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Developments in the sustainable production of algal biofuels

藻类生物燃料可持续生产之发展

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Abstract - **Many recent scientific developments have made the commercial production of algal-based biofuels more economically feasible and adaptable as a drop-in fuel for consumers. These new innovations make the principles of sustainability more significant because of the need to conserve natural resources in the production of biofuels. This paper highlights new scientific discoveries that could significantly improve the production rate for algae biofuel production facilities. This paper will emphasize the concept of designing facilities that blend in with naturally occurring topography to enhance land management principles that are critical for acceptance of this technology where public opinion is important. The scientific, engineering and environmental community will find that sustainable management of algae-based facilities will provide a healthier economic model for the long-term growth for this emerging industry when good public trust is part of the design concept.**

Furthermore, this paper will review fundamental scientific guidelines that can improve sustainable biofuel development in emerging markets throughout North and South America, Europe, the Middle East, Asia and many countries that have large populations and thriving communities near the seacoast. A comparison of different technologies and their reported economic structure will show critical factors that make algae biofuel production more publicly acceptable for industrialized and developing countries. Public perception of this nascent technology could be greatly enhanced by using the guidance of sustainability in creating biofuel facilities that could be economically competitive with conventional petroleum fuels.

Keywords - **Sustainability, economics, design, guidelines**

I. ECONOMICS FACTORS

The information provided is for educational purposes only and reflects observations that are available to the general public. This document merely provides suggestions on the principles of sustainability that may improve the development of biofuel production.

The first critical step in establishing a new production facility for algal biofuels is to establish the market demand for both consumer and military use. The market price and demand in the United States varies by the type of consumer. The United States Department of Defense has a great interest in the development of biofuels because of the overall cost of managing fuel cost to support worldwide operations.

For the military in a conflict situation, the purchase cost of petroleum products is almost incidental when compared to the cost of transporting fuel to the location where it is needed in a war zone. The cost of shipping and danger of shipping the fuel is far higher than the purchase cost. Because of the urgent need to provide liquid fuel in war zones, the military is tremendous financial resources to encourage the development of biofuels that can be produced closer to the intended location of use. Also, biofuels are tested for quality and compatibility with existing engines. Because of all these factors, the U.S. Department of Defense will continue to purchase biofuel for testing at very high prices to encourage the development of infrastructure to produce biofuels that can be dropped into conventional jet engines and many types of land vehicles.

However, for the typical American consumer, the most important factor is reducing fuel cost for their current vehicles. Low cost is the predominant factor for most consumers. Ethanol production from fermentation of corn is the most common biofuel in the United States. Many farmers grow corn in the Midwest of the U.S. and the conversion of corn to ethanol is the primary biofuel available in the U.S. Ethanol is considered a drop-in fuel and widely supported by the American public and automobile industry. Currently, automobiles in the United States can use two different types of ethanol mixture for gasoline-powered vehicles. The blend of 10% ethanol blend with 90% gasoline is the most standard fuel mixture. In addition, the "Flex Fuel" blend of 85% ethanol and 15% gasoline blend is available in many locations.

Algal biofuels will certainly become more important in the future, but their costs to consumers will be crucial in developing a sustainable regional biofuel market. From this concept we can better understand the true financial and economic benefit of algal biofuels. To begin this process, let us review the price of biofuels that have been reported in the U.S. The table shown below indicates both the low and high cost of biofuels recently reported. To illuminate the significant difference between the consumer goals and military use requirements, notice the great variation in the reported price of biofuel in Table (1) below.

