Microalgae Biofuel Production in the Desert Southwest

Exploring the possibility of a renewable, sustainable alternative to fossil fuel energy, and how the desert Southwest of the United States has the potential to be the next center for domestic fuel production.

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10/12/2012

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(ABSTRACT

As evidence of global climate change continues to become more apparent, the world is exploring ways for humans to live sustainable lives on Earth. The combustion of fossil fuels contributes to climate change by introducing greenhouse gases to the atmosphere, and the need for an alternative fuel source is increasingly important. Biofuels from microalgae may provide a fuel source that could meet energy demands while and be less harmful to the environment than fossil fuels. Microalgae production for the use of biofuels provides a renewable, environmentally friendly, and sustainable alternative to fossil fuels. Only requiring light, water, and carbon dioxide, algae has the capability to grow virtually anywhere, however the Southwestern region of the United States would make the most suitable environment for microalgae production. With high amounts of solar radiation, very few cloudy days, and consistent annual temperatures suitable for algae cultivation, the desert Southwest would be the most appropriate area for the production of American energy.

INTRODUCTION

Since the Industrial Revolution, fossil fuels, such as coal and petroleum, have been the main fuel source in the United States. One of the largest coal deposits in the World was within the contiguous United States and off-shore oil drilling provided the US with domestic energy resources. But as the population in the US began to increase, and the use of fossil fuels increased, two issues came about; the finite source of domestic fossil fuels in the US could not support the demand of the growing population, and research showed that the use of fossil fuels was very hazardous to the environment. For years now the United States have been researching possible alternatives to fossil fuels, such as hydroelectric, nuclear, wind, and photovoltaic or solar power. There are positives and negatives to every form of alternative energy, but still the use of fossil fuels dominates the energy industry. In recent years however, a new alternative fuel idea has been gaining popularity. This new idea has the potential to solve both of the major issues fossil fuels create; it is a fast growing and renewable resource that could meet the United States' energy demands and it is also very environmentally friendly. This new fuel is called algae.

Algae can be used as an energy resource by turning it into a biofuel. Biofuel works the same as any other liquid fuel, such as gasoline, by simply releasing energy when burned. Biofuel made from algae would be a reliable alternative to fossil fuels because it can be cultivated in high quantities with only a few resources. In addition, the Desert Southwest region of the United States (Figure 1) would be a very suitable area for algae cultivation. Combining the upsides of using algae for fuel, and the suitable cultivation conditions of the Desert Southwest, algae biofuel has the potential to replace fossil fuels as the major energy resource in the United States.

Figure 1: The Desert Southwest region of the US consists of Arizona, New Mexico, Nevada, Colorado, Utah, Texas and California. (DesertUSA, 2012).

BODY

Algae; most people think of it as the nasty green substance that prevents swimmers from escaping the hot summer heat, but what people do not realize is that algae could hold the key to the future of energy in the United States. Algae, or more specifically microalgae, are single-celled organisms that live in water environments around the world (Figure 2). Through a process called photosynthesis, microalgae use energy from the sun to absorb carbon dioxide (CO_2) out of the air and convert it into carbohydrates, protein, and natural oils called ethanol (Trent, 2012). The natural oils produced by microalgae are what make them efficient biofuels. Biofuels are not a new science, in fact, the first time biofuels were demonstrated was by a man named Rudolph Diesel back in the year 1900 (Patil, 2008). Biofuels are any type of fuel in any physical state that was made from bio matter, or biomass (Patil, 2008). Examples of biofuels can be as simple as firewood, or more complex examples such as liquid ethanol. Today, ethanol biofuel is more commonly produced using plants such as soybeans, wheat, and corn, especially in the United States. The production of biofuels from these plants is badly publicized, and for good reason. First of all, ethanol from these plants are not as efficient as fossil fuels, meaning one would have to burn more ethanol in order to get the same amount of energy as they would from gasoline (Trent, 2012). Second, these crops are used for food more so than for fuel, so the complaint is that using them for fuel will take away from the food yield and drive prices up

