genetically modified algae in a move which is considered a revolution in the fuel used by the world’s fleets and a reduction in the pollution they cause [23]. The trials were performed on a mix of algal oil between 7% and 100% and conventional bunker fuel.

Collaboration between the world’s two biggest shipping fleets is expected to lead to the deployment of renewable marine fuels. Maersk uses more than S6bn of bunker fuel a year for its 1300 ships, and the US navy, the world’s biggest single user of marine fuels, burns around 40 m barrels of oil a year. The navy plans to cut 50% of its conventional oil use a year by 2020. Maersk hopes to achieve similar cuts in the same time.

President Obama admitted on (23-2-2012) that he does not have a “silver bullet” solution for skyrocketing gas prices, but he proposed alternative energy sources such as “a plant-like substance, algae” as a way of cutting dependence on oil by 17 percent [24].

“We’re making new investments in the development of gasoline, diesel, and jet fuel that’s actually made from a plant-like substance, algae – you’ve got a bunch of algae out here,” Obama said at the University of Miami last February [25]. “If we can figure out how to make energy out of that, we’ll be doing alright. Believe it or not, we could replace up to 17 percent of the oil we import for transportation with this fuel that we can grow right here in America.”

The Department of Energy (DOE) currently spends about $85 million on 30 research projects to develop algal biofuels. Obama committed another $14 million to the idea.

With the above statements, and what has been discussed in this paper we feel optimistic about the future of algae based biofuels and expect a take off of the technology in the very near future.

### References

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