

Make your own biodiesel

[Spanish version -- Versión en español](#)

Anybody can make biodiesel. It's easy, you can make it in your kitchen -- and it's BETTER than the petro-diesel fuel the big oil companies sell you. Your diesel motor will run better and last longer on your home-made fuel, and it's much cleaner -- better for the environment and better for health. If you make it from used cooking oil it's not only cheap but you'll be recycling a troublesome waste product. Best of all is the GREAT feeling of freedom, independence and empowerment it will give you. Here's how to do it -- everything you need to know.



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Three choices

There are at least three ways to run a diesel engine on biofuel using vegetable oils, animal fats or both. All three are used with both fresh and used oils.

- Use the oil just as it is -- usually called SVO fuel (straight vegetable oil);
- Mix it with kerosene (paraffin) or petroleum diesel fuel, or with biodiesel, or blend it with a solvent, or with gasoline;
- Convert it to biodiesel.

The first two methods sound easiest, but, as so often in life, it's not quite that simple.

1. Mixing it

Vegetable oil is much more viscous (thicker) than either petro-diesel or biodiesel. The purpose of mixing it or blending it with other fuels is to lower the viscosity to make it thinner so that it flows more freely through the fuel system into the combustion chamber.

If you're mixing veg-oil with petroleum diesel or kerosene (same as #1 diesel) you're still using fossil-

fuel -- cleaner than most, but still not clean enough, many would say. Still, for every gallon of vegetable oil you use, that's one gallon of fossil-fuel saved, and that much less [climate-changing carbon](#) in the atmosphere.

People use various mixes, ranging from 10% vegetable oil and 90% petro-diesel to 90% vegetable oil and 10% petro-diesel. Some people just use it that way, start up and go, without pre-heating it (which makes veg-oil much thinner), or even use pure vegetable oil without pre-heating it, which would make it much thinner.

You might get away with it with an older Mercedes 5-cylinder IDI diesel, which is a very tough and tolerant motor -- it won't like it but you probably won't kill it. Otherwise, it's not wise.

To do it properly you'll need what amounts to an SVO system with fuel pre-heating anyway, preferably using pure petro-diesel or biodiesel for starts and stops. (See next.) In which case there's no need for the mixes.

Blends with various solvents and/or with unleaded gasoline are "experimental at best", little or nothing is known about their effects on the combustion characteristics of the fuel or their long-term effects on the engine.

Higher viscosity is not the only problem with using vegetable oil as fuel. Veg-oil has different chemical properties and combustion characteristics from the petroleum diesel fuel for which diesel engines and their fuel systems are designed. Diesel engines are high-tech machines with very precise fuel requirements, especially the more modern, cleaner-burning diesels (see [The TDI-SVO controversy](#)). They're tough but they'll only take so much abuse.

There's no guarantee of it, but using a blend of up to 20% veg-oil of good quality is said to be safe enough for older diesels, especially in summer. Otherwise using veg-oil fuel needs either a [professional SVO solution](#) or biodiesel.

Mixes and blends are generally a poor compromise. But mixes do have an advantage in cold weather. As with biodiesel, some kerosene or winterised petro-diesel fuel mixed with straight vegetable oil lowers the temperature at which it starts to gel. (See [Using biodiesel in winter](#))

[More](#) about fuel mixing and blends.

2. Straight vegetable oil

Straight vegetable oil fuel (SVO) systems can be a clean, effective and economical option.

Unlike biodiesel, with SVO you have to modify the engine. The best way is to fit a professional [single-tank SVO system](#) with replacement injectors and glowplugs optimised for veg-oil, as well as fuel heating. With the German [Elsbett](#) single-tank SVO system for instance you can use petro-diesel, biodiesel or SVO, in any combination. Just start up and go, stop and switch off, like any other car. Journey to Forever's Toyota TownAce van uses an Elsbett single-tank system. [More](#)

There are also two-tank SVO systems which pre-heat the oil to make it thinner. You have to start the engine on ordinary petroleum diesel or biodiesel in one tank and then switch to SVO in the other tank when the veg-oil is hot enough, and switch back to petro- or biodiesel before you stop the engine, or

you'll coke up the injectors.

More information on straight vegetable oil systems [here](#).

3. Biodiesel or SVO?

Biodiesel has some clear advantages over SVO: it works in any diesel, without any conversion or modifications to the engine or the fuel system -- just put it in and go. It also has better cold-weather properties than SVO (but not as good as petro-diesel -- see [Using biodiesel in winter](#)). Unlike SVO, it's backed by many long-term tests in many countries, including millions of miles on the road.

Biodiesel is a clean, safe, ready-to-use, alternative fuel, whereas it's fair to say that many SVO systems are still experimental and need further development.

On the other hand, biodiesel can be more expensive, depending how much you make, what you make it from and whether you're comparing it with new oil or used oil (and depending on where you live). And unlike SVO, it has to be processed first.

But the large and rapidly growing worldwide band of homebrewers don't mind -- they make a supply every week or once a month and soon get used to it. Many have been doing it for years.

Anyway you have to process SVO too, especially WVO (waste vegetable oil, used, cooked), which many people with SVO systems use because it's cheap or free for the taking. With WVO food particles and impurities and water must be removed, and it probably should be deacidified too.

Biodieselers say, "If I'm going to have to do all that I might as well make biodiesel instead." But SVO types scoff at that -- it's much less processing than making biodiesel, they say.

To each his own.

	Needs processing	Guaranteed trouble-free	Engine conversion	Cost
Biodiesel	Yes	Yes*	No	Smaller outlay
SVO/WVO	Less	No	Yes	Cheaper in the long-run

* Fuel filters might need changing in the first couple of weeks; fuel hoses or seals on some older diesels might need changing. See [Biodiesel and your vehicle](#)

Costs and prices: Biodieselers using waste oil feedstock make biodiesel for 50 cents to US\$1 per US gallon. Most people in the US use about 600 gallons of fuel a year (about 10 gallons a week) -- say US\$1,700 a year (Sept 05). Biodieselers will be paying \$300-360 for their fuel, while a good processor can be set up for around \$100 up. An SVO system costs from about \$500 to \$1,200 or more. So with an SVO system you'll be ahead of fossil-fuel prices within a year, not a long time in the life of a diesel motor, but you're probably still behind the biodieselers.

Will the engine last as long with SVO? Yes, if you use a good system. Recommendations, and much more, [here](#).

(Note: Small quantities of methanol can cost the equivalent of US\$8 to \$10 per US gallon, but experienced biodieselers invariably buy it in bulk for about \$2-3 per gallon.)

Biodiesel

Converting the oil to biodiesel is probably the best all-round solution of the three options (or we think so anyway).

You could simply [buy](#) your biodiesel. Most major European vehicle manufacturers now provide vehicle warranties covering the use of pure biodiesel -- though that might not be just *any* biodiesel. Some insist on "RME", rapeseed methyl esters, and won't cover use of soy biodiesel (which isn't covered by the Euro biodiesel standard). Germany has thousands of filling stations supplying biodiesel, and it's cheaper there than ordinary diesel fuel. All fossil diesel fuel sold in France contains between 2% and 5% biodiesel. New EU laws will soon require this Europe-wide. Some states in the US are legislating similar requirements. There's a growing number of US suppliers and sales are rising fast, though biodiesel is more expensive than ordinary diesel in the US. In the UK biodiesel is taxed less than petrodiesel and it's available commercially.

But there's a lot to be said for the GREAT feeling of independence you'll get from making your own fuel!

If you want to make it yourself, there are [several good recipes](#) available for making high-quality biodiesel, and they say what we also say: some of these chemicals are dangerous, take full [safety](#) precautions, and if you burn/maim/blind/kill yourself or anyone else, that will make us very sad, but not liable -- we don't recommend anything, it's nobody's responsibility but your own.

On the other hand, nobody has yet burned/maimed/blinded/killed themselves or anyone else making homebrewed biodiesel. Large numbers of ordinary people all over the world are making their own biodiesel, it's been going on for years, and so far there have been NO serious accidents. It's safe if you're careful and sensible.

"Sensible" also means not over-reacting, as some people do: "I'd like to make biodiesel but I'm frightened of all those terrible poisons." In fact they're common enough household chemicals. Lye is sold in supermarkets and hardware stores as a drain-cleaner, there's probably a can of it under the sink in most households. Methanol is the main or only ingredient in barbecue fuel or fondue fuel, often sold in supermarkets and chain stores as "stove fuel" and used at the dinner table; it's also the main ingredient in the fuel kids use in their model aero engines. So get it in perspective, there's no need to be frightened. See [Safety](#) and [More about methanol](#) for further information.

Learn as much as you can first -- [lots of information](#) is available. Make small [test batches](#) before you try large batches (see also [Test-batch mini-processor](#)). Make it with fresh oil before you try waste oil -- see next.

Where do I start?

Start with the **process**, **NOT** with the processor. The processor comes later.

Start with **fresh unused oil**, **NOT** with waste vegetable oil (WVO), that also comes later.

Start by making a test batch of biodiesel in a blender using 1 litre of fresh new oil. If you don't have a spare blender, either get a cheap second-hand one, or, better, make a simple [Test-batch mini-processor](#).

Keep going, step by step. Study everything on this page and the next page and at the links in the text. There are checks and tests along the way so you won't go wrong.

Go on, do it! Thousands and thousands of others have done it, so can you. Get some methanol, some lye and some new oil at the supermarket and go ahead -- it's a real thrill!

[Here's](#) the recipe. Or just keep reading, you'll get to the recipe in a minute anyway.

What's next?

Learn, one step at a time. It's all quite simple really, very few biodiesel homebrewers are chemists or technicians, there's nothing a layman can't understand, and do, and do it well. But there is a lot to learn. You'll find everything you need to know right here. We've tried to make it easy for you. You start off with the simplest process that has the best chance of success and move on step by step in a logical progression, adding more advanced features as you go.

- "I am a pipe welder who knew nothing about chemistry but I have learned a lot from this website. It's set up for someone who has never had a chemistry class (me). If I can understand this anyone can." -- Marty, Biofuel mailing list, 23 Oct 2005
- "For anyone starting out or still in the R&D phase of scaling up and tweaking the process to improve quality, disregard anything other than the tried and tested directions at JtF. Print them out. Read them and then re-read them. Follow the instructions, don't add or subtract anything and you will be making quality biodiesel." -- Tom, Biofuel mailing list, 5 Nov 2005
- "My best advice is to follow explicitly the instructions on the J2F website starting from the beginning and you will do just fine. In my own journey of discovery I learned this. You cannot afford to cut corners. Don't be tempted to use less than accurate measures and think that it will be alright. There is no cheating." -- Joe, Biofuel mailing list, 4 Jan 2006

This is how it works -- comment from a Biofuel list member:

"Your website is very well done. I appreciate the layers of technical complexity. You have progressively more technical information layered in an escalating and logical fashion. I like the links as each new item is introduced, the user can click for more specific information on a topic and it opens in a new window. This eliminates the tediousness of having to constantly backtrack to where the new concept was introduced."

The process

Vegetable oils and animal fats are triglycerides, containing glycerine. The biodiesel process turns the

oils and fats into esters, separating out the glycerine. The glycerine sinks to the bottom and the biodiesel floats on top and can be syphoned off.

The process is called transesterification, which substitutes alcohol for the glycerine in a chemical reaction, using lye as a catalyst. See [How the process works](#)

Chemicals needed

The alcohol used can be either methanol, which makes methyl esters, or ethanol (ethyl esters). Most methanol comes from fossil fuels (though it can also be made from biomass, such as wood), while most ethanol is plant-based (though it is also made from petroleum) and [you can distill it yourself](#). There is as yet no "backyard" method of producing methanol. But the biodiesel process using ethanol is more difficult than with methanol, it's not for beginners. (See [Ethyl esters](#).)

Ethanol (or ethyl alcohol, grain alcohol -- EtOH, C₂H₅OH) also goes by various other well-known names, such as whisky, vodka, gin, and so on, but methanol is a poison. Actually they're both poisons, it's just a matter of degree, methanol is more poisonous. But don't be put off -- methanol is not dangerous if you're careful, it's easy to do this safely. Safety is built-in to everything you'll read here. See [Safety](#). See [More about methanol](#).

Methanol is also called methyl alcohol, wood alcohol, wood naphtha, wood spirits, methyl hydrate (or "stove fuel"), carbinol, colonial spirits, Columbian spirits, Manhattan spirits, methylol, methyl hydroxide, hydroxymethane, monohydroxymethane, pyroxylic spirit, or MeOH (CH₃OH or CH₄O) -- all the same thing. (But, confusingly, "methylcarbinol" or "methyl carbinol" is used for both methanol and ethanol.)

You can usually get **methanol** from bulk liquid fuels distributors; in the US try getting it at race tracks. With a bit of patience, most people in most countries manage to track down a source of methanol for about US\$2-3 per US gallon.

For small amounts, you can use "DriGas" fuel antifreeze, one type is methanol (eg "HEET" in the yellow container), another is isopropyl alcohol (isopropanol, rubbing alcohol), make sure to get the methanol one.

Methanol is also sold in supermarkets and chain stores as "stove fuel" for barbecues and fondues, but check the contents -- not all "stove fuel" is methanol, it could also be "white gas", basically gasoline. It must be pure methanol or it won't work for making biodiesel. See [Methanol suppliers](#)

Methylated spirits (denatured ethanol) doesn't work; isopropanol also doesn't work.

The **lye** catalyst can be either potassium hydroxide (KOH) or sodium hydroxide (caustic soda, NaOH).

NaOH is often easier to get and it's cheaper to use.

KOH is easier to use, and it does a better job. Experienced biodieselers making top-quality fuel usually use KOH, and so do the commercial producers. (KOH can also provide potash fertiliser as a by-product of the biodiesel process.)

With KOH, the process is the same, but you need to use 1.4 times as much (1.4025). (See [More about](#)

[lye.](#))

You can get both KOH and NaOH from soapmakers' suppliers and from chemicals suppliers.

NaOH is used as drain-cleaner and you can get it from hardware stores. It has to be pure NaOH. Shake the container to check it hasn't absorbed moisture and coagulated into a useless mass, and make sure to keep it airtight.

The Red Devil-brand NaOH lye drain-cleaner previously sold in the US is no longer made. Don't use Drano or ZEP drain-cleaners or equivalents with blue or purple granules or any-coloured granules, it's only about half NaOH and it contains aluminium -- it won't work for biodiesel.

CAUTION:

Lye (both NaOH and KOH) is dangerous -- don't get it on your skin or in your eyes, don't breathe any fumes, keep the whole process away from food, and right away from children. Lye reacts with aluminium, tin and zinc. Use HDPE (High-Density Polyethylene), glass, enamel or stainless steel containers for methoxide. (See [Identifying plastics.](#)) See [Safety](#)

See also [Making lye from wood ash.](#)

Chemicals for WVO

Isopropanol for titration is available from chemicals suppliers. Some people have used the other kind of Dri-Gas, which is isopropanol, but they found that it's unreliable. Best get 99% pure isopropanol from a chemicals supplier. 70% pure isopropanol is also said to work, but we found it didn't give satisfactory results.

