Alternative Energy:

Bio-hydrogen and Bio-diesel

An Interactive Qualifying Project Report

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By

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1. energy
2. hydrogen
3. bio-diesel

Abstract

Two alternative energy sources, bio-diesel derived from algae and bio-hydrogen produced by a dark fermentation process, were found to be possibly viable for widespread use in the near future. With more research, they could be integrated into our energy infrastructure to lessen reliance on foreign oil as well as other fossil fuels. Current technologies and feasibilities are summarized and some recommendations are presented.

Acknowledgements:

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1. Introduction: Alternative Energies

Mankind is using more resources now than ever before. The United States alone consumed 98,216.2 trillion BTU's of energy in the year 2000[1]. The spread of humans across the globe, in addition to subsequent industrial and economic developments, have increased energy demands, while the looming shortages of fossil fuels stress the urgency of the search for alternate energy sources. As shortcomings and shortages of traditional sources of energy become apparent, research is being focused on better energy sources to power vehicles, homes, and appliances.

Fossil fuels are defined as solid, liquid, or gaseous fuels formed in the ground after millions of years by chemical and physical changes in plant and animal residues under high temperature and pressure. Oil, natural gas, and coal are considered fossil fuels[2]. Alternative energy sources are generally considered to be anything not defined as a fossil fuel. Despite the range of different energy sources that exist, the only sources considered viable are those that are renewable, easily obtained (after the appropriate research has been performed), and able to be easily integrated into the current energy distribution infrastructure. These preferences generally point research in the direction of pure hydrogen, various hydrogen-rich fuels, fuel cells, photovoltaic cells and other methods of direct solar energy collection, wind power, biomass (and fuels derived from it), hydroelectric power, and to a lesser extent, nuclear fission.

A previous Interactive Qualifying Project, Biomass Conversion to Liquid Fuels: Using Plant Oils, by Berk Akinci [3], explored the possibility of large scale conversion of the collected solar energy contained in various plant oils (including soybean oil, palm oil, and oil derived from micro-algae) into useable fuels. Plants were explored as a possible energy source in Akinci's paper because they are one way to convert solar energy to a usable form. Akinci found that it would require 19.9% of the total world yield of oil palm fruit to satisfy the motor gasoline requirement of the United States; if the entire energy demand of the United States were to be met, we would require over 20% more palm fruit than is produced world-wide[4]. Microalgae were found to be a more promising crop. Conservative estimates placed the total land area required to meet the motor gasoline requirements of the United States at less than 3.5% of the total land area of the US, and under 21% to meet the entire energy requirements of the United States[5].

The purpose of exploring alternative energy possibilities is to eliminate the use of fossil fuels that disrupt the natural carbon cycle of the planet[6]. Renewable energy will also help to alleviate the current concern that we are running out of fossil fuels and help prevent future conflicts over fossil fuel resources[7]. A major misconception about alternative energy is that it will improve the environment. In most cases this is not likely to happen, because to do so would violate the second law of thermodynamics, which states the total entropy within a system must always increase with time. Therefore, the environment is likely to stay the same because a pollutant like carbon dioxide (a major contributor to global warming and a product of burning fossil fuels) if not transformed naturally by either chemical or biological reactions, will remain indefinitely in the environment[8].

The development of alternative fuels must be done carefully by evaluating everything that goes into making the fuel and its byproducts when used. A fuel that is not carefully studied may solve a current problem, but it may also create other problems that will need to be addressed in the future[9]. One issue resulting from insufficient study is the increased levels of CO_2 in the atmosphere caused by the burning of fossil fuels. The release of carbon from crude oil fuels increases the total mass of carbon in the atmosphere, and can not be reversed[10]. A carbon neutral fuel would use carbon from the atmosphere, creating and completing a carbon cycle, instead of adding more from resources within the earth. Alternative fuels such as hydrogen and bio-diesel may be the answer to creating a carbon neutral energy source.

2. Hydrogen and Bio-hydrogen:

Hydrogen is an ideal alternative energy source. Hydrogen has the highest gravimetric energy density of any known fuel, it is compatible with electrochemical and combustion processes for energy conversion[11], and it is clean burning, producing only water when combusted. Major drawbacks to this fuel are that hydrogen is extremely hard to produce and store. Storage of hydrogen is difficult due to its small molecular size. Currently, hydrogen is most commonly kept in high pressure tanks which can be very heavy. Another studied method of storing hydrogen is in special materials such as zeolites[12] which lock the hydrogen in their structure. Storing hydrogen can also be very dangerous due to the explosive nature of the element.

Hydrogen is the most abundant element in the universe, accounting for 90 percent of the universe by weight[13]. However, it is not commonly found in its pure form since it readily combines with other elements. For example, hydrogen easily combines with oxygen to form water[14]. Thus, hydrogen is generally produced by electrolysis of water and steam reformation of natural gas (methane)[15]. Electrolysis of water can be a carbon neutral process if solar energy is used to power the system, however electrolysis is usually powered by electricity generated by fossil fuel fired plants. This is not a carbon neutral process. This method accounts for about 4% of the hydrogen produced yearly world-wide[16]. Steam reformation of natural gas is currently the most efficient process of producing hydrogen and accounts for 48% of hydrogen produced world-wide[17]. In this process natural gas is stripped of hydrogen and the remaining carbon is joined with oxygen to form CO_2. Steam reformation of natural gas is not a carbon neutral process; it emits large amounts of carbon dioxide, which comprises 99% of the total emissions by weight[18].

2.1 Bio-hydrogen Production

Bio-hydrogen production is any process of producing hydrogen using a biological process. Unlike the processes stated previously, these are carbon neutral because they use carbon from the atmosphere. There are a wide range of biological systems that generate hydrogen. These systems include direct photolysis, indirect photolysis, and dark fermentation[19].

2.11 Direct bio-photolysis

Photosynthetic production of hydrogen from water is a biological process that can convert sunlight into useful, stored chemical energy by the following general reaction:

$$2H_2O \xrightarrow{light\ energy} 2H_2 + O_2$$

Green algae production of bio-hydrogen is achieved by the deprivation of sulfur-nutrients in the medium in which green algae is grown. The deprivation of sulfur in the growth medium impedes protein biosynthesis and causes the green algae to be unable to perform the necessary turnover of the photosystem-II. Under sulfur deprivation, the photochemical activity of photosystem-II drops, and rates of photosynthetic oxygen evolution drop below those of oxygen consumption by respiration. In effect, sealed cultures of green algae will become anaerobic in the light. In this anaerobic condition the green algae cells will produce hydrogen for 60 to 100 hours. The limiting factor in this system is that the cells must be allowed to replenish their endogenous substrate of starch and protein that are consumed in the hydrogen production process[20,21]. This is accomplished by allowing the algae to photosynthesize normally.

2.12 Indirect bio-photolysis

Cyanobacteria, also known as blue-green algae can also produce hydrogen through photosynthesis via the following processes: [22]

$$12H_2O + 6CO_2 \xrightarrow{\text{light energy}} C_6H_{12}O_6 + 6O_2$$

$$C_6H_{12}O_6 + 12\ H_2O \xrightarrow{\text{light energy}} 12H_2 + 6CO_2$$

The nutritional requirements of cyanobacteria are simple: air (nitrogen and oxygen), water, mineral salts, and light. This makes them ideal for energy production since they require little sustenance. The processes also create little pollution because the bodies of the bacteria can be used to feed fish[23]. Species of cyanobacteria may possess several enzymes directly involved in hydrogen production. These include nitrogenases which catalyze the production of hydrogen as a by-product of nitrogen reduction to ammonia, uptake hydrogenases which catalyze the oxidation of hydrogen synthesized by the nitrogenase, and bi-directional hydrogenases which have the ability to oxidize and synthesize hydrogen[24]. The nitrogenase and bidirectional hydrogenase reaction is shown in Figure 1.

