

Why BioDiesel and Not Hydrogen Cars...

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Widescale Biodiesel Production from Algae

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As more evidence comes out daily of the ties between the leaders of petroleum producing countries and terrorists (not to mention the human rights abuses in their own countries), the incentive for finding an alternative to petroleum rises higher and higher. The environmental problems of petroleum have finally been surpassed by the strategic weakness of being dependent on a fuel that can only be purchased from tyrants.

In the United States, oil is primarily used for transportation – roughly two-thirds of all oil use, in fact. So, developing an alternative means of powering our cars, trucks, and buses would go a long way towards weaning us, and the world, off of oil. The best alternative at present is clearly biodiesel, a fuel that can be used in existing diesel engines with no changes, and is made from vegetable oils or animal fats rather than petroleum.

In this report, we will first examine the possibilities of producing biodiesel on the scale necessary to replace all petroleum transportation fuels in the U.S.

I. How much biodiesel?

First, we need to understand exactly how much biodiesel would be needed to replace all petroleum transportation fuels. So, we need to start with how much petroleum is currently used for that purpose. Per the Department of Energy's statistics, each year the US consumes roughly 60 billion gallons of petroleum diesel and 120 billion gallons of gasoline. First, we need to realize that spark-ignition engines that run on gasoline are generally about 40% less efficient than diesel engines. So, if all spark-ignition engines are gradually replaced with compression-ignition (Diesel) engines for running biodiesel, we wouldn't need 120 billion gallons of biodiesel to replace that 120 billion gallons of gasoline. To be conservative, we will assume that the average gasoline engine is 35% less efficient, so we'd need 35% less diesel fuel to replace that gasoline. That would work out to 78

billion gallons of diesel fuel. Combine that with the 60 billion gallons of diesel already used, for a total of 138 billion gallons. Now, biodiesel is about 5–8% less energy dense than petroleum diesel, but its greater lubricity and more complete combustion offset that somewhat, leading to an overall fuel efficiency about 2% less than petroleum diesel. So, we'd need about 2% more than that 138 billion gallons, or 140.8 billion gallons of biodiesel. So, this figure is based on vehicles equivalent to those in use today, but with compression–ignition (Diesel) engines running on biodiesel, rather than a mix of petroleum diesel and gasoline. Combined diesel–electric hybrids in wide use would of course bring this number down considerably, but for now we'll just stick with this figure.

One of the biggest advantages of biodiesel compared to other alternative transportation fuels is that it can be used in existing diesel engines. This completely eliminates the "chicken–and–egg" dilemma that other alternatives have, such as hydrogen powered fuel cells. For fuel cells, even when (and if) vehicle manufacturers eventually have production stage vehicles ready, nobody would buy them unless there was already a wide scale hydrogen fuel production and distribution system in place. But, no companies would be interested in building that wide scale hydrogen fuel production and distribution system until a significant number of fuel cell vehicles are on the road, so that consumers are ready to start using it.

However, with biodiesel, since the same engines can run on conventional petroleum diesel, manufacturers can comfortably produce diesel vehicles before biodiesel is available on a wide scale. As biodiesel production continues to ramp up, it can just go into the same fuel distribution infrastructure, just replacing petroleum diesel. Not only does this eliminate the chicken–and–egg problem, making biodiesel a much more feasible alternative than fuel cells, but also eliminates the huge cost of revamping the nationwide fuel distribution infrastructure.

II. Large scale production

There are two steps that would need to be taken for producing biodiesel on a large scale – growing the feedstocks, and processing them into biodiesel. The latter step would perhaps be best accomplished by existing oil refineries within the US being converted to biodiesel refineries, but could also be accomplished by new companies building new plants. The main issue that is often contested is whether or not we would be able to grow enough crops to provide the oil for producing the amount of biodiesel that would be required to completely replace petroleum as a transportation fuel. So, that is the main issue that will be addressed here.