Contrary to rumour, "phenol red", sold by pool supply stores and used for checking water, won't work for titrating WVO, its pH range isn't broad enough. Use **phenolphthalein** indicator, specifically 1% phenolphthalein solution (1.0w/v%) with 95% ethanol. Phenolphthalein lasts about a year. It's sensitive to light, store it in a cool, dark place. You can get it from chemicals suppliers. See: [Phenolphthalein](#)

Make your first test batch

Here's what you need:

- 1 litre of new vegetable oil, whatever the supermarket sells as cooking oil
- 200 ml of methanol, 99+% pure
- lye catalyst -- either potassium hydroxide (KOH) or sodium hydroxide (NaOH)
- blender or mini-processor
- scales accurate to 0.1 grams, preferably less -- 0.01 grams is best
- measuring beakers for methanol and oil
- half-litre translucent white HDPE ([#2 plastic](#)) container with bung and screw-on cap
- 2 funnels to fit the HDPE container
- 2-litre [PET](#) bottle (water or soft-drinks bottle) for settling
- two 2-litre PET bottles for washing
- duct tape
- thermometer

See [Accurate measurements](#)

All equipment should be clean and dry.

For methanol, you can use "DriGas" fuel antifreeze from an automotive store. One type of DriGas is methanol, another is isopropanol, make sure to get the methanol one. Also try "stove fuel" from hardware stores or home centres (but check the contents to make sure it's pure methanol, it could also be "white gas", which is gasoline and doesn't work), or try a chemicals supply company. See [Methanol suppliers](#)

You can get lye at hardware stores, or from soapmakers' suppliers (try online). KOH lye works better than NaOH. "Red Devil" lye drain-cleaner is no longer made. Don't use Drano or ZEP drain-cleaners or equivalents with blue or purple granules or any-coloured granules, it's only about half NaOH and it contains aluminium, it won't work for biodiesel. Shake the container to check it hasn't absorbed moisture and coagulated into a useless mass, and make sure to keep it airtight.

1. Safety

Read and observe the [Safety](#) instructions below.

2. Lye

You need to be quick when measuring out the lye because it very rapidly absorbs water from the atmosphere and water interferes with the biodiesel reaction.

Measure the lye out into a handy-sized lightweight plastic bag on the scales (or even do the whole thing entirely inside a big clear plastic bag), then close the lid of the container firmly and close the plastic bag, winding it up so there's not much air in it with the lye and no more air can get in. Have exactly the same kind of bag on the other side of the scale to balance the weight, or adjust the scale for the weight of the bag.

How much to use. NaOH must be at least 96% pure, use exactly 3.5 grams. If you're using KOH it depends on the strength. If it's 99% pure (rare) use exactly 4.9 grams (4.90875). If it's 92% pure (more common) use 5.3 grams (5.33). If it's 85% pure (also common) use 5.8 grams (5.775). Any strength of KOH from 85% or stronger will work.

3. Mixing the methoxide

Use the "[Methoxide the easy way](#)" method -- it's also the safe way. Here's how to do it.

Measure out 200 ml of methanol and pour it into the half-litre HDPE container via the funnel. Methanol also absorbs water from the atmosphere so do it quickly and replace the lid of the methanol container tightly. Don't be too frightened of methanol, if you're working at ordinary room temperature and you keep it at arm's length you won't be exposed to dangerous fumes. See [More about methanol](#).

Carefully add the lye to the HDPE container via the second funnel. Replace the bung and the screw on the cap tightly.

Shake the container a few times -- swirl it round rather than shaking it up and down. The mixture gets hot from the reaction. If you swirl it thoroughly for a minute or so five or six times over a period of

time the lye will completely dissolve in the methanol, forming sodium methoxide or potassium methoxide. As soon as the liquid is clear with no undissolved particles you can begin the process.

The more you swirl the container the faster the lye will dissolve. With NaOH it can take from overnight to a few hours to as little as half-an-hour with lots of swirling (but don't be impatient, wait for ALL the lye to dissolve). Mixing KOH is much faster, it dissolves in the methanol more easily than NaOH and can be ready for use in 10 minutes.

4. The process

Using a blender. Use a spare blender you don't need or get a cheap secondhand one -- cheap because it might not last very long, but it will get you going until you build something better.

Check that the blender seals are in good order. Make sure all parts of the blender are clean and dry and that the blender components are tightly fitted.

Pre-heat the oil to 55 deg C (130 deg F) and pour it into the blender.

With the blender still switched off, carefully pour the prepared methoxide from the HDPE container into the oil.

Secure the blender lid tightly and switch on. Lower speeds should be enough. Blend for at least 20 minutes.

Using a mini-processor. Follow the instructions [here](#) and improvise where necessary -- there are many ways of building a processor like this.

Proceed with processing as above, maintain temperature at 55 deg C (130 deg F), process for one hour.

4. Transfer

As soon as the process is completed, pour the mixture from the blender or the mini-processor into the 2-litre PET bottle for settling and screw on the lid tightly. (As the mixture cools it will contract and you might have to let some more air into the bottle later.)

5. Settling

Allow to settle for 12-24 hours.

Darker-coloured glycerine by-product will collect in a distinct layer at the bottom of the bottle, with a clear line of separation from the pale liquid above, which is the biodiesel. The biodiesel varies somewhat in colour according to the oil used (and so does the by-product layer at the bottom) but usually it's pale and yellowish (used-oil biodiesel can be darker and more amber). The biodiesel might be clear or it might still be cloudy, which is not a



Freshly made biodiesel, 20 minutes after processing

problem. It will clear eventually but there's no need to wait.

Carefully decant the top layer of biodiesel into a clean jar or PET bottle, taking care not to get any of the glycerine layer mixed up with the biodiesel. If you do, re-settle and try again.

6. Quality

Proceed to the [wash-test](#) to check the quality. If your biodiesel doesn't pass the test, [here's](#) what to do next.

7. Washing

If it passes the wash-test then wash the rest of the biodiesel. See [Washing](#). For washing use the two 2-litre PET bottles in succession, with half a litre of tap water added for each of the three or four washes required. Pierce a small 2mm hole in the bottom corner of each of the two bottles and cover the hole securely with duct tape.

Pour the biodiesel into one of the wash bottles. Add the half-litre of fresh water.

a. Bubble-washing. See instructions [here](#). Use a small aquarium air-pump and an air-bubbler stone -- cut the threaded lid off the wash bottles if necessary to get the stone in. After washing and settling, drain off the water from the bottom of the bottle by removing the duct tape from the hole. Block it again with your finger when it reaches the biodiesel. Transfer the biodiesel to the second wash bottle, add fresh water and wash again. Clean the first bottle and replace the duct tape. Repeat until finished.

b. Stirring. See instructions [here](#). If you have a small enough paint stirrer and a variable-speed drill, cut the lids off the bottles as above to accommodate the stirrer. Stir until oil and water are well mixed and appear homogenous. Settle for two hours or more, drain as above for bubble-washing, repeat until finished.

If you don't have a stirrer, don't cut the lids off the wash bottles. Add the biodiesel and the water as above. Screw the cap on tightly. Turn the bottle on its side and roll it about with your hands until oil and water are well mixed and homogenous. Settle, drain as above for bubble-washing, repeat until finished.

8. Drying

When it's clear (not colourless but translucent) it's dry and ready to use. It might clear quickly, or it might take a few days or up to a week. If you're in a hurry, heat it gently to 48 deg C (120 deg F) and allow to cool.

9. Congratulations! You have just made high-quality diesel fuel. Say goodbye to ExxonMobil & Co., you don't need them anymore.

10. Read on!

[Next step](#)

Our first biodiesel

This was just an investigative project for us when we made our first biodiesel more than seven years ago in Hong Kong. Most of the equipment was rough and improvised. Apart from chemicals and some beakers, syringes and so on, the only thing we bought was a set of scales.

We got about 60 litres of used cooking oil from Lantau Island's local McDonald's. There were four 16-litre cans of it, a mix of used cooking oil and residual beef and chicken fats. Two of the tins were solidified, the other two held a gloppy semi-liquid. We warmed it up a bit on the stove (to about 50 deg C, 122 deg F) and filtered it through a fine mesh filter, and then again through coffee filter papers, but it was quite clean -- very little food residue was left in the filters.



We'd also bought 10 litres of the cheapest new cooking oil we could find -- we don't know what kind of oil it was, the tins only said "Cooking Oil" -- and we used this for our first experiment.

It worked, though two of our first six batches failed. We've learnt a lot since then. Now it's easy to make high-quality biodiesel every time without fail. And we don't use open containers for processing now, and neither should you (see [Safety](#), see [Processors](#)) -- and mix the [methanol in closed containers](#) too.



Used cooking oil from McDonald's.

Practices, knowledge, technology, equipment and safety measures have all improved tremendously in the years since we brewed our first batch, thanks mainly to the collaborative work of thousands of biofuellers worldwide at the [Biofuel mailing list](#) and other Internet forums, using the growing body of information at our website and others.

As a Biofuel list member said in 2002: "I just want to say how important what you all are doing here is. Closed-system fuel production, on a local or small regional scale, tied to local resources, using accessible technologies, and dependent on entrepreneurial innovation combined with open-source information exchange -- it's AWESOME. Keep up the good work everyone, before the planet fries."



Simple, safe, efficient [biodiesel processors](#) you can build cheaply and easily

Biodiesel from new oil

Make your first test-batch using one litre of new oil (fresh, uncooked). Follow the instructions [above](#). Check the quality of your biodiesel with this basic [quality test](#).

We had difficulty finding pure methanol in Hong Kong, and eventually paid the very high price of US\$10 per litre for 5 litres from a wholesale chemical supply company. It has to be 99% pure or better.

(See [Methanol suppliers](#))

We used sodium lye drain-cleaner (NaOH, sodium hydroxide) bought in small plastic containers at a local hardware store, not always very fresh. (We recommend using potassium hydroxide, KOH, instead of NaOH. See [More about lye.](#))

We used 2 litres of methanol to 10 litres of vegetable oil, and 3.5 grams of NaOH per litre of oil -- 35 grams for 10 litres. (It's better to start with smaller one-litre test batches.)

We had to be quick measuring out the 35 grams of lye required. Lye is very hygroscopic, it absorbs moisture from the air; summer humidity in Hong Kong is usually about 80% at 30 deg C or more, and the lye rapidly got wet, making it less effective. (See [More about lye.](#))

We mixed the lye with the 2 litres of methanol in a strong, heatproof glass bottle with a narrow neck to prevent splashing. It fumed and got hot, and took about 15 minutes to mix. (*Use **closed** containers for mixing methoxide!* See above, [Mixing the methoxide.](#))

This mixture is sodium methoxide, a powerful corrosive base -- take full [safety precautions](#) when working with sodium methoxide, have a source of running water handy.

Meanwhile we'd warmed the 10 litres of new oil in a 20-litre steel oil drum to about 40 deg C (104 deg F) to thin it so it mixed better (55 deg C, 131 deg F, is a better processing temperature). Don't let it get too hot or the methanol will evaporate. (Methanol boils at 64.7 deg C, 148.5 deg F.)



Midori checks the temperature of the oil.

We'd made a wooden jig with a portable vice clamped to it holding a power drill fitted with a paint mixer to stir the contents of the oil drum. This did a good job without splashing. (Not advised, it's dangerous to use sparking electric motors such as those in drills for processing with open containers. See "[Simple 5-gallon processor](#)" for a much better way.)

Stirring well, we carefully added the sodium methoxide to the oil. The reaction started immediately, the mixture rapidly transforming into a clear, golden liquid. We kept stirring for an hour, keeping the temperature constant. Then we let it settle overnight.

The next day we syphoned off 10 litres of biodiesel, leaving two litres of glycerine by-product in the bottom of the drum.

Biodiesel from waste oil

This is more appealing than using new oil, but it's also more complicated.

First, check for water content. Used oil often has some water in it, and it has to be removed before processing. See [Removing the water](#), below.

Refined fats and oils have a Free Fatty Acid (FFA) content of less than 0.1%. FFAs are formed in cooking the oil, and they interfere with the transesterification process for making biodiesel. With waste

oil you have to use more lye catalyst to neutralise the FFAs. The extra lye turns the FFAs into soap which drops out of the reaction along with the glycerine by-product.

It's essential to titrate the oil to determine the FFA content and calculate how much extra lye will be required to neutralise it. This means determining the pH -- the acid-alkaline level (pH7 is neutral, lower values are increasingly acidic, higher than 7 is alkaline). An electronic [pH meter](#) is best, but you can also use pH test strips (or litmus paper), or, better than test strips, [phenolphthalein](#) solution (from a chemicals supplier).

You can also use red cabbage juice, which changes from red in a strong acid, to pink, purple, blue, and finally green in a strong alkali, or one of the other plant-based pH indicators. See [Natural test papers](#) -- Cabbage, Brazil, Dahlia, Elderberry, Indigo, Litmus, Rose, Rhubarb, Turmeric.

We didn't have a pH meter when we started making biodiesel in 1999 so we used phenolphthalein solution. Phenolphthalein is colourless up to pH 8.3, then it turns pink (or rather magenta), and red at pH 10.4. When it's just starting to turn pink it's reading pH 8.5, which is the measure you want.

Phenolphthalein lasts about a year. It's sensitive to light, store it in a cool, dark place.

Don't be put of or frightened away by titration. It's not difficult, thousands and thousands of non-chemist biodiesel makers have learnt how to do it without difficulty and use it every time they make biodiesel. Just follow the directions, step by step. See also [More about lye](#), [Better titration](#), [Joe Street's titrator](#), [Accurate measurements](#).

Titration

Dissolve 1 gm of lye in 1 litre of distilled water (0.1% w/v lye solution, weight-to-volume).

In a smaller beaker, dissolve 1 ml of the 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 turns clear. (Chopsticks make the best stirrers for titration.)

Add 2 drops of phenolphthalein solution.

Using a graduated syringe or a pipette, add 0.1% NaOH solution drop by drop to the oil-alcohol-phenolphthalein mixture, stirring all the time. It might turn a bit cloudy, keep stirring. Keep on carefully adding the NaOH solution until the mixture starts to turn pink (magenta) and stays that way for 15 seconds.

Take the number of millilitres of 0.1% NaOH solution you used and add 3.5 (the basic amount of NaOH needed for fresh oil). This is the number of grams of NaOH you'll need per litre of the oil you titrated.

Our first titration took 6 ml of 0.1% NaOH solution (not very good oil), so we used $6 + 3.5 = 9.5$ grams of NaOH per litre of oil: 95 grams for 10 litres.



Keith checks the pH of the waste oil.

NOTE: Novices should avoid poor-quality oil like this for their first test-batches with used oil. Find a source of oil that titrates at 2 to 2.5 ml of 0.1% NaOH solution, not more than 3 ml. Leave overcooked oils with high titration levels for later when you have more experience. Again, make small one-litre test batches before processing larger batches of WVO.

Proceed as with new oil, see [above](#): measure out the lye and mix it with the methanol to make sodium methoxide or potassium hydroxide -- it will get slightly hotter and take a little longer to mix as there's more NaOH this time. Make sure the NaOH is completely dissolved in the methanol.

