Save to disk [HELP]
Hide/Show menus

The Answer is Biodiesel

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.

continued ▸

by Michael Briggs

	BIODIESEL	HYDROGEN
Technological Readiness	Can be used in existing diesel engines, which have already been in use for 100 years	At least ten years away
Fuel source	Algae farms or other vegetable crops, or waste conversion. Completely renewable process, with no net CO_2 emissions.	Electrolyzing water (most likely using fossil fuel energy) or reforming fossil fuels. Most likely non-renewable methods with large net CO_2 emissions
Fuel Distribution System	Can be distributed with existing filling stations with no changes.	No system currently exists, would take decades to develop. Would cost $176 billion to put one hydrogen pump at each of the filling stations in the US.
Overall Energy Balance (each unit of energy put in yields....) *[higher is better]*	3.2 units (soy), 4.3 units (rapeseed)	0.5 units (electrolyzing water into hydrogen with renewable sources)
Large scale fuel development cost analysis	For an estimated $169 billion*, enough algae farms could be built to completely replace petroleum transportation fuels with biodiesel	To produce enough clean hydrogen for our transportation needs would cost $2.5 trillion (wind power) or $25 trillion (solar)
Safety	Flash point of biodiesel is over 300° F (considered "not flammable")	Highly flammable

	BIODIESEL	HYDROGEN
Time scale for wide scale use	5–10 years	30–50 years optimistic assumption
Cost of engines	Comparable to existing vehicles	Currently 50–100 times as expensive as existing engines. The cost of the fuel cells themselves will come down significantly the cost of the infrastructure and making the hydrogen will not
Vehicle performance	Significantly better range than gasoline vehicles, comparable power (roughly 700 mile range for Volkswagen Jetta TDI)	Significantly smaller range than gasoline vehicles (180 mile range for Toyotas FCHV)
Tank capacity re–quired for 1,000 mile range in conventional sedan	20 gallons	268 gallons

* "Widescale Biodiesel Production from Algae", Michael Briggs, UNH Physics Department

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. The economic strain on our country resulting from the $100-150 billion we spend every year buying oil from other nations, combined with the occasional need to use military might to protect and secure oil reserves our economy depends on just makes matters worse (and using military might for that purpose just adds to the anti-American sentiment that gives rise to terrorism). Clearly, developing alternatives to oil should be one of our nation's highest priorities.

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. While the so-called "hydrogen economy" receives a lot of attention in the media, there are several very serious problems with using hydrogen as an automotive fuel. For automobiles, 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 paper, I 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, as well as fewer people driving large SUVs when they don't need such a vehicle would of course bring this number down considerably, but for now we'll just stick with this figure. (Note: My point here is not to claim that conservation is not worthwhile, rather to strictly look at the issue of replacing our current use of fuel with biodiesel — to see how achievable that is). I would like to point out though that a preferable scenario would include a shift to diesel-electric hybrid vehicles (preferably with the ability to be recharged and drive purely on electric power for a short range, perhaps 20-40 miles, to provide the option of zero emissions for in-city driving), and with far fewer people buying 6-8,000 pound SUVs merely to commute to work in by themselves. Those changes could drastically reduce the amount of fuel required for our automotive transportation, and are technologically feasibly currently (see for example Chrysler's Dodge Intrepid ESX3, built under Clinton's PNGV program — a full-size diesel electric hybrid sedan that averaged 72 mpg in mixed driving[6,7]).

One of the biggest advantages of biodiesel… is that it can be used in existing diesel engines without modification.

One of the biggest advantages of biodiesel compared to many other alternative transportation fuels is that it can be used in existing diesel engines without modification, and can be blended in at any ratio with petroleum diesel. This completely eliminates the "chicken-and-egg" dilemma that other alternatives have, such as hydrogen-powered fuel cells. For hydrogen vehicles, even when (and if) vehicle manufacturers eventually have production stage vehicles ready (which currently cost around $1 million each to make), 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. With a single hydrogen fuel pump costing roughly $1 million, installing just one at each of the 176,000 fuel stations across the US would cost $176 billion — a cost that can be completely avoided with liquid biofuels that can use our current infrastructure.