TABLE 1, REPORTED PRICES OF U.S. BIOFUELS

Biofuel type	Consumer	Product Type	Price (US $)
Generic (Catalina, Waste vegetable oil, algal biofuel, pyrolysis of wood, many others.)	Military	Various Biofuels (quality assured for specific use)	$ 59.00/ U.S. gallon [1] £ 9,20 /liter
Algal Biofuel	General Consumer and Military	Ethanol	$ 1.27/U.S. gallon [2] £ 0,198 /liter

The price variation is very substantial between military requirements and general requirements. The high cost of biofuel at £ 9,20/liter ($59/gallon) represents a variety of biofuel development technologies. The biofuels for military utilization are from an unspecified source. Because of stringent Air Force requirements, liquid biofuel is quality assured and tested as a drop-in fuel for military application. The low cost of £ 0,198 /liter ($ 1.27/U.S. Gallon) represents biofuel production from one small research facility located in sub-tropical climate of Florida. It is noteworthy to mention that the United States Government has funded the development of biofuel production for the last few years and it is important to emphasize the dedication of many accomplished scientists that have contributed their time and energy on the development of biofuels for both the military and public sector.

Many stakeholders will question the great price differences between military grade and consumer cost for different biofuels. The higher price for military biofuel includes development cost and the cost of quality assurance that is required for military jet engines and diesel vehicles. The lower cost of public sector biofuels centers on the production of low cost ethanol and may not include the cost of quality assurance that is needed for military applications. Biofuel production hinges on the type of raw materials; labor cost production; and the selection of process. The development of algae based biofuel depends also on the type of reactor, type of algae strain, availability of low cost nutrients, and environmental conditions. The lower production cost of biofuels for the general public is focused on drop-in fuels that are accepted by an established market.

II. BIOREACTOR DESIGN DEVELOPMENTS

Fig. 1, Algae growing in an open raceway pond[3]

The most common approach of cultivating algae for biofuel production is centered on facilities that use open raceway ponds as depicted in Fig. 1. In many cases, raceway ponds grow algae with a high lipid content that can be refined to biodiesel. In this commercial production mode, the growth rate of algae is a major component of the overall reactor or process design. Other skilled researchers are focused on developing cutting-edge biofuel reactors for full-scale commercial production. [4] Recently, the Algenol facility depicted in Fig. 2, is located in Fort Myers Florida and has been using an innovative design for the production of ethanol from algae. The design emphasizes the concept of growing algae in clear transparent bags. The concept of growing algae in closed plastic bags is not new, but the overall approach of producing ethanol using an innovative reactor is a real game changer for multiple sustainability objectives.

Fig. 2, Algenol facility produces ethanol in a closed bag system[5]

The development of growing algae in large transparent bags must be analyzed to explain why this progression appears simple, while in fact the technology is very innovative and sustainable. The requirement for solar energy and amount of photons that can penetrate a plastic bag has been well documented by Dan E. Robertson et al. [6] According to Robertson, photo-synthetically active radiation (PAR) with a wavelength from 400 to 700 nm, represents 39% of the total energy directed towards the earth by the sun. However, because of moisture in the air, the ground-incident radiation for photosynthesis is increased to approximately 48% of the total solar radiation available. According to Robertson, different locations receive PAR ranging from a low value of 2380 MJ/m^2/year (Cambridge, MA) for a northern climate to 3460 MJ/m^2/year (El Paso, TX) located in the southern United States.

In the research performed by Robertson, the authors described that natural sunlight can have a reflective index loss of 5% for each media layer of the closed plastic bag. If the bags are made of a protective layer and inner container, then the reflective loss (Fresnel loss) could be 10% of the solar radiation. However, the use of an open pond results in a single/water interface with an estimate Fresnel loss of approximately 2%. Based on this understanding, it would seem that open ponds have lower losses for absorbing PAR.

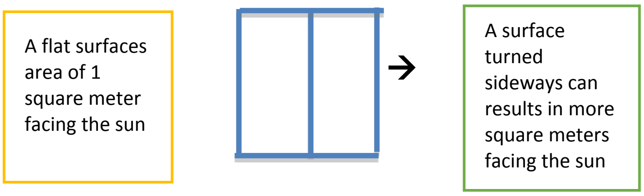
Both the closed system and open raceway ponds receive the same PAR at a fixed location. Furthermore, it has been shown that open ponds have a lower loss of reflective radiation. However, the conversion efficiency for the closed system appears to be greater than an open pond reactor. The closed system converts more of the solar photons than the open raceway pond. The overall conversion efficiency of the closed system is reported to be seven times larger than the conversion efficiency of the open pond system. The efficiency of an algae reactor to capture solar energy appears to depend on other factors beyond reflective losses.