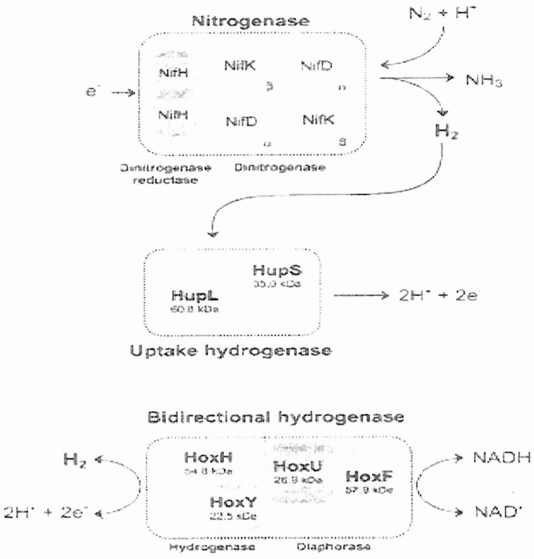

Figure 1 Enzymes and reactions involved in hydrogen production in cyanobacteria[25].

Cyanobacteria can produce hydrogen in two ways. One is identical to the direct bio-photolysis method which is limited by its need for periodic anaerobic conditions, while the other method is the nitrogenase reaction. Although the nitrogenase reaction is an endergonic process, heterocystous nitrogen-fixing cyanobacteria have the ability to sustain hydrogen production with very little nutritional sustenance[26]. This system shows better promise for commercial applications because it can continuously produce hydrogen, unlike direct biophotolysis which need periodic rests from hydrogen production to replenish the endogenous substrate. However the hydrogen production rates of indirect biophotolysis are very low, which limits their practical use.

2.13 Dark fermentation

Hydrogen can be produced by anaerobic bacteria, grown in the dark, which feed on carbohydrate-rich substrates such as sucrose and glucose. Fermentation reactions can be operated at mesophilic (25-40°C), thermophilic (40-60°C), extreme thermophilic (60-80°C), or hyperthermophilic (>80°C) temperatures.[27] Bacteria for a dark fermentation reactor can be harvested from sewage sludge. Since sewage sludge is composed of a wide variety of bacteria, it must be purified by heating. This is done so that the other bacteria do not consume too much of the substrate and turn it into non-hydrogen gasses. To purify the sludge it is heated for a short time to 75 degrees Celsius. The major hydrogen producing bacteria identified in sewage sludge are spore forming *Clostridium* species which are resistant to high temperatures and therefore can withstand the purification process that other bacteria can not[28]. The pH of the sewage sludge must also be carefully controlled to around 5.5 pH, which is the reported optimal growth pH for *Clostridium*[29]. Other species of bacteria that produce hydrogen include *Enterobacter, and Bacillus.* Dark fermentation does not produce pure hydrogen gas like the hydrogen produced by direct and indirect photolysis, but a biogas comprised primarily of hydrogen and carbon dioxide, that may contain trace amounts of methane, carbon monoxide, and hydrogen sulfide[30]. Due to these impurities hydrogen produced by dark fermentation is not directly usable by proton exchange membrane fuel cells, which require pure hydrogen. Separation membrane filters may be used to purify hydrogen produced by dark fermentation[31].

2.2 Bio-hydrogen Reactor Uses

Biohydrogen reactors could be used as distribution centers of hydrogen the same way oil refineries distribute gasoline they may also be used to generate on-site hydrogen at fueling stations for fuel cell powered cars. A biohydrogen reactor could even be small enough to power a single house's fuel cell, powering its electrical, heat, and cooling systems.

2.3 Fuel Cell Consumption of Hydrogen

To assess if a biohydrogen system is capable of providing a proton exchange membrane fuel cell (PEMFC) with enough hydrogen to generate energy for a house, the fuel cell size and the rate of hydrogen consumption needs to be determined. A previous study found that a 5 kilowatt PEMFC would provide 43,800 kilowatt hours in yearly energy production. This is sufficient power to meet the demands of an electrically heated house located in the Pacific Northwest of North America during peak loads [32]. Using the equations shown in Appendix A.1, a 5 kilowatt fuel cell will consume 120 moles/hour of hydrogen[33]. A biohydrogen reactor must provide at least this much hydrogen to be a reliable hydrogen source for a PEMFC to power a single house.

2.4 Rates of Bio-hydrogen Production[*]

The most reliable biohydrogen production method is dark fermentation. Since both direct and indirect biophotolysis rely on energy from the sun, production levels are susceptible to a large drop due to poor lighting conditions. A significant drop in the rate of production could occur due to seasonal variances in the length of daylight as well as geographical location and its inherent changes in sunlight angle[34]. On the other hand, dark fermentation can be operated non-stop as long as it has a steady supply of sucrose substrate. The highest dark fermentation yield reported by one group in Taiwan reached approximately 53.9 mmol $H_2 / (l * h)$[35]. The type of reactor used was a fixed-bed bioreactor which used activated carbon as the fixed bed to immobilize the sewage sludge shown in Figure 2.

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[*] (All calculations used in this section are included in Appendix A.2)

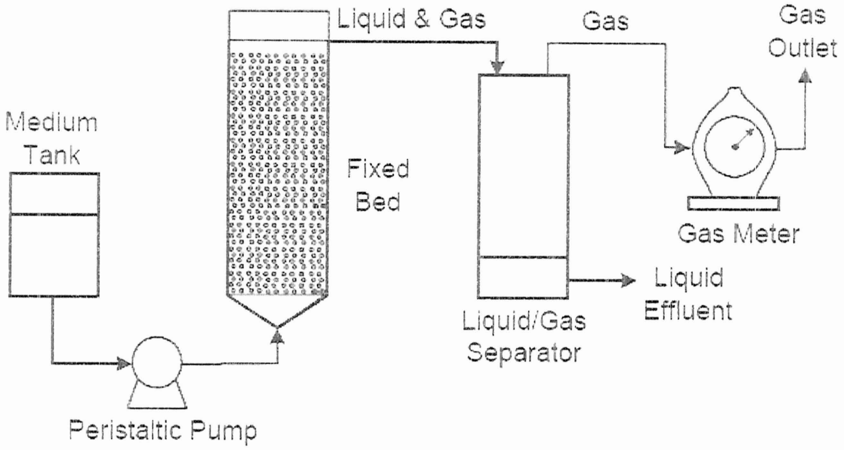

Figure 2 Dark fermentation activated carbon fixed bed bioreactor. Medium tank is a water sucrose solution. The liquid effluent is composed of volatile fatty acids, water and unused sucrose. 80% of sucrose is consumed and turned into biogas.[36],[37]

The reactor also had a total volume of 300 mL and had a hydraulic retention time of one hour. A yield of 53.9 mmol H_2 / (l * h) was calculated to theoretically provide enough hydrogen to power a 5 kW PEMFC if the tank's size was increased to approximately 2,260 liters and the rate of production was not affected by the increase in volume. A tank of 2,260 liters produces 120 moles of hydrogen per hour, which is enough hydrogen to power a 5kW PEMFC that consumes on average 119 moles of hydrogen per hour. A 2,260 liter tank is approximately 2 times the size of a 275 US gallon heating oil tank (1040.9 liters). Therefore, a bioreactor tank of 2,260 liters is not unreasonably sized to store in a basement. This makes dark fermentation a very promising technology for the future.

2.5 Dark Fermentation Substrate†

In order to produce 53.9 mmol H_2 / (l * h), the dark fermentation reactor used by the Taiwanese group consumed 17.8 g of sucrose per hour per liter of solution in the reactor[38]. If the reactor was increased in size to 2,260 liters the reactor would consume 40.23 kg of sucrose an hour if it was run at a hydraulic retention time of 1 hour. This reactor would consume annually 343,700 kg of sucrose per year, or 343.70 metric tons. In the United States there are three major sugar producing crops, sugar cane, sugar beet, and sweet sorghum. On average, sugar cane can produce 49.1 metric tons of sugar per hectare[39] of planted land, sugar beets can produce 11.5 metric tons per hectare[40], and sweet sorghum can produce 12 metric tons per hectare[41]. The total amount of sugar produced in the United States of America is 57,590,500 metric tons. This comes out to be 35,932,000 tons[42] (32,597,300 metric tons) of sugar from sugar cane and 27,550,000 tons[43] (24,993,200 metric tons) of sugar from sugar beets. Each 5 kW fuel cell needs a dark fermentation bioreactor to provide it with hydrogen. Since a dark fermentation bioreactor consumes 344 metric tons of sugar per year, the United States total sugar production can provide enough sugar for 167,560 dark fermentation bioreactors.