The Office of Fuels Development, a division of the Department of Energy, funded a program from 1978 through 1996 under the National Renewable Energy Laboratory known as the "Aquatic Species Program". The focus of this program was to investigate high oil yield algae that could be grown specifically for the purpose of wide scale biodiesel production¹. Some species of algae are ideally suited to biodiesel production due to their high oil content (some as much as 50% oil), and extremely fast growth rates. From the results

of the Aquatic Species Program², algae farms would let us supply enough biodiesel to completely replace petroleum as a transportation fuel in the US (as well as its other main use – home heating oil).

One of the important concerns about wide scale development of biodiesel is if it would displace croplands currently used for food crops. With algae, that concern is completely eliminated, as algae grows ideally in either hot desert climates or off of waste streams. NREL's research focused on the development of algae farms in desert regions, using shallow salt water pools for growing the algae. Another nice benefit of using algae as a food stock is that in addition to using considerably less water than traditional oilseed crops, algae also grows best in salt water, so farms could be built near the ocean with no need to desalinate the seawater as it is used to fill the ponds.

NREL's research showed that one quad (ten billion gallons) of biodiesel could be produced from 200,000 hectares of desert land (200,000 hectares is equivalent to 780 square miles). In the previous section, we found that to replace all transportation fuels in the US, we would need 140.8 billion gallons of biodiesel, or roughly 14 quads. To produce that amount would require a land mass of almost 11,000 square miles. To put that in perspective, consider that the Sonora desert in the southwestern US comprises 120,000 square miles. As can be seen in Figure 1 below, the Sonora desert is located along the Pacific ocean, making it an ideal location for algae farms. The arid climate of the desert is very supportive of algae growth, and the nearby ocean could supply saltwater for the algae ponds. Enough biodiesel to replace all petroleum transportation fuels could be grown in 11,000 square miles, or roughly nine percent of the area of the Sonora desert.

The algae farms would not all need to be built in the same location, of course. In fact, it would be preferable to spread them around throughout the country, to lessen the cost and energy used in transporting the feedstocks. Algae farms could also be constructed to use waste streams (either human waste or animal waste from animal farms) as a food source, which would provide a beautiful way of spreading algae production around the country. The algae farms also yield recoverable methane (commonly referred to as "biomethane" when it comes from biomass). This methane could then be turned into methanol, to provide a biomass derived source of alcohol for turning the algal oils into biodiesel. The left-over sludge remaining makes an ideal fertilizer, high in nitrogen and phosphorous. Such algae farms could also use the waste-streams from agriculture to aid algae growth.

III. Cost

In "The Controlled Eutrophication process: Using Microalgae for CO₂ Utilization and Agricultural Fertilizer Recycling"³, the authors estimated a cost per hectare of \$40,000 for algal ponds. In their model, the algal ponds would be built around the Salton Sea (in the Sonora desert) feeding off of the agricultural waste streams that normally pollute the Salton Sea with over 10,000 tons of nitrogen and phosphate fertilizers each year. The

estimate is based on fairly large scale ponds, 8 hectares in size each. To be conservative (since their estimate is fairly optimistic), we'll arbitrarily increase the cost per hectare by 50% as a margin of safety. That brings the cost per hectare to \$60,000. Ponds equivalent to their design could be built around the country, using wastewater streams (human, animal, and agricultural) as feed sources. We found that at NREL's yield rates, 11,000 square miles (2.82 million hectares) of algae ponds would be needed to replace all petroleum transportation fuels with biodiesel. At the cost of \$60,000 per hectare, that would work out to roughly \$169 billion, to build the farms.

The operating costs (including power consumption, labor, chemicals, and fixed capital costs (taxes, maintenance, insurance, depreciation, and return on investment) worked out to \$12,000 per hectare. That would equate to \$33.8 billion per year for all the algae farms, to yield all the oil feedstock necessary for the entire country. Compare that to the more than \$100 billion the US spends each year just on purchasing crude oil from foreign countries.