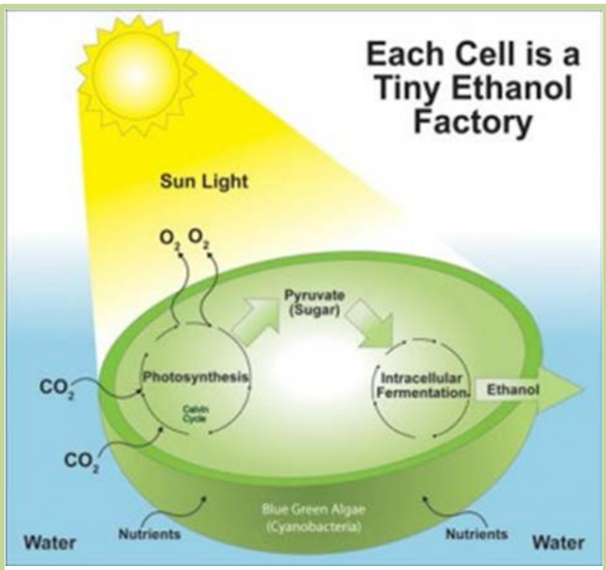

Figure 2: A diagram of a single-celled microalgae organism (Morris, 2009).

(Patil, 2008). Finally, in order to meet the needs of the US, there would have to be massive amounts of these crops, which would take up huge amounts of land and space, and would also be very heavy (Patil, 2008). So even though ethanol biofuels produced from these crops would technically be a renewable resource, they still do not provide the US with a sustainable and environmentally friendly alternative to fossil fuels.

NATURAL OIL CONTENT

So what makes microalgae better than other ethanol producing plants such as corn and soybeans? The answer is in their simplicity. Unlike other ethanol producing plants, microalgae are single-celled organisms. The single-cell structure makes microalgae much less massive than the other ethanol plants, which gives microalgae many advantages. One of the advantages of microalgae is the mass needed to produce biofuel compared to other ethanol counterparts. Microalgae produce natural oils needed for biofuel at a higher rate than any other terrestrial plant (Patil, 2008). In some species of algae, the natural oil content can be as high as 70-80% of the dry weight (Patil, 2008). Furthermore, annual yields of microalgae would be much higher than terrestrial counterparts. If CO_2 is supplied, algae cultivation in the subtropical regions of the world could produce up to 100 grams per square meter per day of dry algae. That amount of dry algae would yield nearly 100 times more oil content than soybeans could produce with the same area of land (Patil, 2008). With yields drastically higher than other ethanol plants, microalgae already seems to be the best alternative.

LAND CULTIVATION: RACEWAY PONDS

Because other ethanol producing plants are all terrestrial plants, meaning they are cultivated in fields and not in water, they require large plots of farmland. The cultivation of terrestrial crops has drawbacks besides land area, which include high labor, transportation, and require a great deal of chemicals for fertilizer and pesticide. Algae, on the other hand, require only three ingredients for growing; water, CO_2 and sunshine. In algae cultivation today, there are two methods that are used. The first method is in large, open-air ponds called raceways. Raceways get their name from the elliptical shape, which resembles an auto racetrack (Figure 3). Raceway ponds are not the most efficient method for algae cultivation, and tend to have more negatives than positives. Raceways take up large areas of land, and can only be built in flat areas (Trent, 2012). On top of that, raceways also require very large amounts of water, which results in the dry weight yield of algae to decrease per unit area of land (Trent, 2012). But the biggest issue with raceway ponds is the open-air design, and the susceptibility to contamination (Sforza et al., 2012). Because the raceways are not sheltered, there is a constant risk for contamination. The raceways themselves are unprotected and susceptible to being contaminated by bacteria or other strains of algae. In addition, open-air cultivation may allow the algae within the raceways to be carried off by turbulent weather, carrier animals, or by some other means and contaminate surrounding water bodies (Snow and Smith, 2012). In the event of algae escaping the raceways and contaminating other water bodies, this could pose a serious toxic problem to wildlife and even humans (Snow and Smith, 2012).