Fig. 3, Electric radiator

An attribute of designing a reactor to absorb distributed solar energy is the amount of surface area that is available for energy or photon transfer. An open raceway pond appears to offer standard growth rate for algae, but this may not be the best approach for producing ethanol from algae. A key component of designing a specialized algal reactor to produce ethanol centers on the available surface area that absorbs solar energy.[7] In the air condition industry, we see the concept of thin metal blades in racks that are used to distribute heat energy from the compressor. In cold northern climates, many homes use a similar approach by using radiators to distribute heat within a limited surface area. Fig. 3 illustrates the concept of long thin blades that radiate heat. Because the blades are thin and perpendicular to the area of heat release, radiation of heat occurs more quickly than using a single flat surface.

Notice in Diagram (1) that we have approximately one square meter of surface area facing the effective area. If the surface area is turned 90%, more of the surface area of the blades becomes exposed. The result is a theoretical six-fold increase in energy release from the same radiator. Diagram (1) below is a depiction of the effect of turning the flat surface of a radiator 90% or turning the blades perpendicular to allow faster transfer of radiating energy. See Diagram (1) that describes turning a flat surface perpendicular to sunlight:

DIAGRAM (1)



If the surface area of the radiator is flat, it does not allow for fast distribution of heat. Because only one side of the surface area is exposed, only one square meter of surface area is available to distribute heat. However, with perpendicular blades of the radiator, this allows for 3 blades with a thin surface area to radiate heat. The actual surface is theoretically 6 times the surface area of a flat panel generating heat.

This is a fundamental concept that appears to occur when growing algae in flat panel-like bags that are perpendicular to the sun.[8] Looking at this from a conventional approach we examine the basic principle of improving the surface area for algae aquaculture. Because the absorption of sunlight occurs only in the top ½ inch to ¾ of the surface of water, increasing the surface area also improves the growth rate because more sun energy can reach the algae culture per square meter. It appears that photons from strong sunlight are reflected from one flat panel and then absorbed by an adjoining panel to increase the overall absorption of solar energy for the closed bag system.

The technique of increasing the surface area appears to improve the growth of rate of algae for a fixed growing area. In a previous book published in 2009[9], my analysis concluded that algae growth of 20 grams per square meter of surface area could not provide a strong incentive for the production of algae for commercialization. However, at a growth rate above 50 grams per square meter of surface area, the production of algae for biofuel production becomes more competitive and feasible for commercial production. The utilization of bags for growing algae promotes a sustainable production process. If the same algae with a growth rate of 20 grams per square meter are cultivated in three vertical bags, the theoretical growth rate becomes 120 grams per square meter, because the surface area of the vertical bags is greater than the surface area of a flat raceway pond. This concept may not be appropriate for all environments or climates, but it does indicate that a flat bag panel design could increase the algae production rate for the specialized process of growing algae for ethanol. The actual growth rate will depend on the available sunlight and the angle of the algae filled bags to the direction of sunlight.

The Algenol facility reports its production rate at 8,000 gallons of ethanol per acre. This is a significant development because a typical field of corn produces approximately 420 gallons ethanol per acre. Because of the tremendous growth rate of algae, this indicates an ethanol biofuel production that is approximately 20 times greater than conventional method of producing ethanol from corn or sugar cane.