2.6 Small to large scale feasibility‡

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† (All calculations used in this section are contained in Appendix A.3)

‡ (All calculations in this section are in Appendix A.4)

In the year 2000, the US Census reported that the population of the United States was 281,421,906[44]. Ignoring the power usage by industry and businesses, and assuming that everyone lived in a four-person house, there would be an estimated 70,355,500 houses that need power. Since the current US production of sugar can only support 167,560 home units, only 0.23 percent of the houses in the US could be supported. Currently the estimated population of Massachusetts is 6,347,097[45]. Making the same assumption about houses and ignoring industry and business again means that an estimated 1,586,774 homes need to be powered in Massachusetts - still too many homes to be powered by a dark fermentation reactors using a sucrose based substrate. Worcester Massachusetts, the third largest city in New England[46], has a population of 172,648. Again making the same assumptions, this would mean there are roughly 43,162 homes in Worcester. This one city could be powered by dark fermentation bioreactors, however, the City of Worcester would consume approximately 14,834,800 metric tons of sugar, or 25.7 percent of the total sugar production of the United States. This is an unreasonable amount of sugar to be used to power a single city that contains only 0.06 percent of the total population of the United States. The total production of sugar in the United States could be increased by including corn and sorghum sugar production, but the addition to the total sugar production would not likely be enough to power the United States. Therefore, dark fermentation using a pure sucrose substrate is not a feasible way to power the United States.

2.7 Starch Dark Fermentation Bio-Reactors§

Sucrose based dark fermentation reactors are only one type of dark fermentation bio-reactor; there are many other experimental bio-reactors in testing. One of the most useful dark fermentation reactors is the starch substrate reactor. Starch is one of the most abundant polysaccharides, and is found in plant biomass such as kitchen leftovers, municipal solid waste, and agricultural residues[47]. By using such wastes as substrate for dark fermentation bio-reactors two goals are accomplished: reducing solid wastes, and producing hydrogen for energy production. Shown in Figure 3, an experimental bioreactor has been developed to work with food waste[48].

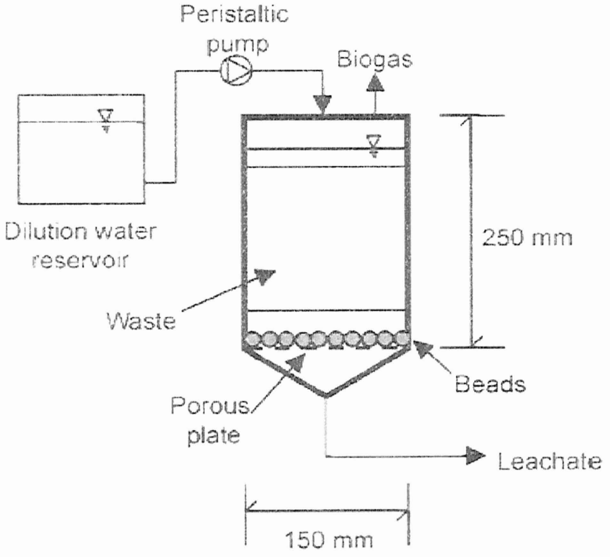

Figure 3[49] Experimental dark fermentation solid food waste bioreactor

This bioreactor was designed to measure how much hydrogen could be produced from a certain amount of food waste substrate, and to determine the best water dilution rate to produce the most hydrogen. This bioreactor used seed

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§ (All calculations in this section are in Appendix A.5) sludge from a sewage treatment plant, purified by boiling, to harvest anaerobic spore-forming bacteria, such as *Clostridium*[50] which are resistant to heat, as in sucrose substrate bioreactors. The pH of the sewage sludge must also be carefully controlled to around 5.5 pH, which is the reported optimal growth pH for *Clostridium*[51]. The reactor used was a leaching-bed reactor with working volume of 3.8 Liters and was operated at 35 degrees C. Dilution water was continuously delivered to the reactor by a peristaltic pump at different rates to determine the best dilution of the substrate as it decomposed. The dilution water was provided to the leaching bed reactor to control environmental conditions during hydrogen fermentation[52]. To collect the leachate, composed of volatile fatty acids, ethanol, and water[53], a perforated plate and beads were installed at the lower part of the bioreactor and the biogas production was measured using a wet gas meter[54]. This bioreactor used 391.3 grams of solid food waste, composed of 61.1% grains, 29.7% vegetables, and 9.2% meat, as a substrate. Of the total solid waste use in the reactor 95% or 371.7 g was considered to be a volatile solid. The volatile solid content can be converted to a theoretical COD (chemical oxygen demand). The theoretical COD of the reactor was 412.6 g. The reactors actual COD was 239.2g making the bioreactor 58% efficient in decomposing the waste. The bioreactor decomposed the food waste into producing 41.5 g COD hydrogen. Since 1 mol of hydrogen is 16 grams COD[55], 2.593 moles of hydrogen were produced. The hydrogen produced was 10% of the total COD reduction composed of hydrogen, volatile fatty acids and ethanol.

The United State wastes about 96 billion pounds of food waste annually[56]. This is approximately 44,000,000,000 kg. If each food waste bioreactor of 391.3 g could be scaled up to provide 120 moles of hydrogen per hour, assuming it does not effect hydrogen production, it would have to contain approximately 18 kg of food waste. Based on the assumption that every 391 g of food waste produces 2.5 moles of hydrogen, the total food waste in the United States would equal 290 billion moles of hydrogen. Since a 5 kW PEMFC will consume 1,050,000 moles of hydrogen per year, the United States food waste can power approximately 278,000 5 kW PEM Fuel Cells. Unfortunately this is only about 0.4% of the assumed houses in the United States (70,355,500[**]). This is better than the pure sucrose substrate dark fermentation bioreactor which can power 0.23% of the United States, but is still not an effective way to power the United States of America. Further development and research into this type of reactor may yield better results.

3. Bio-diesel from Algae

3.1 Bio-diesel

Biodiesel is distributed in several grades, ranging from B5, comprised of 5% biodiesel and 95% petroleum diesel, to B100, which is pure biodiesel. Since blends up to B20 meet ASTM specification D 975 they can be burned in regular diesel engines, and since pure biodiesel meets ASTM specification D 6751, it can be burned in some unmodified diesel engines as well as any modified diesel

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[**] Refer back to section 2.6.

engine[57], [58]. Because of this, biodiesel can be treated the same as petroleum diesel in terms of distribution and use.

Biodiesel is generally obtained by the process of transesterification, in which triglycerides (oils) are combined with ethanol or methanol in the presence of a catalyst to form esters.[59] One type of oil that can be used in this process is obtained from algae. Through photosynthesis, algae convert water and CO_2 to sugars using the absorbed energy from sunlight. Some algae can then store the sugars as fats inside their cells. The two main types of algae that are most productive in this process are diatoms and green algae, primarily because they naturally store large amounts of oils in their cells.[60]

3.2 Formation of Triglycerides

To create triglycerides in a cell, fatty acids are first combined together to form Acyl-CoA. Acyl-CoA is a fatty acid (C15) with coenzyme A (CoA) attached via a thioester bond. Diacylglycerol, formed from phosphatadic acid, is then combined with Acyl-CoA to form triglycerides and water.[61]

$$3FreeFattyAcid(FFA) + glycerol \longleftrightarrow triglycerides + water$$ [62]

3.3 Commercial Production of Triglycerides

Transesterification is the process by which an ester group is exchanged with a more energetic alcohol to form a different ester. This removes the glycerol group from the lipids and leaves methyl-esters, which can be used as biodiesel. The oils are generally reacted with methanol and a catalyst to produce glycerin and methyl-esters. The catalyst is usually sodium or potassium hydroxide, and the methanol is evaporated and recovered for reuse. The glycerin byproduct can be sold to make soaps.[63] Figure 4 displays the steps in transesterification.