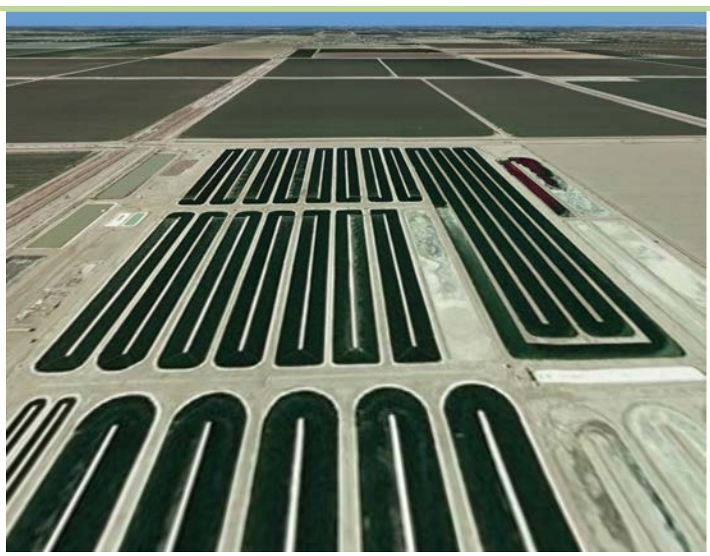

Figure 3: Aerial photo of open-air raceway ponds in Southern California. (Betz, 2011)

LAND CULTIVATION:

PHOTOBIOREACTORS

Figure 4: Photobioreactors for algae cultivation in a controlled environment. (Cal Poly).

The alternative method of algae cultivation, and the solution to open-air raceways, is photobioreactors, or PBRs (Figure 4). Photobioreactors are closed chambers that stimulate microalgae growth in a controlled environment (Sforza et al., 2012). Photobioreactors have a higher initial price tag than raceways, but the returns from PBRs are much higher. As seen in Figures 5a and 5b, PBRs consist of long tubular chambers, which are made of easily sanitized glass (Sforza et al., 2012). The chambers are filled with water for the microalgae to grow in, and exposed to sunlight and carbon dioxide (Sarisky-Reed, 2010). PBRs offer many benefits that raceway ponds cannot. For example, PBRs are in closed environments, which protect the algae and the surrounding environments to contamination (Snow and Smith, 2012). Also, PBRs do not require as much land as the raceway ponds because the chambers can be built anywhere, and the yield equivalent from PBRs is much higher than in raceway ponds (Sforza et al., 2012). Finally, in closed chambers, water loss through evaporation is prevented, which keeps the water requirements for PBRs below that for raceways (Trent, 2012). After the microalgae are grown to sufficient amounts in the PBRs, a process known as transesterfication is used to convert the algae into biofuel. Transesterfication is a process that takes three molecules of alcohol and combines them with one molecule of natural oils that the algae produce

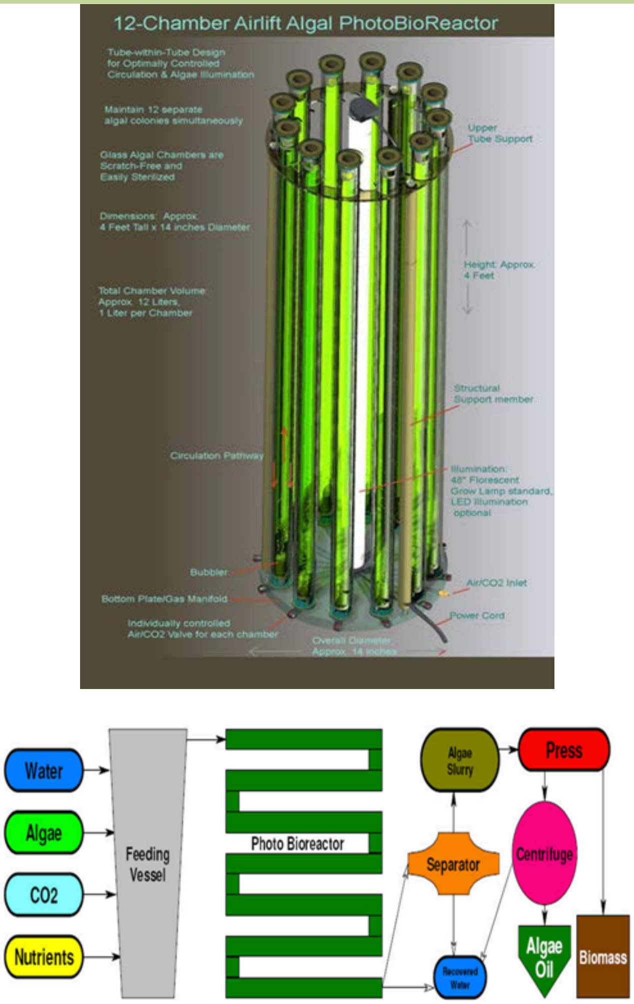

Figure 5a and 5b: Diagrams of PBR technology. (APS).

themselves (Trent, 2012). Through transesterfication, the oils are converted into a bioethanol fuel that is comparable in efficiency to regular gasoline, and even jet fuel (Sarisky-Reed, 2010). Using and improving on current photobioreactor technology, microalgae biofuel has great potential to replace fossil fuels in the United States.