For the Algenol facility, the “growth rate” of algae should be refined to describe the “production rate of ethanol from algae” because this provides a better metric for the process. The type of algae used by the Algenol process may offer additional advantages that are not available to this author. Below is a comparison of the ethanol production for three types of biofuel methods. See Table (2):

TABLE 2, ESTIMATED BIOFUEL PRODUCTION FOR DIFFERENT METHODS

Type of ethanol production	Amount of ethanol production	Land and water requirements
Sugar Cane	662 gallon/acre/year [10] 6.192,3liter/hectare/year	Requires fresh water and farmland
Corn	420 gallon/acre/year 3.928,6 liter/hectare/year	Requires fresh water and farmland (may compete with food crop production)
Algae	8,000 gallon/acre/year 74.831,2 liter/hectare/year	Requires sea water (does not compete with food crop production)

III. LAND MANAGEMENT

Because algae can be grown in bags, this allows for bioreactors that can be installed in areas that do not require flat land. A long practice of farming has been to grow corn and other crops on land than has less than a 6% slope. Growing crops on farmland with greater than a 6% slope encourages the flow of rainwater to carry and disperse essential soil nutrients.

Because algae can be cultivated in transparent bags, algae farming occur on sandy soils, white porous sand, or any location where crops are not grown. The growth of algae as a biofuel does not need the flat ground that we see in large open raceway ponds. Many hillsides with a 10% to 15% slope could be used to grow algae in bags at an angle perpendicular to the hill. This is type of aquiculture would be applicable to subtropical islands or land mass near the ocean that are available for non-traditional farming.

Another feature of using bags as bioreactors is the reduction of evaporation and greater control of contaminants affecting a specific culture. Research scientists grow algae in desert and parched land where groundwater is not plentiful. Near desert locations are preferred by commercial algal facilities because they are out of sight from typical farmland. However, desert locations are prone to strong winds that carry sand, which can frequently damage an open raceway pond. An example is the concept of growing algae on the coastline of a parched or arid land area near the coast line. The use of bags in closed systems eliminates sand and other contaminants from affecting the growth of the algae culture.

Other locations like Hawaii grow algae in open ponds that are susceptible to wind and water damage from severe weather. [11] Hurricane or torrential downpour of water can easily disturb algae growing in open ponds. The flat bag design increases the flexibility of growing algae in locations that are not otherwise feasible or environmental friendly. Because closed bags reduce the likelihood of algae contaminants from reaching the local landscape, this reduces the concern that strong wind could carry algae to location deemed environmental sensitive. An important factor is the ability to grow algae near sensitive ecological areas that have been overwhelmed with nutrient loads from the utilization of fertilizers in farming.

Aquaculture has the potential to increase the value of land not suitable for farming. The average price of farmland in the U.S. is $5,496.[12] However, the value of poor quality soil may increase above the average price of non-farmland if it is utilized for aquaculture, providing an additional incentive for commercial production of algal biofuel.

IV. CONTROL OF CONTAMINANTS

Mainstream scientists are also concerned about preserving sensitive ecosystem and preventing contamination of the algae colony where algae is grown. The algae grown in bags could be seen as an aid in preventing the aquaculture from contaminating the local ecosystem. This approach also makes the growth of algae in a control environment more sustainable since less water is needed to produce ethanol in a closed environment. In a closed environment, the amount of water and nutrients can also be controlled.

Another area of concern is seawater contaminants that can inadvertently affect algae growing in transparent bags. Local pathogens in brackish water could affect the ethanol production of algae in the transparent bags. Local communities may have restrictions or concerns with pathogens that are accidentally added when seawater or brackish water is transferred to transparent bags. An accidentally release of concentrated pathogens enclosed in wastewater or brackish water could cause concerns for the local community, if contaminants are accidentally released to the local aquifer. Therefore, the remediation of pathogens is an important issue

TABLE 3 SOLAR RADIATION METHODS FOR REDUCING WATER CONTAMINANTS

Types of water contaminants	Hours of sunlight required to destroy contaminants	Factors that influence the neutralization of contaminants
Bacteria 1. P. aerugenosa 2. S. Flexneri 3. S. typhi 4. S. enteritidis 5. E coli 6. Sparatyphi B	99.9% of total bacteria population can be destroyed in 5 hours of strong sunlight, assuming the water is stored in clear transparent bottles or other clear transparent container	Geographical location Clarity of the water Seasonal variations Time of day Effective range of sunlight Wall thickness of the container Shape, color or transparency of the container
Mold and Yeast 1. Aspergillus niger 2. Apergillus flavus 3. Candida 4. Geotrichum	It take 3 hours of strong sunlight to destroy contaminants	
5. Penicillium	It takes 6-8 hours of strong sunlight to destroy contaminants	

for local communities that are concerned with airborne or wastewater contaminants arising from commercial aquaculture production. If the water media is non-turbid, then pathogens inside the closed transparent bags could be remediated if brackish water is allowed to stand a full day in bright sunlight.