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 some manufacturers already are (the same can be said for flex-fuel vehicles capable of running on ethanol, gasoline, or any blend of the two). As biodiesel production continues to ramp up, it can go into the same fuel distribution infrastructure, just replacing petroleum diesel either wholly (as B100, or 100% biodiesel), or blended in with diesel. Not only does this eliminate the chicken-and-egg problem, making biodiesel a much more feasible alternative than hydrogen, 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 main issue that is often contested is whether or not we would be able to grow enough crops to provide the vegetable oil (feedstock) 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 point of this article is not to argue that this approach is the only one that makes sense, or that we should ignore other options (there are some other very appealing options as well, and realistically it makes more sense for a combination of options to be used). Rather, the point is merely to look at one option for producing biodiesel, and see if it would be capable of meeting our needs.

For any biofuel to succeed at replacing a large quantity of petroleum, the yield of fuel per acre needs to be as high as possible.

One of the important concerns about wide-scale development of biodiesel is if it would displace croplands currently used for food crops. In the US, roughly 450 million acres of land is used for growing crops, with the majority of that actually being used for producing animal feed for the meat industry. Another 580 million acres is used for grassland pasture and range, according to the USDA's Economic Research Service. This accounts for nearly half of the 2.3 billion acres within the US (only 3% of which, or 66 million acres, is categorized as urban land). For any biofuel to succeed at replacing a large quantity of petroleum, the yield of fuel per acre needs to be as high as possible. At heart, biofuels are a form of solar energy, as plants use photosynthesis to convert solar energy into chemical energy stored in the form of oils, carbohydrates, proteins, etc. The more efficient a particular plant is at converting that solar energy into chemical energy, the better it is from a biofuels perspective. Among the most photosynthetically efficient plants are various types of algaes.

Algae farms would let us supply enough biodiesel to completely replace petroleum as a transportation fuel in the U.S.

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 algaes that could be grown specifically for the purpose of wide scale biodiesel production.[1] The research began as a project looking into using quick-growing algae to sequester carbon in CO_2 emissions from coal power plants. Noticing that some algae have very high oil content, the project shifted its focus to growing algae for another purpose — producing biodiesel. Some species of algae are ideally suited to biodiesel production due to their high oil content (some well over 50% oil), and extremely fast growth rates. From the results of the Aquatic Species Program,[2] 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) — but we first have to solve a few of the problems they encountered along the way.

NREL's research focused on the development of algae farms in desert regions, using shallow saltwater pools for growing the algae. Using saltwater eliminates the need for desalination, but could lead to problems as far as salt build-up in ponds. Building the ponds in deserts also leads to problems of high evaporation rates. There are solutions to these problems, but for the purpose of this paper, we will focus instead on the potential such ponds can promise, ignoring for the moment the methods of addressing the solvable challenges remaining when the Aquatic Species Program at NREL ended.

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, roughly 500,000 acres), if the remaining challenges are solved (as they will be, with several research groups and companies working towards it, including ours at UNH). 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 19 quads (one quad is roughly 7.5 billion gallons of biodiesel). To produce that amount would require a land mass of almost 15,000 square miles. To put that in perspective, consider that the Sonora desert in the southwestern US comprises 120,000 square miles. Enough biodiesel to replace all petroleum transportation fuels could be grown in 15,000 square miles, or roughly nine percent of the area of the Sonora desert. (Note for clarification — I am not advocating putting 15,000 square miles of algae ponds in the Sonora desert. This hypothetical example is used strictly for the purpose of showing the scale of land required.) That 15,000 square miles works out to roughly 9.5 million acres — far less than the 450 million acres currently used for crop farming in the US, and the over 500 million acres used as grazing land for farm animals.

The algae farms would not all need to be built in the same location, of course (and should not for a variety of reasons). The case mentioned above of building it all in the Sonora desert is purely a hypothetical example to illustrate the amount of land required. It would be preferable to spread the algae production around 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. Nutrients can also be extracted from the algae for the production of a fertilizer high in nitrogen and phosphorous. By using waste streams (agricultural, farm animal waste, and human sewage) as the nutrient source, these farms essentially also provide a means of recycling nutrients from fertilizer to food to waste and back to fertilizer. Extracting the nutrients from algae provides a far safer and cleaner method of doing this than spreading manure or wastewater treatment plant "bio-solids" on farmland.