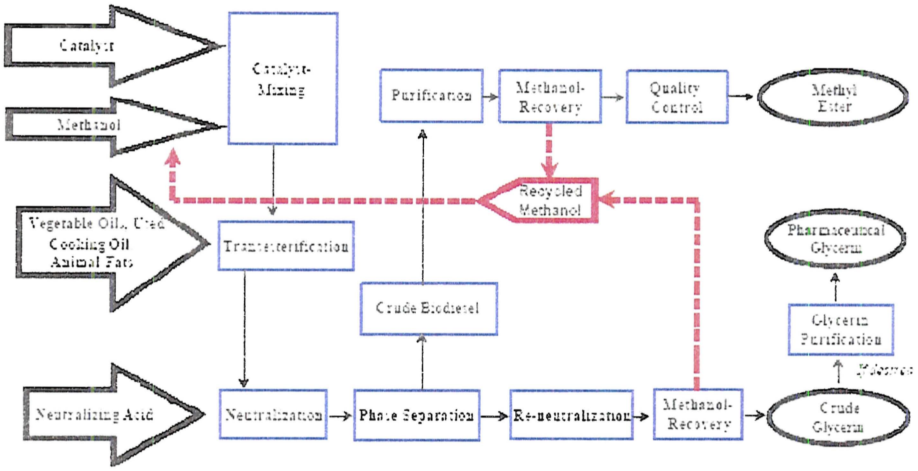


Figure 4 – Processes of Transesterification[64]

3.4 Concepts

One design that could be used in a large-scale algae farm is a circular, raceway-type design, as seen in Figure 5. The pond is only a meter deep because no useable amount of light penetrates water beyond that depth. The shallow pond design allows for maximum light absorption by the algae. Waste CO_2 is pumped into the pond to allow the algae to fix it with water to make sugars and oils. As the algae go through their normal life cycle, sugars are used as food for the cell and oils are stored in cell membranes. [60]

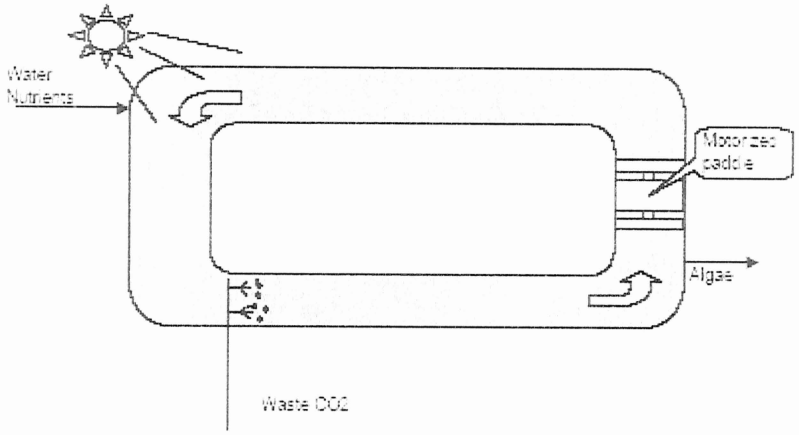


Figure 5 Raceway algae pond design [60]

The algae are then removed from the aqueous solution by a filtration system to separate the oil rich algae from the rest of the water solution. The algae are then lysed, and the oil is separated from the cell walls and organelles by exploiting the difference in the density of the oils and that of the other cellular components. Once the oils are harvested from the algae they must go through the chemical process of transesterification to produce biodiesel [60]. The sugars separated from the cells are a waste product of this process. The sugars may be utilized by other energy producing processes that consume sugars, like dark fermentation to produce hydrogen.

A long-term goal of the aquatic species algae farm program was to reach an output of 50 grams of algae per square meter of pond surface area per day. The energy yield from algae is high because they are over 50% oil by weight. Table 1 shows the optimal outputs from a facility built in New Mexico. The lipid content is half of the total body weight of the algae; the other half is attributed to proteins and sugars.[65]

Table 1 - Energy Produced from Facility (Raw Data)

Facility Information:	
Facility size	1.00 [hectare] = 10,000 [m^2]
Pond Size	1000 [m^2]
Total CO_2 processed (per year)	204,176 [mt]*
Algal Productivity (per day)	45 [g/m]
Algal Production (gross, yearly)	104,490 [mt]*
Lipid Production (gross, yearly)	52,245 [mt]*
Algal Information	
Lipid Content of Algae	0.50 wt. fr. Dsb**
Protien Content of Algae	0.26 wt. fr. Dsb**
Carbohydrate Content of Algae	0.16 wt. fr. Dsb**
Ash Content of Algae	0.08 wt. fr. Dsb**
Facility Energy Production	
Energy Produced (yearly)	691,791x10^6 [kcal]

* metric ton

** weight fraction dry solids basis

All information provided by:

Kiran Kadam, Ph.D. National Renewable Energy Laboratory

Applications of biotechnology and genetic engineering have revealed a possible trigger gene for algae to produce more lipids. The trigger gene can be activated by inducing stress on the organism, such as by depriving the media of essential nutrients. Such nutrients are Silicon (Si) and Nitrogen (N). The lack of Si in the diet shifts the metabolic pathway of making carbohydrates to making lipids, and reduces the rate of cell division because Si is a component in diatom cell walls.[60]

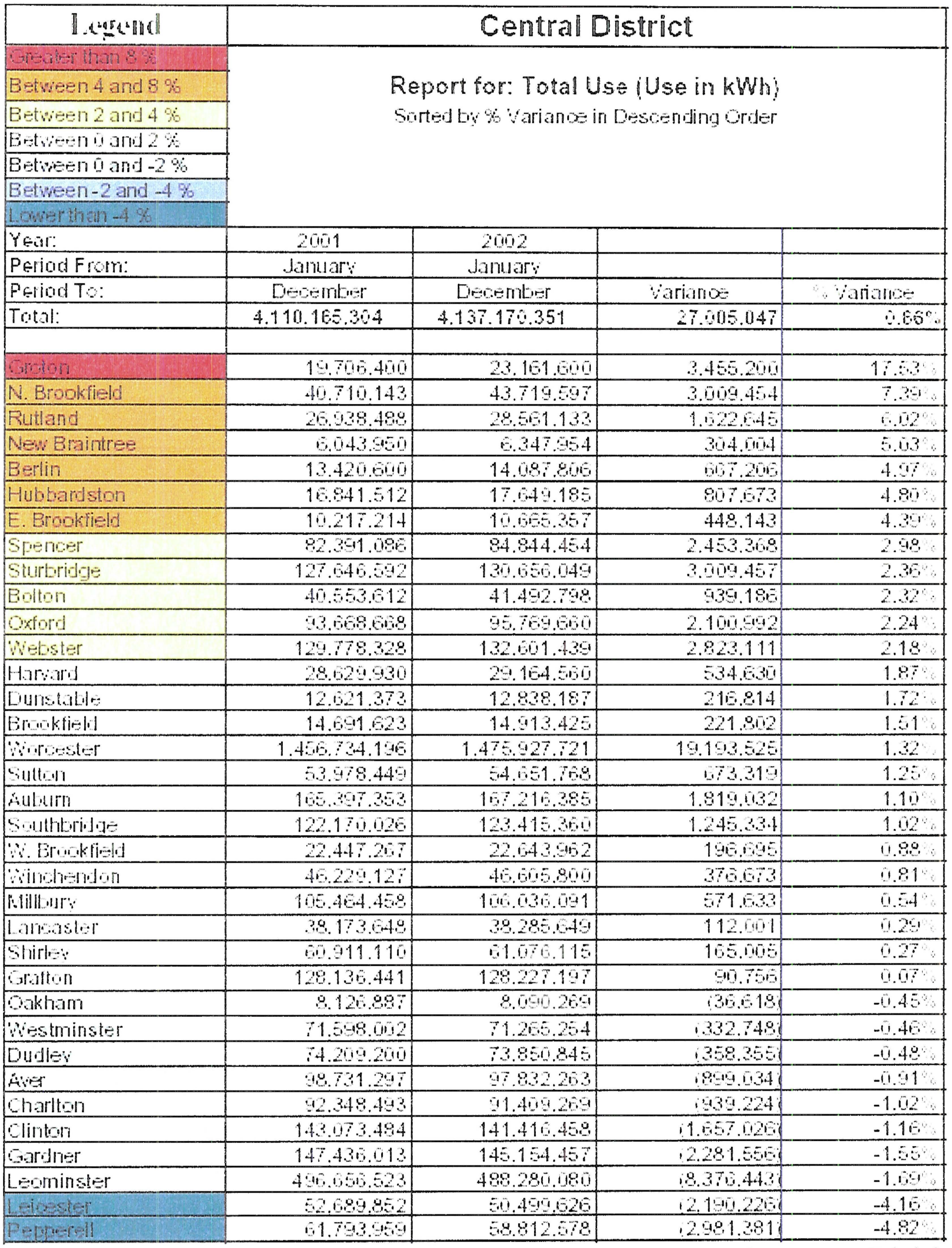
Table 2 shows the theoretical yield calculations of an algae farm based on data from the Roswell, New Mexico plant. An algae farm with a pond size of 1000 m^2 can produce 691,791 million kcal/year. The kcal/year can be converted into other useful units such as kWh/year, gal of oil/year, and barrels of oil/year. The 1000 m^{2} pond can produce 8.08x10^{8} kWh every year.[66]