UNICEF performed a study in 1979 using solar disinfection for treating drinking water in the Middle East.[13] The report indicated that non-saline low turbidity water could be effectively treated for many pathogens by using solar disinfection. It was concluded that many types of bacteria in water could be destroyed or controlled by the lethal effect of ultraviolet light (UV). The study revealed that 99.9% of subjected coliform bacteria population could be destroyed in 300 minutes by sunlight. The study revealed that sunlight ranging from 315 to 400 nm is the most lethal region for killing pathogens and accounts for 70% of the bacterial destruction potential. This band of wavelength is known as the near ultraviolet region and referred as black light, which is not visible by the human eye.

The visible light having a wavelength of 400 to 750 nm accounts for 30% of bacterial destruction capacity. The intensity of treating water in bottles or plastic bags happens when the intensity of sunlight is greatest between ten o'clock to two o'clock in the afternoon. The control of biological contaminants in transparent bags may not be necessary for the production of ethanol from algae. In addition, many production facilities may not be susceptible to biological contamination. However, if a local community is affected by biological contaminants from a wastewater source or seawater, then the utilization of lethal UV light treatment may offer a low cost treatment option.

In addition, seawater and wastewater could be turbid and additional filtration treatment steps could be required before solar UV radiation is used for bacteria destruction. The utilization of solar UV light is sustainable because it reduces the need for chemical disinfection.

In addition, the solar UV pathogen destruction process may be used in communities that are concerned with the water discharged after the algae is removed from the closed bags. After the algae is filtered, the remaining process water could be disinfected by solar UV treatment. A closed system UV disinfection process is sustainable and should be part of a facility that is concerned with pathogen contaminants. The results of the UNICEF study for the treatment of water by direct sunlight is described in the Table 3.

V. BENEFITS OF ETHANOL PRODUCTION

Biofuel production could be considered sustainable for several reasons if the design, construction and operation of the aquaculture is adapted to the use of the least disruptive methods. The production of ethanol biofuel from algae can provide for the long reduction of carbon emissions as described in the following reduction equation Eq. (1):

$$2CO_2 + 3H_2O \rightarrow C_2H_5OH + 3O_2$$

The Algenol facility has reported that they are able to produce 8,000 gallons/acre-year. For the purpose of this evaluation, it will be assumed that this technology can be distributed and applied over a 100 acre area. A 100 acre aquiculture facility is the anticipated size a commercial facility and would provide 800,000 gallons of ethanol while providing significant CO2 reduction. Table (4) describes the amount of seawater, and carbon dioxide required to produce ethanol on a 100 acre facility. An analysis of Table (4) indicates that a 100 acre facility would produce approximately 800,000 gallons of ethanol per year. Notice the significant amount of CO_2 that can be reduced or recycled with the production of algae to ethanol. The reduction of CO_2 in the production of ethanol from algae makes this a sustainable process.

TABLE 4 PRODUCTION GOALS FOR 100 ACRE ALGAE FACILITY

Carbon reduction potential for ethanol production from algae in 100 acre - closed bag system				
Unit Type	100 Acre ethanol Facility	Sea Water (3.5% saline) or brackish water	Weight Carbon Dioxide	Weight Ethanol (100%)
US	800,000 gallons	722,870 gallons	10,076,800 lbs/year 5,038.4 US tons/year	5,267,600 lbs/year or 2,633.8 US tons/year
Metric	3.028.328 liter	2.736.300 liter	4.570.735 kg/year	2.389.354 kg/year

VI. SUSTAINABILITY

The demand for water, food and energy resources are also growing with the continuous increase in world population. Our political and industrial leaders are all working for the common good of delivering basic materials and services at the lowest price. However, without a strong focus on the concept of sustainability the goods and services provided by the industrial community may not continue for future generations.