These projected yields of course depend on a variety of factors, sunlight levels in particular. The yield in North Dakota, for example, wouldn't be as good as the yield in California. Spreading the algae production around the country would result in more land being required than the projected 9.5 million acres, but the benefits from distributed production would outweigh the larger land requirement.

III. Cost

In "The Controlled Eutrophication process: Using Microalgae for CO_2 Utilization and Agircultural 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 agircultural 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 ponds, 8 hectares in size each. To be conservative (since their estimate is fairly optimistic), we'll arbitrarily increase the cost per hectare by 100% as a margin of safety. That brings the cost per hectare to $80,000. 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, 15,000 square miles (3.85 million hectares) of algae ponds would be needed to replace all petroleum transportation fuels with biodiesel. At the cost of $80,000 per hectare, that would work out to roughly $308 billion to build the farms.

Extracting the nutrients from algae provides a far safer and cleaner method of doing this than spreading manure or wastewater treatment plant "bio-solids" on farmland.

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 $46.2 billion per year for all the algae farms, to yield all the oil feedstock necessary for the entire country. Compare that to the $100–150 billion the US spends each year just on purchasing crude oil from foreign countries, with all of that money leaving the US economy.

These costs are based on the design used by NREL — the simple open-top raceway pond. Various approaches being examined by the research groups focusing on algae biodiesel range from being the same general system, to far more complicated systems. As a result, this cost analysis is very much just a general approximation. Some systems could be considerably more expensive, but could also see considerably higher yields, resulting in less land being required. How exactly the economics play out will hopefully be decided over the next few years as some of these groups research algal biodiesel bring their systems to commercialization status.

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 10% of the volume of the biodiesel. Among the most land-efficient and energy-efficient methods of producing alcohol is from hydrolysis and fermentation of plant cellulose. In the early days of the automobile, most vehicles ran on biofuels, with Henry Ford himself being a big advocate of alcohol produced from industrial hemp (not to be confused with marijuana). 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 biomass from the mustard (after harvesting the seed) could be used as the cellulose feedstock for producing alcohol 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] So, highly pressurized to 250 atmospheres, hydrogen's volumetric energy density is only 7.2% of that of biodiesel. The result being that with similar efficiencies of converting that stored chemical energy into motion (as diesel engines and fuel cells have), a hydrogen vehicle would need a fuel tank roughly 14 times as large to yield the same driving range as a biodiesel powered vehicle. To get a 1,000 mile range, a tractor trailer running on diesel needs to store 168 gallons of diesel fuel. When biodiesel's slightly lower energy density and the greater efficiency of the engine running on biodiesel are 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.

At current usage rates, the United States will deplete its projected natural gas reserves in 46 years — or deplete the currently proven reserves in roughly 10 years.

There are two main options for producing hydrogen — generating it from water, and extracting it from other fuels. With each case, the energy efficiency is well below 100% (i.e. you have to put more energy into separating the hydrogen than the chemical energy the hydrogen itself has). 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 through steam reformation. At current usage rates, the United States will deplete its projected natural gas reserves in 46 years — or deplete the currently proven reserves in roughly 10 years (we use around 22.5 trillion cubic feet (tcf) a year, and have a little over 200 tcf of proven reserves). 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 that we cannot run out of. For hydrogen, it is only renewable when it is extracted from biomass, or when the hydrogen is produced by electrolyzing water using renewable energies (wind, solar, etc.). The option of producing it from biomass is not particularly enticing. It can be done through gasification and steam reformation, but with a disappointingly low thermal efficiency. The need to compress or liquify (or bind in another form such as a metal hydride) the hydrogen for transport and storage further reduces the efficiency, and increases the cost. Biomass can be converted to liquid fuels more efficiently, yielding a fuel with far higher energy density, and that can work in existing, affordable vehicles. So, since biomass derived hydrogen is less appealing than liquid biofuels, 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 efficiency for its production. Ultimately we want to know how much energy you get back for each unit of energy you put into developing the fuel — or the Energy Return on Investment (EROI). The higher the EROI, the better.