Carefully add the methoxide to the warmed oil while stirring, and mix for an hour. Settle overnight, then syphon or decant off the biodiesel.

Check the quality of your biodiesel with this basic [quality test](#).

The first five times we did this, using 10 litres of waste oil each time, we got biodiesel (a bit darker than the new oil product) and glycerine three times, and twice we got [jelly](#). The answer is to be more careful with the titration: do it two or three times, just to be sure. With poor-quality oils that have high titration levels do [bracket tests](#) as well. Do everything you can to improve the [accuracy of your measurements](#) so you get consistent results. Read on, and you'll learn how to make high-quality biodiesel every time, without fail. (It's a LONG time since we made jelly!)

The production rate was less than with new oil, ending with 8-9 litres of biodiesel instead of 10. With care and experience the production rate improves.

Moving on to bigger things

When you're confident that you can get good results every time, even using oil from different sources, then it's time to scale up the process to provide your fuel needs. Now that you have a feel for the process and know what to expect, you'll have a much better idea of what sort of processor you want than if you'd started off building the processor (as many do) rather than learning the process first. See [Biodiesel processors](#).

However, one-litre test batches are not just something for beginners. It's a basic technique you'll always use. Many experienced biodiesel makers do test batches with each batch of oil. Many not only titrate the oil every time to calculate the right amount of lye to use, they also do ["bracket" tests](#) in sequence, followed by wash tests. You learn a lot that way, your fuel gets better, life gets easier.

In fact life is already easier -- people who start off making 40-gallon batches often never learn the accuracy and discipline that comes from making one-litre test batches first. Their fuel quality suffers for it, and when they encounter that inevitable "problem batch", they suffer for it too.

But if you've followed the instructions here carefully, you'll be familiar with all the variables, you'll have good methodology, and you'll be in a much better position to trouble-shoot a problem batch successfully.

Keep a Biodiesel Journal -- make notes, keep records. Get some small glass jars and keep samples of all your batches, clearly labelled and cross-referenced to the notes in your journal. You won't regret it.

When scaling up from small test-batches to a full-sized processor, be aware that the process will probably need some adjusting. All the various processing methods use averages and approximations because processors vary so widely. Use the [fuel quality tests](#) to fine-tune it to your particular processor. See [Scaling up](#).

Removing the water

Water in the oil will interfere with the lye, especially if you use too much lye, and you'll end up with jelly. Test first for water content -- heat half a litre or so of the oil in a saucepan on the stove and monitor the temperature with a thermometer. If there's water in it it will start to "snap, crackle and pop" by 50 deg C (120 deg F) or so. If it's still not crackling by 60 deg C (140 deg F) there's no need to dewater it.

See Mike Pelly's recommendations: [Removing the water](#).

Here's another way, from [Aleks Kac](#) -- it uses less energy and doesn't risk forming more Free Fatty Acids (see below) by overheating. Heat the oil to 60 deg C (140 deg F), maintain the temperature for 15 minutes and then pour the oil into a settling tank. Let it settle for at least 24 hours. Make sure you never empty the settling vessel more than 90%.

Here's what [Biofuel mailing list](#) member Dale Scroggins says about water removal:

Water in vegetable oil can exist as free water, which will eventually settle to the bottom of a vessel; as suspended droplets, which may settle if the oil is heated, or the droplets are coalesced; and as water in solution with other impurities in the oil. Free water is the easiest to remove. The droplets are removed most efficiently by coalescing and draining. Suspended droplets that cannot be coalesced and water in solution are more problematic.

Boiling off the water is more difficult than it appears on the surface. Colligative properties of solutions (and some mixtures) can make removal of the last traces of water almost impossible. Water mixed with oil will not boil at the same temperature and pressure as pure water. As water is removed, more heat or lower pressure will be required to remove more water. If the oil contains salts or semi-soluble fatty acids, distillation is even more difficult.

As the percentage of water in the solution decreases (its molar fraction) its vapor pressure will continue to drop. Lowering pressure in the system alone may be insufficient to sustain vaporization when the solution becomes concentrated (the molar fraction of the solute greatly exceeds that of the solvent). Results will vary depending upon the nature of the water-soluble impurities in the oil. Few solutions are ideal, in terms of Raoult's law, and in used vegetable oil, there is no way to know what solutes are in the oil.

The important thing is how well-used, or overused, the oil is. Titration will tell you that. The higher the titration result, the more water it's likely to contain, and the more difficult it will probably be to remove the water.

Start with heating to 60 deg C and settling, as Aleks Kac recommends, and if that doesn't give satisfactory results, try boiling it off, as Mike Pelly recommends. Then try processing small test batches

of a litre or less first. If you still have difficulties, try to find better-quality oil.

Washing

Biodiesel must be washed before use to remove soaps, excess methanol, residual lye, free glycerine and other contaminants. Some people (fewer and fewer of them) say washing isn't necessary, arguing that the small amounts of contaminants cause no engine damage.

Read what the **Fuel Injection Equipment (FIE) Manufacturers** (Delphi, Stanadyne, Denso, Bosch) have to say about these contaminants:

[Summary](#) -- html

[Full document](#) -- Acrobat file, 104kb

See also: **Determining the Influence of Contaminants on Biodiesel Properties**, Jon H. Van Gerpen et al., Iowa State University, July 31, 1996 -- 12,000-word report on contaminants and their effects. Acrobat file, 2.1Mb:

<http://www.biodiesel.org/resources/reportsdatabase/reports/gen/gen014.pdf>

Myth:

- > I did notice that a lot of the chemistry in the book was wrong.
- > His main argument seemed to be against losing the energy in
- > the methanol that was washed out.

The "energy" does you no good if your particular thermodynamic cycle can't take advantage of it. What is the cetane rating of methanol?

-- Ken Provost, Biofuel mailing list, "Re: washing?"

Quite so. The cetane rating of methanol is only 3, very low. Low cetane-number fuel in a diesel causes ignition delay and makes the engine knock. The high-speed diesel engines in cars and trucks are designed to use fuels with cetane numbers of about 50. The US biodiesel standard specifies a cetane number higher than 47, the EU standard specifies higher than 51. The methanol in unwashed biodiesel doesn't "make a great fuel anyway". It's also very corrosive. The EU biodiesel standard specifies less than 0.2% methanol content.

Quality biodiesel is well-washed biodiesel. Filtering it is no use, and letting it settle for a few weeks won't help much either. Anyway washing the fuel is easy.

See [Washing](#)

Using biodiesel

You don't have to convert the engine to run it on biodiesel, but you might need to make some adjustments and you should check a few things.

Petroleum diesel leaves a lot of dirt in the tank and the fuel system. Biodiesel is a good solvent -- it tends to free the dirt and clean it out. Be sure to check the fuel filters regularly at first. Start off with a new fuel filter.

If a car has been left standing for a long time with petroleum diesel fuel in the tank the inside of the tank may have rusted (water content is a common problem with petro-diesel fuel). Biodiesel will free up the rust, and it could clog the particle filter inside the tank. At worst the car simply stops, starved of fuel. It's not a very common problem, but it happens. See: [Biodiesel and your vehicle -- Compatibility: Filters](#).

A common warning is that biodiesel, especially 100% biodiesel, will rot any natural or butyl rubber parts in the fuel system, whether fuel lines or injector pump seals, and that they must first be replaced with resistant parts made of Viton. But rubber parts in diesel engine fuel systems have been rare or non-existent since the early 1980s -- it seldom happens, and when it does happen it's not catastrophic, you have plenty of warning and it's easily fixed. See: [Biodiesel and your vehicle -- Compatibility: Rubber](#).

See [Biodiesel and your vehicle](#)

Safety

Please read this whole section right to the end.

Wear proper protective gloves, apron, and eye protection and do not inhale any vapours. Methanol can cause blindness and death, and you don't even have to drink it, it's absorbed through the skin. Sodium hydroxide can cause severe burns and death. Together these two chemicals form sodium methoxide. This is an extremely caustic chemical.

These are dangerous chemicals -- treat them as such! Gloves should be chemical-proof with cuffs that can be pulled up over long sleeves -- no shorts or sandals. Always have running water handy when working with them. The workspace must be thoroughly ventilated. No children or pets allowed.

Organic vapor cartridge respirators are more or less useless against methanol vapors. Professional advice is not to use organic vapor cartridges for longer than a few hours maximum, or not to use them at all. Only a supplied-air system will do (SCBA -- Self-Contained Breathing Apparatus).

The best advice is not to expose yourself to the fumes in the first place. The main danger is when the methanol is hot -- when it's cold or at "room temperature" it fumes very little if at all and it's easily avoided, just keep it at arm's length whenever you open the container. Don't use "open" reactors -- [biodiesel processors](#) should be closed to the atmosphere, with no fumes escaping. All methanol containers should be kept tightly closed anyway to prevent water absorption from the air.

We transfer methanol from its container to the methoxide mixing container by pumping it, with no exposure. This is easily arranged, and an ordinary small aquarium air-pump will do. The methoxide is mixed like this -- [Methoxide the easy way](#), which also happens to be the safe way. The mixture gets quite hot at first, but the container is kept closed and no fumes escape. When mixed, the methoxide is again pumped into the (closed) biodiesel processor with the aquarium air-pump -- there's no exposure to fumes, and it's added slowly, which is optimal for the process and also for safety. See [Adding the methoxide](#).

Once again, making biodiesel is safe if you're careful and sensible -- nothing about life is safe if you're not careful and sensible! "Sensible" also mean not over-reacting, as some people do: "I'd like to make biodiesel but I'm frightened of all those terrible poisons." In fact they're common enough household

chemicals. Lye is sold in supermarkets and hardware stores as a drain-cleaner, there's probably a can of it under the sink in most households. Methanol is the main or only ingredient in barbecue fuel or fondue fuel, sold in supermarkets and chain stores as "stove fuel" and used at the dinner table. It's also the main ingredient in the fuel kids use in their model aero engines. So get it in perspective: be careful with these chemicals -- be careful with ALL chemicals -- but there's no need to be frightened of them.

For fire risks, see [Hazards](#)

More about methanol

Question: Just how dangerous is methanol?

Fact: Methanol is a poisonous chemical that can blind you or kill you, and as well as drinking it you can absorb it through the skin and breathe in the fumes.

Question: How much does it take to kill you?

Short answer: Anything from five teaspoons to more than half a pint, but nobody really knows.

Fact: Human susceptibility to the acute effects of methanol intoxication is extremely variable. The minimum dose of methanol causing permanent visual defects is unknown. The lethal dose of methanol for humans is not known for certain. The minimum lethal dose of methanol in the absence of medical treatment is put at between 0.3 and 1 g/kg.

That means it's thought to take at least 20 grams of methanol to kill an average-sized person, or 25 ml, five teaspoonsful. Or it might need more than three times as much, 66 grams, 17 teaspoonsful, or maybe more, and even then it'll only kill you if you can't reach a doctor within a day or two, and maybe it still won't kill you.

But it definitely can kill you. If you drink five teaspoonsful of pure methanol you'll need medical treatment even if it doesn't kill you. Yet people have survived doses of 10 times as much -- a quarter of a litre, half a pint -- without any permanent harm. But others haven't survived much lower doses. Getting rapid medical attention is crucial, though the poisoning effects can be slow to develop.

Authorities advise that swallowing up to 1.3 grams or 1.7 ml of methanol or inhaling methanol vapour concentrations below 200 ppm should be harmless for most people. No severe effects have been reported in humans of methanol vapour exposures well above 200 ppm.

Out of 1,601 methanol poisonings reported in the US in 1987 the death rate was 0.375%, or 1 in 267 cases. It might have been only 1 in more than a thousand cases because most cases weren't reported. Most cases were caused by drinking badly made moonshine, which is a worldwide problem.

Fiction: "Methanol is ... a very active chemical against which the human body has no means of defence. It is absorbed easily through the skin and there is no means of elimination from the body, so levels of methanol dissolved in the blood accumulate."

That's from a British website trying to sell Straight Vegetable Oil (SVO) solvent additives by frightening people with the alleged perils of biodiesel. See [The SVO vs biodiesel argument](#)

Fact: 30 litres of fruit juice will probably contain up to 20 grams of methanol, near the official minimum lethal dose. Methanol is in the food we eat, in fresh fruit and vegetables, beer and wine, diet drinks, artificial sweeteners.

Not only that, methanol occurs naturally in humans. It's a natural component of blood, urine, saliva and the air you breathe *out*. It's there anyway even if you've never been exposed to chemical methanol or its fumes.

Methanol is eliminated from the body as a normal matter of course via the urine and exhaled air and by metabolism. Getting rid of it takes from a few hours for low doses to a day or two for higher doses. Some proportion of a dose of methanol just goes straight through, excreted by the lungs and kidneys unchanged. The normal background-level quantities of methanol in humans are eliminated and replenished all the time as a matter of course.

Fiction: It's largely biodiesel's methanol content that's being blamed when the same British SVO website charges that biodiesel is wasteful and environmentally irresponsible.

Fact: Methanol is readily biodegradable in the environment under both aerobic and anaerobic conditions (with and without oxygen) in a wide variety of conditions.

Generally 80% of methanol in sewage systems is biodegraded within 5 days.

Methanol is a normal growth substrate for many soil microorganisms, which completely degrade methanol to carbon dioxide and water.

Methanol is of low toxicity to aquatic and terrestrial organisms and it is not bioaccumulated. (It's toxic mainly to humans and monkeys.)

Environmental effects due to exposure to methanol are unlikely. Unless released in high concentrations, methanol would not be expected to persist or bioaccumulate in the environment. Low levels of release would not be expected to result in adverse environmental effects.

Fiction: A European SVO fuel website using similar anti-biodiesel tactics claims: "Biodiesel is a chemically altered plant oil. However the process to chemically change the structure of Pure Plant Oil is a very costly operation and requires a lot of energy, as it removes the glycerine substituting it by methanol as well as adding other chemicals, making the end-product poisonous and equally hazardous as fossil diesel fuel."

Fact: There is no free methanol in washed biodiesel. All the national standards require washing. According to US EPA studies methyl esters biodiesel is less toxic than table salt and more biodegradable than sugar. It has none of the toxic or environmental hazards of fossil diesel fuel.

To put it all in some perspective, methanol is the main or only ingredient in barbecue fuel or fondue fuel, sold in supermarkets and chain stores as "stove fuel" and used at the dinner table. It's also the main ingredient in the fuel kids use in their model aero engines.

Yes, methanol is a dangerous chemical, but quite how dangerous it may be is a little hard to say, and it causes surprisingly little harm. If you're careful and sensible and treat it with caution it won't harm you either. Many thousands of biodiesel homebrewers worldwide have been using it for years without serious mishap.

In our view, the difference between methanol and the really dangerous chemicals is that although methanol is poisonous, it's a natural chemical, you'd find it in the Garden of Eden too. It's not something nature's simply never heard of before and has no way of handling and neither do you, unlike too many of the 100,000-odd "new" chemicals now in use which aren't readily biodegradable and do accumulate, and spread, and keep being implicated in cancer clusters and bizarre sexual distortions of frogs and so on and on and on.