The basic philosophy of sustainability is to ensure that natural resources are not depleted for our grandchildren and their future generations. The concept of sustainability is to improve the quality of life, so that we can all live healthier lives. Below are critical sustainability factors that are important for the production of ethanol from algae.

1. Fresh water resources are becoming more limited. The use of brackish water or seawater is a sustainable approach for algal biofuel production.
2. The utilization of fertilizer in biofuel could compete with the demand of fertilizers in farming. The use of nitrates, phosphate from wastewater or brackish water is a sustainable approach for algal biofuels.
3. Closed bag reactors for algal biofuel production do not require agriculture farmland or forest land. Fresh water requirements are reduced because of less evaporation loss. The utilization of unfertile or parched land is sustainable approach for algal biofuels.
4. The production of algal biofuels reduces carbon emissions and is a sustainable approach at biofuel production.
5. The use of solar radiation to destroy bacteria and mold reduces the need for chemical additives and is a sustainable approach for algal biofuel production.
6. The use of closed plastic bags can also reduce the potential for contamination and is a sustainable approach for the production of ethanol from algae.

The six critical factors listed above should be incorporated in the planning stages of a commercial facility. The sustainable production of algae to biofuels can be costly, and many countries have undertaken the bold step of funding research programs on the production of liquid fuel from solar energy. Since our modern culture requires an uninterrupted need of liquid fuels, the amount of carbon in the atmosphere will surely keep increasing over the next century as people burn more fossil fuels. However, the engineering and scientific community has been working on a solution for many years. The answer is the production of biofuel using the nutrients of carbon emissions and wastewater pollutants that are the result of human activity. A large-scale facility that produces ethanol from algae must recycle the nitrates and phosphate from wastewater and carbon emissions from large emission sources whenever possible to ensure a sustainable process.

VII. COMPARISION OF ETHANOL PRODUCTION METHODS

The sustainable production of ethanol from algae appears to more sustainable than producing ethanol from sugar cane or corn. Firstly, the amount of land required for production is approximately 1/20th of the land required for corn farming. Secondly, because of the reduced amount of land required for production of ethanol from algae, almost 19 acres of land become available for absorbing additional rainfall. This is a significant savings of water resources that makes the production of ethanol very sustainable. In addition, because high slope land can be utilized for aquaculture, this process can be used on hillside and other locations that are not suitable for traditional farming methods. Also, sandy soil or land that is not fertile enough for traditional farming methods can be utilized, increasing the utilization of land that is not otherwise valuable. This technology could in theory improve the value of land in rural areas.

Furthermore, the ability to disinfect bacteria, mold and yeast in situ reduces the amount of chemical required for production. This lowers the cost of production along with reducing the amount of labor cost for maintaining a production facility. Again, the use of solar energy to neutralize contaminants makes this process very sustainable. Because algae is produced in closed bags, this reduces the evaporation of water making ethanol production more sustainable because less total water is required. Also, since the closed bag system prevents algae from contaminating the local environment, the closed system could be more appealing to a community that is apprehensive about aquaculture in their community.

Shown in Table (5) is a review of the factors that makes ethanol production from algae sustainable.

VIII. CONCLUSION

The reported high cost of biofuel for military application is the result of stringent quality assurance requirements for specific military applications. The lower cost of biofuel reported for general civilian use is based on ethanol production from algae using an innovative method where quality assurance is not as stringent. Ethanol production from algae appears to offer significant sustainability advantages that are dependent on climate, availability of land and grade of land

