

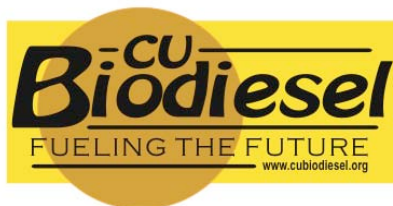
Synergy of the Americas

A Model for Biodiesel Production



Written by Evan Belser & Nick Hedlund

Generous contributions from John Bush, Gabe Ciafre, David Giwosky, Robert Schorlemmer, Martin Stenflo, Melanie Zauscher and the people of Centro Las Gaviotas.



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This document should be of interest to anyone concerned with understanding and addressing the most significant social and ecological challenges of the twenty-first century.

More specifically, however, this document is intended as a resource manual for individuals, communities, and/or organizations interested in the possibilities of biodiesel production, as vegetable derived fuels are an exemplar of sustainable development. Our hope is that this document will not be used merely as an “academic tour” of some abstract renewable energy landscape, but will inspire concrete action that will contribute to the evolution of the planet.

This document is a concise gathering of our knowledge and is enriched by the wisdom of other biodiesel experts. Our experience began as biodiesel homebrewers and lobbyists for its use in Boulder, Colorado under the auspices of Boulder Biodiesel and CU Biodiesel. The project with Gaviotas in Colombia widened our understanding of biodiesel production technology (palm oil is quite different than soy and canola oil) and introduced us to a drastically different social and economic landscape than we knew in Colorado.

We hope that both our triumphs and mistakes will serve you in your work to more easily create a project of your own, however that may look. By synthesizing some of our contextually specific insights with your own unique knowledge, then reinterpreting it and applying it within your local setting, our hope is that you can more effectively realize your dreams.

“La Madurez Consiste en Realizar los Suenos.” (Maturity Consists in the Realization of your Dreams.)
-Centro Las Gaviotas, Orinoquia Colombiana

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Project Narrative

The Project of the Twenty-First Century

As we begin a new millennium, we are confronted with a world of unprecedented crises, latent with both danger and opportunity. A growing consensus of scientists, scholars, and community leaders now recognize that the world is facing an unprecedented challenge. Pervasive ecological and social crises mark our current age as an unparalleled epoch of human history. While we have successfully confronted profound challenges many times before, never before have we faced such daunting *global* challenges that threaten our very existence as a species. We have indeed arrived at a crucial and portentous turning point in late modern civilization.

In a matter of decades human civilization has caused the profound contamination of the planet's water, air, and soil; the destabilization of the climate; massive species extinction; topsoil loss; deforestation; overfishing; the bioaccumulation of toxins; endocrine disruption; the depletion of groundwater; the breakdown of the ozone layer; acidification; desertification, the loss of evolutionary potential and all this while almost 6.4 billion people continue to reproduce and consume natural resources at exponentially increasing rates. It is therefore little wonder that every living system on the planet is currently in a state of decline¹. In withholding all the ghastly statistics, we presume it to be relatively clear that the continuation of our current path is a recipe for disaster, as has been amply documented.²

Furthermore, we also face significant challenges in terms of explicit social and economic concerns. Current forms of economic globalization have tended to benefit the few and not the many; the top 20% earn 90 times the income of the poorest 20%, while consuming over 11 times as much energy; 1.2 billion live without safe drinking water; 1.1 billion go hungry; 1.2 billion live without electricity for light; 4.2 billion can't read; and roughly 60 million human beings starve to death every year. Such astonishing conditions imply the notion of underdevelopment. This is global *underdevelopment*, implicating in particular, industrialized democracies, since we allow such injustice to persist.

Any intelligent analysis of such a situation cannot simply reduce the problem down to one causal agent, because linear chains of cause and effect do not exist in our complex, globally interconnected world. However, it is possible to critically discern the most salient interrelationships and pronounced factors. Systemic analysis looks at these interrelationships and factors within networks of causation and "solves for pattern." What

¹ Hawken, Paul. *The Ecology of Commerce*. p.22. Harper Business publishers. New York, 1993.

² See *State of the World*, and *Vital Signs*, a series of annual reports published by the Worldwatch Institute in collaboration with the United Nations. Also Hawken (1993), Orr (1994), and Capra (2002) offer excellent accounts.

is one pattern that connects the numerous problems that we see—from terrorism to war to economic inequality and extreme weather events? The answer: the geopolitics of fossil fuel.

In our contemporary world, such analysis is extremely useful because it can clarify our challenges and strategically prioritize our plan of action. For example, if we want to create greater security and peace in the world while mitigating human suffering, the best thing that we can do is to work towards a renewable energy economy. If we are concerned with a whole range of issues rather than just one or two, then such a systemic approach is likely our best platform for action. For example, if you are concerned with the issues of ecological sustainability, social justice, global security, and economic prosperity then you can address them all simultaneously by working to develop a feasible renewable energy paradigm.

Unprecedented Opportunity: Renewable Energy & Sustainable Development

Addressing the crises of the twenty-first century is not only about trying to solve problems and stop bad things from happening. Beyond the potential dangers of current predicament, we are presented with an incredible opportunity to create, for the first time, a just and sustainable world. In the words of systems theorist Ervin Laszlo, this is a momentous opportunity “for a historically unprecedented global project that would create the basis for a far wealthier, more equitable, and ultimately, much more peaceful world.” This possibility is within our grasp and there are certainly many ways to contribute to its emergence. In our analysis, renewable energy seems to be a central part of a systemic approach to creating a better world and an integral aspect of sustainable development.

As such, we believe that linking up renewable energy with sustainable development is crucial. While renewable energy is important everywhere, its social potential in the less developed world is highly pronounced. However, many renewable energy technologies are very expensive, high tech, and fabricated by and for the affluent population. Until very well funded organizations such as the World Bank and IMF step up to the plate and begin to significantly back renewable energy technologies such as solar and wind, their enactment will be stymied.

Biodiesel, in contrast, is one of the few renewable energy technologies that transcends such pitfalls; it is low-tech, viable for local production, easy to use, and in most tropical regions it is economically competitive. The potential for biodiesel to stimulate growth in multiple sectors of the economy is also enticing; biodiesel can create both industrial and agricultural economic opportunity. Furthermore, biodiesel does not require a new infrastructure- the existing one for petroleum diesel fuel is perfect- and is therefore highly practical. As such, we believe that biodiesel should be considered seriously as an important tool for sustainable development. It is our hope that our project in Colombia,

along with this document, will help to further the use of biodiesel as a powerful tool for sustainable development.

To be clear, we do not intend to force this technology down the throat of less developed nations with imperialistic fervor. The very notion of “development” often carries connotations of imperialism and neo-colonialism and is often perceived as a subtle form of colonialism cloaked in the language of social science. Skepticism of the notion of development is often warranted due to the history of its inception in the post-colonial context. Indeed, under the guise of modernization theory, many of the early so-called development projects likely were implemented largely for the purposes of securing the economic interests and geopolitical dominance of the industrialized democracies of the North, most prominently the United States and Britain. Nonetheless, an authentic form of development is possible. Moreover, we believe that the Gaviotas Biodiesel Project embodies a synergistic, co-operative, horizontal, and sustainable form of development. The following is a basic description of our project in Colombia

Gaviotas, Biodiesel, and Sustainable Development in Colombia

Although plagued by ongoing civil war, narcotrafficking, and widespread poverty, Colombia is also the site of one of the most inspiring social and environmental success stories ever told—the community of Gaviotas. In the latest chapter of Gaviotan history, what author and environmentalist Paul Hawken calls “the ongoing saga of what real, hands-on sustainability means,” our team from Colorado joined the effort by sharing our knowledge of vegetable-based fuel with the people of Gaviotas and together we build a biodiesel production facility at their center in Bogota, Colombia’s capital. In an effort of international cooperation the project demonstrates the potential of renewable energy technologies—particularly biodiesel—to create economic prosperity by doing what is most ecologically sustainable.

The community of Gaviotas was founded in the early 1970s by a group of scientists and engineers. For the past three decades the Gaviotans, made up of peasants, scientists, artists, and former street kids, have worked to create what has been called “an oasis of imagination and sustainability” in the remote, barren savannas of eastern Colombia, a region known for its particular political unrest. Spearheaded by visionary Paolo Lugari, Gaviotas has taken sustainable development and appropriate technology from abstraction to reality by developing their own windmills, solar collectors, and organic agriculture techniques. Moreover, they have regenerated the indigenous rainforest by planting millions of trees, enhancing biodiversity as well as the Earth’s ability to remove and store thousands of tons of the greenhouse gas carbon dioxide (CO₂), reducing the impacts of climate change. However, Gaviotas has continued to use petroleum-based diesel fuel to power their tractors and vehicles, because no other viable alternatives have been available. It was only recently that the possibility of using an ecological alternative to fossil fuels at Gaviotas has emerged.

In October 2003, Paolo Lugari was commissioned to deliver a keynote address at the Sustainable Resources Conference in Boulder, Colorado. It was there that the California based organization Friends of Gaviotas connected Lugari with the biodiesel community in Boulder, particularly Martin Stenflo of Boulder Biodiesel and Andrew Azman from CU Biodiesel, two of the country's most thriving grassroots biodiesel organizations. Stenflo and Azman invited Lugari to visit Boulder Biodiesel's production facility, where he was inspired instantly and a vision born. "This is exactly what we need in Gaviotas," exclaimed Lugari. Thereafter, we in Boulder have maintained an ongoing dialogue with Lugari and Centro Las Gaviotas, the Bogota based organization that supports the community of Gaviotas and related projects.

As the project took form, we began to design a processor and make preparations to travel to Colombia to assist with the completion of the facility. The Design was completed in March and sent down to Centro Las Gaviotas so that they could order the necessary equipment and begin to assemble to plant. On April 12, 2004 our six member team—Evan Belser, John Bush, David Giwosky, Nicholas Hedlund, Martin Stenflo, and Melanie Zaucher—traveled to Centro Las Gaviotas for a three-week consultation regarding system design and construction, as well as refining the chemical processes related to palm biodiesel production. On a side note, we purchased carbon credits (through the Better World Club, mitigators of atmospheric carbon accumulation) so that our travel would not contribute to climate change. The processor was built in less than a month and can produce four hundred thousand gallons of biodiesel a year, made with waste grease from local restaurants as well as locally grown crude palm oil. Several varieties of palm will be planted in Gaviotas next year such that they will be able to produce their own sustainably produced oil and therefore create a cost-effective closed loop cycle, which promises to enhance the already numerous benefits of biodiesel.

Within the first six months, many of the imperfections of the facility have been accounted for. The Gaviotas philosophy is that, provided you are actively doing something, then you are making no mistakes but only learning more. When recently asked what problems they've encountered in the facility, he answered, "there are no problems; we are in the continuous process of optimization." At the time of this document's completion, the facility had produced over 20 metric tons of high quality biodiesel, all of which has been used by the organization, mostly in the community of Gaviotas.

With all the advantages of biodiesel in mind, Paolo Lugari sees this United Nations endorsed project as the first of many biofuels projects that will later incorporate biomass, ethanol, and hydrogen, among others. In particular, Lugari believes that the cultivation of crops for biofuels could ripple throughout rural farming communities (campesinos), bringing a bit of prosperity and hope to the poverty stricken regions of Latin America. "This technology will spread through the countryside, empowering communities and eradicating poverty. No technology can call itself appropriate without doing just that." says Lugari in his characteristically impassioned tone. As such, Lugari believes that biofuels hold a powerful potential for sustainable development. Lugari emphasizes the

accessibility of biodiesel and its related production. It can be integrated on a community level and does not require an engineering background; it involves and brings together schooled and unschooled people and is easy to produce. For example, the plant manager at Gaviotas has only a fourth grade education, yet operates the facility with proficiency. Biofuel, as conceived by Gaviotas, represents the convergence of multiple concerns and agendas; it addresses economic, social, and ecological concerns simultaneously, thus exemplifying a systemic approach to sustainable development. It is therefore little wonder that the United Nations calls Gaviotas “a model for sustainable development,” and continues to offer active endorsement. Furthermore, the U.N. minister for Colombia has expressed support for the project and plans to tour the facility. Lugari stresses that our collaboration takes the development model to a new level as it embodies a horizontal, mutually beneficial approach of information sharing, international cooperation, and cross-cultural synergy. This approach stands in stark contrast to the traditionally imperialistic “modernization” projects characteristic of most development efforts. “This is a symbiotic project. We, the Colorado team, benefit as much as the Gaviotans do,” says Melanie Zauscher, a dual citizen of the U.S. and Colombia.

Since Gaviotas is one of the most advanced sustainable communities, it is sometimes called a utopia. But Lugari argues that, “utopia literally means *no place*. We call Gaviotas a *topia*, because it’s real.” Indeed, Gaviotas is a real place from which the world can learn. In an age of profound geopolitical, economic, and ecological instability, Gaviotas is a concrete demonstration that a more stable and prosperous world is not only possible, but also practical. The renewable energy technologies of Gaviotas, and in this case, biodiesel, embody an awareness that the challenges of the twenty-first century—economic, social, and ecological— cannot be tackled in isolation but must be addressed as a whole. Noble Laureate Gabriel Garcia Marquez has called Paolo Lugari the “inventor of the world,” and the recent biodiesel project shows that this invention is not static, but rather is an ongoing evolution, promising to challenge our notions of what is possible for decades to come.

Superior Hydrocarbons

Petroleum diesel fuel is- beside sulfur-based lubricating oils, residual oils (hydrotreated and solvent dewaxed), mineral oils, distillates, alkaryl amine, benzenamine, phosphorodithioic acid, zinc salts and other additives- made of hydrocarbons. These hydrocarbons are a refined product from crude oil, which is mostly decomposed plant and animal matter that's been in the Earth for well over 40,000,000 years.

Biodiesel fuel is also made of hydrocarbons, each attached to a molecule of methanol. These hydrocarbons are derived from plants or from animal fats and have had the glycerin content removed by a chemical change.