IV. Other issues

To make biodiesel, you need not only the vegetable oil, but an alcohol as well (either ethanol or methanol). The alcohol only constitutes about 20–25% of the volume of the biodiesel, so the volume of alcohol needed is only about 1/4 the volume of oil. One of the most land-efficient and energy-efficient way of producing methanol is using pyrolysis on biomass. One of the additional benefits of this method is that the process produces both methanol as well as charcoal, which can be burned for energy production (replacing coal, and producing no net CO₂ emissions or sulfate emissions). In the early days of the automobile, most vehicles ran on biofuels, with Henry Ford himself being a big advocate of methanol produced from industrial hemp (not to be confused with marijuana, which is significantly different). The Department of Energy's "Mustard Project" has focused on the prospect of growing mustard for the dual purposes of biodiesel and organic pesticide production. Their process focused on alternating mustard crops with wheat. One nice effect of this is that the wheat could be used as the cellulose feedstock for producing alcohol through pyrolysis for biodiesel production.

V. Hydrogen?

Hydrogen as a fuel has received widespread attention in the media of late, particularly ever since the Bush administration proclaimed that developing a hydrogen economy would clean our air, and free us of oil dependence. There are many problems with using hydrogen as a fuel. The first, and most obvious, is that hydrogen gas is extremely explosive. To store hydrogen at high pressures for as a transportation fuel, it is essential to have tanks that are constructed of rust-proof materials, so that as they age they won't rust and spring leaks. Hydrogen has to be stored at very high pressures to try to make up for its low energy density. Diesel fuel has an energy density of 1,058 Btu/cu.ft. Biodiesel has an energy density of 950 Btu/cu.ft, and hydrogen stored at 3,626 psi (250 times atmospheric pressure) only has an energy density of 68 Btu/cu.ft.⁴ Hydrogen's energy density is only 7.2% of

that of biodiesel. Even if the hydrogen fuel cell is twice as efficient as a diesel engine, running on hydrogen stored at 250 atmospheres would yield an equivalent vehicle only 14% of the range of a vehicle running on biodiesel, with equivalent space set aside for fuel storage. To get a 1,000 mile range, a tractor trailer running on diesel needs to store 168 gallons of diesel fuel. When the greater efficiency of the engine running on biodiesel is taken into account, it would need roughly 175 gallons of biodiesel for the same range. But, to run on hydrogen stored at 250 atmospheres, to get the same range would require 2,360 gallons of hydrogen. Dedicating that much space to fuel storage would drastically reduce how much cargo trucks could carry. Additionally, the cost of the high pressure, corrosion resistant storage tanks to carry that much fuel is astronomical.

There are two options for using hydrogen in a fuel cell – using compressed hydrogen produced by electrolyzing water, and extracting hydrogen from other fuels. I will look at each individually, and then analyze the use of hydrogen as a fuel in general. Currently, most hydrogen used industrially is extracted from natural gas. At current usage rates, the United States will deplete its natural gas reserves in 46 years. If the use of natural gas for transportation (whether directly, or as hydrogen extracted from natural gas) increases dramatically, the time it will take before we use up all of our reserves will decrease correspondingly. One of the primary reasons for looking for alternatives to petroleum is to decrease our dependence on foreign fuels. If we spend trillions of dollars converting to using natural gas, only to use up our own reserves in a decade or two, we would find ourselves back in the exact same position of being dependent on foreign sources.

Thus, the focus needs to be on renewable fuels. For hydrogen, it is only renewable when it is extracted from biofuels, or when the hydrogen is produced by electrolyzing water using renewable energies (wind, solar, etc.). The most logical biofuel to use in fuel cells would be biodiesel, due to its high energy balance and energy density. But, let's consider the option of producing hydrogen through electrolysis.

VI. Hydrogen electrolyzed from water

The first way to look at a potential transportation fuel is to examine the overall energy balance. The energy balance tells you how much energy you get back for each unit of energy you put into developing the fuel. The higher the energy balance, the better the fuel source. The lower the energy balance, the more energy that has to be put into producing the fuel per amount of energy yielded when using the fuel.