There are no reports of carcinogenic, genotoxic, reproductive or developmental effects in humans due to methanol exposure. Its environmental effects if any are minimal and short-lived.

Biodieselers can and do use methanol safely and the biodiesel fuel we make from it is safe and clean.

-- With information from: **United Nations Environment Programme / International Labour Organisation / World Health Organization: International Programme On Chemical Safety, Environmental Health Criteria 196 - Methanol**, from IPCS INCHEM, "Chemical Safety Information from Intergovernmental Organizations", in cooperation with the Canadian Centre for Occupational Health and Safety (CCOHS)

<http://www.inchem.org/documents/ehc/ehc/ehc196.htm>

See also:

Safety (MSDS) data for methyl alcohol

http://ptcl.chem.ox.ac.uk/MSDS/ME/methyl_alcohol.html

Methanol MSDS

<http://www.bu.edu/es/labsafety/ESMSDSs/MSMethanol.html>

Methanol as a plant nutrient

"Methanol is a fixed-carbon nutrient source for plants." -- From "Agriculture and Methanol", Chapter 7, *Methanol Production and Use*, ed. Wu-Hsun Cheng and Harold H. Kung, ISBN 0-8247-9223-8, 1994 (10th printing)

"Methanol treatments of C3 plants [most food crops] have been found to result in growth improvement... As a plant source of carbon, methanol is a liquid concentrate: 1 cc of methanol provides the equivalent fixed-carbon substrate of over 2,000,000 cc of ambient air... Methanol treatments are a means of placing carbon directly into the foliage... The application of 10-100% methanol to some crops increased photosynthetic productivity... The uptake of methanol by plants in light leaves no significant residual methanol above baseline as detectable by chromatography within 15-30 minutes of penetration. Treatment with methanol is therefore an inexpensive, safe, and effective means of providing plants with a source of fixed carbon and carbon dioxide... An economical means of inhibition of photorespiration has been sought for

decades, and methanol may well provide the solution... The control of photorespiration across the food crops of the world could double yields." -- Greg Harbican and Peter G., Biofuel mailing list, 8 Sep 2004. For discussion see:

<http://snipurl.com/j94f>

Methanol and Plants

<http://snipurl.com/j94e>

Use for wash water - methanol

Note however that the authors of *Methanol Production and Use* caution that the application of methanol to crops still requires further study before we all "rush out to spray methanol".

Most of the excess methanol used in the biodiesel process ends up in the glycerine by-product layer, and the rest stays in the biodiesel. If you don't [reclaim](#) it for re-use (you should!) the portion that's in the biodiesel gets washed out when you wash the fuel, mostly with the first wash. The first wash-water probably won't contain more than 5-6% methanol (as well as some sodium or potassium lye and some soap). You could try spraying it on half a small patch of weeds and don't spray the other half to see what happens. Choose a bright sunny day.

Make your own biodiesel (contd.)

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Ethyl esters -- making ethanol biodiesel

Making ethyl-esters biodiesel using ethanol is a tricky process, not as simple as making methyl esters with methanol. It's not for novices -- learn how to make biodiesel with methanol first.

Methods and recipes for ethyl-esters biodiesel are available here, along with a How-To from a master home-brewer who has been making and using his own ethyl-esters biodiesel for years.

See: [Ethanol biodiesel](#)

Reclaiming excess methanol

Depending on the kind of oil you're using, it takes from 110-160 millilitres of methanol per litre of oil to form the methyl esters molecule. But you also need to use an excess of methanol to push the conversion process towards completion -- the total used is usually 20% and more of the volume of oil used, 200 ml per litre or more.

Much of the excess methanol can be recovered after the process for reuse, simply by boiling it off in a closed container with an outlet leading to a simple condensor.

Methanol boils at 64.7 deg C, 148.5 deg F, though it starts vaporizing well before it reaches boiling point.

Unlike ethanol, methanol does not form an azeotrope with water and relatively pure methanol can be

recovered -- pure enough to reuse in the next batch.

The methanol can be recovered at the end of the process, or just from the glycerine by-product layer, since at least 70% of the excess methanol collects in the by-product and it's that much less material to heat. See [Methanol condenser](#).

Recovering the methanol at the end of the process seems convenient because it's already hot, and you can get the methanol back from both the fuel and the glycerine by-product at the same time. But it can push the reaction into reverse, converting the biodiesel back into glycerides. **Prof. Michael Allen** says:

Removing methanol from the reactor product is a no-no because it reverses the reaction you have just carried out. Without the excess methanol, the ester and the glycerol react to provide an equilibrium mix which is less than desirable. That excess methanol serves a very real purpose in pushing the equilibrium yield up. But once the glycerol is completely separated, the reverse reaction cannot take place and we can get back the excess methanol.

Some people do it before separating it anyway (they often use a vacuum). We'd rather not risk ending up with anything less than good process completion. It's best to recover the methanol separately from the unwashed biodiesel and the glycerine by-product.

For the by-product, heat to 65-70 deg C (149-158 deg F). As the methanol evaporates, leaving an ever-lower proportion of methanol in the mixture, the boiling point will increase, so you'll have to keep raising the temperature to keep the methanol vaporizing. It goes up to 100 deg C (212 deg F) or more, and then it starts to froth and you have to stop or you'll get frothy brown by-product in your methanol condensate. But the bulk of the methanol should have been recovered by then.

If you have a market for potassium fertiliser and/or industrial-grade glycerine (about 80-90% pure) which makes it worth the cost of the phosphoric acid you'll need, it's best to [separate the by-product](#) into its components first. Adding the phosphoric acid separates the soaps (FFAs) from the glycerin and frees the catalyst, but it won't separate without the methanol. After separation the methanol is left in the glycerine fraction and can be removed then.

It's probably more efficient to use flash evaporators to recover the methanol from either the biodiesel or the separated by-product.

More about lye

The catalyst used in transesterification of vegetable or animal fats and oils is lye -- either sodium hydroxide (NaOH, caustic soda), or potassium hydroxide (KOH). NaOH might be easier to get and cheaper to use, KOH is easier to use and it mixes with methanol much more easily. KOH does an all-round better job than NaOH.

Keep it dry

Lye is hygroscopic -- it absorbs water from the atmosphere. So make sure you get fresh lye, and keep the container tightly sealed.

When weighing it out, don't leave it exposed to the air for any longer than necessary. In humid weather we weigh it out into plastic bags,



From a faulty batch of lye (rare) -- the semi-translucent half-pearls are fresh, but the chalky white lump on the right is carbonated. After only a second or two exposed to the air the fresh half-pearls are already absorbing a sheen of moisture.

one on either side of the scale to equalise the extra weight of the bag. As soon as it's weighed out, close the container, close the bag, and add the lye to the methanol as quickly as possible.

If the weather's really damp, you can do the whole weighing process entirely inside a big clear plastic bag. If you feel it still might be too moist even inside the bag, put some lye in an open container inside the bag to absorb the moisture first.

We buy 85% KOH in 20 kg lots, 44 lb, and transfer it from it's tough airtight clear plastic bag this way:

Everything goes inside a large clear plastic bag -- the sealed bag of KOH, 10 empty 500 g HDPE plastic containers with wide mouths, bungs and tight-fitting lids, a little KOH in another 500 g HDPE container with the lid off to absorb moisture, some tough cord, and a pair of scissors. Then use two knots of cord to seal the large bag closed.

We cut two holes in the side of the large bag and taped a resistant plastic glove into each of them. With your hands in the gloves, it's easy to work efficiently and safely transferring the KOH inside the large bag, with no water present.

When it's done, press all the air out of the KOH bag and tie it closed with two knots of the cord. Make sure all the filled HDPE containers are properly closed. Take your hands out of the gloves, cut the knots closing the big bag, take out all the HDPE bottles, the scissors and the remaining cord. Press all the air out of the big bag, and tie it closed with two knots of cord.

Lye also absorbs carbon dioxide from the atmosphere and becomes carbonated if not stored properly. Carbonated lye is chalky white, fresh lye is almost translucent. You can still use carbonated lye if it's not too severe, but you'll have to use a bit more. Add about 25%, or better, check it against a titration with fresh lye.

Where to get it

You can get both NaOH and KOH from soapmakers' suppliers and from chemicals suppliers. NaOH might be more readily available and cheaper than KOH, but try to find KOH, it's worth the effort.

Lye usually comes in flakes and 5mm pearls or half-pearls, or small pearls (1-2 mm), which with NaOH are usually 99%+, but might be more expensive. Any of these will do if the purity is about 96% or better for NaOH. In the US, Red Devil lye is pure NaOH, if you can still get it (it's no longer manufactured).

Don't use Drano or ZEP drain-cleaners or equivalents with blue or purple granules or any-coloured granules, it's only about half NaOH and it contains aluminium -- it won't work for biodiesel. It's best to get your lye from soapmakers or chemicals suppliers. Suppliers for schools might have smaller quantities.

Using KOH

KOH is not as strong as NaOH -- use 1.4 times as much KOH (actually 1.4025 times).

Titration is basically the same.

You can use either KOH solution or NaOH solution for titration. Unlike NaOH, your KOH probably won't be pure, but as long as you use the same strength of KOH for both the titration solution and the reaction it won't make any difference.

Mix the KOH solution the same as for NaOH: add 1 g of KOH to 1 litre of water. Or do it the **Better titration** way. For each 1 millilitre of solution used in the titration add 1 g of KOH to the basic amount.

You can also use the usual 0.1% w/v NaOH solution and convert the end result for KOH, see below.

Instead of the basic 3.5 grams of NaOH per litre of oil, use $3.5 \times 1.4 = 4.9$ grams of KOH (4.90875). So, if your titration was 3 ml, use $3 + 4.9 = 7.9$ g KOH per litre of oil.

One more complication: KOH is generally not as pure as NaOH. KOH is usually 92%, 90% or 85% pure -- check the label. We use half-pearls assayed at 85%, with good and reliable results. KOH is available at 99% strength, but it's hard to find and it's expensive, and anyway 92% or 85% work just fine.

Adjust the basic lye quantity according to the strength of the KOH: the basic 4.9 grams of KOH at 100% strength would be:

85% KOH -- 5.8 (5.775) grams

90% KOH -- 5.5 (5.454) grams

92% KOH -- 5.3 (5.336) grams

To substitute KOH for the 3.1 grams of NaOH per litre of oil used in the acid-base process:

85% KOH -- 5.1 (5.115) grams

90% KOH -- 4.8 (4.831) grams

92% KOH -- 4.7 (4.726) grams

To convert NaOH quantities for KOH:

For 85% KOH use 165% of the NaOH amount (x 1.65).

For 90% KOH use 155.83% of the NaOH amount (x 1.56).

For 92% KOH use 152.45% of the NaOH amount (x 1.52).

Example: You're using 85% KOH and the titration needed 3 ml of KOH solution to bring the pH to 8.5.

Number of grams of KOH required for the reaction:

Basic amount: 5.8 g KOH (5.775)

Titration result: 3 ml

Add: 3 g KOH

Total: 8.8 g (8.775) of 85% KOH required per litre of WVO.

Using 0.1% NaOH solution for titration and the same WVO as above: the titration result is lower, it only needs 1.8 ml to reach pH8.5. (Actually 1.82 ml, according to the calculation.)

Basic amount: 3.5 g NaOH

Titration result: 1.8 ml (1.82)

Add: 1.8 g NaOH (1.82)

Total: 5.3 g NaOH (5.32)

Convert for 85% KOH:

$5.3 (5.32) \times 1.65 = 8.8 \text{ g (8.778) of 85\% KOH per litre of WVO.}$

We usually use NaOH solution for titration and convert the result for our 85% KOH, but in practice NaOH solution and KOH solution both work equally well.

One reason for preferring NaOH solution is that it's usually the standard used in describing FFA content of different oils -- 2 ml titration WVO or 5 ml titration WVO invariably refers to ml of 0.1% NaOH solution, unless otherwise specified. In the example above, the WVO would be described as 1.8 ml titration WVO.

KOH dissolves in methanol much faster and more easily than NaOH does, and doesn't "clump" together as NaOH can do. When you use KOH the glycerine by-product is liquid and won't solidify.

KOH is easier to use than NaOH. It's more flexible and adaptable and it gives generally better results. We seldom use NaOH (except for titration).

How much lye to use?

It requires 3.5 g of NaOH lye or the equivalent of KOH (see above) per litre of oil as catalyst to transesterify new, unused oil.

This makes standard-quality biodiesel within the usual processing parameters of methanol quantity, agitation, processing duration and processing temperature.

Fresh cooking oil contains a standardised amount of Free Fatty Acids (FFAs), which can slow or stop the transesterification process. The lye is alkaline and neutralises the FFA by turning it into soap, which drops out with the glycerine layer, and with 3.5 grams of NaOH per litre of oil there's enough left over to catalyse the biodiesel reaction.

Used cooking oil (WVO) needs more NaOH than new oil, not to serve as the catalyst but to neutralise the extra FFAs formed in cooking the oil. The hotter and longer it's cooked, the more FFA it contains, and the more lye is needed to neutralise it.

You have to titrate the oil to determine the FFA content and, from that, how much extra lye will be required. Titration measures the pH of the oil, that is, the acid-alkaline level (pH7 is neutral, lower values are increasingly acidic, higher than 7 is increasingly alkaline, or "base"). From this you can calculate how much extra lye will be needed to neutralize the extra FFA.

Too much lye will make extra soap, with very alkaline biodiesel that's difficult to wash, with loss of production, or it can ruin the reaction when the ratio of soap to biodiesel reaches a point where the whole batch turns into "glop soap".

Too little lye will mean some of the oil is left unreacted. See below:

[How the process works](#)

[The basic lye quantity -- 3.5 grams?](#)

Good-quality oil that hasn't been cooked too much or overheated is quite forgiving, but with poor-quality WVO with a high Free Fatty Acid (FFA) content, accurate titration is more important. The higher the FFA level, the more sensitive the reaction, the more precise you have to be with titration and

everything else, the more reactive agents you'll need -- and the lower will be the production rate.

Basic titration

For processing used oil, it's essential to titrate the oil to determine the Free Fatty Acid (FFA) content and calculate how much extra lye will be required to neutralise it.

An electronic pH meter is best, but you can also use phenolphthalein solution (from a chemicals supplier).

Dissolve 1 gram of pure sodium hydroxide lye (NaOH) in 1 litre of distilled or de-ionized water (0.1% w/v lye solution) (weight to volume).

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. If you're using phenolphthalein, add 2 drops of phenolphthalein solution.

Using a graduated syringe, add the 0.1% lye solution drop by drop to the oil-alcohol-phenolphthalein solution, stirring all the time. It might turn a bit cloudy, keep stirring. Keep on carefully adding the lye solution until the solution stays pink (actually magenta) for 15 seconds.

Take the number of millilitres of 0.1% lye solution you used and add 3.5 (the basic amount of lye needed for fresh oil). This is the number of grams of lye you'll need per litre of oil.

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.

Potassium hydroxide (KOH) can also be used for titration, see **Using KOH**, above.