Both kinds of hydrocarbons are perfectly suitable for use in a Diesel engine without any kind of modification. Their performance and fuel economy are nearly identical. One substantial difference is that biodiesel needs no lubricating additives like petroleum does because it's naturally lubricious. Longer engine life and less frequent maintenance are reported with dedicated biodiesel use, once natural rubber components of the fuel system have been replaced, a minor alteration. Biodiesel actually acts as a solvent, knocking loose from an engine residuals from petroleum diesel use. The engines fuel filter will need to be monitored for this reason.

An energy balance is a measure applied to fuels that states the amount of energy required to produce the fuel in terms of the amount of energy contained in the fuel itself. Because petroleum diesel requires the drilling of the Earth's crust, extraction of crude oil, energy intensive distillation of this crude oil, huge amounts of transport (mostly from the Middle East to the United States), it has an energy balance of 1:0.6. That is, for every unit of energy exerted for getting diesel fuel to the local pump, only 0.6 units of energy arrive. Biodiesel is quite the opposite. This has an energy balance of 1:3.5- a tremendous difference. So a gallon of biodiesel requires about 1/6 the energy to produce than does a gallon of petroleum diesel. Similarly, using one gallon of biodiesel offsets the six gallons of petroleum diesel. The difference is mostly due to the ease of biodiesel production and because vegetable oil or animal fats are gathered in an area, produced there and used in Diesel engines there. Indeed biodiesel is a fuel well suited for distributive generation, an energy paradigm that provides independence from foreign oil markets and their related geopolitical complexities.

Beside matters of engine performance and efficiency of production, the emissions of a fuel are crucially important. Petroleum diesel fuel is a tremendous polluter of the air, ground and water. Tailpipe emissions are detrimental to health of all Earth's organisms and ecosystems, and the devastation caused by drilling, refining and transportation of oil is irreversible. Burning fossil fuels is equivalent to transferring enormous amounts of carbon from deep within the Earth to the atmosphere, our air for breathing.

Because biodiesel is made of hydrocarbons from vegetable oils or animal fats, the carbon emitted upon burning it is the same net carbon that those plants and animals used for nourishment in the prior months and years. Thus, biodiesel deposits no net carbon into the atmosphere- it is carbon neutral. In this way biodiesel is an exemplar of renewable energy; its production depletes resources at a pace that they are naturally

replenished. Compared to those of diesel fuel, the emissions of particulate matter, sulfur dioxide, carbon monoxide and total unburned hydrocarbons from biodiesel are significantly less than those from petroleum diesel³.

The concepts of *sustainable* and *renewable* are founded on the principle that we must only use the amount of energy that comes to our ecosystem naturally and also leave enough for a healthy sustenance for the natural environment. Herman Daly wrote that the Earth is an “ecosystem that is finite, non-growing, and materially closed, while open to flow-through (throughput) of solar energy that is also finite and non-growing.”⁴ This reality has not yet dawned on humankind; each day the fossil fuel based global economy uses 10,000 times the amount of energy that the sun provides in that day- 27 years of stored solar energy exhausted every 24 hours⁵. This will not last. It’s an impossibility.

Between the two kinds of hydrocarbons, biodiesel is undeniably the finer choice. Enough ancient sunshine has been taken from the Earth- instead try last season’s sunshine into your tank and feel the difference.

³ US EPA. A Comprehensive Analysis of Biodiesel Impacts an Exhaust Emissions. Page 4. October, 2002.

⁴ Daly, Herman. Ecological Economics and the Ecology of Economics. Edwar Elgar Publishing; Northhampton, MA. 1999.

⁵ Hawken, Paul. The Ecology of Commerce. p.21. Harper Business publishers. New York, 1993.

Straight Vegetable Oil as a Fuel for Diesel Engines

Though biodiesel, chemically *modified* vegetable oil, is the focus of this document, there is another method to of using vegetable oil for fuel. It is possible to use unmodified vegetable oils as a neat fuel for Diesel engines. Straight vegetable oil (SVO) has been shown to be an effective fuel for many applications and has been used in different parts of the world for many years. However, practical results vary, depending on the type and condition of the vegetable oil, engine, and fuel system. For this reason, SVO should still be considered as an experimental fuel, and may be found unsuitable for some applications. Better results are generally found with indirect injection engines, and with inline injection pumps. However, this is not to exclude direct injection engines or rotary injection pumps, particularly if the engine and injection system are in good working condition.

Diesel engines do not use carburetors and rely on spontaneous combustion for fuel ignition, so the fuel must be atomized upon injection into a very fine mist to ensure a complete burn. Although the fuel injection system is designed for petroleum diesel, similar results can be found with SVO if the viscosity of the oil is lowered to nearly that of petroleum diesel fuel. This is typically accomplished by heating the SVO to a relatively high temperature (about 70-80 °C) primarily by utilizing waste heat from the engine.

In this type of system, two separate fuel systems are used. One involves petroleum diesel or biodiesel as a “start/stop” fuel; the other involves SVO as an “operating” fuel. So, for example, if biodiesel is used as a “start/stop” fuel and SVO is the “operating” fuel, then the engine would initially be started cold on biodiesel. Once sufficient temperature is reached, it is switched to SVO, which is then used for the majority of engine operating time. Prior to engine shutdown, the engine is switched back to the biodiesel for just enough time to purge the fuel injection pump and injectors of the SVO fuel so that it can be started again cold on biodiesel. The engine operating systems, including injection timing, injection pressure, engine/valve timing, and compression pressure, can remain unchanged. However, due to the higher viscosity of the vegetable oil, worn injectors and/or injection pumps may present problems if injector pressure is lower than normal.

Some oils are inherently better to use than others, related mostly to their respective melting points and oxidative stability. Oils with a higher melting point can require more heat in colder climates to become useful, and can present handling difficulties. If the melting point is higher than the ambient temperature for a particular climate, then the oil will need to be kept warm for transferring it.

Fuels that readily become oxidized can present operating problems, as peroxides and polymers can form in the oil. Polymerization occurs faster in conditions of high heat and pressure such as found in the fuel system of a Diesel engine. The polymers formed are plastic-like solids and can gum up the fuel filter or other parts of the injection system, and do not thin out with heat as readily as the oil will. Engine failure can result. A good indicator of the oxidative stability is the iodine value, which is available for most vegetable oils. Oils with a low iodine value are more stable than those with a high value. The higher the level of saturated fatty acids present in the oil, the lower the iodine value and the more resistant to oxidation the oil will be, as the oxygen reacts with the carbon-carbon double

bonds present in unsaturated fatty acids. However, saturated fats have a higher melting point than unsaturated fats. These oil characteristics are more thoroughly explained in the opening section of the chapter titled *The Ingredients: Chemistry & Safety*.

Therefore, tropical climates are in many ways ideal for SVO as a fuel for diesel engines. The oils available in the tropics, such as palm or coconut, are often high in saturated fats, thus presenting a low iodine value and good oxidative stability. Since the ambient temperatures are generally higher, the higher melting points of these oils are not generally problematic. In addition, palm and coconut oils have a higher cetane rating than canola or sunflower oil, and are much higher yielding oil crops than those found in colder climates because they can be harvested many times throughout the year.

Used cooking oil is commonly used as a fuel for SVO systems. Canola, sunflower, safflower, palm, and many others are commonly found in used cooking oil, along with beef tallow, lard, or other fats depending on what was cooked in the oil. Most of these oils are suitable for use in SVO systems. An important factor is how long the oil was used and how old it is. The high heat of cooking damages the oil, creates free fatty acids, and accelerates the oxidation process. Neither of these are good for the oil if it is to be used as a fuel. Generally, problems can be avoided by using oil that was not kept in a fryer for an extremely long time, and using the oil soon after it is collected. Oil that was used for cooking and then left to sit for a long time should be avoided.

In Colombia a Ford tractor from the community of Gaviotas was converted to run on straight palm oil. The Neoteric G3 SVO-Max Kit was used. This is a two-tank system as described above that uses a combination of engine heat and electrical heat to achieve the ideal operating temperature for SVO. The kit utilizes three principle components. The first is the HOT STK, which is a coolant-heated fuel standpipe, located in the SVO tank. Hot engine coolant is routed through the unit, which therefore radiates heat into the tank as well as directly heating the SVO as it is pulled through the standpipe. The next unit is the Vormax, a fuel water separator/filter assembly that is also heated by hot engine coolant. The third unit is called the Veg-Therm, a DC powered electric heater. It is basically a length of heated pipe that is installed in the fuel line close to the injection pump. This provides the last boost of heat as the oil passes through it. The fuel selection is accomplished using a six-port valve, and allows for fuel feed and return to and from both tanks. A selector switch is mounted on the dashboard.

John Bush led this endeavor with Henry Moya, a mechanic/engineer member of Centro Las Gaviotas. The Gaviotans did not want an extra tank for SVO getting in the way of operation, so chose to modify the existing tank by adding a smaller tank inside to hold start/stop fuel, main chamber of existing tank for SVO.

They wanted the option of using petroleum diesel in main tank. Since lubricity of petroleum diesel is compromised with excessive heat, electric heater (Veg-Therm) component was connected to on/off switch. Wired to ignition switch and fuel selector switch, veg-therm can only be operated with ignition switch turned on and fuel selector set on main tank. However, the toggle switch allows the tractor to be operated from this tank without veg-therm turned on. A valve may be installed on the coolant line heating

fuel standpipe and filter for use with diesel fuel in hot environment. This is not a concern with biodiesel however, as biodiesel has excellent lubricity and can be safely used when heated to normal coolant temperatures.

To ensure that fuel return did not contaminate start/stop fuel tank with SVO, no fuel return line was fitted to this tank. Initially the start/stop fuel system was looped, but this caused operating difficulty for unknown reasons, perhaps air buildup in lines. So both fuel return lines from 6-port valve were teed together and run to the main tank. Caution is exercised when operating under start/stop tank with excessively full main tank. Since under this condition fuel is pulled from start/stop tank but returned to main tank, overflow could occur. However, in this particular engine, fuel return is very small in volume, so this problem is unlikely.

Hot coolant was initially run off of upper radiator hose but did not work because there was not enough pressure to send coolant through system. Henry Moya suggested taking it directly off engine block. Both these theories proved false when we actually tried it, as coolant was plenty hot and had plenty of pressure from water pump to circulate rapidly through system. A plug was removed from engine block and a barb fitting installed for a hose. The coolant was returned to engine circuit just before the water pump by removing a similar plug and installing a barb fitting. This turned out to be ideal as it required no cutting of existing hoses, and hot coolant actually reached fuel system sooner because it was taken directly from engine block, not radiator hose which gets no flow until operating temperature is reached and thermostat opens.



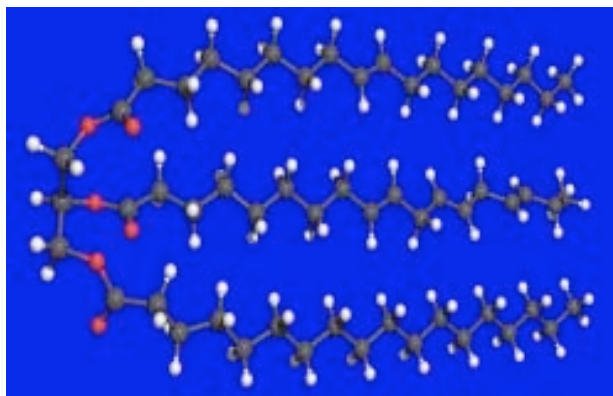
The Ingredients: Chemistry & Safety

Vegetable Oil • Waste Grease • Methanol • Ethanol •
Sodium Hydroxide • Potassium Hydroxide • Sulfuric Acid
• Biodiesel • Glycerin

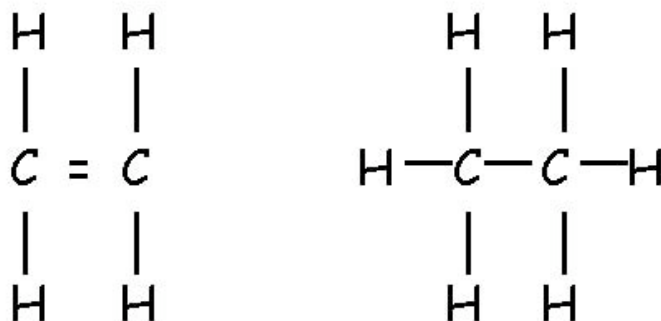
Knowledge of these substances will provide valuable insight into the production of biodiesel and the use of straight vegetable oil as fuel.

Vegetable Oil. Knowledge of the chemical makeup and behavior of vegetable oil (VO) is absolutely essential to using straight or modified vegetable oil as fuel.

VO consists of molecules, called triglycerides, each composed of three fatty acids (hydrocarbon chains) linked to a glycerin molecule. This is true for all varieties of VO. However the viscosity, melting point, density, color, taste and other characteristics may vary significantly from one type of oil to another. These differences can, for the most part, be attributed to two properties of the oil: the varying saturation levels of the hydrocarbon chains that compose the triglycerides (details of saturation proceed this paragraph) and the lengths of the VO's hydrocarbon chains, ranging from 8 to 22 and in different proportions for each VO. Moreover, a single sample of VO commonly contains up to 14 varieties of these chains with varying saturation levels, and the proportions of each determine the characteristics of the VO sample.¹ Thus, VO is not a homogenous substance.



Saturation is a measure of the amount of hydrogen on a hydrocarbon chain. In each chain, carbon atoms are linked in series. In the case that each carbon link is connected to another carbon on either side and to two hydrogen atoms, all single bonds, then the chain is fully saturated. A carbon link that is unsaturated is one that has a double bond to the adjacent carbon atom instead of two single bonds to a hydrogen and carbon atom. Thus, a fully saturated hydrocarbon chain is one with no double bonds between the carbon atoms. An unsaturated carbon chain can have one or more double bonds, or triple bonds. Unsaturated simply means that it does not contain only single bonds. Monounsaturated fats contain one double or triple bond. Polyunsaturated fats contain more than one.



Two bonded links of a hydrocarbon chain: double bond on the left, single on the right.

The following tables, provided by National Renewable Energy Labs (NREL) show the chemical structure of the most common types of hydrocarbons found in vegetable oils (Table 1) and each's presence (measured in weight percent) in various vegetable oils and animal fat (Table 2).