Cultivation Resourses: Sunlight

With the technology of photobioreactors providing an efficient microalgae cultivation method, and transesterfication providing a sustainable fuel producing method, the next step is to find a suitable geographic environment to invest in PBR infrastructure. In order to pinpoint the most appropriate area for algae production in the United States, many factors must be considered; such as land, sun exposure, water, CO_2 sources, temperature, evaporation, and susceptibility to severe weather (Sarisky-Reed, 2010). Since the most effective form of microalgae cultivation is through PBRs, some of the factors can be ruled out, such as evaporation and severe weather (Trent, 2012). Algae are autotrophic organisms, which mean that in order to survive they need sufficient amounts of **in**coming **sol**ar radi**ation**, or insolation (Sarisky-Reed, 2010). In the United States, the Desert Southwest regions have by far the highest intensities of insolation every year, as shown in Figure 6 (Sarisky-Reed, 2010). The most suitable environments for algae cultivation need to have at least 2800 hours of sunlight every year, have annual daily temperatures of 12°C or greater, and have at least 200 freeze-free days each year (Sarisky-Reed, 2010). Figure 7 shows the all the areas that meet the criteria for suitable algae production according the DOE Roadmap, which correlates very closely to the high insolation areas in the Southwest.

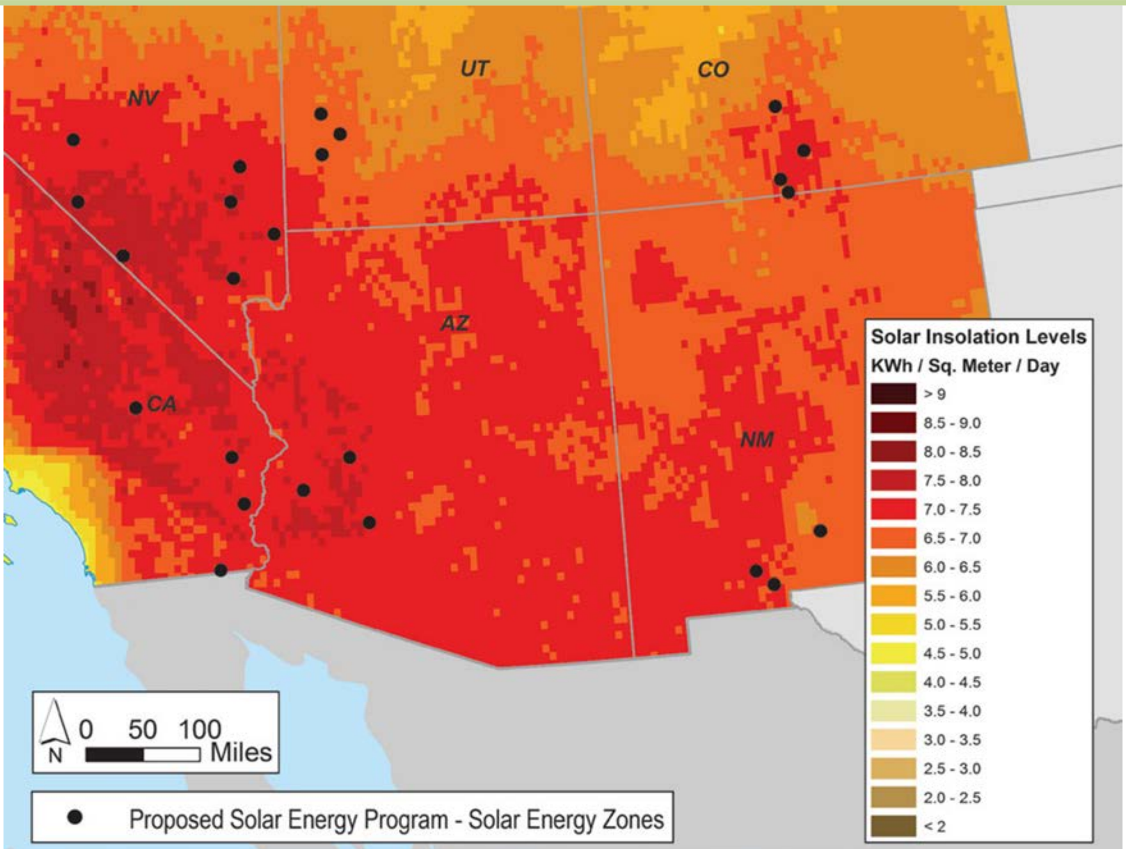

Figure 6: Annual insolation amounts in the Desert Southwest. (Walston et. al., 2012).

Figure7: Suitable areas for algae cultivation (Sarisky-Reed, 2010).

CULTIVATION RESOURCES: WATER