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 inefficiency of using electricity to produce and use hydrogen means it makes far more sense to first use any newly installed solar or wind power as direct electricity consumption, rather than for hydrogen vehicles.

A common dream from the environmentalist community is having a solar panel on the roof of a home to electrolyze water, producing hydrogen for a fuel cell vehicle. It's a nice dream, but not particularly realistic. As a real world example, consider Honda's facility in California that requires an 8 kW solar array to produce enough hydrogen to drive one small hydrogen vehicle roughly 7,500 miles per year.[8, 9, 10] Such an array could power several homes in California, but is only enough for powering one small car half the normal driving range in the US. For an average family with two vehicles that drive an average distance of 15,000 miles per year, an array of 32 kW would be needed — considerably more with larger vehicles. A 32 kW array would cost on the order of $160,000, and could not be installed just on the rooftop of a single home

— it would likely require the south-facing rooftops of at least 4-8 houses to power the vehicles from one home (and that's if you live in sunny California — in less sunny regions you'd need considerably more). The inefficiency of using electricity to produce and use hydrogen means it makes far more sense to first use any newly installed solar or wind power as direct electricity consumption (in houses, businesses, etc.), rather than for hydrogen vehicles. A home in California could meet all of its electric needs with perhaps a 2-4 kW array, depending on the household efficiency. Yet to power their vehicles it would require a 32 kW array or more. With so few people installing the much smaller arrays needed to meet their electrical needs, how likely is it that many would install (or be able to afford to install) a much larger array for their vehicles?

Why does it require so large an array? Look at the efficiency. Electrolysis systems are around 70% efficient (smaller scale systems are less efficient, large scale industrial ones are higher — 70% is a rough average). That means that for each unit of energy you put in, the amount of recoverable energy in the hydrogen produced is equal to 0.7 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 is roughly 85% efficient, liquefaction considerably lower. I will ignore the cost of transporting hydrogen, the efficiency of which is far lower than transporting biodiesel. Since it is highly unlikely that clean solar or wind power would be used for electrolyzing water to make hydrogen (see the above paragraph), I will assume that it would use coal or natural gas derived electricity (this could also come from burning biomass). Most such power plants operate with efficiencies below 40%, but I will use that very favorable figure.

So, the hydrogen fuel can be produced with an overall efficiency of 23.8% — or an EROI of 0.238. Current generation fuel cells are 40–60% efficient. Assuming a very favorable 60% efficiency, that reduces the overall energy return down to 14.28%. That means that for each unit of energy in the form of fuel burned to make electricity, only 14.28% of it is usable for powering the electric motor in a fuel cell vehicle. Steam reformation of natural gas is a far more likely scenario for hydrogen production, as it can be done with roughly a 66% efficiency. Including compression (85%) and use in a fuel cell (a very favorable 60%, with 45% being more likely), the overall efficiency is then 33.6% (or a fossil energy balance of 0.336). The problem is natural gas is not a renewable resource, and the US could not meet the demand of a nationwide hydrogen economy fed off natural gas. We would simply be replacing foreign oil dependence with foreign natural gas dependence. With natural gas being much more expensive (and inefficient) to transport over long distances, this isn't a desirable scenario.

With natural gas being much more expensive (and inefficient) to transport over long distances, this isn’t a desirable scenario.

The limited range of hydrogen powered vehicles makes them comparable to electric vehicles in many ways. The energy efficiency, 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 70% efficiency for electrolysis. Using the charged bat–

teries and an electric motor to propel a car has an efficiency in the 90% range, giving electric cars an overall energy efficiency of around 81% (once the electricity is produced, so not counting energy losses at that end). By contrast, once the electricity is produced, the efficiency is only around 32%. As can be seen, if the desire is to use electricity to power our vehicles, it is far more efficient to do so with electric cars, rather than hydrogen fuel cell vehicles. Electric vehicles are also far cheaper, another plus. This is why diesel-electric hybrids with the ability to be recharged and operate solely on electric power for a short range are an ideal choice for people who live in cities, or have short commutes to work. It allows fairly efficient zero-emissions operation on short commutes, while the diesel engine running on biodiesel allows zero net greenhouse gas emissions and practically-zero regulated emissions on longer trips.