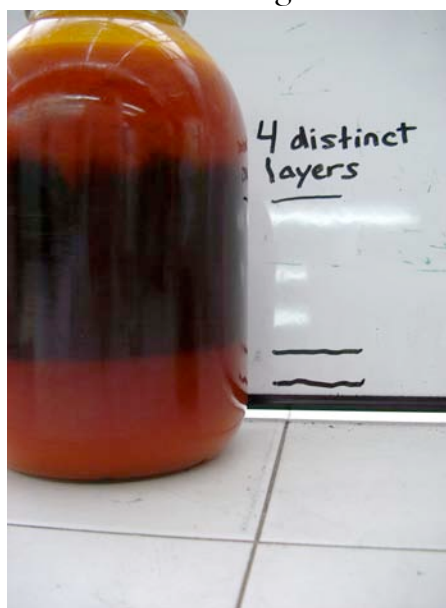
| Table 1: Chemical Structure of Fatty Acids | | |
|--|--------------------------------------|---|
| Fatty Acid Name | # of Carbon Atoms: # Double Bonds | Chemical Structure (= denotes double bond placement) |
| Caprylic | C8 | $\text{CH}_3(\text{CH}_2)_6\text{COOH}$ |
| Capric | C10 | $\text{CH}_3(\text{CH}_2)_8\text{COOH}$ |
| Lauric | C12 | $\text{CH}_3(\text{CH}_2)_{10}\text{COOH}$ |
| Myristic | C14 | $\text{CH}_3(\text{CH}_2)_{12}\text{COOH}$ |
| Palmitic | C16:0 | $\text{CH}_3(\text{CH}_2)_{14}\text{COOH}$ |
| Palmitoleic | C16:1 | $\text{CH}_3(\text{CH}_2)_5\text{CH}=\text{CH}(\text{CH}_2)_7\text{COOH}$ |
| Stearic | C18:0 | $\text{CH}_3(\text{CH}_2)_{16}\text{COOH}$ |
| Oleic | C18:1 | $\text{CH}_3(\text{CH}_2)_7\text{CH}=\text{CH}(\text{CH}_2)_7\text{COOH}$ |
| Linoleic | C18:2 | $\text{CH}_3(\text{CH}_2)_4\text{CH}=\text{CHCH}_2\text{CH}=\text{CH}(\text{CH}_2)_7\text{COOH}$ |
| Linolenic | C18:3 | $\text{CH}_3(\text{CH}_2)_2\text{CH}=\text{CHCH}_2\text{CH}=\text{CHCH}_2\text{CH}=\text{CH}(\text{CH}_2)_7\text{COOH}$ |
| Arachidic | C20:0 | $\text{CH}_3(\text{CH}_2)_{18}\text{COOH}$ |
| Eicosenoic | C20:1 | $\text{CH}_3(\text{CH}_2)_7\text{CH}=\text{CH}(\text{CH}_2)_9\text{COOH}$ |
| Behenic | C22:0 | $\text{CH}_3(\text{CH}_2)_{20}\text{COOH}$ |
| Eurcic | C22:1 | $\text{CH}_3(\text{CH}_2)_7\text{CH}=\text{CH}(\text{CH}_2)_{11}\text{COOH}$ |

Table 2: Composition, Percent by Weight, of Various Oils

| Fatty Acid Fat or Oil | C8:0 | C10:0 | C12:0 | C14:0 | C16:0 | C16:1 | C18:0 | C18:1 | C18:2 | C18:3 | C20:0 C22:0 | C20:1 C22:1 | Other |
|-----------------------|------|-------|-------|-------|-------|-------|-------|-------|-------|-------|----------------|----------------|-------|
| Tallow | -- | -- | 0.2 | 2-3 | 25-30 | 2-3 | 21-26 | 39-42 | 2 | -- | 0.4-1 | 0.3 | 0.5 |
| Lard | -- | -- | -- | 1 | 25-30 | 2-5 | 12-16 | 41-51 | 4-22 | -- | -- | 2-3 | 0.2 |
| Coconut | 5-9 | 4-10 | 44-51 | 13-18 | 7-10 | -- | 1-4 | 5-8 | 1-3 | -- | -- | -- | -- |
| Palm Kernel | 2-4 | 3-7 | 45-52 | 14-19 | 6-9 | 0-1 | 1-3 | 10-18 | 1-2 | -- | 1-2 | -- | -- |
| Palm | -- | -- | -- | 1-6 | 32-47 | -- | 1-6 | 40-52 | 2-11 | -- | -- | -- | -- |
| Safflower | -- | -- | -- | -- | 5.2 | -- | 2.2 | 76.3 | 16.2 | -- | -- | -- | -- |
| Peanut | -- | -- | -- | 0.5 | 6-11 | 1-2 | 3-6 | 39-66 | 17-38 | -- | 5-10 | -- | -- |
| Cottonseed | -- | -- | -- | 0-3 | 17-23 | -- | 1-3 | 23-41 | 34-55 | -- | -- | 2-3 | -- |
| Corn | -- | -- | -- | 0-2 | 8-10 | 1-2 | 1-4 | 30-50 | 34-56 | -- | -- | 0-2 | -- |
| Sunflower | -- | -- | -- | -- | 6 | -- | 4.2 | 18.7 | 69.3 | 0.3 | 1.4 | -- | -- |
| Soybean | -- | -- | -- | 0.3 | 7-11 | 0-1 | 3-6 | 22-34 | 50-60 | 2-10 | 5-10 | -- | -- |
| Rapeseed | -- | -- | -- | -- | 2-5 | 0.2 | 1-2 | 10-15 | 10-20 | 5-10 | 0.9 | 50-60 | -- |
| Linseed | -- | -- | -- | 0.2 | 5-9 | -- | 0-1 | 9-29 | 8-29 | 45-67 | -- | -- | -- |
| Mustard | -- | -- | -- | -- | 3 | -- | 1.5 | 15-60 | 12 | 5-10 | -- | 10-60 | -- |

The standard measure of saturation is iodine value (IV), which is, roughly, the amount of iodine a sample of VO absorbs. Again, any VO is composed of hydrocarbon chains with varying saturation levels- iodine value is a measure of the average saturation level of the oil's chains. Because the iodine acts to break a carbon-carbon double bond and form a single bond with these carbon atoms, iodine is only absorbed at unsaturated links of hydrocarbon chains. Thus, the greater a VO's iodine value, the less saturated it is.

Saturation level is the primary determining factor for a VO's melting point- the temperature it changes completely between its liquid and solid state. Because the less saturated parts of the oil become liquid at lower temperatures than do the more saturated parts, there is a range for some oils when it's part liquid and part solid, as is the case for the crude palm oil shown on the right. The greater the number of double bonds in the triglycerides of VO, the less willing is each



molecule to conform to its surroundings and, therefore, the less willing is the VO to be solid. Stated simply, the less saturated an oil, the lower the melting point; the more saturated an oil the more likely that it is solid at moderate temperatures.

Though this section's objective is to detail the chemistry of VO, saturation level is inextricably linked to a VO's potential to be useful as a fuel in Diesel engines, and so is briefly addressed here. Melting point, detailed above, is a crucial consideration for cold weather operation of biodiesel or straight vegetable oil- an engine can't run on a solid fuel.

Oil's IV is also positively correlated to the potential for that oil to polymerize, or chemically change to a different and more dense, plastic-like material. This change is accelerated when the oil is exposed to increased heat and pressure- as are the conditions of a Diesel engine. Because such material has dire consequences if passed through an

engine, polymerization potential is a necessary consideration for choosing fuels for use in an SVO system. However, once oil is chemically changed to biodiesel, polymerization is much less a concern. Polymerization has been known to happen with high percentage blends of biodiesel with petroleum diesel in high pressure common rail injection systems.

Cetane number is the measure of a fuel's tendency to ignite, and ignite completely when put under pressure. This is one of the primary gauges of the level of performance one will get when using that fuel. Cetane number is negatively correlated to IV, and the higher the cetane number the better the fuel. ⁱⁱ

The preceding information regarding melting point and cetane number is presented with exact values in the following table, compiled by Journey to Forever from the Liberty Vegetable Oil Company database.

| Type Oil/Fat | Melting Range, °C | | | Iodine Value | Cetane Number |
|-----------------------|-------------------|--------------|-------------|--------------|---------------|
| | Oil/Fat | Methyl Ester | Ethyl Ester | | |
| Coconut oil | 20-24 | -9 | -6 | 8-10 | 70 |
| Palm kernel oil | 20-26 | -8 | -8 | 12-18 | 70 |
| Palm stearine | 35-40 | 21 | 18 | 20-45 | 85 |
| Palm oil | 30-38 | 14 | 10 | 44-58 | 65 |
| Tallow | 35-40 | 16 | 12 | 50-60 | 75 |
| Lard | 32-36 | 14 | 10 | 60-70 | 65 |
| Olive Oil | -12 | -6 | -8 | 77-94 | 60 |
| Palm oleine | 20-25 | 5 | 3 | 85-95 | 65 |
| Rapeseed oil, h. eruc | 5 | 0 | -2 | 97-105 | 55 |
| Cotton seed oil | 0 | -5 | -8 | 100-115 | 55 |
| Rapeseed oil, i. eruc | -5 | -10 | -12 | 110-115 | 58 |
| Corn oil | -5 | -10 | -12 | 115-124 | 53 |
| Sunflower oil | -18 | -12 | -14 | 125-135 | 52 |
| Soybean Oil | -12 | -10 | -12 | 125-140 | 53 |

Vegetable oil invariably has some amount of monoglycerides and diglycerides (molecules with one or two fatty acids attached to the glycerin molecule) as well as free fatty acids (FFAs), those hydrocarbon chains not linked to a glycerin molecule at all.

Unrefined oils have higher levels of gums, vegetable matter and other impurities than do refined oils. In working with oil in the lab, especially in the chemical reactions to make biodiesel, these impurities may have interfere and yield unforeseen results. Each oil is unique and must be treated as such.

Given that vegetable oil is edible, they pose very few environmental and human health hazards. In a lab, take care not to spill oil on floors or on equipment because vegetable oil is very slippery. Also, rags soaked in vegetable oil or biodiesel must be disposed of properly either by drying each individually or stored them in safety can. The oxidation of high IV VO's is exothermic and may produce volatile flames.

Waste Vegetable Oil. Grease, or Waste Vegetable Oil (WVO), is vegetable oil that has been used for cooking. It is chemically different from virgin oil and thus needs to be treated accordingly.

As described in the previous section, the characteristics of different kinds of oil vary tremendously. Once oil is used for cooking, meaning it's heated to a high temperature, for some amount of time, exposed to every imaginable type of food, metal, water, salt and more the oil's property's have changed unpredictably. This is the reality of using WVO and indeed the challenge.



Most pertinent is the increase in the oil's content of FFAs. The heat has broken many of the triglycerides into its component parts, releasing acidic FFAs to mix with the intact mono-, di- and triglycerides. The process of creating biodiesel involves the chemical reaction of acidic VO or WVO with a basic catalyst. Thus, if the oil has a lower pH, the process must be altered. The methods for measuring and addressing FFA content are detailed farther in this document.

Also pertinent is the high amount of particulate matter, mostly food, suspended in the oil. Methods for filtering and removing water must be used to make fuel from WVO.

There is one important environmental consideration for WVO. Whereas virgin oil is a valuable commodity, WVO is widely deemed trash and is treated as such. Massive amounts of grease, produced by an ever-growing human population, are dumped into or onto the Earth, harming plant and animal life and disrupting ecosystems. Utilizing this abundant resource for fuel, and therefore proving its worth, is simultaneously an act of recycling and offsetting petroleum use. The rendering industry often makes use of WVO, however biodiesel has higher economic value than do the products of this industry.

Methyl Alcohol or Methanol ($\text{CH}_3\text{-OH}$).ⁱⁱⁱ This simple alcohol, also known as wood alcohol, is used as an antifreeze, solvent, high performance fuel and as a denaturant for ethyl alcohol. In biodiesel production, it bonds with free fatty acids after their bonds are broken by the catalyst to form methyl esters, the chemical name for biodiesel.

Physical State: Liquid
Appearance: clear, colorless
Odor: alcohol-like - weak odor
Vapor Pressure: 128 mm Hg @ 20 deg C
Vapor Density: 1.11 (Air=1)
Evaporation Rate: 5.2 (Ether=1)
Viscosity: 0.55 cP 20 deg C
Boiling Point: 64.7 deg C @ 760.00mm Hg
Freezing/Melting Point:-98 deg C

Autoignition Temperature: 464 deg C
Flash Point: 11 deg C
Explosion Limits, Lower:6.0 vol %
Upper: 36.00 vol %
Solubility: miscible
Specific Gravity/Density:.7910g/cm3
Molecular Formula:CH₄O
Molecular Weight:32.04

Chemical Stability: Stable under normal temperatures and pressures.
Conditions to Avoid: High temperatures, incompatible materials, ignition sources, oxidizers.
Incompatibilities with Other Materials: numerous, exercise caution
Hazardous Decomposition Products: Carbon monoxide, irritating and toxic fumes and gases, carbon dioxide, formaldehyde.

One must exercise extreme caution when handling methanol as it's a highly volatile alcohol with low flash and boiling points. Moreover, it has the ability to fill its surroundings with a volatile cloud and produces invisible flames. Methanol must be kept from sources of flame or high temperature.

Contact with methanol, single incident or prolonged exposure must also be prevented. Any serious contact or injury must be checked by a physician. Symptoms and treatment:

Eyes: corneal irritation, inflammation, injury; must rinse thoroughly

Skin: irritation to dermatitis; must wash with soap and rinse thoroughly

Ingestion: blindness, gastrointestinal irritation, central nervous system depression; must give conscious victim small amounts of milk or water, must induce vomiting for unconscious victim

Inhalation: central nervous system effects (headaches, convulsion, death), blindness; must NOT give mouth-to-mouth resuscitation but rather provide oxygen with artificial mechanism. Note: ensure that the respiratory protection is sufficient.