Table 2 -Energy From Facility [kWh]	
Energy produced from facility (yearly)	691,791 million [kcal] = 691,791,000,000 [kcal]
Energy Conversions:	1 [kcal] = 3.96 [Btu]
	1 [kWh] = 3,412 [BTU]
	1 [gal] oil = 140,000 [BTU]
	42 [gal] = 1 [Barrel]
6.91x10^{11} [kcal/yr] * 3.96 [BTU/kcal] = 2.730x10^{12} [BTU/yr]	
2.730x10^{12} [BTU/yr] / 3,412 [BTU/kWh] = 8.00x10^{8} [kWh/yr]	
All conversion information provided by: Robert Fogt. Online Conversion. 1997-2002 http://www.onlineconversion.com/ Last accessed: Dec. 2, 2003.	

The algae farm facility constructed in New Mexico was 10,000 m^{2}, of which only 1,000 m^{2} was pond area. This land area is roughly the size of two soccer fields (6,400 m^{2} per soccer field). All further calculations in this IQP are made with the assumption that for every 1,000 m^{2} of pond area, 10,000 m^{2} of facility are necessary to process the algae produced. Since the facility size versus pool size may not scale linearly, this estimate may be too small or too large, but it is necessary in order to provide a rough calculation of the land required for a facility on a larger scale than was studied.

The third largest city in New England[67], the City of Worcester, consumed 1.5 billion kWh of electricity in the year 2002, as seen in Table 3.

Table 3 - City of Worcester Consumption (Mass Electric)



Legend	Central District			
Greater than 8 %				
Between 4 and 8 %	Report for: Total Use (Use in kWh)			
Between 2 and 4 %	Sorted by % Variance in Descending Order			
Between 0 and 2 %				
Between 0 and -2 %				
Between -2 and -4 %				
Lower than -4 %				
Year:	2001	2002		
Period From:	January	January		
Period To:	December	December	Variance	% Variance
Total:	4,110,165,304	4,137,170,351	27,005,047	0.66%
Groton	19,706,400	23,161,600	3,455,200	17.53%
N. Brookfield	40,710,143	43,719,597	3,009,454	7.39%
Rutland	26,938,488	28,561,133	1,622,645	6.02%
New Braintree	6,043,950	6,347,954	304,004	5.03%
Berlin	13,420,600	14,087,806	667,206	4.97%
Hubbardston	16,841,512	17,649,185	807,673	4.80%
E. Brookfield	10,217,214	10,665,357	448,143	4.39%
Spencer	82,391,086	84,844,454	2,453,368	2.98%
Sturbridge	127,646,592	130,656,049	3,009,457	2.36%
Bolton	40,553,612	41,492,798	939,186	2.32%
Oxford	93,668,668	95,769,660	2,100,992	2.24%
Webster	129,778,328	132,601,439	2,823,111	2.18%
Harvard	28,629,930	29,164,560	534,630	1.87%
Dunstable	12,621,373	12,838,187	216,814	1.72%
Brookfield	14,691,623	14,913,425	221,802	1.51%
Worcester	1,456,734,196	1,475,927,721	19,193,525	1.32%
Sutton	53,978,449	54,651,768	673,319	1.25%
Auburn	165,397,353	167,216,385	1,819,032	1.10%
Southbridge	122,170,026	123,415,360	1,245,334	1.02%
W. Brookfield	22,447,267	22,643,962	196,695	0.88%
Winchendon	46,229,127	46,605,800	376,673	0.81%
Millbury	105,464,458	106,036,091	571,633	0.54%
Lancaster	38,173,648	38,285,649	112,001	0.29%
Shirley	60,911,110	61,076,115	165,005	0.27%
Grafton	128,136,441	128,227,197	90,756	0.07%
Oakham	8,126,887	8,090,269	(36,618)	-0.45%
Westminster	71,598,002	71,265,254	(332,748)	-0.46%
Dudley	74,209,200	73,850,845	(358,355)	-0.48%
Ayer	98,731,297	97,832,263	(899,034)	-0.91%
Charlton	92,348,493	91,409,269	(939,224)	-1.02%
Clinton	143,073,484	141,416,458	(1,657,026)	-1.16%
Gardner	147,436,013	145,154,457	(2,281,556)	-1.55%
Leominster	496,656,523	488,280,080	(8,376,443)	-1.69%
Leicester	52,689,852	50,499,626	(2,190,226)	-4.16%
Pepperell	61,793,959	58,812,578	(2,981,381)	-4.82%

All information provided by Galgano, Robert D. Bay State West Division Massachusetts Electric Company.[68]

Since the output of the algae farm is 808 million kWh/year, the City of Worcester would only need to appropriate 18,000 m^2 for an algae farm facility to power the city for a full year. Since the total amount of energy consumed by the Central District of Massachusetts is 4.1 billion kWh[69], the land area needed for algae farm facility to produce that amount of energy would be 51,000 m^2.

In the year 2000, the state of Massachusetts consumed 5.187×10^{10} kWh of electricity.[70] Since the total output of an algae farm facility is 8.08×10^8 KWh, the state of Massachusetts would need 64,000 m2 of pond area to produce enough energy to facilitate the needs of the state.

One possible location for an algae pond could be Salisbury Pond in Worcester, MA. The surface area required for an algae pond that will produce enough energy for the City of Worcester is approximately 1,800 m^2. Salisbury Pond has a surface area of 14.54 acres, which is equivalent 58,829 m^2.[71] This location could provide more than enough pond area to feed the electrical needs of the city of Worcester.

Another possible location for an algae farm is the Worcester Regional Airport, which has run into financial and political trouble over the past few years. According to Adrian Walker, a Boston Globe columnist, the Worcester Regional Airport has fewer than three flights a day and is costing the city one million dollars every year.[72]

The airport is on a 2.04 square mile piece of land.[73] That is about 5.28×10^6 m^2. Under optimum growing conditions, the site could provide many times the pond area needed to supply electrical power for the Central District of Massachusetts, and even with facility size taken into account, would provide almost twice the land required to power the state of Massachusetts.

A problem at the New Mexico algae growth facility was keeping a constant temperature. The ponds were subjected to temperature fluctuation because the temperature changed significantly from day to night. For optimal production there needs to be at a relatively constant warm temperature. This could be remedied by having the pools covered by a greenhouse-type structure to keep the heat in through the night. Constant temperatures will provide a steady productivity.[74]

Algae farms look promising because the source can be carbon neutral, and the concepts involved are simple to understand and relatively easy to implement. Unfortunately biodiesel is currently not as cost-effective as petroleum diesel. The cost of biodiesel varies between $1.40 and $4.40 per gallon, which could pose a problem in competition with petroleum diesel. The cost analysis of the biodiesel was calculated using $50 per ton of CO_2. A solution to this problem could be to use wastewater as a carbon source. Wastewater is the used water from a residence or industry that contains dissolved or suspended matter. This would eliminate buying and shipping costs associated with another carbon source. [75]

The environmental impacts that can be made by converting current petroleum based combustion engines to utilize biodiesel are significant. The emissions from cars in several categories are decreased significantly.
As shown in Table 3, all values are decreased except for nitrogen oxides, which increased by 5.8%. Nitrogen oxides contribute to acid rain and smog, so a sharp increase in production of these oxides could prove problematic.[76]

Table 3 Tailpipe emission changes with Biodiesel fuels as compared to diesel fuel. [77]

Emission	B100*	B20**
Carbon Monoxide	-43.2%	-12.6%
Hydrocarbons	-56.3%	-11.0%
Particulates	-55.4%	-18.0%
Nitrogen oxides	–5.8%	–1.2%
Air toxics	-60% to –90%	-12% to –20%
Mutagenicity	-80% to –90%	-20%
Carbon dioxide***	-78.3%	-15.7%

*Average of data from 14 EPA FTP Heavy Duty Test Cycle tests, variety of stock engines
**Average of data from 14 EPA FTP Heavy Duty Cycle tests, variety of stock engines
***Life cycle emissions

The nitrous oxide, NOx emissions, can be deminished using combustion technologies. NOx emissions' main parameter is the combustion temperature of the fuel. Varying the air-fuel ratio in the combustion process, adjusting the injection timing, and engine operating temperature can control the NOx emissions.[78]

The major obstacle that needs to be overcome is the overwhelming cost of biodiesel vs. the cost of petroleum diesel. Although the current price of biodiesel varies greatly per gallon due to the refining process, the cost of petroleum diesel is still considerably lower.