Better titration

Unless you have a very accurate scale, it's not easy to measure exactly 1 gram of lye. It's much easier to measure 5 g accurately than 1 g, so mix 5 g of lye with 500 millilitres of distilled or de-ionized water to make a stock solution.

Before titration measure out 5 ml of the stock solution, add 45 ml of distilled or de-ionized water. This makes a 0.1% w/v lye solution.

It's also not easy to measure exactly 1 millilitre 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.

Warm the mixture gently by standing the beaker in hot water, stir until all the oil disperses and it becomes a clear mixture.

Then titrate as usual, measuring millilitres of stock solution used. When it reaches pH8.5 count up the number of millilitres used as usual and divide by 4. This will give a much more precise measurement.

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.

Accurate measurements

When "newbies" have problems making their first test batches and it doesn't pass the quality tests it's most often because of inaccurate measurements, or they didn't follow the instructions closely enough. Here's some general advice on being more accurate.

Weights

Truly accurate scales are expensive, unless you can pick up a second-hand set in good condition. Even then, it pays to check your scales for accuracy.

A good way of doing this is with new coins. Find out from your bank, or the Central Bank, what the weight is (in grams) of the coins in your country. If you get a full set of new coins you can use them in combination to check the accuracy of a wide range of weights.

With a balance-type scale (two sides with a fulcrum between them), get two full sets of coins, and figure out different combinations to put on each side; you should also be able to use this to achieve smaller gradations than your scale allows: aim to measure a tenth of a gram, 0.1 grams, preferably less -- 0.01 grams is best.

At 0.1-gram accuracy, with a one-litre test batch, measuring the 3.5 grams of NaOH required might give you 3.4 grams or 3.6 grams instead, or anything in between the two. With fresh oil this margin of error or even more won't matter, if you get everything else right you'll have good results.

That margin of error won't matter with test batches of used cooking oil (WVO) either, IF you heed the advice to avoid oils with titration levels higher than about 3 ml of 0.1% NaOH solution for your first test batches.

WVO with higher titration levels and higher levels of Free Fatty Acids will not be so forgiving, there's much less margin for error -- leave them for later when you're more experienced.

Small test-batches of high-FFA oils with titration levels higher than 6 or 7 ml will be easier with scales accurate to 0.01 grams and might need [bracket tests](#) as well, and you'll probably do better with the two-stage [acid-base process](#), which is also not for novices.

Volumes

If you have a standard millilitre measure that you know is accurate, use it to check all your various measuring flasks, syringes, pipettes, etc. Otherwise, check them against each other. With syringes or pipettes, or whatever you use to add the 1 ml of oil and the 0.1% lye solution to the titration mixture, you should be able to measure 0.1 ml accurately or better.

Smaller syringes are more accurate for titration, 5 ml syringes are a bit big, 2.5 ml will do. We use 1 ml clear plastic syringes, long and narrow, marked in tenths and tenths-of-tenths of 1 ml -- 0.01 ml. The measurement scale is 2-1/4" long (5.5 cm) so it's easy to read. They're cheap, you can get them from hobby shops (you don't need the needles).

Work with good lighting and on a white surface. First draw the syringe plunger back about 1/8" (2 mm) to take in some air. Then insert the end into the oil or NaOH solution and fill the syringe. Hold it up level with your eye, preferably with a well-lit white wall in the background, keep it vertical, and carefully empty a few drops, drop by drop, until the *bottom* of the surface meniscus is level with the 1 ml mark. When emptying the syringe into the titration vessel, don't empty it completely -- the one millilitre volume ends at the end of the scale, which leaves a little extra in the spout. Empty the syringe only to the end of the scale, with the bottom of the surface meniscus level with the 0 mark.

Use measuring flasks the same way. When filling them hold them vertical, with a well-lit white wall in the background, and with the gradation mark for the quantity you want level with your eye. Measure from the bottom of the surface meniscus.

Always keep your glassware and other measuring equipment meticulously clean. Barely visible smears of dried caustic residue or other chemicals can upset your results.

Joe Street's titrator

Joe Street of Ontario, Canada, made a titrator kit that he says makes the process easy and repeatable even in the field, by incorporating a small heater and magnetic stirrer in a small portable low-cost unit.

"What I needed was a way of warming the mixture of test oil and isopropyl alcohol, which is required for an accurate titration, and I thought it would be nice if agitation was included so that it would not be necessary to stop and shake or stir the solution with a stick while simultaneously trying to carefully control the flow of 0.1% caustic solution used in the titration. A laboratory grade stirring hotplate would be really nice but I could not justify the cost of \$500.00 to \$1000.00. Necessity is the mother of invention..."



Constant heat, constant agitation of the titration sample (note the test tube at the right end of the box)

Joe's titrator only cost him a few dollars. "It was quite simple to put together and was done in less than a day," he says. "Now I have both hands free and can dribble the solution smoothly without interruption just watching for the indicator to go off. I made my life easier by fixing two of the variables: the heat is always consistent, and so is the agitation."

Full how-to instructions at **Biofuel cooperative**, Joe's website:
<http://www.nonprofitfuel.ca/Titrator.html>

pH meters

It's said you can't reliably use an electronic pH meter for titration, nor to check the pH of biodiesel, because biodiesel is not an aqueous solution. Not quite true -- biodiesel is hygroscopic and will always have about 1,200-1,500 ppm water content absorbed from the atmosphere, if from nowhere else. With titration, you're adding water with the 0.1% NaOH solution. And laboratory-standard titration equipment uses electronic pH meters.

We have three pH meters, one of them rather expensive, and we did some comparisons, with

phenolphthalein, fresh from a laboratory supplies company in Tokyo, and with various test strips. We used WVO from several sources, and fresh oil as a check. The results were checked with test batches. In each case, the three pH meters agreed with each other and produced good test-batch results. Phenolphthalein results were consistently slightly higher, but the test-batch results were still good. The test-strips came a poor third -- not as precise as pH meters and phenolphthalein. People do use them with apparent success, but we don't think test strips are precise enough for titration.

See [Technical tips](#) for advice on using and maintaining pH meters.

Phenolphthalein

Phenolphthalein is often confused with "phenol red" (phenolsulphonephthalein), obtained at pool supply stores and used for checking water. It's not the same thing, and phenol red won't work for titrating WVO, its pH range isn't broad enough. It ranges from about pH 6.6, at which point it's yellow, through orange, to a maximum of pH 8.0, red. It's at its most accurate at pH 7.4. For accurate titration you need to be able to measure pH 8.5.

Phenolphthalein is colourless up to pH 8.3, then it turns pink (magenta), and red at its maximum of pH 10.4. When it just starts turning pink and stays that way for more than 15 seconds, it's measuring pH 8.5.

With good-quality oil with low FFA levels you might just get away with using phenol red for titration, but for higher FFA levels it isn't accurate enough. Use phenolphthalein -- specifically, 1% phenolphthalein solution (1.0w/v%) with 95% ethanol.

Phenolphthalein lasts about a year. It's sensitive to light, store it in a cool, dark place.

pH meters vs phenolphthalein

Which is better? There's lots of argument about it. [Biofuel mailing list](#) member **Jim MacArthur** (aka "the skapegoat"), who teaches chemistry at Three Rivers Community College in Poplar Bluff, MO, had this to say about it:

I can shed some light on using pH meters vs. phenolphthalien (PHTH) for titration from a chemist's perspective.

As acids become weaker, it is important to become more careful in the selection of a chemical indicator (such as PHTH), as the change in pH is much slower than it is for a strong acid titration. PHTH is the most commonly used indicator for strong acid titrations because it has such a clear color change. Fortunately it appears to change color over the same range as the equivalence point for FFAs (Free Fatty Acids).

The difficulty in either method is knowing what the equivalence point is going to be. This will vary based on the type of oil and the degree of hydrogenation. I don't suspect it will vary much, but it will vary. If your goal is a pH of 8 or 9, then using PHTH is going to be as good as a pH meter. If you have a better idea of what the equivalence point is going to be, then a pH meter works better.

The point is there are a number of reasons why PHTH may not work as well as a pH meter in

some cases yet works fine in other cases. This is something I think everyone will have to decide for themselves. -- the skapegoat, Jun 2005

High FFA levels

Most people find their used cooking oil generally gives a titration of 2-3 ml, but some used oils can have much higher FFA levels than this -- we've seen horrific titration levels of 9.6 ml. "Horrific" because FFAs are not good for you -- it's a very bad idea to eat food from a restaurant that does that to their cooking oil. Another biodieseler reported titration levels of 16 ml -- black stuff with the consistency of sump oil.

We did succeed in making biodiesel with our 9.6 ml oil. It's not easy to process oil like this with the usual single-stage base process. You're likely to end up with about 50% production half the time, and maybe not a very good product, and glop the rest of the time. If you're really precise with everything you can do it -- we managed to get a consistent 75% production with the single-stage base process, good product, easy wash.

The oil has to be thoroughly dried first -- traces of water make a bigger difference with high FFA levels, because there's more lye for the water to react with. And the reaction itself releases traces of water, especially with high levels of lye.

The better answer is to use the [Foolproof](#) two-stage acid-base method, which effectively handles high FFA levels and still produces high production rates with low levels of reactants and easy washing.

You can also deacidify the oil.

Deacidifying WVO

In commercial oil refining this is done with lye (NaOH), which saponifies the Free Fatty Acids, converting them to soaps which can then be removed, but it usually requires a centrifuge to separate it. This is an easier way, no need for a centrifuge.

Use the titration amount of NaOH -- eg, 9.6 grams per litre of oil for our high-FFA 9.6 ml WVO (see above). Mix the NaOH with 40 ml of water per litre of oil. It gets hot. Use a stainless steel container, mix it outside (by stirring), and take care! This is very corrosive stuff, take full safety precautions, have running water handy.

When the NaOH is fully dissolved add the solution to the oil (room temperature), stir gently by hand until thoroughly mixed. Be gentle!

Settle overnight. This leaves soapstock at the bottom. The water stays with the soapstock.

Filter to remove the soapstock -- no need for fine filtering, fine steel mesh will do (like a fine tea strainer). Again, do it gently.

Now process the filtered WVO as usual for fresh oil -- 3.5 grams NaOH per litre of oil, but use 25% methanol, process at 55 deg C (130 deg F), with good and prolonged agitation as usual.

In our tests the product was good, the production rate was 80%. With high-FFA oil like this, it's a much easier process than the normal single-stage, and it's nice not to have to make such strong methoxide as a straight single-stage process would require with this oil, 13.1 grams of lye per litre oil, or more like 13.6 grams (it needs a bit of excess lye).

It's an alternative -- better than straight single-stage base for oil like this, and while it won't get as high a production rate as the acid-base method, and it uses more catalyst and gives you more co-products, it's very quick and simple.

This is also useful if you're making [ethyl esters biodiesel](#), using ethanol rather than methanol: the ethyl esters process doesn't work well with oils with more than about 2 ml titration.

As always with a new process, try it first with a small sample, say 1 litre of oil. Be gentle when mixing it -- if you agitate it too much it won't separate easily. If that happens, try heating it, and be more gentle next time.

You can add the soapstock to the glycerine layer after separation and neutralize as usual to [separate catalyst, glyc and FFAs](#).

The soapstock can be used for producing soap, or turned into calcium soap, which is something like Dubbin and has an extremely low water solubility. Useful stuff. "Thus an equimolar amount of calcium chloride may be directly added to the soapstock and prompt separation of the calcium soap by precipitation from a relatively pure saline (NaCl) solution will ensue. Calcium soaps are useful industrial ingredients, for instance as demoulding agents." -- Chemical Reactions of Oil, Fat and Fat Based Products -- Neutralization (chemical processing)

<http://alfa.ist.utl.pt/~fidel/creac/sec34b.html>

Mix some calcium chloride in a little water (careful, it gets hot, don't splash) and add it to the soapstock a little at a time, stirring it in, until it separates.

No titration?

There are three ways of avoiding titration:

1. Use the [two-stage base-base method](#);
2. Use the [two-stage acid-base "Foolproof" method](#);
3. Do a series of [test batches](#) using graded quantities of lye and compare the results. Start off with maybe 6 g of lye per litre (3.5 g for the transesterification and 2.5 g for extra FFAs). If that works really well, then go ahead. Otherwise try more tests, at 5 g, then at 7 g; if, say, 7 g is better, try 6.5 g and 7.5 g, and so on until you get satisfactory results.

See also [Stock methoxide solution](#) and [Poor man's titration](#), below.

Satisfactory results mean that you get a good, clean "split" (ie separation), that it settles well, leaving a clear product with not too much soap formation, a good production rate, and, most important, that it washes easily without frothing.

There are people who claim titration isn't necessary, just use 6 or 6.5 g per litre and you'll be fine. Don't listen to them! They might have always done it that way and they've driven 20,000 miles already in their diesel without any problems, but 20,000 miles is nothing in the life of a diesel motor. Oils vary

considerably from place to place -- even the fabled "stable source of supply" can't be all that stable, unless it's a food processing factory with a standardized operation. If it's the usual restaurant or canteen, that would mean they cooked exactly the same number of identical meals in exactly the same way, every day. It just ain't so.

Sometimes the "no titration" folks point to Aleks Kac's two-stage methods, neither of which use titration, though they're both based on an "average" lye requirement of 6.25 g/litre. But two-stage processes work in a different way, and this cannot be applied to a single-stage process. In fact even with two-stage processes we do a titration, just to know what sort of oil we're working with.

They also point to [Mike Pelly's](#) statement that he usually needs between 6 and 7 g of lye -- but Mike also says titration is the "most critical" step in the process: "Make your titration as accurate as possible." And: "It's a good idea to do this entire process [titration] more than once to ensure that your number is correct." In fact Mike has a stable source of supply for his WVO, but he checks it regularly just the same, by titration and/or with test batches.

Titration won't tell you everything about your oil, but it will tell you more than anything else will (short of Gas Chromatograph analysis), and the more you know about your oil the easier your life will be. It is a basic technique in making biodiesel, not to be avoided.

The basic lye quantity -- 3.5 grams?

This is the amount of lye (NaOH, sodium hydroxide) required as catalyst to transesterify 1 litre of fresh, uncooked oil. For used oils, titration determines the amount of lye needed to neutralize the Free Fatty Acid (FFA) content, and this quantity is added to the basic figure of 3.5 grams per litre.

In fact 3.5 grams is an empirical measure -- an average. Different oils have slightly different requirements, and even the same type of oil varies according to how and where it's grown. Other estimates are 3.1 g, 3.4 g, and some people have set it as high as 5 g.

Here is what we've found. For most fresh oils and low-FFA used oils (with titration levels less than 2-3 ml), 3.5 grams works just fine. For high-FFA used oils, use more lye -- up to about 4.5 g instead of 3.5 g. Do small test batches to see what works best.

Different oils also require different amounts of methanol -- see [How much methanol?](#) For oils and fats requiring more methanol -- coconut, palm kernel, as well as tallow, lard, butter -- again, use more lye, up to 4.5 g, even with new oils, and especially when it's used. Once again, do small [test batches](#) first.