If the desire is to use electricity to power our vehicles, it is far more efficient to do so with electric cars, rather than hydrogen fuel cell vehicles.

What is the energy efficiency for producing 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% (when only looking at fossil energy input — input from the sun, for example, is not included). 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 approaching 55% (better than fuel cells), but for the moment we'll just use current car-sized diesel engine technology). That 3.2 energy balance is for biodiesel made from soybean oil — a rather inefficient crop for the purpose. Other feedstocks such as algaes can yield substantially higher energy balances, as can using thermochemical processes for processing wastes into biofuels (such as the thermal depolymerization process pioneered by Changing World Technologies). Such approaches can yield EROI values ranging from 5-10, potentially even higher.

ENDNOTES

1 http://www.nrel.gov/docs/legosti/fy98/24190.pdf
2 http://www.nrel.gov/docs/legosti/fy98/24190.pdf
3 http://www.unh.edu/p2/biodiesel/pdf/algae_salton_sea.pdf
4 http://www.osti.gov/fcvt/deer2002/eberhardt.pdf
5 http://www.nrel.gov/docs/legosti/fy98/24089.pdf
6 http://www.autointell.net/nao_companies/daimlerchrysler/dodge/dodge-esx3-01.htm
7 http://www.allpar.com/model/intrepid-esx3.html
8 http://www.eere.energy.gov/hydrogenandfuelcells/hydrogen/iea/pdfs/honda.pdf
9 http://www.caranddriver.com/article.asp?section_id=27&article_id=4217&page_number=1
10 http://www.caranddriver.com/article.asp?section_id=27&article_id=4217&page_number=2

LAST PAGE READ

info

ABOUT THE AUTHOR

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 Michael Briggs 603-862-2828; email michael.briggs@unh.edu.

DOWNLOAD THIS

This manifesto is available from http://changethis.com/9.Biodiesel

SEND THIS

Click here to pass along a copy of this manifesto to others.
http://changethis.com/9.Biodiesel/email

SUBSCRIBE

Learn about our latest manifestos as soon as they are available. Sign up for our free newsletter and be notified by email. http://changethis.com/subscribe

info

WHAT YOU CAN DO

You are given the unlimited right to print this manifesto and to distribute it electronically (via email, your website, or any other means). You can print out pages and put them in your favorite coffee shop's windows or your doctor's waiting room. You can transcribe the author's words onto the side–walk, or you can hand out copies to everyone you meet. You may not alter this manifesto in any way, though, and you may not charge for it.

NAVIGATION & USER TIPS

Move around this manifesto by using your keyboard arrow keys or click on the right arrow (→) for the next page and the left arrow (←). To send this by email, just click on ✉ .

HAVING PROBLEMS SAVING TO DISK?

First, make sure you have the latest version of Acrobat Reader 6 which you can download from http://www.adobe.com/products/acrobat/readstep2.html. If problems persist, it may be due to your Acrobat Reader settings. To correct the problem (for Windows), a reader, J. Hansen, suggests going to your Acrobat Reader Preferences > Options > Web browser Options. Check the "Display PDF in Browser" option. Then click on Save to Disk .

KEYBOARD SHORTCUTS	PC	MAC
Zoom in (Larger view)	[CTL] [+]	[⌘] [+]
Zoom out	[CTL] [–]	[⌘] [–]
Full screen/Normal screen view	[CTL] [L]	[⌘] [L]

LAST PAGE READ | MORE →

info

BORN ON DATE

This document was created on 29 November 2004 and is based on the best information available at that time. To check for updates, please click here to visit http://changethis.com/9.Biodiesel

COPYRIGHT INFO

Cover image from stock.xchng http://sxc.hu/index.phtml

ABOUT CHANGETHIS

ChangeThis is a vehicle, not a publisher. We make it easy for big ideas to spread. While the authors we work with are responsible for their own work, they don't necessarily agree with everything available in ChangeThis format. But you knew that already.