4. Conclusions

In order for a hydrogen economy to ever work in the United States of America, a cheap and efficient way of producing hydrogen must be developed. Dark fermentation may provide the answer to creating a hydrogen economy with careful research and development. One benefit to developing dark fermentation is that it can be a carbon neutral energy source. In addition a food waste dark fermentation bioreactor can utilize wastes. This makes food waste bioreactors a truly renewable energy source. Further development of food waste bioreactors may increase the total possible hydrogen production to levels capable of sustaining a portion of the United States' energy needs. The addition of organic municipal waste, such as animal and human waste, in addition to food waste may significantly increase hydrogen production levels.

Biodiesel is a proven technology that has revealed few problems in the past, most of which can be corrected through suggested resolutions. Biodiesel can be easily integrated into the current economy with few changes to current diesel engines.

Bio-hydrogen and bio-diesel are two energies that are both carbon neutral and renewable. Both can be harvested and produced easily. Although the infrastructure is not yet adequate for hydrogen, the possible benefits of both energy forms warrant further investigation.

Appendix A:

A.1: Equations used to find Hydrogen consumption of a Fuel Cell[79]

Maximum Thermodynamic Efficiency

$$\eta\_max = \frac{\Delta gf}{\Delta hf}$$

Key: *η_max = Maximum Thermodynamic Efficiency, Δgf = Change in Gibbs free energy, Δhf = Change in enthalpy of formation*

Maximum Cell Voltage

$$E\_max = \frac{-\Delta hf}{z \cdot F}$$

Key: *E_max =Maximum cell voltage, Δhf = Change in Enthalpy of formation, z = number of electrons transferred per molecule, F = Faraday Constant*

Actual Cell Efficiency

$$cell\_efficiency = \frac{V\_c}{E\_max}$$

Key: *V_c = Cell voltage, E_max = Maximum cell voltage*

Overall Cell Efficiency

$$\eta = \mu\_f \cdot \left[\frac{V\_c}{E\_max}\right]$$

Key: *η = Overall Cell Efficiency, μ_f = Fuel utilization coefficient, V_c = Cell voltage, E_max = Maximum cell voltage*

Rate of H2 consumption for a single cell

$$fuel\_usage = \frac{I}{2 \cdot F}$$

Key: *I = Current, F= Faraday Constant*

Rate of H2 consumption for a stack of cells.

$$\text{fuel\_usage} = \frac{I \cdot n}{2 \cdot F}$$

Key: *I = Current, F= Faraday Constant, n = Number of cells in stack*

Output Power Calculation

$$P\_e = V\_c \cdot I \cdot n$$

Key: *P_e = output power, V_c = Cell Voltage, I = Current, n = Number of cells in stack*

Alternate hydrogen consumption equation output in mole/sec

$$\text{fuel\_usage} = \frac{P\_e}{2 \cdot V\_c \cdot F}$$

Key: *P_e = output power, V_c = Cell voltage, F = Faraday constant*

Converting mole/sec to mole/hour

$$\text{fuel\_usage} \cdot (S) \cdot (M) = \text{Fuel\_used\_per\_hour}$$

Key: *S = Seconds in a minute, M = Minutes in a hour*

Table of input values to equations and the respective outputs

Input	Name	Output	Unit	Comment
2	Z			number of electrons transferred per molecule (z=2 for H2)
96485	F		coulombs / mole	Faraday constant
.5	η_max			maximum thermodynamic efficiency
	Δgf	-142925	Joules / Mole	change in Gibbs free energy
-285850	Δhf		Joules / Mole	change in enthalpy of formation
	E_max	1.48131833963829	Volts	Maximum Cell Voltage
	cell_efficiency	.525882910617457		
.779	V_c		Volts	Cell Voltage
.95	μ_f			fuel utilization coefficient
	H	.499588765086584		overall cell efficiency
	fuel_usage	.0332615703865054	Moles / Second	
	I	6418.48523748395	Amps	
	N	1		Number of cells in fuel cell stack
5000	P_e		Watts	
60	S		seconds	
60	M		Minutes	
	Fuel_used_per_hour	119.74165339142	Moles / Hour	

A.2: Calculations from Rates of Hydrogen Production

1) Converting production rate of (1.32 Liters H2 / Liter culture/ Hour[80]) to (Moles H2 / Liter Culture/ Hour.

A) Assuming Hydrogen is an ideal gas

-P*V = n*R*T

Key: P= Pressure, V= Volume, n = Number of moles, R= Universal Gas Constant (8.314KJ/(Kmol*K))[81], T= Temperature (Kelvin only)

B) Assuming the reaction takes place at 101.3KPa (1 atm[82]) and 303°K (30°C)

$$101.3KPa * V = .001Kmole * 8.314KJ/(Kmole * Kelvin) * 303Kelvin$$

V= .0248Kliters Which equals 24.86L hydrogen per mole of hydrogen at 303K and 1 atmosphere.

C) 1.32L H2 * (1 mole H2 / 24.38 L) = .0539 moles or 53.9 milli moles H2

2) Calculating Tanks Size

A) A 5 Kilowatt fuel cell needs 119.7moles H2/Hour

B) The reactor produces .053 moles H2/Liter Culture/Hour

C) (119.7 molesH2/Hour) / (.053 molesH2/Liter Culture/Hour) = 2258.49 Liters of Culture needed to produce 119.7 Moles of Hydrogen per hour. Rounded up to 2260 liters to make sure enough hydrogen is produced since production rates can vary[83].

3) Converting US Gallons to Liters.

A) 1 Gallon [U.S. Liquid] * 3.785412 = 1 Liter[84]

A.3: Calculations from Dark Fermentation Substrate

1) Calculating consumption rates of sucrose.

A) When the Hydraulic retention time is one hour and the rate of sucrose consumption is 17.8 grams per hour per liter of solution.

17.8g * 2260 liters = 40,228 grams or 40.228 Kilograms per hour

B) 40.228Kg/Hour * 24Hours/Day * 365 Days/Year = 343708Kg or 343.708 Metric Tons

A.4:Calculations from Small to Large Scale Feasibility

1) Population Calculations

A) Total population of United States 281,421,906[85]

281,421,906 people / 4 (people/house) = 70,355,500 Houses

B) Percentage of houses capable of being powered by dark fermentation.

187,662 units / 70,355,500 houses = .002667 * 100 = .2667 percent of houses in the United States.

C) Population of Massachusetts 6,347,097[86] people.

6,347,097 people/ 4 (people / house) = 1,586,774 houses

D) Population of Worcester Massachusetts 172,648 people

172,648 people / 4 (people / house) = 43,162 houses

2) Worcester, Massachusetts sucrose consumption if powered by dark fermentation reactors.

A) 172,648 House with units * 343.708 Metric Tons consumed per unit per year = 14,835,124.69 metric tons consumed per year.

3) Percent of total US Sugar consumed by Worcester if powered by dark fermentation.

A) 64,501,100 Metric tons of sugar produced per year in the United States

14,835,124.69 metric tons/ 64,501,100 metric tons = .2299 * 100 = 22.9% of US produced sugar consumed by Worcester.

A.5: Calculations from Starch Dark Fermentation Bioreactors

1) Calculating hydrogen production of food waste (starch) Bioreactor.

A) 1 mol of hydrogen = 16 grams COD Hydrogen[87]

B) 41.5g (COD H2) / 16g (COD H2 / Mole H2) = 2.593 moles H2

2) Calculating amount of food waste needed to produce 119.7 moles of hydrogen per hour.

A) 119.7 (moles H2) / 2.593 (moles H2) = 46.16

B) 412.4 g COD food waste[88] needed to produce 2.593 moles of hydrogen

C) 412.4 g COD * 46.16 = 18,929.9 g COD food waste

3) Calculating total number of 5 kW PEMFC's that can powered from total food waste in the United States.