The second resource needed for microalgae production is water. In general, water is hard to come by in the Desert Southwest. A shortage of water would normally be a major hindrance for the cultivation of algae, but there is a solution that overcomes the water shortage and also provides benefits for surrounding municipalities; wastewater recycling. Microalgae have the capability to thrive in water that may not be suitable for other organisms (Sarisky-Reed, 2010). Not only can microalgae survive in salty and polluted water, but through a process called eutrophication microalgae can use the chemicals and nutrients to treat the water and make it fresh (Trent, 2012). Essentially, growing algae with wastewater resources serves as a triple-positive; the wastewater already has the nutrients needed to stimulate algal growth, the wastewater is treated to safe levels for reuse, and the recycling of water is extraordinarily helpful in a desert region with low water resources. In addition, algae production could be achieved in coastal regions of the Southwest, particularly Southern California, as proposed by the National Atmospheric Space Administration's (NASA) Offshore Membrane Enclosures for Growing

Algae (OMEGA) program (Trent, 2012). OMEGA was proposed by NASA Oceanographer Jonathan Trent as an idea for sustainable algae production in coastal regions. OMEGA works by growing algae in floating plastic PBRs that are buoyed offshore (Trent, 2012). The PBRs are placed in locations near municipalities that dump wastewater into the ocean. The plastic PBRs are made of semipermeable membranes that allow water, some salt, and other nutrients from the wastewater into the PBR, but keep the microalgae contained inside (Trent, 2012). The OMEGA system provides the same benefits as regular wastewater treatment, but the water supply is even less of an issue because it would take place in the ocean.