When discussing hydrogen as a fuel, people usually take a very simplified approach. When used in a fuel cell, the only by-product of using hydrogen as a fuel is water. However, that completely ignores the issue of where the hydrogen came from in the first place. It is tempting to think that this hydrogen would be produced by electrolyzing water using renewable energy sources, such as wind. To see how realistic this approach is, it is important to analyze the overall energy balance, and henceforth the amount

of energy that would need to be produced for the fuel to be used on a wide scale.

The place to start with hydrogen is electrolysis (directly separating the hydrogen and oxygen atoms in water molecules, using electricity). While biodiesel is produced by growing crops and transesterifying the oils, hydrogen as a fuel could be produced by electrolyzing water. Electrolysis systems are around 60% efficient. That means that for each unit of energy you put in, the amount of recoverable energy in the hydrogen produced is equal to 0.6 units. The hydrogen then needs to be compressed to high pressures for storage in fuel tanks (due to the low energy density, hydrogen has to be stored at high pressures so that vehicles can have a reasonable range). Compressing the hydrogen takes energy, but for the moment we will ignore this energy cost, as well as the cost of transporting hydrogen (likewise, we will ignore the cost of transporting biodiesel. Transporting biodiesel should be more efficient, since hydrogen needs to be stored and shipped in high pressure stable metal containers (which are very heavy), whereas biodiesel can be shipped in the same fuel trucks used today. The mass of the fuel tanks for transporting hydrogen is a greater percentage of the energy yield in the fuel than for biodiesel)).

So, the hydrogen fuel can be produced with an energy balance of 0.6:1 (0.6 units produced per unit of energy input, a 60% efficiency). Current generation fuel cells are 50–60% efficient. Assuming a 60% efficiency, that reduces the overall energy yield from 0.6:1 down to 0.36:1. That means that for each unit of energy that goes into producing the fuel (hydrogen), 0.36 units of energy gets used for moving a vehicle.

The limited range of hydrogen powered vehicles makes them comparable to electric vehicles. The energy balance, however, is completely different. While a hydrogen vehicle would use electricity to electrolyze water to get hydrogen for fuel, an electric vehicle uses electricity to charge batteries. Battery charging systems are around 90% efficient, compared to the 60% efficiency for electrolysis. Using the charged batteries to propel a car has an efficiency in the upper 90% range, giving electric cars an overall energy efficiency of around 85%, or 0.85:1. The energy balance of electric vehicles is more than twice as efficient as a car powered with hydrogen produced through electrolysis.

Now let us consider biodiesel. Based on a report by the US DOE and USDA entitled "Life Cycle Inventory of Biodiesel and Petroleum Diesel for Use in an Urban Bus"⁵, biodiesel produced from soy has an energy balance of 3.2:1. That means that for each unit of energy put into growing the soybeans and turning the soy oil into biodiesel, we get back 3.2 units of energy in the form of biodiesel. That works out to an energy efficiency of 320%. The reason for the energy efficiency being greater than 100% is that the growing soybeans turn energy from the sun into chemical energy (oil). Current generation diesel engines are 43% efficient (HCCI diesel engines under development, and heavy duty diesel engines have higher efficiencies, but for the moment we'll just use current car-sized diesel engine technology). That brings the overall energy balance down to 1.38:1, roughly three times better

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than the 0.36:1 of the hydrogen fuel cell car. This figure means that for each unit of energy that goes into growing the crops and producing the biodiesel, 1.38 units of energy are available to be used for moving the vehicle, a net gain of 38%, compared to a net loss of 64% for hydrogen. With the improved energy balances of other crops such as mustard and algae compared to the 3.2:1 of soy, this energy balance would be even better.

The UNH Biodiesel Group is working on improving the technology for growing algae on waste streams for biodiesel production. UNH has filed a provisional patent application and is seeking partners to develop the technology. For more information contact:

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