Ethyl Alcohol or Ethanol (CH₂-OH).^{iv} The referent of layman's use of 'alcohol', ethanol or grain alcohol is made by fermentation (sugar metabolism of yeast in the absence of oxygen) and subsequent distillation. Industrial ethanol is commonly made from ethylene, a petroleum product and is sometimes denatured, mixed with toxic substances to make it non-food grade so as to avoid taxation. Ethanol can be used for producing biodiesel, acting to bond with free fatty acids to form ethyl esters, or another form of biodiesel. It's mandatory that ethanol for biodiesel production be as free of water as possible (199 proof). Due to the ethanol's affinity to water it is difficult to keep the water content to an acceptable level. For this reason, variable results have been observed in making biodiesel from ethanol.

Physical State: Liquid
Appearance: clear, colorless
Odor: aromatic odor
Vapor Pressure: 25 mm Hg
Vapor Density: 1.6 (ethanol)
Evaporation Rate:2.0
Boiling Point: 173.3 deg F

Freezing/Melting Point:-90 deg C
Autoignition Temperature: 685 deg F (362.78 deg C)
Flash Point: 13 deg C (55.40 deg F)
Explosion Limits, Lower:3.3 (ethanol)
Upper: 19 (ethanol)
Solubility: Soluble in water.

Specific Gravity/Density:0.7905

Chemical Stability: Stable. This material may be sensitive to peroxide formation.

Conditions to Avoid: ethanol is sensitive to peroxide formation, incompatible materials, ignition sources.

Incompatibilities with Other Materials: numerous, exercise caution

Hazardous Decomposition Products: Carbon monoxide, carbon dioxide.

As is the case with methanol, ethanol is highly volatile and must be kept from sources of flame or high temperature. One must exercise extreme caution when handling ethanol. Though non-industrial ethanol is less toxic than methanol, care must be exercised. Any serious contact or injury must be checked by a physician. Symptoms and treatment:

Eyes: irritation to inflammation to corneal injury; must rinse thoroughly

Skin: irritation, defatting of the skin, dermatitis; must wash with soap and rinse thoroughly

Ingestion: blindness, central nervous system depression; kidney and liver damage; must give conscious victim small amounts of milk or water, must induce vomiting for unconscious victim

Inhalation: central nervous system effects (headaches, convulsion, death), blindness, respiratory tract irritation; must NOT give mouth-to-mouth resuscitation but rather provide oxygen with artificial mechanism.

Sodium Hydroxide (NaOH).^v Also known as caustic soda, lye and sodium hydrate, NaOH is used as a drain cleaner and in industry for production of paper, textiles and detergents. It is a strong base that is a byproduct of the production of chlorine, the electrolysis of an aqueous solution of sodium chloride. Exposed NaOH will absorb water and carbon dioxide from the air so keep this stored in an airtight container. This chemical acts as the catalyst in producing biodiesel as it breaks apart vegetable oil molecules, allowing the removal of glycerin and the freeing of fatty acids to bond with the chosen alcohol, this forming biodiesel.

Physical State: Solid/Liquid Mixture

Appearance: white to gray

Odor: Practically odorless

Freezing/Melting Point: 800 deg C

Decomposition Temperature:> 225 deg C

Solubility: Reacts.

Specific Gravity/Density: 1.2000g/cm³

Molecular Formula: HNa

Molecular Weight: 23.9968

Conditions to Avoid: Incompatible materials, exposure to air, contact with water, temperatures above 220°C.

Incompatibilities with Other Materials: Acids - alcohols - carbon dioxide - hydrogenhalides.

Hazardous Decomposition Products: Carbon monoxide, carbon dioxide, hydrogen gas.

NaOH is very caustic and must never come into contact with skin. Also, it is highly reactive with water and produces heat upon contact with liquids, so ensure that mixing is done intentionally and slowly when handling large amounts. Any serious contact or injury must be checked by a physician. Symptoms and treatment:

Eyes: irritation and possible burns; must rinse thoroughly

Skin: severe irritation and possible burns especially if skin is wet; must wash with soap and rinse thoroughly

Ingestion: severe gastrointestinal tract irritation with nausea, vomiting, burns; must give conscious victim small amounts of milk or water, NEVER induce vomiting, get medical aid

Inhalation: severe respiratory tract irritation; if victim is not breathing give artificial respiration, if breathing is impaired provide oxygen. Note: ensure that the respiratory protection is sufficient for NaOH exposure.

Potassium Hydroxide (KOH)^{vi}. This is a strong base used in agriculture to decrease the acidity of soils. This is one of many varied uses for this chemical; others include chemical peeling of fruit and vegetables, food production, and even wart removal. KOH is also known as lye, potassium hydrate, caustic potash. This substance is an alternative catalyst to NaOH in biodiesel production.

Physical State: Liquid or solid, anhydrous form is <15.5% water

Appearance: white

Freezing/Melting Point: 400 deg C

Solubility: soluble

Specific Gravity/Density: 2.044 @20 deg C

Molecular Formula: KOH

Molecular Weight: 56.10

Chemical Stability: Stable under normal temperatures and pressures.

Conditions to Avoid: Incompatible materials.

Incompatibilities with Other Materials: Acids - organic materials - acrolein - nitro compounds - halogens - acid anhydrides - phosphorus - potassium - metals.

Hazardous Decomposition Products: Hydrogen gas, oxides of potassium.

Safety considerations regarding KOH are similar to NaOH; it is caustic and has an exothermic reaction with many liquids. One must exercise extreme caution when handling KOH due to its toxicity. Contact with KOH is harmful. Any serious contact or injury must be checked by a physician. Symptoms and treatment:

Eyes: severe eye injury, ulceration of conjunctiva and cornea; must rinse thoroughly

Skin: deep ulcerations of skin; must wash with soap and rinse thoroughly, cover burns with loose bandage

Ingestion: circulatory system failure, perforation and burning of digestive tract; must give conscious victim small amounts of milk or water, NEVER induce vomiting, get medical aid

Inhalation: chemical pneumonitis, pulmonary edema, severe irritation of upper respiratory tract; if victim is not breathing give artificial respiration, if breathing is impaired provide oxygen. Note: ensure that the respiratory protection is sufficient for KOH exposure.

Sulfuric Acid (H₂SO₄)^{vii}. With a pH of 0.3, H₂SO₄ or 'battery acid' is an extraordinarily strong acid and thus a health hazard. It's useful in the production of dyes, fertilizers and explosives. Its presence in the acid pretreatment of WVO, Esterification, facilitates the formation of esters from free fatty acids.

Physical State: Liquid

Appearance: clear colorless - oily liquid

Odor: odorless

pH: 0.3 (1N Solution)

Vapor Pressure: 1 mm Hg @ 145.8 C

Vapor Density: 3.38

Evaporation Rate: Slower than ether.

Viscosity: 21 mPas @ 25 C

Boiling Point: 340 deg C
Freezing/Melting Point: 10.35 deg C
Decomposition Temperature: 340 deg C
Solubility: Soluble.

Specific Gravity/Density: 1.841
Molecular Formula: H₂SO₄
Molecular Weight: 98.0716

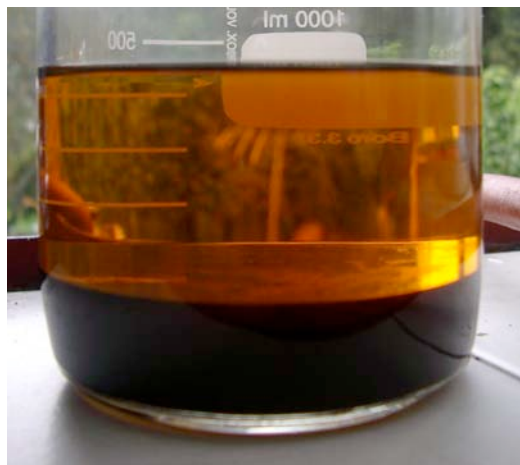
Chemical Stability: Combines vigorously with water with the evolution of heat. Reported to have exploded when in a sealed container. This was most likely due to pressure of hydrogen by reduction of water.
Conditions to Avoid: Incompatible materials, ignition sources, metals, excess heat, combustible materials, organic materials, reducing agents, exposure to moist air or water, oxidizers, amines, bases.
Incompatibilities with Other Materials: numerous, exercise caution
Hazardous Decomposition Products: Oxides of sulfur, irritating and toxic fumes and gases.

Again, sulfuric acid poses serious health danger if not handled correctly. Any contact at all must be checked by a physician. Symptoms and treatment:

- Eyes: severe eye burns, irreversible damage, conjunctivitis and permanent corneal opacification; must rinse thoroughly, never keeping eyes closed or rubbing eyes
- Skin: burns, rash and tissue necrosis; must wash with soap and rinse thoroughly destroy contaminated clothing
- Ingestion: severe and permanent damage of digestive tract, systemic toxicity with acidosis; must give conscious victim small amounts of milk or water, NEVER induce vomiting, get medical aid
- Inhalation: irritation of respiratory tract, pulmonary edema, burns, even death due to results of inhalation; if victim is not breathing give artificial respiration, if breathing is impaired provide oxygen. Do NOT provide mouth-to-mouth resuscitation. Note: ensure that the respiratory protection is sufficient for H₂SO₄ exposure.

Biodiesel (methyl- or ethyl- esters). Chemical Definition: mono-alkyl esters of long chain fatty acids, derived from VO or animal fat. Biodiesel consists of VO hydrocarbon chains that have been detached from the glycerin molecule and in its place a molecule of methanol or ethanol is attached. Small quantities of other materials (water, glycerin, soap, unreacted VO molecules) may be in biodiesel; fuel quality standards exist (ASTM D 6751) that state acceptable levels of these materials in a high quality fuel.

Boiling Point: 3150 deg C at 760 mm HG Pressure
Melting Point: -10 deg C
Vapor Pressure: Less Than 1 mm HG at 720 deg C
Specific Gravity: 0.87 at 250 deg C
Solubility in Water: Negligible at Room Temperature
Flash Point: 218 deg C^{viii}



Presented here is important information from Biodiesel Use and Handling Guidelines, a production of National Renewable Energy Labs (NREL), a division of the US Department of Energy. In short, it states that biodiesel is non-toxic and far safer to humans and the environment in its production and handling than is petroleum diesel.

- β Safety and Environmental Regulation Composition Information: Biodiesel contains no hazardous materials.
- β Handling and Storage: Store in clean, dry, approved diesel equipment between 50° F and 120° F. Keep away from oxidizing agents, excessive heat, and ignition sources.
- β Inhalation: Negligible danger unless heated to produce vapors. Vapors or finely misted materials may irritate the mucous membranes and cause irritation, dizziness, and nausea. If this occurs remove to fresh air.
- β Eye Contact: May cause irritation. Irrigate eye with water for at least 15 to 20 minutes.
- β Acute Oral Toxicity/Rates: Biodiesel is nontoxic and there are no hazards anticipated from ingestion incidental to industrial exposure. If ingested, give one or two glasses of water to drink. By comparison, table salt (NaCl) is nearly 10 times more toxic.
- β Skin Irritation – Humans: A 24-hr. human patch test indicated that undiluted biodiesel produced very mild irritation. The irritation was less than the result produced by a 4 percent soap and water solution. Wash with soap and water. Avoid contact with hot fuel as it may cause burns. PVC coated gloves are recommended to prevent skin contact. May soften skin.
- β Aquatic Toxicity: A 96-hr. lethal concentration of biodiesel for bluegills was greater than 1000 mg/L. Lethal concentrations at these levels are generally deemed "insignificant" according to NIOSH (National Institute for Occupational Safety and Health) guidelines in its Registry of the Toxic Effects of Chemical Substances.
- β Biodegradability: Biodiesel degrades about four times faster than petroleum diesel. Within 28 days, pure biodiesel degrades 85% to 88% in water. Blending biodiesel with diesel fuel accelerates its biodegradability. For example, blends of 20% biodiesel and 80% diesel fuel degrade twice as fast as #2 diesel alone.
- β Fire Fighting Measures: Firefighters should use self-contained breathing apparatus to avoid exposure to smoke and vapor. Combustion produces carbon monoxide and carbon dioxide along with thick smoke. Fires may be extinguished with dry chemical, foam, halon, CO₂, or water spray (fog). Oil soaked rags can cause spontaneous combustion if not handled properly. Before disposal, wash rags with soap and water and dry in well-ventilated area.
- β Accidental Release/Spills: Remove sources of ignition, contain spill to smallest area possible. Stop leak if possible. Pick up small spills with absorbent materials such as paper towels, "Oil Dry," sand, or dirt. Recover large spills for salvage or disposal. Wash hard surfaces with safety solvent or detergent to remove remaining oil film. Greasy nature will result in a slippery surface.

Glycerin ($C_3H_8O_3$).^{ix} This sweet, syrupy alcohol is what's removed from vegetable oil in the production of biodiesel; each of the OH sites in CH₂-OH-CH-OH-CH₂-OH is where a fatty acid is detached. It's a common ingredient in soap, lubricant, and personal care products. Note that the following information is for pure glycerin and the byproduct of biodiesel production contains many impurities and excess alcohol in addition to glycerin.

Physical State: Liquid
Appearance: clear
Odor: faint odor
Vapor Pressure: .0025 mm Hg @ 5
Vapor Density: 3.17 (H₂O=1)
Boiling Point: 290 deg C
Freezing/Melting Point: 20 deg F
Autoignition Temperature: 400 deg C

Flash Point: 193 deg C
Decomposition Temperature: 290 deg C
Explosion Limits, Lower: 1.1
Solubility: Miscible in water. Insol. in chloroform,
Specific Gravity/Density: 1.4746
Molecular Formula: C₃H₈O₃
Molecular Weight: 92.0542

Chemical Stability: Stable.
Conditions to Avoid: Incompatible materials, ignition sources, excess heat.
Hazardous Decomposition Products: Carbon monoxide, irritating and toxic fumes and gases, carbon dioxide.

Though glycerin does not pose any significant hazards, consult a physician if any symptoms from contact with glycerin are serious or persist. Symptoms and treatment:

Eye: May cause eye irritation; flush eyes with plenty of water for at least 15 minutes, occasionally lifting the upper and lower eyelids

Skin: May cause skin irritation; flush skin with plenty of soap and water for at least 15 minutes while removing contaminated clothing and shoes.