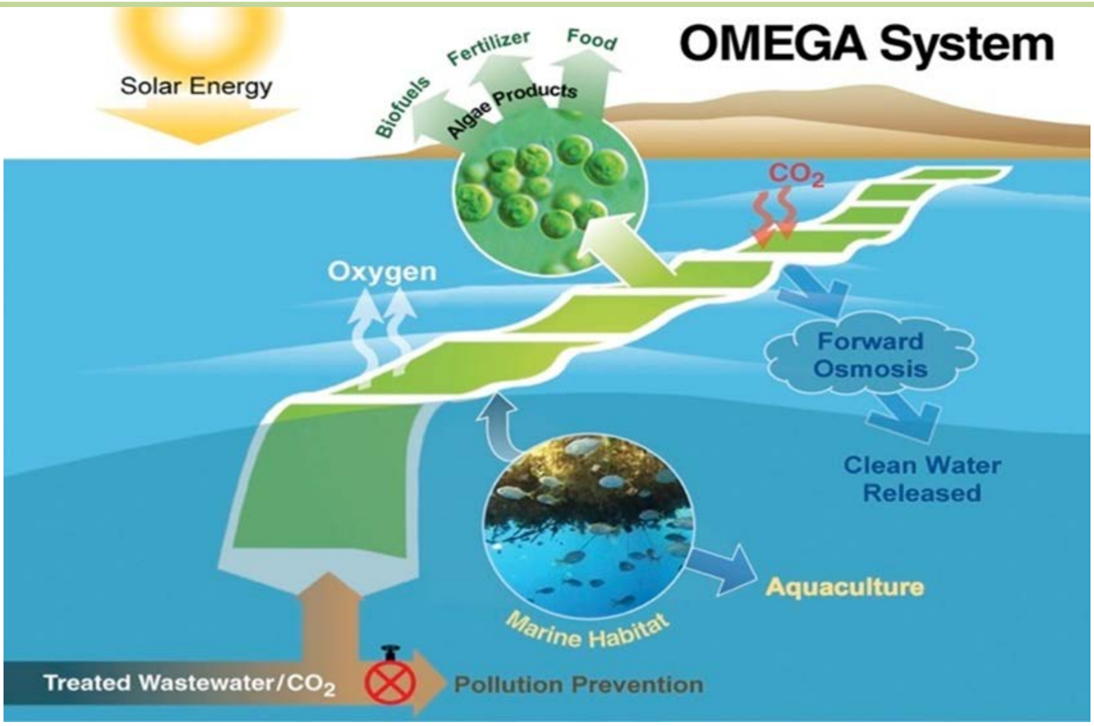

Figure 8: NASA's OMEGA System for offshore algae cultivation. (Culler, 2012).

CULTIVATION RESOURCES: CARBON DIOXIDE

The final resource required for algae cultivation is CO_2. CO_2 is naturally prevalent in the atmosphere, and serves an important role. CO_2 is a greenhouse gas that helps trap the Earth's emitted radiation and keep the surface warm enough to sustain life (Sarisky-Reed, 2010). However, the burning of fossil fuels has greatly increased the amount of CO_2 in the Earth's atmosphere to hazardous levels. The cultivation of algae and use of microalgae biofuels can serve as a sustainable solutions for CO_2 emissions. Algae, like all plants, require CO_2 to stimulate photosynthesis. Algae naturally absorb CO_2 from the atmosphere, but large-scale production of microalgae for biofuel would require large amounts of CO_2. Similar to the use of water, there is a method for obtaining large amounts of polluted CO_2 from factories. Large amounts of CO_2 are emitted daily from power plants, oil refineries, and other industrial factories; in fact, the generation of electricity from coal burning power plants accounts for over 80 percent of CO_2 every year in the United States, as shown in Figure 9 (Sarisky-Reed, 2010). If algae infrastructure could be located in areas within close proximity to power plants or other industrial

CATEGORY	CO_2 EMISSIONS (Million Metric Ton/Year)	NUMBER OF SOURCES
Ag Processing	6.3	140
Cement Plants	86.3	112
Electricity Generation	2,702.5	3,002
Ethanol Plants	41.3	163
Fertilizer	7.0	13
Industrial	141.9	665
Other	3.6	53
Petroleum and Natural Gas Processing	90.2	475
Refineries/Chemical	196.9	173
Total	**3,276.1**	**4,796**

Figure 9: CO2 emissions in the US for 2010. (Sarisky-Reed, 2010).

facilities, the CO_2 emitted from those factories could be captured and fed to the algae through bubblers at the base of PBRs (Sforza, 2012). This would ensure the algae have sufficient amounts of CO_2 for photosynthesis, and would also serve as a CO_2 fixation process for the factories (Sarisky-Reed, 2010). Not only does CO_2 serve as a nutrient source for the microalgae, but it also helps control temperatures in the PBRs. The Desert Southwest may be a suitable environment for microalgae cultivation in terms of insolation, but with high insolation comes high temperatures. When growing microalgae in contained PBRs, there is a risk of cooking the algae, but pumping CO_2 gas into the PBRs through bubblers would help keep the temperatures inside the PBRs cool enough for the microalgae to survive (Trent, 2012). Furthermore, if and when microalgae production makes the jump to large-scale production levels, the entire world could see CO_2 amounts in the atmosphere drastically drop from hazardous to natural levels. Large-scale cultivation of algae would mean more CO_2 capture and fixation, and large-scale production of microalgae biofuel would mean far less CO_2 emissions.

CONCLUSION

As the use of fossil fuels is proving to be an unsustainable energy method and the combustion of fossil fuels is having hazardous consequences on the atmosphere and the environment. The United States are in dire needs of an alternative to fossil fuels, and microalgae biofuel has the potential to replace fossil fuels and offer added bonuses. Microalgae biofuel is a renewable energy resource that can be cultivated through photobioreactors. It would make sense for these PBRs to be located in the Desert Southwest region of the United States. With more than adequate amounts of insolation, sustainable water resources in wastewater facilities, and sustainable CO_2 resources in power generating facilities, the Desert Southwest is the most logical choice for sustainable microalgae cultivation and biofuel production.

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