Mixing the methoxide

See [Methoxide the easy way](#). You can use the easy method with 4-gallon HDPE carboys or similar containers with screw-on caps (preferably with bungs as well). First the methanol, then add the lye gradually. Swirl it about from side to side rather than shaking it up and down.

If you shake it a lot, and often, it can be ready a lot sooner than 24 hours -- in just a few hours or even as little as half an hour, some people say. But DON'T use it until ALL the lye is thoroughly dissolved. If you use a white translucent HDPE container you can see any undissolved lye at the bottom of the container.

KOH -- potassium hydroxide -- dissolves in methanol much faster than NaOH, sodium hydroxide. It can be ready in as little as 10 minutes.

We use HDPE carboys with two screw-on caps and an aquarium air-pump to transfer the mixed methoxide to the reactor vessel via plastic tubing (the braided translucent type), with no exposure at all. Clean, safe and simple. See [Methoxide transfer](#). We transfer the methanol from its tank to the carboys the same way.

For HDPE, see below, [Identifying plastics](#)

Stock methoxide solution

Stock methoxide solution is very useful for making test batches, with a series of tests made in a [blender](#) using different amounts of lye for each. Rather than measuring tiny amounts of lye for each half-litre (or whatever) test batch, make a stock solution using one litre of methanol and 50 grams of lye. Then you can dilute quantities of the stock solution to whatever strength each test batch requires. If you're making half-litre test batches and using 20% methanol, measure out the methoxide this way:

If titration was, say, 3 ml, you'll need 3 + 3.5 grams of NaOH lye (the basic amount) for the reaction -- that's 6.5 grams per litre of oil. For half a litre of oil, that would be 3.25 grams and 100 ml of methanol at 20%.

It's easy to calculate that 65 ml of the stock methoxide solution will contain 3.25 grams of lye. So measure out 65 ml of the stock, and top it up with 35 ml of pure methanol to make 100 ml (20%).

For a test of 6 grams per litre of oil, you'll need 60 ml of the stock, top it up with 40 ml of pure methanol to make 100 ml. For a 7 grams per litre test, measure out 70 ml of the stock, top up with 30 ml of pure methanol. And so on.

Didn't figure the calculation? For a half-litre test at the rate of 6.5 grams of lye per litre of oil, divide 6.5 by 2 = 3.25 grams. The stock solution is one litre of methanol plus 50 g of lye. To calculate the amount of stock solution needed, multiply 1000 (1000 ml per litre) by 3.25 divided by 50 = 65 ml. For 20% methanol, 20% of 500 ml (half a litre) = 100 ml. 100 ml minus 65 ml = 35, so add 35 ml of pure methanol to the 65 ml of stock to make up 100 ml containing 3.25 grams of lye, equivalent to 6.5 grams of lye per litre of oil with 20% methanol.

Once mixed, methoxide won't last forever, but it's good for a few weeks. Don't make large amounts -- one litre is good for a dozen or more tests. If in any doubt, make up a fresh batch. Include what's left of the old mixture in the methoxide for your next full-sized batch of biodiesel. (With thanks to Todd Swearingen of Appal Energy.)

Poor man's titration

Essentially, the "poor man's bracket method" of titration is lining up a half-dozen pint jars of the same type, placing 200 millilitres of oil in each, adding methoxide of differing concentration to each and observing the reactions.

The easiest way to alter the concentrations is to prepare a stock solution of methoxide. Mix up a stock solution of 20 grams of NaOH with 400 ml of methanol. Your oil volume of 200 ml is 1/5th of one litre, meaning that you should reduce the usual 20% methanol volume proportionately, to 40 ml. However, it is suggested that you reduce it only to 50 ml to ensure that there is no shortage of alcohol.

For instance, if you want to see what 6.5 grams of NaOH per litre of oil will achieve in the way of a reaction, you need 1.3 grams of NaOH for a 200 ml test batch (6.5 divided by 5 = 1.3). The stock solution is 20 grams of NaOH per 400 ml of methanol: it's easy to calculate that 26 mls of stock methoxide will contain 1.3 grams of NaOH ($400 \times 1.3 / 20 = 26$). Combine 26 mls of the stock methoxide with 24 mls of pure methanol (= 50). With 1/5-sized samples, that amount is exactly what you want, the same ratio as 6.5 grams of NaOH to one litre of oil.

Number your six identical test jars from 1 to 6. For this example, they'll contain the equivalent of 5.0 grams, 5.5 grams, 6.0 grams, 6.5 grams, 7.0 grams and 7.5 grams of pure NaOH per litre of oil processed. You'll have 1/5th of one litre of oil/fat in each jar (200 ml), with 50 ml of methanol, however, each jar will have a different concentration of lye, ranging from 5.0 grams to 7.5 grams. Calculate the proportions of stock methoxide solution and pure methanol for each of the samples as in the paragraph above.

Add the following to each sample:

- 1) 20 ml stock solution + 30 ml pure methanol (5.0 grams/litre of oil)
- 2) 22 ml stock solution + 28 ml pure methanol (5.5 grams/litre of oil)
- 3) 24 ml stock solution + 26 ml pure methanol (6.0 grams/litre of oil)
- 4) 26 ml stock solution + 24 ml pure methanol (6.5 grams/litre of oil)
- 5) 28 ml stock solution + 22 ml pure methanol (7.0 grams/litre of oil)
- 6) 30 ml stock solution + 20 ml pure methanol (7.5 grams/litre of oil)

When all of the methoxide portions are prepared, add them to their respective jars of oil. Seal all lids tightly. Vigorously shake the contents of each jar 50 times. Repeat the agitation several times over a period of 10 minutes.

Let all samples settle. If settling can be conducted in a shallow water bath at 120 deg F (49 deg C) all the better.

Observe. The reason for using jars of the exact same type is to assist in more accurate visual comparison and conclusions. If possible transfer the contents of the jars to a 250-500 ml graduated cylinder for a more precise comparison. The appropriate amount of lye can be reasonably estimated based upon the volume of glycerin cocktail that settles out in each sample.

To fine-tune it, try one test batch 0.25 g on each side of the batch that had the most glycerin cocktail. Say that was with the 5.5 gram sample, do three more tests, for 5.25 grams, 5.5 grams and 5.75 grams. (With thanks to Todd Swearingen of Appal Energy.)

How much glycerine? Why isn't it solid?

Newcomers to biodiesel making their first batches sometimes think it all went wrong because the glycerine didn't go solid.

Messages sent to the [Biofuel mailing list](#):

"I did my first test batch of wvo biodiesel over the weekend. Although I appear to have formed a layer of glycerine on the bottom of the flask, it is not congealed, but is still liquid at room temperature (24 hours later). Did something go wrong?"

"The glycerin I got from my first batch is thinner than molasses at room temp. Why would it remain so thin? The information I have found suggests that it should be solid, or close to it, at room temperature."

Others think it "didn't work" because there wasn't "enough" glycerine:

"I did a first test batch of 3 litres WVO, adding 600ml methanol and got only 350ml of glycerine. I didn't really know what to expect, but 10% relative to the original stock seemed kind of low to me."

"I did a blender test batch of biodiesel last night. I titrated to 2ml, so I used 5.5g of lye and mixed it in with 200ml of methanol. I then heated the oil up (1 litre), and put it in the blender, and mixed for 15-20 minutes. It quickly began to separate and the biodiesel at the very top inch of the blender after the first 15 minutes or so was quite clear. I woke up in the morning and only 125 ml of glycerine settled out. Shouldn't there be at least 200 ml of glycerine settled at the bottom? There are only two layers, the top, light and slightly cloudy, and the dark glycerine. Where is the extra 75 ml of glycerine?"

In fact in all four cases the tests worked just fine.

There is no "set" amount of by-product, such as 200ml per litre, and there is no rule that the by-product must be solid at room temperature.

What's much more important is that in each of the cases above, the test batch produced a good "split" -- the glycerine separated and settled to the bottom, and, if they'd followed the directions carefully, the rest would have been good biodiesel, needing no more than settling and washing. It "worked", it's just fine, move on to bigger and better things!

How much glycerine?

"For 'back of the envelope' accuracy, whether fat or oil, to two significant digits one can estimate the molecular weight of the oil to be about 900 (slightly high) and the density is about 0.9 so the fat/oil contains about one mole per liter, therefore one mole of glycerin is present. The molecular weight is 94 so you would get about 94 grams of glycerin from a liter of fat/oil. The density is about 1 so you would get about 94 ml per liter of oil." -- Bob Allen, Biofuel mailing list

But the so-called "glycerine layer" is not just glycerine, it's a variable mixture of glycerine, soaps, excess methanol, and the catalyst (lye). Better to call it the by-product layer.

The overall amount varies according to the oil used (more soap with heavily-used oil), the process used



Just made 20 minutes earlier, and still settling.

(less soap with the [acid-base two-stage method](#)), the amount of excess methanol used (most of the excess methanol ends up in the by-product layer).

Why isn't it solid?

It's mainly the soaps combined with the glycerine that can cause it to solidify. Soaps made from saturated fats such as stearin are harder than those made from unsaturated fats such as olein, so the type of oil used makes a difference (see [How much methanol?](#) for compositions of different oils).

More important is how much soap there is -- the more soap, the more likely the by-product layer will solidify, no matter what oil you used.

Other factors:

- Excess methanol makes the by-product layer thinner
- Too much lye creates excess soap
- Using potassium hydroxide (KOH) as the catalyst instead of sodium hydroxide (NaOH) produces a liquid by-product that won't solidify. (See [Using KOH.](#))

See: [Glycerine](#)

PET bottle mixers

Despite claims to the contrary, this is not a good way of making biodiesel. It is useful if you're doing a demonstration, though it makes it look simpler than it really is.

PET bottles are transparent plastic soft-drinks bottles, generally 1/2 or 1 or 2 litres. "PET" stands for Polyethylene Terephthalate -- see below, [Identifying plastics](#)

Here's how the PET bottle fans do it: warm up the oil (or maybe not), funnel it into the PET bottle, add the (pre-mixed) sodium methoxide, screw on the cap, shake the bottle up and down 10 times or maybe 40 times, leave it for an hour, and it's done.

Well, maybe. Or maybe not -- it's a good recipe for an incomplete reaction.

For test batches, here's a better way: warm the oil to 55 deg C (131 deg F). Pour it into the PET bottle, add the methoxide, screw on the cap, shake vigorously up and down 40 times or more. Then stand the bottle in a bath of hot water to maintain the temperature -- keep the water in the bath at around 55 deg C. Shake again every 5 minutes, for up to two hours, maintaining the heat all the time. This will have a much better chance of not leaving unreacted and partly reacted material in the mix. See below: [How the process works.](#)

Better still, make one of these instead: [Test-batch mini-processor](#)

Biodieseler Greg Yohn, who developed this technique in the first place, along with Steve Spence and other seasoned biodieselers who've used it for years, all say it's useful ONLY for demonstration purposes, and so do we. Use new oil, and best do it in private first so you don't risk making a fool of yourself. The value of the "method" for demonstrations is that it doesn't matter much if the reaction is incomplete and leaves unreacted material in the mix, just as long as you get separation and the glycerine drops out -- you're demonstrating the process, NOT making fuel, and in a transparent PET

bottle you can clearly see it all happening. And it's non-messy.

Viscosity testing

Viscosity levels are a comparative indicator of biodiesel quality. Unfortunately, and despite claims to the contrary, that's all they are, a comparative indicator: this batch is better than that batch. Even at the laboratory or industrial level, viscosity testing alone cannot tell you if the process has gone far enough before reaching equilibrium and that there are not unacceptably high levels of harmful unreacted and partly reacted materials in your fuel.

Unconverted monoglycerides (MGs) and diglycerides (DGs) are fuel contaminants that can cause injector coking and engine damage. MGs and DGs are very similar in viscosity to biodiesel and stay in solution with it after an incomplete reaction, they can't be washed out. The allowed maximums are low: less than 1% for DGs and less than half that for MGs. Viscosity tests might get you within 5% accuracy, not nearly close enough for a useful quality check.

The same goes for density -- specific gravity measures (SG). Even both viscosity and density together can't assure you that the reaction has gone far enough towards completion. About the only sure way to know that is with a Gas Chromatograph or expensive laboratory tests which few biodieselers can afford. Short of a GC the best indicator of a completed reaction is the wash -- easy washing and a crystal-clear product. See [Quality tests](#). See below: [How the process works](#).

Nonetheless, viscosity can be a useful indicator, especially with test batches. You can check viscosity with a 100 ml pipette and a stopwatch -- time exactly how long it takes 100 ml of your fuel to empty from the pipette. Or use a [viscosity meter](#). Excess methanol in the fuel will render the results meaningless, so you must wash the biodiesel first. Measure some petro-diesel for a comparison. Remember that viscosity is sensitive to temperature -- try it at two or three different temperatures. See the various quality-specification tables [here](#) for some guidance.

Aleks Kac offered this advice to a Biofuel mailing list member struggling to get his [home furnace](#) working with biodiesel:

Kinematic viscosity is measured in "Stokes". You cannot measure it at home without a viscosimeter. There is a comparative way, though. Take a liquid with a known viscosity value (petroleum heating oil, look the value up in an engineering manual) and let a known volume flow through an upside-down plastic water bottle with a drinking straw glued in a hole in the screw top. Stop the time with a stopwatch. Do the same with your biodiesel (same volume) and compare the results. Generally a smaller diameter straw will produce more accurate results. If the time of your sample is 1.5 the time of your control sample (petroleum oil), this means its viscosity is roughly 1.6-ish that of the control sample. -- [Aleks Kac, 6 Nov 2001](#)

You can use two straws, the second one to let air in for a smooth flow of oil -- see how we do it with small test batches of methoxide: [Adding the methoxide](#)

Measure specific gravity (SG) by weighing a specific volume of the fuel. Remember that volume is also sensitive to temperature. A litre should weigh about 880 g at 15.5 deg C.

See [Quality testing](#)

How the process works

What is meant by "completion" and "equilibrium"?

First, vegetable or animal fats and oils are triglycerides (TGs), composed of three chains of fatty acids bound by a glycerine molecule (see diagram in next section below).

Triglycerides are esters. Esters are acids, such as fatty acids, combined with an alcohol, and glycerine (glycerol) is a heavy alcohol.

The transesterification process converts triglyceride esters into alkyl esters (biodiesel) by means of a catalyst (lye) and an alcohol reagent, usually methanol, which yields methyl esters biodiesel -- the methanol replaces the glycerine.

In transesterification the triglyceride molecule is broken into three separate methyl ester molecules plus glycerine as a by-product. The lye catalyst breaks the bond holding the fatty acid chains to the glycerine, the glycerine falls away, the fatty acid chains then bond with the methanol.

It happens in three stages (this has nothing to do with the single-stage or two-stage processes). First, one fatty acid chain is broken off the triglyceride molecule and bonds with methanol to form a methyl ester molecule, leaving a diglyceride molecule (DG) -- two chains of fatty acids bound by glycerine. Then a fatty acid chain is broken off the diglyceride molecule and bonded with methanol to form another methyl ester molecule, leaving a monoglyceride molecule (MG). Finally the monoglycerides are converted to methyl esters -- completion.