Ingestion: Ingestion of large amounts may cause gastrointestinal irritation. Low hazard for usual industrial handling. May cause headache; never give anything by mouth to an unconscious person. Do NOT induce vomiting. If conscious and alert, rinse mouth and drink 2-4 cupfuls of milk or water.

Inhalation: Inhalation of a mist of this material may cause respiratory tract irritation; Remove from exposure to fresh air immediately. If not breathing, give artificial respiration. If breathing is difficult, give oxygen.

Laboratory Biodiesel Production using Methanol

Oil Analysis • Titration • Free Fatty Acids • Esterification
vs. Supplemental Catalyst • Transesterification • Settling •
Quality Assessment • Washing • Superior Diesel fuel

Mastery of these procedures is mandatory before the design, construction and use of any biodiesel production facility.

Premises

First, the behavior of oil can largely be attributed to its molecular structure. Table 1 and 2 in the previous section provide a great deal of information about the compositions of many kinds of oil, namely the chemical structure of the various triglycerides, what percentage of each is in the oil and the oil's saturation level, designated by iodine value. These microscopic details and the macroscopic behavior of the oil are indeed related; one must develop a strong understanding of this relationship. Table 3, in the previous section, provides melting ranges, a macroscopic characteristic, for many of the same oils addressed in the first two tables.

Second, in the case of WVO, it's important to know that some amount of glycerin-hydrocarbon chain bonds are severed but the chains themselves are unaltered; they have the same lengths and saturation levels as was the case before the oil went into the fryer. In short, the source of the vegetable oil used for cooking makes a difference and is helpful in analyzing WVO. On a separate note, if WVO has been used excessively or has begun to decompose (both common) then it's possible that the effort needed to purify it is more valuable than the resulting fuel. This is more possible if using ethanol, as the oil must have very low FFA content. This judgment needs to be made, and preliminary oil analysis in the lab will likely make this judgment easy.

Third, modifying vegetable oil into biodiesel does not change the length and saturation level of the individual fatty acids, but only the alcohol to which they're attached. So, the melting range of biodiesel varies with the oil's saturation level (Table 3). Oil must be liquid to transport (between containers in a lab, tanks in a production facility) and for the chemically change to biodiesel, and biodiesel must be liquid to use in an engine.

Fourth, biodiesel production requires patience. Many stages of the procedure require settling time, and in every case the more time left for settling the better.

The final premise of laboratory biodiesel production is that despite what is known about each of the many factors that determine the outcome of a batch of biodiesel, there exist margins of error and sometimes outcomes are inexplicable. Undoubtedly, one must be well versed in the production methods and in the chemistry of the oil which provide a starting point, but the finest way to account for every factor is to make test batches, tweaking ingredient ratios and production conditions, until the results are perfect. This takes time and resources, but is required. Once the lab-determined results are translated to a large-scale facility, the smallest of inaccuracies may yield unacceptable biodiesel.



Oil Preparation & Analysis

Water and any substantial impurities must be removed, especially from WVO. Passing the oil through a fine wire mesh is sufficient at this stage (the biodiesel will later be filtered down to at least 5 microns). Take into account those naturally occurring impurities (gums, vegetable matter, etc) that will remain after this preliminary filtering, as they may be accountable for unexpected results.

Drying the oil (removing water) can be done by heating the oil to 120°C until bubbling ceases. Note: There is serious potential that, upon reaching 100°C and boiling, water that's settled to the bottom of the container (closest to the heat source) will violently bubble and force the hot oil upwards and out of the container. This may cause burning or worse if the batch is large. Therefore the heated mix must be stirred ceaselessly, bringing the water from the bottom back into the oil. In time it will evaporate off. The safer, less energy intensive and more time consuming method is to heat the oil to 60°C for 15 minutes, transferring the sample to a settling container and, after a few hours of settling, using the top 95% or so has been been dried.



Both methods work well for small samples, but the large amount of energy required to boil off the water is wasteful on large scale. If using ethanol instead of methanol, the energy intensive method is required because it removes more water (any moisture in the oil will wreck ethanol biodiesel production). After these preparatory steps, the oil sample is just that, oil, and not water or impurities that are likely to stymie successful biodiesel production.

Crucially important in analyzing oil is determining its acidity, stated in terms of its content of FFAs. As previously explained, new vegetable oil and especially waste vegetable oil contain FFAs (acidic hydrocarbon chains) that are not attached to glycerin (basic alcohol). The exact level of FFAs must be determined by titration. The titration number is the primary measure of how intensively the oil was used for cooking and how challenging will be the process of making good biodiesel. What follows are the 'basic' and 'better' titration methods provided by Journey to Forever. For each, an electronic pH

meter or phenolphthalein solution is needed to measure pH. Litmus paper is not suggested, especially for highly saturated, and therefore viscous, oils.

Basic titration using NaOH:

1. Dissolve 1 gram of lye in 1 liter of distilled or de-ionized water (0.1% lye solution).
2. In a smaller beaker, dissolve 1 ml of dewatered WVO oil in 10 ml of pure isopropyl alcohol. Warm the beaker gently by standing it in some hot water; stir until all the oil dissolves in the alcohol and the mixture turns clear. Add 2 drops of phenolphthalein solution.
3. Using a graduated syringe, add 0.1% lye solution drop by drop to the oil-alcohol-phenolphthalein solution, stirring all the time, until the solution stays pink (actually magenta) for 10 seconds.
4. With a pH meter or test strips, use the same procedure without adding the phenolphthalein. Add the 0.1% lye solution drop by drop as before until the pH reaches 8.5.
5. This number of drops is your titration value and will come into play during biodiesel production

Better titration using NaOH: Unless you have a very accurate scale, it's not easy to measure exactly 1 gram of sodium hydroxide. It's much easier to measure 5 gm than 1 gm, so mix 5 gm of sodium hydroxide with 500 milliliters of distilled or de-ionized water.

1. Before titration measure out 5 ml of the stock solution, add 45 ml of distilled or de-ionized water. This makes a 0.1% lye solution.
2. It's also not easy to measure exactly 1 milliliter of oil. Instead of the usual 1 ml of oil and 10 ml of isopropyl alcohol, mix 4 ml of oil in 40 ml of isopropyl alcohol in a glass beaker.
3. Warm the mixture gently by standing the beaker in hot water, stir until all the oil disperses and it becomes a clear mixture.
4. Then titrate as usual, measuring milliliters of stock solution used. When it reaches pH8.5 count up the number of milliliters used as normal and divide by 4. This will give a much more precise measurement.
5. To save on isopropyl alcohol, use 2 ml of oil in 20 ml of isopropyl and divide the results by two – still twice as accurate.
6. This number of drops is your titration value and will come into play during biodiesel production

Titration Modification for using KOH:

KOH is not as strong as NaOH – use 1.4 times as much KOH (actually 1.4025 times). Titration is the same, just use a 0.1% KOH solution instead of NaOH solution, and use 1 gm of KOH for every milliliter of 0.1% solution used in the titration.

The two methods for addressing FFA content are introduced here, and are outlined in greater detail in the following sections. The first, referenced as the 'supplemental catalyst method', is to introduce additional catalyst to the reaction, enough to create soap from the reaction of catalyst and FFA (which either settles out or is washed out of the biodiesel) and also to make the mono-, di- and triglycerides into biodiesel. The second method makes use of the FFAs by first combining them with methanol in an acid pretreatment, making esters. This method is called 'esterification', the act of making esters of fatty acids.

Making Biodiesel: A Conceptual Introduction

Transesterification is the process of chemically modifying vegetable oil into biodiesel and glycerin, and is separate from addressing FFAs (which are not vegetable oil). More accurately, it's the chemical reaction in which the hydrocarbon chains of vegetable oil mono-, di- and triglycerides are freed from the glycerin molecule by reaction with a

catalyst (NaOH or KOH) and, in turn, react with a strong alcohol (methanol or ethanol) to form methyl or ethyl esters (biodiesel). Transesterification has only two products, biodiesel and glycerin, though impurities (benign or otherwise) may be present. Again, an ester is a fatty acid attached to an alcohol, and as glycerin is an alcohol, *transesterification* is the chemical change of one type of ester to another- a glycerin ester into an alkyl ester.

When carrying out transesterification batch at-a-time, the catalyst is dissolved in the alcohol, forming methoxide, which is then mixed thoroughly with heated vegetable oil. Left to settle, the glycerin is denser than biodiesel and falls to the bottom of the settling container. This 'batch' method, as opposed to continuous flow reactions, is what is covered in this guide.

Vegetable oil is measured by volume at room temperature. Indeed its density will decrease once heated to 55°C, but measurement of heated oil is more difficult. If the amounts of catalyst and alcohol are consistently stated in terms of unheated oil, then confusion will be avoided.

The prescribed amount of methanol is rather ambiguous, and this ambiguity will be explained here. The precise amount of methanol required to transesterify each of the mono-, di-, or tri-glycerides varies depending on the type of oil; the higher the saturation level the more methanol is required per unit of VO. Journey to Forever supports the findings of Christian Lenoir, who researched the presence of fatty acids in vegetable oils, their molecular weights and from this derived the stoichiometric amount of methanol required for each. The results are presented in Table 4.

However, the actual amount required for a successful reaction is about 60-100% of this prescribed amount. This excess methanol acts more as a catalyst to help drive the reaction to completion and does so in two ways. One, the low viscosity of methanol makes the mixed substance more free flowing, allowing for better interaction of the reactants. Two, and more importantly, excess methanol is needed so the hydrocarbon chains, freshly relieved of its bond to glycerin and eagerly looking for another alcohol, will find methanol instead of settling for glycerin or nothing at all. The excess methanol is mostly contained in the settled glycerin and can be recovered from this, a sensible and conservative use of materials.

How much catalyst is needed depends on which of the two FFA methods is utilized. If the chosen method for addressing FFAs is the supplemental catalyst method, then, per liter of oil, [3.5 + the titration value] grams NaOH or [4.9 + titration value] grams KOH are required. In the presence of a metallic base catalyst FFAs react instantly with the alkali metal ion, Na⁺ or K⁺, to form soap and [titration value] grams are required to form soap with the FFAs.

Table 4: Prescribed Amounts of Methanol

| Fat or Oil | Total Molecular Weight | Density at 50°C | Percent by volume of methanol |
|---------------|------------------------|-----------------|-------------------------------|
| Tallow | 858.54 | 0.88 | 12.4 |
| Lard | 863.73 | ~0.9 | 12.7 |
| Butter | 797.64 | 0.89 | 13.6 |
| Coconut | 674.51 | 0.91 | 16.3 |
| Palm Kernel | 704 | 0.89 | 15.4 |
| Palm | 847.28 | 0.9 | 13 |
| Safflower | 879.1 | 0.91 | 12.6 |
| Peanut | 885.02 | 0.9 | 12.3 |
| Cottonseed | 867.38 | 0.9 | 12.6 |
| Maize | 872.81 | 0.9 | 12.6 |
| Olive | 8780.65 | 0.9 | 12.6 |
| Sunflower | 877.22 | 0.91 | 12.5 |
| Soybean | 882.82 | 0.91 | 12.5 |
| Rapeseed | 959.04 | 0.89 | 11.3 |
| Mustard | 925.43 | 0.9 | 11.8 |
| Cod Liver Oil | 908.81 | 0.91 | 12.1 |
| Linseed | 872.4 | 0.91 | 12.7 |
| Tung | 873.68 | 0.92 | 12.9 |

If esterifying the oil instead, only 3.5 grams NaOH or 4.9 grams KOH are needed per liter of oil in transesterification because all the FFAs have already been converted into methyl esters during esterification. In this process, the FFA reacts with methanol to form methyl esters and water, facilitated by the presence of sulfuric acid (1 mL 95% pure H₂SO₄ per liter of VO). After 24 hours of settling, the water has made its way to the bottom of the container and, similarly to the drying method, the vast majority at the top of the container can be transesterified. The same amount of methanol is required for both methods, but 40% is used during esterification and 60% during transesterification as opposed to 100% during transesterification with the supplemental catalyst method.

Both FFA methods can be successful. When the FFA level is very high, though, using supplemental catalyst increases the chances of unmanageable soap formation, an unwanted addition to Diesel fuel. Washing biodiesel of soap works, but is more difficult with high levels of soap. Moreover, the supplemental catalyst method wastes catalyst (by converting it to soap) and FFAs (by not forming them into biodiesel). Catalyst is a valuable ingredient to biodiesel production and should be used for just that, not to create unwanted soap. One also runs the risk of using too much catalyst. Journey to Forever states, "it is critical that a minimal amount of lye is used, as lye will continue to attack ester bonds, even those of biodiesel. Too much lye will break the biodiesel ester bonds; some of the broken bonds will mate with the lye and form excess soap, and others will match up with a water molecule to form FFAs, which dissolve back into the biodiesel."

The above criticisms of the supplemental catalyst method apply only if the oil sample has high FFA content (titration value of about 3 or more) because all these problems are positively correlated to the FFA content. For many oils, this method is simpler than esterification and produces excellent results if the catalyst amount is accurate.

For these reasons, esterification is a better method for addressing moderate and high levels of FFAs. Admittedly, it requires the use of an additional, and hazardous chemical and requires more time and space, but more reliably produces better biodiesel and higher yields.

An excellent way to drive the reaction to completion is to have an intermediary settling between two stages of transesterification. By adding 75% of the alcohol-catalyst mixture to the oil, mixing and allowing to settle, a great deal of the glycerin will settle within an hour and can be removed. With a lower amount of glycerin, the equilibrium of the reaction has shifted. Add the remaining alcohol-catalyst to the re-heated mixture, mix and leave to settle.

As glycerin is much more dense than is biodiesel, gravity is utilized to allow the glycerin to settle top the bottom of the settling container, leaving biodiesel as a distinct layer atop the glycerin layer. Simple means of accelerating settling include gentle heating (decreasing the viscosity of all the contents and thereby reducing the friction between glycerin and biodiesel as they separate) and increasing the force of gravity by centrifuge. Indeed, the type of oil, quality of reaction, excess of methanol, etc account for varying settling speeds.

In a small lab batch, 1 to 2 days is usually sufficient time for settling. In unwashed biodiesel, it's common that glycerin will continue to settle out over long periods in storage, testament to the time required for complete settling.