A) 96,000,000,000 pounds of food waste * .4535924 = 44,000,000,000 kg

B) 44,000,000,000 kg * (1000g / 1 kg) = $4.4 * 10^{13}$ g of food waste

C) ($4.4 * 10^{13}$ g / 391.3 (g/bioreactor)) = $1.1*10^{11}$ bioreactors of 391.3 capacity.

D) $1.1*10^{11}$ (bioreactors) * 2.593 (moles H_2 / bioreactor) = $2.9 * 10^{11}$ moles H_2

E) 120 (moles H_2 consumed per hour by a 5 kW PEMFC) * 24 (hours/day) * 356 (days/year) = $1.05 * 10^{6}$ moles H_2 consumed per year by a 5 kW PEMFC

F) $2.9 * 10^{11}$ (moles H_2) / $1.05 * 10^{6}$ (moles H_2 per 5 kW PEMFC) = 278,000 PEMFC's

Appendix B Correspondence by E-mail

B1: Correspondence with Agency of Industrial Science and Technology

----- Original Message -----
From: James Ehnstrom
To: webmaster@aist.go.jp
Sent: Thursday, October 30, 2003 7:02 PM
Subject: [AIST]<-

I am part of a research group doing a study on Biodiesel production from Algae. I was looking at some information from your site and could not obtain some necessary information. I am currently researching the amount of energy produced from 1 gram of algae per square meter. These numbers come from another source,

A Look Back at the U.S. Department of Energy's Aquatic Species Program: Biodiesel from Algae
Could you please send me any information that you may have concerning this subject. Any and all help that you could provide would be very much appreciated.

James Ehnstrom
Worcester Polytechnic Institute

----- Original Message -----
From: "EREC - Hesse, Paul" <phesse@nciinc.com>
To: <jte@WPI.EDU>
Cc: "Erec Responses" <erecresponses@nciinc.com>
Sent: Tuesday, November 04, 2003 10:23 AM
Subject: 756751 - Re: 'Ask An Energy Expert re: biodiesel from algae

****
Energy Efficiency and Renewable Energy Clearinghouse (EREC)
PO Box 3048, Merrifield, VA 22116
Phone: in USA: 1-800-363-3732
Email: doe.erec@nciinc.com
****

Dear James Ehnstrom:

Thank you for your inquiry to Ask an Energy Expert, a service of the U.S. Department of Energy's Energy Efficiency and Renewable Energy Clearinghouse (EREC), as follows:
- - - - - - - - - - - - -

InquiryText: I am part of a research group doing a study on Biodiesel and Biohydrogen production from Algae. I was looking at some information from a paper and could not obtain some necessary information. I am currently researching the amount of energy produced from 50 gram of algae per square meter. These numbers come from:
A Look Back at the U.S. Department of Energy’s Aquatic Species Program: Biodiesel from Algae
Could you please send me any information that you may have concerning this subject. I am interested in information concerning energy conversion from gram of algae to gallon or liter of Biodiesel. I am aware of the plant that was constructed in Roswell New Mexico, but not the particulars. Any and all help that you could provide would be very much appreciated.'

That document is pretty much what you're going to find related to government funded research into that topic. Additional potentially useful information/sources of information:

www.afdc.doe.gov
www.biodiesel.org
www.pipeline.to/biodiesel/
www.americanbiodiesel.com/
www.soygold.com/Default.htm
www.oly.com
www.bioxcorp.com
www.veggievan.org/
www.woodgas.com/DoItYourself.htm#Diesel
www.dancingrabbit.org/biodiesel/makeit.html
www.dancingrabbit.org/biodiesel/resources.html
www.sierrarailroad.com/powertrain/index.html
www.eere.energy.gov/consumerinfo/refbriefs/ta2.html

Articles from Home Power magazine (www.homepower.com)
"Going Pro with Biodiesel," E. Kolod, (No. 89) pp. 24-29, June/July 2002. Describes small-scale, commercial biodiesel production.
"Getting Off the Petroleum Grid with Biodiesel," S. Durkee, (No. 93) pp. 32-39, Feb/March 2003.
"My Car Runs on Vegetable Oil....Straight Vegetable Oil," G. Leis, (No. 95), pp. 70-74, June/July 2003.

"Biodiesel Company Sets Fast Pace with Waste Materials," D. Emerson, BioCycle, (44:03) pp. 50-51, March 2003.

Energy Balance/Life-Cycle Inventory of Ethanol, Biodiesel, and Petroleum Fuels," MN Dept of Ag., www.mda.state.mn.us/ethanol/balance.html

"Biodiesel: A Cleaner, Greener Fuel for the 21st Century," A. Wilson, Environmental Building News, (12:1), pp 1, 7-15, January 2003.

We hope this helps, and on behalf of the US Department of Energy thank you for your interest in energy efficiency and renewable energy. Please contact us again if we can be of additional assistance.

Sincerely,
Paul Hesse

B2: *Correspondence with Kiran Kadam of the National Renewable Energy Labboratory*

----- Original Message -----
From: James Ehnstrom
To: michael_pacheco@nrel.gov
Sent: Thursday, October 30, 2003 7:16 PM
Subject: Biodiesel conversion

I am part of a research group doing a study on Biodiesel and Biohydrogen production from Algae. I was looking at some information from your site and could not obtain some necessary information. I am currently researching the amount of energy produced from 1 gram of algae per square meter. These numbers come from
A Look Back at the U.S. Department of Energy's Aquatic Species Program: Biodiesel from Algae
Could you please send me any information that you may have concerning this subject. Any and all help that you could provide would be very much appreciated.
James Ehnstrom
Worcester Polytechnic Institute

----- Original Message -----
From: "Kadam, Kiran" <kiran_kadam@nrel.gov>
To: <jte@WPI.EDU>
Cc: "Finkelstein, Mark" <mark_finkelstein@nrel.gov>; "Pacheco, Michael" <michael_pacheco@nrel.gov>
Sent: Tuesday, November 04, 2003 12:22 PM
Subject: Biodiesel conversion

To: James Ehnstrom (Worcester Polytechnic Institute)
Re. Algal energy
We did some cost analysis a few of years ago, and I can give you the numbers from the same. Please bear in mind that the analysis assumes optimistic criteria/operating parameters, i.e., they represent a mature technology rather than what is achievable today. With this caveat in mind, the numbers are as follows:

Facility size ha 1,000
Total CO2 processed mt/yr 204,176
Lipid content wt. fr. dsb* 0.50
Protein content wt. fr. dsb 0.26
Carbohydrate content wt. fr. dsb 0.16

Ash content wt. fr. dsb 0.08
Productivity g/m2/d 45
Algal production, gross mt/y 104,490
Lipid production, gross mt/y 52,245
Energy of algae produced 106 kcal/yr 691,791
*weight fraction dry solids basis.
You can calculate the required algal energy parameter from the table. You can also check out the following papers:
Microalgal Technology for Remediation of CO2 from Power Plant Flue Gas: A Technoeconomic Perspective," K. L. Kadam and J. J. Sheehan, World Resource Review, 8(4), 493-504, 1996.
The Use of Microalgae for Assimilation and Utilization of Carbon Dioxide from Fossil Fuel-Fired Power Plant Flue Gas," Zeiler, K. G., D. A. Heacox, S. T. Toon, K. L. Kadam and L. M. Brown, Energy Convers. Mgmt., 36(6-9), 707-712, 1995.
Power-Plant Flue Gas as a Source of CO2 for Microalgae Cultivation: Economic Impact of Different Process Options," K. L. Kadam. Energy Convers. Mgmt., 38, S505-S510, 1997.
Environmental implications of power generation via coal-microalgae cofiring. K. L. Kadam. Energy 27(10), 905-922, 2002.

Hope this helps. Let me know if you have any more questions.