TABLE 5 COMPARISON OF ETHANOL PRODUCTION METHODS

Algae in closed bags system	Corn	Sugar Cane
Utilization of sea water or brackish water	Requires Fresh Water	Requires Fresh Water
Utilization of Wastewater or water from Secondary or Tertiary Treatment (high in Nitrates and Phosphates	Requires Commercial Fertilizers Commercial fertilizers have a higher cost than using nutrients from wastewater	Requires Commercial Fertilizers Commercial fertilizers have a higher cost than using nutrients from wastewater
Utilization of land not suitable for farming. Can be cultivate on land with a grade or slope greater than 6%. Technology could be adaptable on contoured land or hill side.	Common farmland Land may have a graded slope less than 6% to prevent excessive runoff of nutrients	Common farmland near a large fresh water source[1] Land may have a graded slope to allow growth of sugar cane near a large body of fresh water
Possibility of contamination is reduced by keeping the growth media in a closed container	Fungus, insect, mold, bacteria or fungus is possible and requires herbicides and pesticides	Fungus, insect, mold, bacteria or fungus is possible and requires herbicides and pesticides
Fresh water requirements are limited. Sea water is abundant. The bags are a closed system limiting the amount of water required to produce ethanol	Shortage of rainfall or drought could affect the growth of corn stock	Shortage of rainfall or drought or overabundance of rain could affect the growth of sugar cane
Growing algae is closed system reduces the risk of low rainfall or floods. The closed system also prevents water evaporation. Droughts or flood damage is reduced.	Corn growth cannot be applied to areas that have low availability of fresh water. Also, extreme weather or flooding could damage the corn crop.	Sugar can growth cannot be applied to areas that have low availability of water. Extreme weather or flooding could damage the sugar cane production.
Higher production rate, utilization is 1/19th of the land requirements for corn	Lower ethanol production rate Requires 19X times more land to produce ethanol than the closed algae method	Lower ethanol production rate Requires 12X times more land to produce ethanol than the closed algae method
Because land requirements are much less than conventional, more rainwater is able to penetrate the aquifer. Process used less than 1/20th water resources need for growing corn	Most of the rainfall is used to grow corn. Heavy downpours of rain could wash away soil nutrients	Most of the rainfall is used to grow corn. Heavy downpours of rain could wash away soil nutrients

available for aquaculture. Another factor is the limited availability of fresh water resources and low cost nutrients. Because corn and sugar cane are dependent on commercial fertilizers, the production of ethanol from these farming methods competes with food crops for the same natural resources.

Ethanol production from algae is more sustainable because of the lower demand for natural resources. The low cost production of ethanol from algae is more likely to be adaptable to communities that have arid farmland near the seacoast. The availability of ethanol production from non-agricultural land provides additional sustainability benefits for communities that are affected by climate change. Some communities may not have alternatives to farming and ethanol production from algae in a closed bag system may offer economic benefits. In addition, some communities may not have sufficient access to petroleum fuels and the sustainable production of ethanol from algae could provide drop-in liquid fuel at a competitive cost.

The production of ethanol from algae is sustainable because it can substantial reduce carbon dioxide. For every kilogram of ethanol that is produced, approximately two kilograms of carbon dioxide is removed from the environment. The production of biofuels from algae enhances the sustainability of environment because it reduces carbon dioxide in the overall environment. The recycling of carbon dioxide emission for the production of biofuels is more sustainable if wastewater and polluted seawater is used as the primary source of nutrients for production. A biofuel facility that is able to recycle carbon emission and wastewater could be considered the best sustainable approach for long term production of ethanol when non-agricultural farmland is utilized.

The utilization of non-agricultural land for ethanol production from algae also reduces total land requirements. Algae grown in a closed system requires approximately 1/20th of the amount of land required for ethanol production from corn. The utilization of poor quality soil for algae growth opens up another method for ethanol production that is not available from corn based farming. Because algae can be grown in bags for the production of ethanol, terrain with a slope greater than 6 degrees can be utilize on land that is not currently utilized. Ethanol from algae does need the same nutrients or land requirement that are required for corn or sugar cane based farming methods and is more sustainable because it does not compete with food crops. This also reduces the amount of total fresh water required for commercial operation. When ethanol is produced from algae in a closed system, it hypothetically allows 19 acres of farmland, for crop production. This is a significant improvement in the sustainable production of biofuel that is not mentioned with other commercial production methods.