Esterification/Transesterification Lab Procedure

Herein are the detailed steps for first esterifying oil and then transesterifying it into biodiesel. Only use oil that has been filtered for substantial impurities and rid of water.

Esterification

- A1. Measure the volume of oil or fat to be processed.
- A2. Heat this oil to 35°C, ensuring that it's entirely liquid
- A3. Determine the stoichiometric amount of methanol (found in previous section) plus 60-100% excess. Measure 40% of this sum and add to the heated oil.
- A4. Mix gently for 5 minutes. The mixture will become murky.
- A5. Using an accurate delivery mechanism, add 1 mL of 95% sulfuric acid per liter of oil or fat.
- A6. Holding the temperature at 35°C, stir gently for one hour.
- A7. Remove from heat and stir gently for another hour.
- A8. Leave to settle for a minimum of 8 hours.

Methoxide Solution

Take every precaution when handling catalyst, methanol and especially a solution of catalyst in alcohol. In dissolving, heat is released and must not put excessive strain on the container, which must have a strong seal and be corrosive resistant plastic or glass. Also, catalyst is eager to absorb moisture from the air. This will interfere with transesterification and should be avoided.

- B1. Pour 60% of the methanol amount described in step 3 above into the container.
- B2. To this add 3.5 grams NaOH or 4.9 grams KOH per liter of oil and close the container immediately. Catalyst, more so NaOH, clumps easily and should be added gradually to the methanol, not vice versa.
- B3. With enough time, the catalyst will dissolve, though gentle stirring accelerates this.

Transesterification

- C1. Add 50% of the methoxide solution to the unheated, acid treated mixture. The sulfate ion in the sulfuric acid combines with the sodium ion of NaOH or potassium ion of KOH to form salt (sodium sulfate or potassium sulfate).
- C2. Heat this to 55°C, be prepared to hold this temperature for the entirety of transesterification. Take care to not boil off the methanol already in the mixture. Be aware of the temperature, keeping it well below methanol's boiling point, accounting for higher elevation.
- C3. Begin gentle mixing.
- C4. At this stage exist two options:
 - a. Slowly stir in the second half of the methoxide solution. Mix vigorously for 15

- minutes.
- b. Slowly stir in 25% of the methoxide solution (half of the remaining amount). Mix vigorously for 15 minutes, then pour contents into container with drain at bottommost point. After a short time, the majority of the glycerin will have settled and can be drained out and set aside. Bring the mix back to 55°C and slowly stir in the last 25% of the solution. Mix vigorously for 10 minutes.
- C5. Transfer the contents to a proper (closed, glass or high density plastic) settling container. Leave to settle for 2 days to ensure complete settling.

Supplemental Catalyst Transesterification Lab Procedure

Herein are the detailed steps for transesterifying vegetable oil, using supplemental catalyst to account FFA content. Only use oil that has been filtered for substantial impurities and rid of water.

Methoxide Solution

Take every precaution when handling catalyst, methanol and especially a solution of catalyst in alcohol. In dissolving, heat is released and must not put excessive strain on the container, which must have a strong seal and be corrosive resistant plastic or glass. Also, catalyst is eager to absorb moisture from the air. This will interfere with transesterification and should be avoided.

- A1. Determine the stoichiometric amount of methanol (found in previous section) plus 60-100% excess. Measure this amount into the container.
- A2. The titration value of the oil plus the amount needed for virgin oil (3.5gr NaOH or 4.9 gr KOH) is the amount of catalyst per liter of oil that needs to be dissolved in the methanol. Catalyst, more so NaOH, clumps easily and should be added gradually to the methanol, not vice versa.
- A3. With enough time, the catalyst will dissolve, though gentle stirring accelerates this.

Transesterification

- B1. Measure the oil at room temperature.
- B2. Heat the oil to 55°C, be prepared to hold this temperature for the entirety of transesterification.
- B3. Begin gentle mixing. At this stage exist two options:
 - A. Slowly stir all of the methoxide solution. Mix vigorously for 15 minutes.
 - B. Slowly stir in 75% of the methoxide solution. Mix vigorously for 15 minutes, then pour contents into container with drain at bottommost point. After a short time, the majority of the glycerin will have settled and can be drained out and set aside. Bring the mix back to 55°C and slowly stir in the last 25% of the

solution. Mix vigorously for 10 minutes.

B4. Transfer the contents to a proper (closed, glass or high density plastic) settling container. Leave to settle for 2 days to ensure complete settling.

Quality analysis

The objective in producing biodiesel from VO, WVO is to esterify as many FFAs as are present in the oil (or make them into soap as is the case with the supplemental catalyst method), then transesterify as many of these as well as the mono-, di- and tri-glycerides originally present in the oil into methyl or ethyl esters, thereby removing as much of the glycerin content of the oil as possible.

In a batch that meets this objective, the settled products of transesterification will be in two distinct layers. The top layer is nearly entirely biodiesel. Invariably, some amount of methanol, soap, glycerin, catalyst, water, partially or non-reacted mono-, di-, and tri-glycerides will be suspended in this top layer, as will any changed or unchanged impurities that were in the VO, WVO initially. In a good reaction, levels of all these will be low, and, oftentimes, the biodiesel after sufficient settling is perfectly suitable for use in a diesel engine.

In the bottom layer is mostly glycerin and methanol, sodium sulfate (a salt, the product of the sulfate ion from the sulfuric acid from esterification with the sodium or potassium ion of the catalyst from transesterification), and heavy impurities that likely had nothing to do with the reaction and simply settled out. The percentage yield of glycerin is only useful to compare different batches made from the same oil; there is not set amount one should expect to yield from oil as it varies between oils. It is true that a very low amount of glycerin is suspect, and one should ensure that enough catalyst and lye were used to carry out the reaction.

In a batch that misses the objective, there are countless possible results. The most common unwanted result are non-distinct layers after separation. This is usually due to a slight inaccuracy of the amount of reactants. Soap formation is common, and looks like cloudy to solid white matter at the bottom of the biodiesel layer, sitting atop the glycerin. As stated before, soap formation is a product of catalyst with FFAs and of glycerin or FFAs with water, so either water entered the reactants at some point or a slight bit too much lye was used. In the case that not enough catalyst was used, there will be unacceptable levels of mono-, di- and tri-glycerides. This partially and completely unreacted oil will likely be suspended in the biodiesel, perhaps settled to the bottom of the top layer.

Even worse is when no settling happens and the entire settling container is filled with a homogenous goop. Any number of causes may yield this effect: large enough presence of water; far excess of catalyst; methanol deficiency; improperly heated or mixed esterification or transesterification; a mystery reaction of the reactants with some impurity in the oil sample, etc. Ensure that the FFAs were handled properly (by either of the two

methods) and that the oil, alcohol and catalyst are free of water. Try another batch with different levels of catalyst and additional alcohol.

Listed in Table 5 are the American Society for Testing and Materials (ASTM) requirements for petroleum diesel and biodiesel. ASTM classifies biodiesel as a fuel additive and not as a fuel itself.

| Fuel Property | Petroleum Diesel | Biodiesel (Broo) |
|------------------------------|------------------|------------------|
| Fuel Standard | ASTM D975 | ASTM D6751 |
| Fuel Composition | C10-C21 HC | C12-C22 FAME |
| Lower Heating Value, Btu/gal | 131,295 | 117,093 |
| Kinematic Viscosity @ 40°C | 1.9-4.1 | 1.9-6.0 |
| Specific Gravity kg/l @ 60°C | 0.85 | 0.88 |
| Density, lb/gal @ 15°C | 7.079 | 7.328 |
| Water, % by volume | 0.05 | 0.05 |
| Carbon, weight % | 87 | 77 |
| Hydrogen, weight % | 13 | 12 |
| Oxygen, by dif. Weight % | 0 | 11 |
| Sulfur, weight % | 0.05 | 0.05 |
| Flash Point, °C | 60 to 80 | 100 to 170 |
| Cloud Point, °C | -15 to 5 | -3 to 12 |
| Pour Point, °C | -35 to -15 | -15 to 16 |
| Cetane Number | 40 to 55 | 48 to 60 |
| BOCLE Scuff, grams | 3,600 | >7,000 |
| HFRR, microns | 685 | 314 |
| Acid Number, mg KOH/g | 0.08% max | n/a |
| Free Glycerin, mass % | 0.02% max | n/a |
| Total Glycerin, mass % | 0.24% max | n/a |

ASTM testing is highly accurate, performed in professional laboratories. It's the authors' stance that excellent biodiesel can be produced without concern for ASTM certification. This is why: with the low tech methods outlined in this chapter and a great attention to detail, one may produce a fuel that performs beautifully in a Diesel engine and will do so over hundreds of thousands of miles. One need only manipulate an oil in the lab, determine the optimal 'recipe' that performs well in a wash, pass the biodiesel through a 2-5 micron filter and given generous settling time for water to fallout. Those ASTM standards that are most important for a fuel's performance in a Diesel engine will be met or surpassed with ease.

Washing

This process is meant to remove impurities (those that can be removed) from biodiesel, after it is separated from the glycerin layer. These include methanol, soap, glycerin, catalyst, and some impurities. However, FFAs, mono-, di-, and tri-glycerides will remain suspended in this top layer, as they are not water-soluble and can't be carried out in a wash. With correct chemistry and some luck, a mix of biodiesel and mono-, di-, and tri-glycerides can be re-reacted and fully transesterified.

As a lab exercise, washing provides valuable insight into the quality and completeness of transesterification- in mixing water with biodiesel, any soap, unreacted oil, and unused catalyst present will make themselves known (the wash water will be extremely soapy or the biodiesel and water will become suspended together in an emulsification). What follows are two methods for washing.

Mist wash: in this method, warm water is finely misted (as with a spray bottle) onto the surface of the biodiesel, and because water is denser than biodiesel, water falls through the biodiesel picking up the soluble impurities along the way. The soapy, white, impurity-laden water gathers at the bottom of the wash container. Water is misted through until it emerges clear, indicating that all soluble impurities have been removed from the biodiesel.

Bubble wash: in this method, water is gently added to the biodiesel, one part water to two biodiesel, so there are two distinct layers. A bubbling mechanism, like an aquarium airstone, is placed at the bottom of the container to produce very fine air bubbles. Because these bubbles start in the water layer, water still encases the air upon reaching and passing through the biodiesel. Here, as with the mist method, small amounts of water interact with the biodiesel, drawing out soluble impurities. Upon reaching the surface of the biodiesel, the bubble bursts, and the water falls, passing through the biodiesel layer once more. Once this water is impurity-saturated, it can no longer extract any more from the biodiesel. So, either the used water is replaced by fresh water, or the biodiesel is moved to a new container for the second wash. Commonly, three washes is



Left: crude palm biodiesel wash.
Right: WVO, sunflower biodiesel wash.

sufficient- the last of which does little except ensure that no impurities are left (the water ought to be very clear). Certainly, the cleaner water from second and third washes is not impurity-saturated and can be reused for a first or second wash of another batch of biodiesel.

In both methods, it is crucial that this water-biodiesel interaction be as gentle as possible, especially when too much catalyst or glycerin is present. In some cases, emulsification occurs. This is the formation of a thick, cloudy goop, resulting from an agitation of water with glycerin, soap, mono-glycerides or some combination of these. In severe emulsifications, the entire container becomes emulsified and neither biodiesel nor water is distinguishable; in mild cases of emulsification there is a murky area between the layers.

Restated, emulsification is an indication that excessive catalyst is present, FFA were not addressed and are still present or the oil was not completely transesterified so monoglycerides caused the emulsification. These are some of the most common problems in biodiesel production and in this way washing indicates that the reaction wasn't quite right.

Techniques for breaking emulsifications include gentle heating (which also makes slightly murky biodiesel clear) and introducing phosphoric acid (citrus acid and vinegar are also effective) in small amounts (2mL of 10% phosphoric acid or less per liter of wash water) to the wash water. Some producers even add acid to the wash to prevent emulsification rather than counteract it. Adding acid to a rather basic emulsification acts to break up the soap into salts of the metallic alkali ions and the negative ion component of the acid and FFAs, causing the emulsification to dissolve. Some emulsifications with enough time will settle completely.

Handling of the Glycerin Byproduct

That which settles out of the biodiesel layer after transesterification is mixed substance of glycerin, soap and impurities and is liquid because these are all in a solution of the excess methanol from the reaction. This substance is not waste, and can be refined into its component parts. By adding phosphoric acid (H_3PO_4) the soap is converted back to FFAs and the entire mixture separates into three distinct layers, with catalyst-phosphorus on the bottom, glycerin-methanol-water in the middle, and FFAs on the top. Separating the middle layer (admittedly difficult to do with a small sample) is the goal because the methanol can be recovered and reused and the glycerin will be a valuable, refined product.

The amount of phosphoric acid to use is proportional to the amount of catalyst used in transesterification. This exposes another advantage to using esterification because less phosphoric acid (an expensive chemical) will be needed in glycerin purification. Journey to Forever reports that 1.5-1.7 mL of 85% phosphoric acid per gram of catalyst works well. The authors can only speak from limited experience; we urge producers to test Journey to Forever's suggestion and research the matter further.

Recovering the methanol from the glycerin is simple. This is done by heating the solution to above the boiling point of methanol and trapping the vapors with a condenser. Provided the heat didn't boil off the water, it will remain in the glycerin. For safety and so as to not lose any methanol, this system ought to be closed. With proficiency in recovering methanol, a producer need only use the stoichiometric amount required for the oil because the excess will be reused many times over.

The catalyst phosphorus layer can be composted. Sodium, potassium and phosphorus are all valuable nutrients in a healthy soil, provided they're not in excess. The FFA can also be composted, used as a biodegradable weed killer or burned (though it won't climb a wick). This section concludes that all products of biodiesel production are valuable and, in the case of compostables, part of a closed-loop system of crops to biodiesel to crops.