The problem is that the process can run out of reagent or catalyst before it gets that far, or agitation, temperature or processing time may be inadequate.

The result is some unconverted or partly converted material remaining in the biodiesel. Well, so what if the process isn't completed? SVO (straight vegetable oil) is a good fuel anyway, so what's it matter if some of it is unreacted? But it's not just unreacted material that's the problem so much as the partly-reacted stuff. Diglycerides and monoglycerides are bad things to put in your diesel. Diglycerides don't burn well and lead to coking problems, monoglycerides can lead to corrosion and other problems -- bad fuel.

"The level of glycerol, mono- and diglycerides at levels of 0.1% (a factor of 1/1000 or less of the main ester components) or lower appears necessary for optimum engine performance." (International Conference on Standardization and Analysis of Biodiesel, Session 2, "Interaction Between Engine and Fuel", Vienna, November 6-7, 1995 -- to be published.) -- From "Analytical Methodologies for the Determination of Biodiesel Ester Purity -- Determination of Total Methyl Esters", NBB Contract #:520320-1, Richard W. Heiden, Ph.D., R. W. Heiden Associates, February 27, 1996
http://www.biodiesel.org/resources/reportsdatabase/reports/gen/19960227_gen-221.pdf

So, either don't process it at all and use SVO (which can have its own problems), or process it PROPERLY.

In fact the process never reaches 100% completion, it always reaches equilibrium first, so there will always be some unreacted glycerides left. The various [**national biodiesel standards**](#) stipulate just how

much is allowable, and it's not very much: diglycerides range from less than 0.4% to less than 0.1% by mass, monoglycerides less than 0.8% by mass.

The first part of the process happens rapidly, which is why some people think it only needs a few shakes and that's it. Not so. If it takes X minutes to convert half the TGs to DGs, it takes almost as long, another X minutes, to convert half the remaining TGs, then a further X minutes for the remaining half, and so on. So the process goes more and more slowly, and never quite arrives -- there's always half left. Finally comes a point when the remaining half is insignificant, and, indeed, within the limitations set by the various quality standards. But it's very easy to fall short of that point and end up with nasties in your beautiful clean eco-friendly nice-smelling home-brewed fuel, and in your motor.

See [Kinetics of Palm Oil Transesterification in a Batch Reactor](#), by D. Darnoko and Munir Cheryan, University of Illinois, for what actually happens during the biodiesel process reaction. (Acrobat file, 72Kb)

You CAN make high-quality biodiesel, all it takes is a little care. On analysis, biodiesel made by homebrewers with no qualifications and no special equipment using the methods detailed at this website has proved the equal of professionally made commercial fuel or better. Professional mechanics checking their motors have been amazed by the lack of wear and corrosion. You can do it too. See [Quality](#)

Message to the [Biofuel mailing list](#) from a biodiesel dealer in the US:

"Currently I resell commercial manufactured biodiesel in Atlanta, GA. Over the past two years I have seen the quality of this fuel vary greatly. Funny thing about the "commercially manufactured" biodiesel... One of the big arguments against backyard biodiesel (from industry folks) is quality, yet every batch that I have made, and every batch I have seen by a homebrew biodiesel maker has been much better than the "fuel" I am reselling. Individuals with small-scale setups seem to really care, take their time, and craft their fuel... after all, most are using it in their own cars, not selling to the boiler fuel market."

For beginners, start off with good practices: follow the instructions carefully, be meticulous with your titration, make sure your measurements are as accurate as you can make them. Learn as much as you can. You'll soon get a feel for it, and then, once you're familiar with the process in all its aspects, you'll be able to decide what's best for you in your situation, with your source of oil, on your budget, and just where you can relax a little and take calculated shortcuts, based on your own experience.

NOTE: It's a common misconception that biodiesel has lower viscosity than SVO or WVO because the transesterification process shortens the carbon chain length of the fatty acid molecules in the oil.

This is not so. The biodiesel molecule is indeed smaller and less complex. Transesterification converts the triple-chain triglyceride vegetable oil molecule to three single-chain methyl ester molecules, but the chain lengths of the fatty acids themselves remain the same. The fatty acid composition of biodiesel depends on the feedstock and is not changed by transesterification.

Animal fats, tallow and lard

Many people make biodiesel from tallow, lard or chicken fat. It makes great fuel, but like the fat it's made from, it has a high melting point -- when the temperature falls below about 15 deg C (60 deg F), the fuel starts to go solid. It's strictly summer fuel.

Some people have difficulty processing animal fat.

Frequently asked question: "I have access to a source of animal fat that is used for deep frying. I have tried to make biodiesel from it but only succeed in producing a very soapy gloop. Is there a difference between using animal fat and waste veggie oil? Help!" -- Leo, Biofuel mailing list, 26 Apr 2006

Answers: "No real difference between the two, at least not relative to making fuel. The suggestion would be to use KOH instead of NaOH for starters. That should help end your thickening/soap issue. Don't jump the gun with large batches until you get the small stuff right if you're still having problems." -- Todd

"Animal fat (tallow) has a different chemical make-up than vegetable oil. You need to do much more purification. You get soap (glycerin) like results with vegetable oil, just not as much. I think that if you use a stronger caustic agent to separate mixture components, you may have more success." -- Randall

"You're aware that saturated fats and oils tend to make harder soaps? Combining factors such as the greater ratio of saturated glycerides and the common practice of overdosing caustic as 'insurance' by new initiates to biodiesel and the groupies of others who prescribe the method as a guaranteed cure-all, there will be inevitable and needless occurrences of failed reactions due to the formation of 'glop soap.' Animal fats do need to be rendered thoroughly to remove as much proteinaceous material as possible prior to processing. But the 'chemical make-up' is essentially no different than any other triglyceride, other than the ratio of saturated acids to unsaturated acids. It's the ratio of fatty acids to each other that defines an oil or fat, giving each its general properties." -- Todd

"Tallow, lard, butter, vege oil, etc. are all the same chemically save very, very minor differences which don't impact the transesterification reaction. Fats and oils are treated the same as to volume of methanol, reaction time, and amount of catalyst. Impurities, mainly water present, will impact yields, and soap production, but starting with relatively pure oils and fats requires no different treatment." - Bob A.

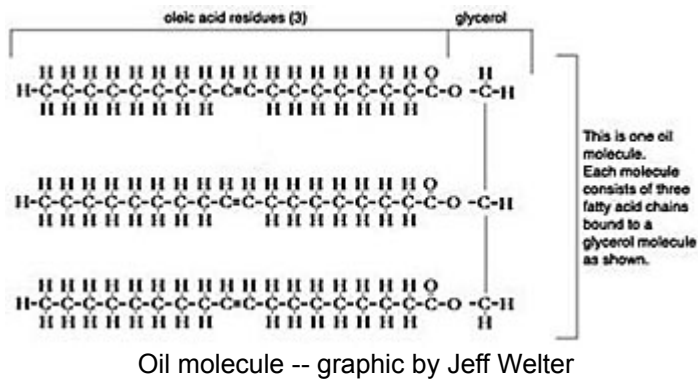
"I stand corrected." -- Randall

"I have processed 100% virgin beef tallow fat with the 2 stage base - base process with great success. I used 200 ml methanol / liter fat and 6.7 g NaOH Processed for 2 x 2hours at 58 - 60 deg C. That batch washed better and easier than any other WVO I had dealt with. The only drawback is cold weather, it will crystalize around 15 deg C (59 deg F). Otherwise it is great fuel with a light yellow color like the fuel from virgin rapeseed oil. Good luck with it." -- Andrew

"I have also had excellent results from beef tallow using the acid/base two stage process. Although when washing, I thought I was getting loads of soap out even on the third or fourth washes. It turned out that my water was too cold, I was bringing the temperature of the biodiesel down to below 15 deg C and forming waxes. I then washed with lukewarm water and got perfect results, crystal clear wash water on the third wash." -- Bob C.

"Last time we rendered deer tallow and made biodiesel from it we were stonewalled after an overnight temp of 56 deg F (13 deg C)." -- Todd

What are Free Fatty Acids?



Again, vegetable or animal oils and fats -- what we make biodiesel from -- are triglycerides, composed of three chains of fatty acids bound by a glycerine molecule.

Free fatty acids (FFAs) are fatty acids that have become separated from the triglycerides, leaving diglycerides, monoglycerides and free glycerine. This is caused by heat, water in the foods cooked in the oil, or oxidation. The hotter the oil gets and the longer it's cooked, the more FFAs it will contain.

As glycerine is an alcohol (glycerol), a fatty acid attached to it (a glyceride) forms an ester. A "transesterification" is the conversion (switching) of one ester into another -- a glyceride ester into an alkyl ester in the case of biodiesel, where methanol (or ethanol) replaces the glycerine.

An "esterification" is the conversion of a non-ester into an ester. FFAs are non-esters. FFAs are converted into esters by acid esterification in the first stage of the two-stage acid-base biodiesel process, but cannot be converted by the more common single-stage base transesterification process. Here the FFAs must be removed from the process, or they will dissolve in the biodiesel being formed, yielding an acidic, poor-quality fuel that will not meet quality standards.

In transesterification, extra lye is used to neutralize the FFA content of the oil, turning it into soaps. These soaps drop out of the process as a by-product, joining the so-called "glycerine layer" at the bottom -- often more of a "soap layer" as it may contain more soap than glycerine.

The basic lye quantity used in transesterification acts as a catalyst, not a neutralizer. Lye attacks ester bonds, breaking the bond, and the alcohol drops off, leaving an open-ended fatty acid chain. With glycerides the alcohol that drops off is glycerine. The affinity of the replacement methanol or ethanol for the resulting open bond is strong enough to prevent the glycerine reattaching to the fatty acid.

This is also why 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. It is this excessive formation of FFAs that the "acid number" in the US ASTM and other national quality standards refers to.

While it is unavoidable that some FFAs are formed by biodiesel ester bonds being broken, excess lye increases the proportion.

According to the [Fuel Injection Equipment \(FIE\) Manufacturers](#) (Delphi, Stanadyne, Denso,

Bosch), FFAs can corrode fuel injection equipment, cause filter plugging and the build-up of sediments on fuel injection parts.

-- With information from Todd Swearingen of Appal Energy, and DieselNet/Ecopoint Inc.

<http://www.dieselnet.com/>

Which method to use?

Three main choices, all of them here:

[Single-stage base -- Mike Pelly;](#)

[Two-stage base-base -- Aleks Kac;](#)

[Two-stage acid-base "Foolproof" method -- Aleks Kac.](#)

What's the difference?

The single-stage base method is the place to [start](#). The two-stage processes are advanced methods, not for novices -- learn the basics thoroughly first. Single-stage base is the original method, and still the most widely used, tried and trusted. It's the simplest method, especially for new oils which don't need titration.

A lot of beginners want to use WVO but they're put off by the titration, thinking it's too complex. Actually it's simple enough -- just follow the [directions](#). However, the single-stage process produces more and more uncertain results the higher the FFA content gets in WVO, with lower production levels even when it works well.

The two-stage base-base method avoids the need for titration and produces good results even with higher FFA levels. It's the method-of-choice for animal fats.

Growing numbers of biodieselers are now turning to the "Foolproof" two-stage acid-base method, especially with high-FFA oils. Here are some of the reasons:

- Less base catalyst needed.
- Less soap production.
- Higher conversion rates as a result of less soap formation.
- Less emulsion formation in the wash.
- Less loss of fuel in the wash as a result of emulsion formation.
- Less wash water as a result of less soap formation.
- Less neutralizing acid needed for the wash.
- Less acid needed to neutralize base during glycerine recovery.
- High-quality product.

The negatives:

- A little extra processing time.

Even with higher-FFA oils the production rate should be 100% or more by volume (biodiesel has a lower density than the original oil).

In fact the same advantages apply to new oil, although to a lesser extent. Many biodieselers who turn to the "Foolproof" method for high-FFA oils soon make it their method-of-choice for all oils.

Here's some advice from Aleks Kac on using the Foolproof method: "Stick to the recipe, to the letter. There's two years of trial and error research in this. Do not change, simplify or speed up anything. It will take care of all sorts veg fats, even heavily used. The 'solid' portion must be reduced to less than 50% because of the much lower acid-stage temperature. Animal fats content is best at less than 25% for pork or chicken and less than 10% for bovine. These fats at greater concentration should be processed with the [two-stage base-base method](#)."

Still, if your oil is quite good and usually titrates at 3 ml or less, you might well be satisfied with the single-stage process.

Why can't I start with the Foolproof method?

It says at the top of the [Foolproof acid-base process](#) page: "NOTE: The two-stage biodiesel processes are advanced methods, not for novices -- learn the basics thoroughly first. The single-stage base method is the place to start. Start here."

Here being here:

[Where do I start?](#)

But novices sometimes take no notice and plough ahead with the acid-base process anyway. Sometimes they also take no notice of the advice on Test batches: "Whenever you're trying a new method, it's always a good idea to make small test batches of a litre or less first to familiarize yourself with the process before moving on to bigger batches."

All too often it results in a highly discouraging 40 gallons of glop. "It doesn't work!" they wail. It works. It also works to heed the advice of the many who've gone before you. "DO AS THEY RECOMMEND and bio will come," said a recent novice at the Biofuel list.

"But it doesn't sound difficult at all, in fact it sounds easier since there is no need to titrate. So what am I missing?"

Quite a lot. First, we think it's worthwhile titrating your oil anyway -- the more you know about it the better, and titration will tell you more than anything else does.

Avoiding learning how to do titration is a VERY BAD reason for using the acid-base process! Titration is a basic skill needed for making biodiesel, no matter which process you use. Anyway, it's easy enough:

[Basic titration](#)

[Better titration](#)

Second, it's not just a question of whether or not novices can get it to work. Some do -- mostly they seem to get away with it. But that's a pity just the same, because it's doubtful that they'll get the best out of it. The acid-base method is very flexible, people bend it and twist it every which way in adapting it to their preferences and needs, and you just can't do that unless you have a good overall feel of the process as a whole, not just of this one method.

Another novice at the Biofuel list said he had good chemistry knowledge so he could afford to skip the

"newbie" stuff. But: "Well, my first test batch is done, and the end result is less than spectacular..."

Suddenly he found himself facing an ocean of variables, and since he had no "feel" for what was supposed to be happening he had no way of finding out what he'd done wrong. Several things, as it turned out.

One answer:

"This is why this isn't a good place to start. If you were more experienced you might have had a better idea of how to translate the mixing instructions for a full-sized batch to the small scale you're using. Maybe it translates direct, maybe not -- I don't know how fast your drill stirs it, nor what rate of agitation it gets with that paint stirrer, but, comparatively, neither do you, and that makes it difficult for you. Starting instead with single-stage base and fresh oil, you begin with fewer variables and they're less critical, and it's a logical progression from there. Now you're facing too many variables and you don't have the experience to assess them -- and you're more likely to make mistakes anyway because you lack a basis of comparison."

He relented and went back to the beginning, processing 1 litre of fresh oil by the single-stage base method. "Despite people saying that in different ways, I hadn't heard it until now. All I was hearing was that you have to start with the single-stage process then graduate to the foolproof process. This just seemed like trying to learn something one way then do it in a completely different way, which doesn't make sense."