Kiran Kadam, Ph.D.
National Renewable Energy Laboratory, 1617 Cole Blvd., Golden, CO 80401, USA
Tel. - 303 384 6829; Fax - 303 384 6877
e-mail - kiran_kadam@nrel.gov
<<...OLE_Obj...>> <http://www.nrel.gov/biotechnology>
<<...OLE_Obj...>> <http://www.nrel.gov>

----- Original Message -----
From: "James Ehnstrom" <jte@wpi.edu>
To: "Kadam, Kiran" <kiran_kadam@nrel.gov>
Cc: "Finkelstein, Mark" <mark_finkelstein@nrel.gov>; "Pacheco, Michael" <michael_pacheco@nrel.gov>
Sent: Monday, November 10, 2003 2:16 PM
Subject: Re: Biodiesel conversion

Some of the information provided is a little confusing to me, please clarify.

Facility size ha 1,000
Does ha stand for hectare? which means 10,000 m^2? Is this the size of the entire facility i.e. pond, refinery, storage tanks for CO2? The information provided in
A Look Back at the U.S. Department of Energy's Aquatic Species Program: Biodiesel from Algae

talks about 1,000 m^2 pond systems. Were they simply refering to the pond size and not the size of the facility?

Energy of algae produced 106 kcal/yr 691,791
Is 106 kcal/yr mean the actual value would be 691,791 * 106 = 7.33 * 10^8 kcal/yr? An advisor of mine suggested a missing symbol 10^6, actual value of 691,791 * 10^6 = 6.91 * 10^11 kcal/yr?

James Ehnstrom
Worcester Polytechnic Institute

----- Original Message -----
From: "Kadam, Kiran" <kiran_kadam@nrel.gov>
To: "'James Ehnstrom'" <jte@WPI.EDU>
Cc: "Finkelstein, Mark" <mark_finkelstein@nrel.gov>; "Pacheco, Michael" <michael_pacheco@nrel.gov>
Sent: Monday, November 10, 2003 7:30 PM
Subject: RE: Biodiesel conversion

Answers to your queries:

"ha" does stand for hectare; this is standard SI notation.

1000 ha is pond area. It is a key parameter since it impinges on excavation
costs and algae productivity. The cost of peripheral land is not
significant. If the mentioned DOE report states 1,000 m^2 pond systems, it
is referring to the pond area and not the size of the overall facility.

Energy of algae produced is 691,791 million kcal/yr. My original table had
superscripts and your server does not support the format.

Kiran Kadam

B.3 Correspondence with Energy Efficiency and Renewable Energy Clearinghouse (EREC)

----- Original Message -----
From: James Ehnstrom
To: donna.gindes@ee.doe.gov
Sent: Monday, November 03, 2003 3:39 PM
Subject: Biodiesel Research

I am part of a research group doing a study on Biodiesel and Biohydrogen production from Algae. I was looking at some information from a paper and could not obtain some necessary information. I am currently researching the amount of energy produced from 50 gram of algae per square meter. These numbers come from:
A Look Back at the U.S. Department of Energy's Aquatic Species Program: Biodiesel from Algae
Could you please send me any information that you may have concerning this subject. I am interested in information concerning energy conversion from gram of algae to gallon or liter of Biodiesel. I am aware of the plant that was constructed in Roswell New Mexico, but not the particulars. Any and all help that you could provide would be very much appreciated.

James Ehnstrom
AIM jimmyjames13183
cell 5086621588

----- Original Message -----
From: <Donna.Gindes@EE.DOE.GOV>
To: <jte@WPI.EDU>
Sent: Tuesday, November 04, 2003 12:28 PM
Subject: Re: Biodiesel Research

Hi -

I'm checking with colleagues about your request, and either the appropriate
colleague or I will get back to you.
I'll be out of the office next week (and most of this one),

Thank you for your interest in renewable energy.

Donna

____
Donna Gindes
Public Affairs/Communications
U. S. Department of Energy
Boston Regional Office
Tel: 617-565-9714 Fax: 617-565-9723
www.eere.energy.gov/bro/

----- Original Message -----
From: <Donna.Gindes@EE.DOE.GOV>
To: <jte@WPI.EDU>
Sent: Friday, November 07, 2003 3:52 PM
Subject: Re: Biodiesel Research

Hi -

Someone in the U.S. Department of Energy's Biomass Program in the Office of

Energy Efficiency and Renewable Energy in D.C. should be back in touch
with you on this in the near future.

All good wishes with your research.

Donna

Donna Gindes
Public Affairs/Communications
U. S. Department of Energy
Boston Regional Office
Tel: 617-565-9714 Fax: 617-565-9723
www.eere.energy.gov/bro/

B.4 Correspondence with Sergio Cherenzia for WPI Professor Mathisen

----- Original Message -----
From: James Ehnstrom
To: mathisen@wpi.edu
Sent: Friday, November 21, 2003 12:05 PM
Subject: Institute Pond

I'm doing my IQP on Biodiesel and Biohydrogen production from Algae. I determining the feasibility and pactical application of this technology. I am trying to determine the size of Institute Pond, and was given your name. If you could please forward the necessary information that would be very much appreciated.

James Ehnstrom
Worceter Polytechnic Institute
cell 5086621588

----- Original Message -----
From: Sergio Cherenzia
To: jte@WPI.EDU
Sent: Monday, December 08, 2003 11:20 AM
Subject: Info on Salisbury Pond

James,

I'm responding to you with regard to the information you requested from Professor Mathisen. I am one of the students working with him on an MQP surrounding the high sediment loads entering Salisbury Pond, essentially filling it up and threatening the future existence of the pond. I believe Professor Mathisen mentioned sending you the suface area, volume, and flows entering the inlet at Salisbury Pond.

Surface Area - 14.54 acres
Volume - (1987) - 2.06 X10^6 ft^3
(1977) - 2.56 X10^6 ft^3
(1973) - 4.24 X10^6 ft^3

The volumes were taken from an MQP (*Salisbury pond sediment dredging feasibility study*, April 2001), referenced from a study conducted by CDM (camp, dresser, and Mckee). As you can see, the pond has been filling up, and the volume has probably reduced since 1987. Their study may have more information for you.

As for flows, it will vary from rain event to rain event. The west culvert entering Salisbury Pond contributes slightly more flow than the east culvert. During one rain event, we recieved about 0.7 inches of rain. The intensity of the storm was not consistent, but there were two peaks in rainfall intensity which translated into a couple conditions of high flow. The typical low flow conditions resulted in 3 - 5 cubic feet per second. The high flow condition was about 40 cubic feet per second. In between these two conditions the flow ranged between the two.

If there is anything else that I can help you with just let me know. I'm not sure the scope of your work, so hopefully this will help. Good luck with your project.

Sergio Cherenzia

B.5: Correspondence with Robert Galgano of MassElectric

----- Original Message -----
From: Galgano, Robert D.

To: jte@WPI.EDU
Sent: Wednesday, December 03, 2003 1:52 PM
Subject: KWH Sales

This chart shows the information for kWH sales for the cities and towns in Central Massachusetts served by Mass Electric.
The city of Worcester had 1,456,734,196 kWH in 2001, and 1,475,927,721 kWH in 2002.

Robert D. Galgano
Manager of Distribution Planning and Engineering,
Bay State West Division
Massachusetts Electric Company
939 Southbridge Street
Worcester, MA 01610
508-860-6358

Attached Chart.

----- Original Message -----
From: James Ehnstrom
To: Galgano, Robert D.
Sent: Wednesday, December 03, 2003 3:37 PM
Subject: Re: KWH Sales

Thanks for the info. Very much appreciated.

James Ehnstrom
Worceter Polytechnic Institute
cell 5086621588

B.6: Correspondence with Don Chappell of the South Deerfield WWTP

----- Original Message -----
From: James Ehnstrom
To: sdwwtp@valinet.com
Sent: Monday, January 19, 2004 12:54 AM
Subject: Biodiesel Research

I am part of a research group doing a study on Biodiesel and Biohydrogen production from Algae. One possible site for an algae farm would be a wastewater treatment facility, using the waste as a carbon source for the algae. I am curious as to what the total area of your treatment tanks is, specifically where there is a high concentration of carbon. Could you please send me any information that you may have concerning this subject. Any and all help that you could provide would be very much appreciated.

James Ehnstrom
Worceter Polytechnic Institute

----- Original Message -----
From: Don Chappell
To: James Ehnstrom
Sent: Wednesday, January 21, 2004 11:47 AM
Subject: Re: Biodiesel Research

It sounds like you have an intriguing idea. We have two complete mix aeration tanks 68'x68'x15' with a total volume of 500,000 gallons each.

Don Chappell, Chief Operator
South Deerfield WWTP

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