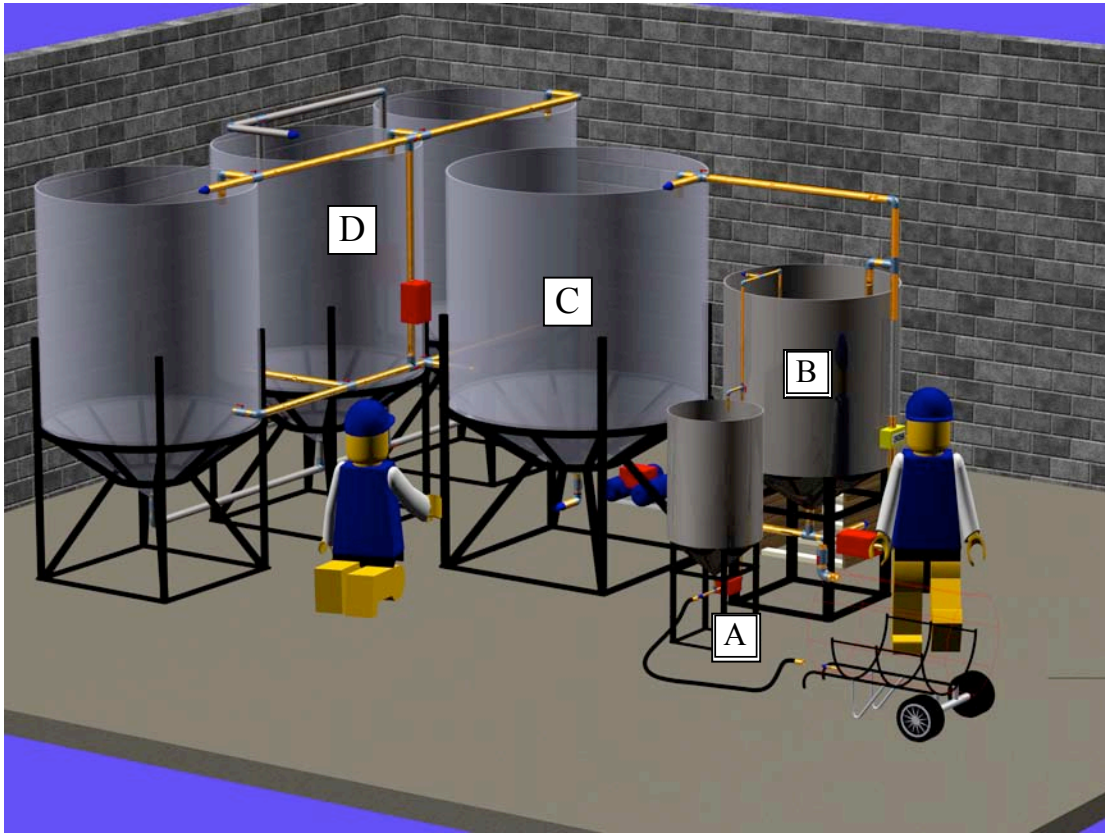
Biodiesel Production Facility

The Colorado team's biodiesel production experience was with simple and inexpensive processors in Colorado, and in this way we were expert biodiesel homebrewers. Given the opportunity to design and consult the construction of a much larger and more professional facility in Colombia, our team did not adopt more advanced production methods such as continuous flow, ultrasound or microwave mixing, or other strategies commonly used by European and US biodiesel industries. Such technology is not always appropriate. The value of our contribution to the Gaviotas biodiesel project was our expertise of producing biodiesel with a conceptually simple, low tech and highly effective method, namely batch production. We see the incredible potential for our knowledge, passed to the visionary, compassionate and accomplished people of Colombia to spread throughout South and Central America, wherever it had potential for enactment.

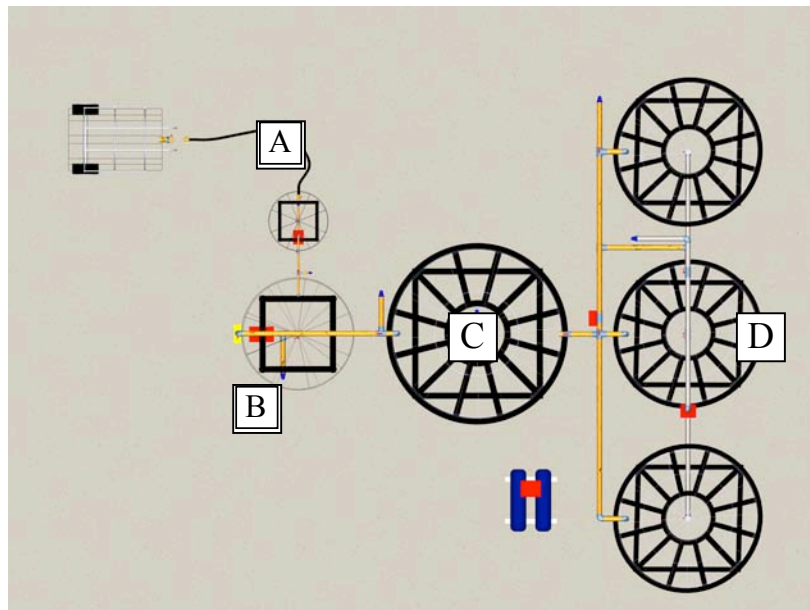
This section is a presentation of design criteria for a batch biodiesel production facility and the design we created for Centro Las Gaviotas is used as an example. It is not strictly a case study; the information herein is dynamic and useful for all kinds of facilities. A large biodiesel production facility is really just an up scaling of lab procedures; no matter the design of the facility, the chemical structure of vegetable oil, new or used, as well as the chemical and physical processes of esterification, transesterification, settling, washing, glycerin purification, etc are the same. Thus, the concepts of previous section are paramount. With mastery of these concepts one may enact his/her creativity to design a facility.

It must be stressed that this information is provided to inspire similar projects and supply basic requirements and does not purport to contain every detail of a facility, an unrealistic intention of a publication. A facility ought to be designed for its specific purpose, incorporating scale and pace of production, climate, capabilities of its engineers, the oil supply and the needs of the end user of the fuel. Our hope is that this guide can save you from doing much of the conceptual work we and others have already done.

Though many of the materials used in a biodiesel production facility are non-toxic, the possibility of spills, explosions, chemical burns and more are very real. Eye, skin and respiratory protection are essential. The facility must be well ventilated, have fire extinguishers and have a weak acid like vinegar on hand to neutralize catalyst burns. Proper containment precautions must be taken to minimize impacts of a spill.



Technical illustration of the Gaviotas Facility



Aerial view of the facility floor plan.

On the previous page are two technical drawings of the Gaviotas biodiesel production facility. These are simplified so as to be an effective reference for the following discussion of the function of each part and their interrelatedness. Label A is located at the methanol delivery system and methoxide mixer. Label B is the transesterification vessel, though two such vessels are in the actual facility. Label C is the tank in which the products of transesterification are transferred for settling (the settling tank) and label D is placed on the wash system. The storage tanks for vegetable oil, waste vegetable oil, finished biodiesel and glycerin byproduct are not included. The facility functions as follows.

Dry, filtered vegetable oil is measured and pumped from storage into the transesterification vessel (B). Here it is either esterified and left to settle (an overnight procedure) or is heated for immediate transesterification without esterification (if the supplemental catalyst method is utilized).

Separate from this, methanol is transferred from 55-gallon drums to the methoxide mixer (A) by a flexible hose, and then catalyst is measured and added to the methanol. These contents are gently mixed until the catalyst is completely dissolved. Once this happens, the methoxide solution is pumped to the transesterification vessel and main reaction begins. After sufficient mixing lasting roughly an hour, the contents are pumped to the large settling tank (C) where previous batches are already settled and awaiting the wash. The completely settled biodiesel is pulled from a high point of the settling tank for washing, and the completely settled glycerin is pulled from the bottom of the settling tank and transferred to glycerin byproduct storage.

In the wash (D) the settled biodiesel is pumped into an available tank (other washes are likely in progress or are settling) and water, half the volume of the biodiesel, is gently added to the bottom. The bubbling system is activated and left to wash the biodiesel. Afterward, the impurity-saturated water is pumped out of this tank and replaced with fresh water for the next washes. Once a wash is performed in which the water remains clear (usually the third) the biodiesel gets transferred to a storage tank, where a bit more water will fall out and the biodiesel is ready for use. The reusable water is transferred to another wash tank for the first wash of another batch of biodiesel.

The sizes of these component parts in relation to one another must be determined. The objective is to not have any 'bottlenecks' in the process of making biodiesel otherwise the equipment will spend time latent. The facility's settling capacity and wash capacity will be large, many times the size of the transesterification vessel because the materials must spend long periods of time here. In Colombia, only one settling tank was installed, though two or more may have been a better choice.

As mentioned before, two identical transesterification vessels were built in Colombia so if all the feedstock needed esterification, then the facility could accommodate it. This also creates great potential to increase the production capacity by simply adding more settling and wash space and working both vessels full time.

An integral part of the size decisions is the schedule of operations, incorporating the time needed for each step. The time allocated for settling and washing are predominant factors as is the choice between esterification or the supplemental catalyst method. All these factors must be considered if the facility is to be used in an optimal way.

Piping and Pumps

For larger facilities the transferring of all materials (liquid feedstock, methanol, water, etc) ought to be done through hard piping by motorized pumps. This is not necessary, but is less time consuming than manual methods of transferring materials. Also, a *closed system*, in which all materials are not exposed to air, is usually safer. Such a system contains the harmful vapors within and reduces the chance of spills.

An appropriate diameter for the facility piping must be determined. Small piping is less expensive and lighter, but doesn't allow for rapid flow of materials. Every section of pipe will contain fluid only intermittently (most are used for transferring single batches of methoxide, vegetable oil, biodiesel or water) and so must be arranged so the pump that moved the fluid can empty the pipe completely. This is considerably easier with small pipes and does not require as powerful a pump.

In the Gaviotas facility, 1.5" mild steel piping was used for the entire methoxide system and 2" mild steel piping was used for everything else. In retrospect, 1.5" or even 1" pipe could have been used instead of the 2". We encountered difficulty in construction and in emptying the pipes completely. Moreover, the transfer times, even for 350 gallons at a time, were quick relative to the pace of the settling and wash system.

The pump for methanol and methoxide must be explosion proof and corrosion resistant. Pumping methanol is potentially the most hazardous step in the entire facility so ensure that the pump is suitable for the job. Pneumatic (air powered) pumps are excellent for handling methanol and methoxide.

The pumps that handle feedstock, biodiesel, glycerin and water have fewer requirements. It's sensible to install identical pumps for all these applications so backup replacement parts, or even an entire replacement pump is suitable for each one. Also, the cost may be lower if purchasing a number of identical pumps at one time.



On either side of every pump in the facility there should be an easy disconnect, and a valve just beyond that. So, if a pump needs to be isolated for maintenance or removed altogether, it can be without altering the hard pipes. A union serves the same purpose.

Each pump should handle as many applications as possible, yet also be fixed in a permanent location. Creative use of valves and intelligent facility layout will allow for this.

Pumps are expensive and spend most of their time idle, awaiting its next task. For example, the pump at the methoxide vessel delivers the methanol into the vessel and then pumps the methoxide to the transesterification vessel. The pump at the transesterification site delivers the feedstock from storage, recirculates the fluid for circular mixing, and transfers the transesterified contents to the settling tank. The biodiesel pump at the water wash site takes the settled biodiesel from the settling tank to any of the wash tanks, moves biodiesel from one wash tank to any other, and also delivers the washed biodiesel to storage. The water pump at the wash site transfers water from one tank to another or to disposal. Water delivery is a simple

procedure and can be done sensibly with a common hose.

We were please with the pump control panel we installed in Colombia. From this spot all the pumps could be switched on and off. Such a panel requires quite a lot of wire, but saves quite a lot of scurrying about the facility. Timers and monitoring devices may be kept at this spot as well.

There are countless configurations of tanks, pipe systems and pumps. Optimization of resources and time was imperative in the Gaviotas facility and so demanded lots of planning.

Feedstock Delivery & Storage

Feedstock (vegetable oil, waste vegetable oil or animal fat) may arrive in small containers, large tanker trucks or drums and, depending on the type, have any variety of characteristics. Ease of delivery and transfer to storage should be made a priority so as to eliminate spills and wasted time.



Passing the feedstock through a fine wire mesh filter will suffice prior to its transfer to a settling tank. This way suspect impurities will be eliminated so they don't interfere with the chemical reactions but also so that feedstock storage tanks and transfer pumps and pipes won't accumulate unwanted particulates. If transferring waste vegetable oil from 5 gallon restaurant containers, for example, the filter can be placed over the input to the storage tank and each container can be poured through this. This is labor and time intensive and it may be worthwhile to have a pump capable of moving highly viscous and chunky grease through a crude filtering system and into the storage tank. The choice depends on the volume of feedstock, its quality, method of delivery and more.



Feedstocks that are liquid at ambient temperature may be stored in a high density, flat bottom plastic tank, with an appropriate input and output. The input ought to be at the top most point and fitted with a mesh filter if filtering is not performed prior to this. If not sufficiently pre-filtered, particulate matter may settle out of the feedstock and will require removal. A simple solution for this is to have two outputs, one at the very bottom to remove particulate-laden feedstock, and one above this from which clean feedstock may be pulled out

for processing.

So that the feedstock may be transferred, it must be liquid. So for highly saturated feedstocks or any that are solid at ambient temperature, the storage tank will require mild heating. Many resistance heaters are absolutely not compatible with a plastic tank; a rustproof metal is required for this. If a means of heating the tank without danger of

melting or warping is devised then plastic may be used. Here is an excellent opportunity for solar hot water.

All storage tanks must be well covered and accessible for occasional cleaning. Drain valves ought to be installed at various heights (or at least one near the output) so a sample of the feedstock can be extracted for lab analysis. On this note, the stored feedstock may require occasional mixing to ensure that a sample, taken from an arbitrary spot, is representative of the entire tank.

Drying the Feedstock

Whereas in the lab boiling water off the feedstock was viable, the less energy intensive method of drying biodiesel is a safer and better method on a larger scale. As explained before, this involves keeping the feedstock at 60°C for 15 minutes, then allowing it to settle for 24 hours thus allowing the denser water to settle from the oil. (Perhaps the transesterification vessel can be used for this heating.) The top 90% will be dry feedstock. For more saturated feedstocks with a high melting range, this method may need to be modified because, though the water may settle out, the feedstock will become solid after 24 hours. This will require heat to liquefy it so it may be transferred for transesterification.