Also, because ethanol is fermented in closed bags, this reduces the need for large fermentation facilities commonly found with ethanol production from corn or sugar cane. Ethanol from algae is less susceptible to drought because brackish water and wastewater could be used for growth. Another advantage is the low cost of producing ethanol from algae because the required nutrient can be taken from wastewater while corn and sugar cane are dependent on commercial fertilizers.

Clear transparent plastic bags can be effective at pretreating process water to reduce contaminants in the closed system. The cost of treating wastewater containing phosphate and nitrates, before adding an algae culture, can be significantly reduced by using solar radiation. Using ultraviolet light to kill pathogens reduces the need for chemical additives to reduce contaminants when algae are grown in bags. The application of solar energy for treatment of contaminant in water is more sustainable because of the reduced need for sterilization of the growth environment and reduced evaporation rate. The application of low cost solar radiation with a closed system ensures airborne bacteria, mold or yeast, which could contaminate an open raceway pond system, does not affect a local community.

Because these factors, the production of ethanol from algae grown in closed bag environment should be explored further to determine if this unique production method can be applied to different climates and environmental conditions.

CONVERSTION FACTORS

1 U.S. Dollar = 0.72 Euros
1 U.S Dollar = 0.59 British Pounds
1 US Gallon = 3.78541 liters
1 gal/acre/year = 9.3539 liters/hectare/year
Density of ethanol = .789 kg/liter
Density of seawater = 1.025 kg/liter

REFERENCES

[1] D. Alexander, "U.S. Force Tests biofuel at $59 per gallon", July 15, 2012 http://www.reuters.com/article/2012/07/15/us-usa-military-biofuels-idUSBRE86E01N20120715

[2] Algenol, http://en.wikipedia.org/wiki/Algenol, June 17 2014

[3] U.S. Department of Energy http://www1.eere.energy.gov/bioenergy/images/nm_raceway_pond.png

[4] J. R.Banemann,., "Microalgae Biofuels and Animal Feeds: An Introduction", January 2011,

[5] D. Markham, "Algae biofuel process by Algenol yields 8000 gallons per acre at $1.27 per gallon", http://ecopreneurist.com/2014/04/17/algenol-produces-8000-gallons-algae-biofuel-per-acre-1-27-per-gallon/

[6] Dan E Robertson , Stuart A. Jacobson, Frederick Morgan, David Berry, George M Church, Noubar B. Afeyan, "A New Dawn for industrial photosynthesis", Springer, 13 February 2011

[7] L Wondraczek, M Batentschuk, M.A. Schmidt, R. Borchardt, S. Scheiner, B. Seemann, P. Schweizer, and C.J. Barbac, "Solar spectral conversion for improving the photosynthetic activity in algae reactors", Nature Communications 4, Article number 2047, June 25, 2013

[8] G.c. Zittelli, L Rodolfi, N. Bassi, N. Biondi, and M. R. Tredici, "Photobioreactors for Microalgal Biofuel Production", Algae for Biofuels and Energy, Springer Science+Business Media, 2013

[9] A. DuPont, "An American solution for reducing carbon emissions-averting global warming – creating green energy and sustainable employment", DuPont Group Publisher, n.p. p 72, 2009

[10] C. Stillman, "Cellulosic Ethanol; a greener alternative", Citizens League for Environmental Action Now, (CLEAN), June 2006, http://www.cleanhouston.org/energy/features/ethanol2.htm

[11] J. Lane, "Major changes in the algae production industry-Raceway ponds were never meant to be used for industrial algae production" press release, August 28, 2012, http://www.prlog.org/11961418-major-changes-in-the-algae-production-industry.html

[12] J Bunge, "Farmland values continue to retreat", Wall Street Journal, Pg. A2, May 16, 2014

[13] A Acra, Z Raffoul, and Y. Karahagopian, "Solar disinfection of drinking and Oral Rehdratoin Solutions" Department of Environmental Health, Faculty of Health Science, Ameican University of Beirut, 1984