There are flash evaporators that will effectively dry the feedstock by simply passing it through once. Ensure that such an evaporator is not hot enough to damage the oil and increase the FFA level -it should heat the feedstock quickly to 100°C but not far above. These evaporators are oftentimes cost restrictive.

Perhaps a separate storage tank for dried feedstock is sensible for a facility. Or, a large storage tank that is continuously heated and filled with undried feedstock from a center point will have quite dry feedstock on the very top, suitable for biodiesel production. Admittedly this is more complicated- the water that settles will need to be drained from the bottom.

Transesterification Vessel

This vessel has numerous requirements: it must have an input for feedstock, another for alcohol-catalyst solution, be completely airtight with a pressure release for safety, be capable of heating its contents to precisely 55°C, have a mechanism for thoroughly mixing its contents, an output to the settling tank, be extremely durable and firmly grounded and be accessible for maintenance... indeed much of the facility design and construction time should be dedicated to the transesterification vessel.

This vessel must be stainless steel and have a conical bottom so its contents may be completely drained. The pitch of this bottom need only be slight. The vessel we created in Bogota had three walls, the



inner most to contain the liquid, the second to contain the hot water or glycol used to heat the reactants and a third to seal off a layer of insulation. It sat on strong legs, elevated off the ground just enough for access to the piping and valves at the bottom output. Any vessel ought to be at least 20% larger by volume than the sum of feedstock and methoxide; we made about 1100 L batches in our more than 1300 L vessel. This was handmade made entirely by the Centro Las Gaviotas team.

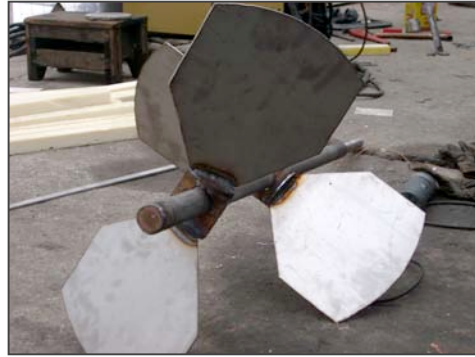
The top of the vessel was sealed with a flat stainless steel cap, with an intermediary corrosion proof seal, fastened with removable nuts and bolts. This cap was welded to a steel structure that gave it greater strength, but also supported the bearings for the drive shaft of the mixing blade. This structure continued off the side of the tank and was hinged to the side of the vessel. This way the entire top could be easily unbolted and swiveled off the vessel.

The Centro Las Gaviotas team are experts in solar hot water so they decided to feed hot water into the vessel's insulated sleeve to heat the reactants. Because the temperature needs to be very close to 55°C, whatever heating method is used needs to be precise. Commercially available heat bands that wrap tanks work also, but are less efficient and are no more precise. They do not require that the container have multiple walls though.

The feedstock input was placed not on the removable top but on the side of the vessel, very near the top. A flow meter was installed to measure the amount of feedstock put into the vessel. The alcohol-catalyst input was just beside the feedstock input. There is only one output, located at the center of the conical bottom. The piping configuration is such that the contents could be drained to a glycerin tank, the settling tank, waste disposal or re-circulated back to the feedstock input for re-circulative mixing.



To drive transesterification to completion, we adopted two-stage transesterification, pulling off glycerin after adding only part of the methoxide (this is outlined in the lab section). Our piping was designed so the vessel contents could be pumped to a glycerin storage tank, but we had no way of knowing when we had drained enough of the glycerin. All the partially reacted feedstock had to remain in the vessel, but as much glycerin as possible should be removed after the first settling. The system is closed and we had no way of knowing what we were draining. A clear section of piping, commercially bought, was installed but still the contents were not lit and we could discern nothing. We resorted to taking intermittent samples- an inconvenient and still inaccurate method. We discussed using a flow meter, and draining a fixed amount of liquid that we were confident was glycerin. A density meter to indicate when biodiesel is flowing is probably the solution to this predicament.



Beside re-circulative mixing, a motor was attached atop the hinge described above which turned a belt which rotated a vertical shaft that passed through an airtight bearing at the center of the vessel's top. Firmly attached to this shaft were four mixing blades that created chaotic mixing of the vessel's contents. Moreover, baffles were welded to the inside walls of the vessel to keep liquid from 'hiding' along the edges of the vessel. The contents were mixed for one hour.

To test this mixing blade, the vessel was filled with water and the motor started. The blades turned and mixed very well, however the blades were too big and so moved large amounts of the liquid at once, causing drastic weight transfers of liquid. The entire vessel began to sway and the motor was immediately shut off. The surface area of the blades was reduced and this problem was solved.

The transesterification vessel is also perfect for heating oil for drying purposes and for esterification. In fact, a vessel can be used for the heating, mixing and settling of esterification and then used for transesterification the next day- no transferring required. Two identical vessels were made, side-by-side in Bogota, creating many possible ways and schedules to make biodiesel. If possible, pressure and temperature gauges should be installed so the facility engineers may know as much as is possible about the contents of the vessel.

Creating the Methoxide

This is the most dangerous operation in a facility. Exercise every precaution.

It's likely that the supply of methanol will be in 55 gallon drums, with a 2" and a 1" bung. This was the case in Bogota. To deliver the methanol from these drums to a vessel for mixing the solution, we purchased a hand-operated mechanism to grasp the drum, lift it into the air and turn it on its side. A flexible fuel hose is attached to the threaded 2" bung, and a splashproof vent was attached to the threaded 1" bung. The opposite side of the hose attached to hard piping and a pump pulled the methanol out. See this mechanism in the picture below, placed in front of the alcohol-catalyst mixing vessel and the larger transesterification vessel. We also sized the processor so that an entire drum of methanol is used for every batch to avoid methanol measurement. Admittedly this limits the facility capabilities because our transesterification batches must always be the same size. A flow meter, placed at the input to the methoxide vessel will solve this and allow for accurate measurement of methanol for a variety of batch sizes.

No matter your methanol delivery system, it ought to be a closed system, not allowing any vapors to escape. Once in the hard piping of the facility, it will be air tight.

The vessel used to make the solution need only have a single wall, made of stainless steel with a conical bottom. We built a cap top and mixing system just as described in the transesterification vessel, though everything is about 25% the size. It's crucial that the pump and motor for the alcohol-catalyst solution be explosion proof. Remember that heat is released when catalyst is dissolved in alcohol; the vessel must be strong enough to handle this.

A challenge in a closed methoxide mixer is to know when the catalyst has completely dissolved. Our pneumatic pump rattled when it was processing solid catalyst, so when it was quiet we mixed for another 5 minutes and decided it was done. Imprecise... but we were correct.

Catalyst must be added to this vessel once the methanol is already inside. We suggest a 2" threaded bung be installed into the vessel's top, a 2" valve attached to this, and a funnel attached to the valve. This way, the measured catalyst can be quickly and safely added to the vessel- open the valve, pour in the catalyst, and close the valve. Certainly there are other quick and safe ways to add the catalyst.



Settling

This tank is similar to the storage tanks already described. It will likely be the largest tank in the facility, flat bottomed, and made from high density plastic. As previously mentioned, multiple settling tanks may be ideal for a facility. Upon transferring the hot content from transesterification, methanol vapors oftentimes escape in large quantity- a wasteful and hazardous phenomenon, so the settling tank should be hermetically sealed.

The only input to the settling tank will be directly from the transesterification vessel and its best that it be hard pipe ending near the middle point between the top and bottom of the tank along the side. This way, those batches that have already had time to settle in this tank won't be disrupted by the dumping of a newly made batch.

There should be a number of outputs, at varying heights. Glycerin should always be pulled off the very bottom of the tank, biodiesel for washing off the surface of the tank's contents. There will likely be a murky area somewhere in between these points that needs more time (or removal if it was a bad batch). With a number of output valves arranged vertically and equidistant, the facility's engineers are able to sample the content at all levels and extract what they please. Initially, this was not done in Bogota and would have been useful because the first batches, and sporadic ones since, were not perfect. Whether the murky stuff needs to be isolated, set aside for weeks to settle, or re-reacted can be determined with some lab analysis, but a sample needs to be attained first.

The products of transesterification need ample time to settle thoroughly, at least 2 days. With a large enough settling tank, the top layer will always be very well settled. Patience will pay off in the wash and in glycerin purification/methanol recovery.

Washing

The principles to washing described in the lab section are identical on a larger scale. Biodiesel should only be transferred to be washed after complete settling, best taken from the top of the settling tank. Wash tanks should be high density plastic (or rust proof metal) with vertical sides. Half this amount of water is added to the bottom of this wash tank, delivered gently through the biodiesel. In Colombia a hard pipe that nearly reached the bottom was used to deliver the water. Adding the water is potentially an agitating process and should be done as gently as possible.

At the bottom of the tank is the bubbling device. We created a 'grate' of small plastic piping, all well sealed and made to span the entire bottom of the tank. Holes, 2 millimeters each, were drilled in this grate every 2 centimeters or so. At one point the grate is connected to a pipe that leaves the top of the tank and is connected to an air compressor. Provided the compressor is properly sized (not so much air that the force of the bubbles agitate the wash but enough that all the holes are bubbling) this system will send small bubbles up through the layer of biodiesel.

Similarly to the settling tank, there ought to be a number of outputs at equidistant heights to pull off water, biodiesel or emulsification if need be. This will make the washing system more dynamic, able to handle all kinds of washing results.

As stated in the lab section, three washes is usually sufficient. This is partially the reason we chose to have three wash tanks in Colombia. The piping was designed so that either the biodiesel, or the water could be transferred between tanks. So, a sample of biodiesel is washed three times in one of the tanks or each of the tanks is designated for first, second or third washes of every batch of biodiesel. We decided on the former, taking the water out of a tank after a wash and replacing it with fresh water. Less total liquid needs to be moved this way and troublesome batches could be isolated in one tank and washed however many times or treated with acid for emulsification.



Product Storage

Biodiesel can be stored in any high density plastic container or any tank approved for petroleum diesel fuel. Consider the ambient temperature and saturation level of the biodiesel to ensure that it remains liquid. Mild heating will solve any biodiesel clouding, and will aid the precipitation of small quantities of water from the fuel which tends to happen for weeks after the wash. Be sure to have an output to drain water that's accumulated over time. A 3,000 gallon tank from an old truck was restored for biodiesel storage in Colombia.

If vehicles will fill up directly from the biodiesel storage tank, then equip it with a pump of some sort (a hand crank pump works fine), preferably with a meter. Otherwise a pump will be needed to transfer the fuel into smaller containers.

The mix of glycerin, methanol and impurities can be stored in a similar container. This will remain liquid so long as enough methanol is present. No system has been built to recover methanol or refine glycerin yet, but the Gaviotas team are already designing one.



Biodiesel Information Sources

Though this document is comprehensive and presents the fundamental principles of using vegetable oil as fuel, a wealth of information is available. We urge you to visit these sites, follow the countless links from them and learn what they have to offer. These range from introductory level to the most professional material, and provides for a variety of interests and projects.

Journey To Forever www.journeytoforever.org

Iowa State Research www.me.iastate.edu/biodiesel

National Renewable Energy Labs www.nrel.gov

National Biodiesel Board www.biodiesel.org

SVO Information Sources

Complete 2-Tank Kits and Other SVO-Specific Products

www.biofuels.ca - Neoteric Biofuels (also has a single-tank kit available)

www.greasecar.com - Greasecar

www.greasel.com - Greasel

www.diesel-therm.com - ATG

Single Tank Systems

www.elsbett.com

Diesel Fuel Heating Systems

www.davcotec.com - heated fuel filters, model 234 is designed for SVO/Biodiesel

www.webb-sales.com - Vormax filter and HotStk standpipe heater

www.arctic-fox.com - heated fuel lines, in-tank heaters and standpipes, etc

www.espar.com - fuel fired coolant heaters

www.parker.com/racor/ - heated fuel filters

General Information & Discussion

www.journeytoforever.org/biodiesel_svo.html - Journey to Forever's SVO page

www.biodiesel.infopop.cc/eve - follow the links to the SVO forum

ⁱ United States Department of Energy, NREL. *Biodiesel Handling and Use Guidelines*, p 1. September, 2001

ⁱⁱ Journey to Forever (www.journeytoforever.org), *Vegetable Oil Yields and Characteristics*

ⁱⁱⁱ National Institute for Occupational Safety and Health (NIOSH), *Pocket Guide to Chemical Hazards*. <http://www.cdc.gov/niosh/npg/npg.html>; Iowa State University Methanol MSDS: <http://avogadro.chem.iastate.edu/MSDS/methanol.htm>

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- ^{iv} NIOSH: <http://www.cdc.gov/niosh/npg/npg.html>; Iowa State University (ISU) Ethanol 95% MSDS: <http://avogadro.chem.iastate.edu/MSDS/ethanol.htm>
- ^v NIOSH: <http://www.cdc.gov/niosh/npg/npg.html>; ISU Sodium Hydroxide MSDS: <http://avogadro.chem.iastate.edu/MSDS/NaH.htm>
- ^{vi} NIOSH: <http://www.cdc.gov/niosh/npg/npg.html>; ISU Potassium Hydroxide 2M: <http://avogadro.chem.iastate.edu/MSDS/KOH-0.1Mto5pct.htm>; OxyChem MSDS.
- ^{vii} NIOSH: <http://www.cdc.gov/niosh/npg/npg.html>; ISU Sulfuric Acid 18M MSDS: <http://avogadro.chem.iastate.edu/MSDS/H2SO4.htm>
- ^{viii} Soy Gold Biodiesel MSDS (<http://www.soygold.com/soydiesel-msds.htm>)
- ^{ix} NIOSH: <http://www.cdc.gov/niosh/npg/npg.html>; ISU Glycerine MSDS: <http://avogadro.chem.iastate.edu/MSDS/glycerine.htm>
- ^x United States Department of Energy, NREL. *Biodiesel- Clean, Green Diesel Fuel*, p2, February 2002. Acid Number, Glycerin quoted from Yokayo Biofuels.