"... so what am I missing?"

One answer:

"If everything goes exactly right, nothing. The problem is when something doesn't, and you have NO IDEA what's going on 'cuz you've never seen all the possible quirks of even the basic process.

"...What's all this white stuff?... Nothing seems to be happening... There's this weird layer, and I'm wondering if it's biodiesel... etc etc."

Another answer:

"I can mention that from a beginner's perspective, starting with pure vegetable oil and single-stage base is a really valuable learning process. It gives you an idea of what outcomes look like, and the [shake test](#) provides feedback on the quality of the process. I am still playing around with variables (processing time, %lye, %methanol, etc.) using pure vegetable oil, before moving to waste vegetable oil.

"As many people continue to emphasize, process quality is really important, and that seems to be best learned in small steps. My game plan is also to get to the 2-stage acid/base with waste vegetable oil, but I still have a lot to learn before getting there. I think what the experienced folks are cautioning is that troubleshooting a more complex process is extremely difficult (and perhaps frustrating) if you don't have a solid grounding in the basics. I hope this helps. Good luck with your experiments!"

The response:

"After reading the links to the discussion groups that you attached I see that the basics is to get a feel of the process and see the correct colors and textures using the process that has the best

chance of success, then use that as a baseline for future mini batches using WVO. Then progress to larger scaled processing, then full scaled process, and then finally graduate to the two-stage method, with knowledge that the resultant biodiesel is clean and pure enough to run through my beloved TDI."

Right!

"I would like to testify that the acid base method on JtF WORKS and it works well. That said you will never get it to work unless you start at the beginning. Keith is not kidding - get to know the oil." -- Jim, Biofuel mailing list, 12 May 06.

See:

<http://snipurl.com/pie8>

[Biofuel] Biodiesel test results

11 Apr 2006

D.P. wrote:

I am interested in biodiesel and used your foolproof method to make biodiesel. Four litres so far... wow eh! However I have since constructed a 200-litre biodiesel reactor out of scrap stainless steel so I can run my VW TDI without modification. My degree is in chemistry but my main forte is a mechanical aptitude.

The main question I do have about your foolproof method of making biodiesel is during the acid catalyzed process. I have tried four times to get separation... I have 100 litres in my new reactor and I do not want to have a goopy mess.

Reply:

It says at the top of Aleks's pages:

"NOTE: The two-stage biodiesel processes are advanced methods, not for novices -- learn the basics thoroughly first. The single-stage base method is the place to start. [Start here.](#)"

Please don't take offence, but while you may have a background in chemistry, you wouldn't be the first chemist who had to go back to the beginning with this and got it right in the end. With only four litres behind you (four failures apparently) you're a novice, you have to get a feel for it first, and you're not starting at the beginning.

You're not ready for 100-litre batches yet, stick to one-litre tests. Even if you can get it to work at that level, transferring the process from a one-litre batch to a 100-litre reactor that you've never used before might not be as simple as you think. The only good advice is to go back to the beginning, with small batch tests of new oil using the standard single-stage base method.

-- Keith Addison

From D.P., some months later -- "Starting from the beginning":

Dear Keith:

Just a short note to thank you for such an excellent website for biodiesel. I took your advice and went back to the basics. I am now making quality biodiesel with excellent separation and water washing is easy. Test batches thru my home-made reactor are a must. Keep up the good work

and keep encouraging anyone who wishes to make a difference.

Sincerely...

Biodiesel in gasoline engines

Biodiesel can also be used in gasoline (spark-ignition) engines, but only as an additive. People have had good results with it, but it's still experimental, there are no guarantees.

Biodiesel in 2-stroke gasoline engines: Many people have used biodiesel as replacement 2T lube oil in two-stroke gasoline (petrol) engines. [Biofuel mailing list](#) member **Martin R.** of Australia uses it in his chain saw, at a mix of 1 to 20 with gasoline. "It works fine," he says. "After using the saw for 2.5 hours in one go on dead Australian hardwood with no hiccups I was very impressed to say the least."

List member **Franklin Del Rosario**, biodiesel maker in Manila in the Philippines, uses it in his motorcycle:

Biodiesel was first used as 2T replacement in the Philippines by a group who added a viscosifier and sold it as 2T replacement for tricycle taxi use at several places outside Manila.

The biodiesel, pure or blended with oil additive, performed better than 2T mineral oil as lube oil, according to the testimony of the tricycle drivers who tried it. Their motors ran smoother and quieter than before, the engine block did not heat up, others experienced better engine performance, no more carbon build-up inside the cylinder and muffler, no oil dripping on the exhaust pipe and most of all no more smoke.

I use B100 biodiesel as lube oil for my 1983 Yamaha 125 cc two-stroke motorcycle instead of Shell 2T lube oil which I previously used. I mix biodiesel with gasoline at a ratio of 1:20. I replaced all rubber fuel lines, carburetor gasket etc., cleaned the fuel tank, and changed to a new spark plug. The motor is running smoothly on city driving, the smoke has improved because no more 2T lube oil.

The Yamaha was retired before because of the smoke it produces using mineral 2T oil. With biodiesel as a lube oil it runs better than before and with less smoke at the exhaust pipe. I took my motorcycle to the emission test center and it passed the gas standard limit with better results than a new motorcycle which used mineral 2T oil.

The results were as follows:

Data reading
CO2 -- 2.90%
CO -- 3.39%
HC -- 5396ppm
O2 -- 13.29%
AFVR -- 20.95
LAMBDA -- 1.44

Standard Gas Limit

CO2 -- 20.00%
CO -- 6.00%
HC -- 10000PPM
LAMBDA -- 1.00 +/- 0.99

Result -- Passed

The main property of the lube oil is not the viscosity but rather the ability to mix well with gasoline while maintaining its lubricity (ability to provide a film of oil at the metal surface) to prevent wear of the crank shaft, connecting rod & piston pin and cylinder wall. Biodiesel's lubricity is enough to do the job and it can be improved by adding compatible oil additives to increase the film strength of of the biodiesel.

BD is a fuel with 11% of oxygen by weight, this property alone can help gasoline to burn well reducing smoke emission and leaving no trace of oil at exhaust muffler. -- Franklin Del Rosario, January 2004

Biodiesel in 4-stroke gasoline engines: List member Gregg Davidson wrote:

In June of this year, I posed a question about "Biodiesel in gasoline engines". I received a reply from list member JC in Taipei. He advised me that he had mixed biodiesel with gasoline for his car, using no more than a 15% mix. I have had success following his example and had no engine problems. One of the three vehicles I tested this in is a Chrysler Town & Country mini van with a 3.3 L V-6 Flex Fuel Engine, the other two are Jeep Grand Cherokees with 4.0 L I-6 engines. Even though the van can run on E-85, I do not use ethanol blends because E-85 is not available in my home state of Georgia. -- Gregg Davidson, October 2004

Franklin Del Rosario wrote:

I'm please to inform our group about using a biodiesel blend with gasoline fuel to power a 4-stroke gasoline engine. The company I work with has a fleet of service cars, most of them are Japanese Nissan, Toyota and Honda. I persuaded one of our company drivers to try biodiesel in a gasoline engine at 200-300 ml of biodiesel to 50 litres of gasoline mixed together in the fuel tank.

We choose a Nissan Cefiro because it emitted a foul odor of unburned hydrocarbons irritating to the eyes and nose during engine warm up and idling. I poured 200 ml of biodiesel into the tank, shook the body for a while and started the engine. After 5 to 7 minutes of idling speed, the exhaust odor improved dramatically and at the end of the day of driving the odor of unburned hydrocarbon was gone and engine purred better than before because biodiesel lubricates the fuel system, the upper combustion chamber, as well as the valve ports. Because of this other drivers tried it in Honda cars. The immediate result was no more odor of unburned hydrocarbons and visible trace of water condensation at the exhaust tail pipe as if the car was new.

I tried using biodiesel as an anti-wear additive for a four-stroke gasoline motorcycle engine and the result was the same.

My friend owns a surplus service car, a gasoline engine Toyota. His car was due for the yearly renewal of LTO registration, and he had a problem because his old car smoked badly and one of the requirement for LTO registration is to test the car at the emission test center. Cars must pass the Emission Standard set by the government before renewal of LTO registration. I challenged

him to try biodiesel as a fuel additive, without any engine modification, changing of oil or cleaning of air filter except cleaning of exhaust pipe by water hose to remove carbon particle clinging to the pipe wall. He did so and took the car to the emission test center. The result was very promising

Emission Standard

CO % (V) -- 3.5

HC (ppm) -- 600

Running condition gradual increase of rpm

Gas analyzer final result of service car were the following

CO % -- 1.25

HC (ppm) -- 278

PASSED

Biodiesel as an anti-wear and smog additive for gasoline fuel is very encouraging. -- Franklin Del Rosario, January 2004

Storing biodiesel

Frequently asked question: "I read somewhere that biodiesel has a short shelf life. Does biodiesel have an expiry date or a use-by date?"

Answer: We have some biodiesel we made six years ago that hasn't degraded. It's been kept sealed in an HDPE plastic container with a bung and a lid. Others report 4-year-old biodiesel still being usable.

- "We opened up a drum from our first reactor that was four years old a couple of weeks ago, 45 gallons of it. It had been sitting outside in a 55 gal steel drum with approximately 5 inches of airspace over the it. It has been through some record-breaking winters and several high-heat cycles unattended. Even though this was an unintentional test, it's showing us some things. This batch was 50% soy 50% wvo processed at the same time. There was a little bit of cloudiness but not much, which was easily removed by simply stirring. One of our trucks has run almost a week on it with no change in performance from the freshest batch..."
-- Philip S. Okey, Biofuel mailing list, 28 Jul 2004
- "The findings that we have are that biodiesel does more readily oxidize than petrol diesel. So if left in an open container the shelf life is very short. It will still burn after being oxidized but not nearly as well. On the other hand, most of us would be storing our biodiesel in a sealed container, which limits the oxidation to the amount of air and surface area. The best thing to do is to store it in a sealed container that is as full as practically possible. This limits oxidation to a level that probably won't be noticeable."
-- Doug Memering, Biofuel mailing list, 11 Sep 2005

"A study on the stability of the methyl and ethyl esters of sunflower oil reports that ester fuels (biodiesel) should be stored in airtight containers, the storage temperature should be < 30 C, that mild steel (rust-free) containers could be used, and that tert.-butylhydroquinone (TBHQ), an oxidation inhibitor, has a beneficial effect on oxidation stability (166). Methyl esters were slightly more stable than ethyl esters."

-- From: Storage stability, **Biodiesel: The Use of Vegetable Oils and Their Derivatives as Alternative Diesel Fuels**, G. Knothe, R.O. Dunn, and M.O. Bagby, in *Fuels and Chemicals from*

Biomass. Washington, D.C.: American Chemical Society. Download full-text article:

[Acrobat file, 912kb](#)

[MS Word file, 212kb](#)

The US industry group, the National Biodiesel Board (NBB), recommends using biodiesel within six months, but they're being overcautious as usual. Or maybe it's not overcautious if the fuel is to be subjected to the existing petro-diesel infrastructure (dirty and wet). But homebrewers don't have that problem.

Frequently asked question: What is the shelf life of biodiesel? Can I make 6 months of fuel at a time?

Answer: Yes, if you store it properly.

See also:

[Oxidation and polymerisation](#)

[Iodine Values](#)

Lamps and stoves

Lamps that work with biodiesel.

Stoves that work with biodiesel.

Other uses

Wood treatment. Biodiesel is very useful stuff. "We must be crazy to burn it!" Mike Pelly once said, only half-jokingly. He's a carpenter and had just finished refitting his house with wooden interiors. He and his wife treated all the wood with biodiesel, floors included. The smell was soon gone (and it's a pleasant enough smell anyway), and the results were fine. We also use it for wood treatment, nice! (But we found it can attract mould, especially in wet weather.)

It's an excellent **lubricant**, very slippery. It's better than household lubricating oils, and it's non-obnoxious and non-toxic -- it won't matter much if the kids swallow some by mistake. Great for gardeners, especially organic gardeners, nothing better for lubricating your tools and keeping them clean and rust-free, and non-toxic. Great in the workshop too. Great if you live in an old Japanese farmhouse with wooden sliding doors!

Biodiesel is used as a **lubricating additive** for low-sulphur petroleum diesel fuels. With diesel engines, upper engine parts are lubricated by the fuel itself. Diesel motors are not lasting as long as they did because of the lack of lubrication with low-sulphur fuel (500ppm), let alone the new ULSD ultra-low-sulphur fuel (15 ppm), and biodiesel solves the problem. Adding just 1% biodiesel improves the lubricity up to 65%. Research suggests that just 0.4% to 0.5% is enough. In France it's compulsory, biodiesel is added to all diesel fuel at between 3% and 5%; other countries are following suit.

Better than detergent

"A couple of weeks ago, while doing laundry, I opened up the dryer and found all the clothes and the

inside of the dryer coated in a multitude of colors. A box of crayons had made the trip through the wash and disintegrated in the heat of the dryer. I tried using regular liquid detergent on a rag to remove the crayon stains and got almost nowhere with a lot of vigorous scrubbing. Well, I saturated a cloth with some homebrew biodiesel and started on the stains, with very little scrubbing, all the crayon was easily removed in seconds. totally took everything that was stained off the dryer drum, in seconds, no work at all!!!

"So, I sat down with a toothbrush and bowl of BD and started in on the 8 pairs of khakis, the scrubbing starting freeing up the chunks of crayon imbedded in the material, it didn't take it totally out but seemed to break it up greatly. After the pants were all scrubbed and saturated with BD, I put back into the wash on hot with normal liquid detergent and everything came out perfectly clean after the first wash, really impressive!!

"So I had a shirt with a deep ink stain in the pocket, poured some BD in the pocket and scrubbed with a toothbrush, went through a normal wash and the ink stain was gone in one wash, again, impressive!

"I do have one pair of white khakis that I haven't attempted to clean yet. I'm trying to "force" my son to wear them to school as an attempt to teach him a lesson about checking his pockets before washing the clothes. What I want to do is just soak them in BD and see if that would work instead of all the toothbrushing that was involved in cleaning his other clothes.

"Anyway, sometimes it pays to 'look outside the box', in this case, the detergent box." -- k5farms, [Biofuel mailing list](#), 15 Mar 2003

"Found the same thing in 'dissolving' Ohio crude oil and crude/grime out of work clothes. Lay the clothing in a bathtub, 'saturate' the stain with a homemade liquid veg oil soap, brush a few seconds with a warm-water soaked scrub brush, apply biodiesel from a dish soap squeeze bottle. Scrub to your heart's content.

"The soap/water suspension pulls a good bit of the surface grunge off first, with the biodiesel removing the balance of the oil embedded and soaked into the fibers. The suspension also seems to keep the oily effect of the biodiesel from getting locked into the fiber, which can give the look of wet spots (oil soaked spots) even when the garment is dry.

"Prior to figuring this out the alternative was lacquer thinner, soap and water --- home 'dry cleaning' and toxic as hell." -- Todd Swearingen, [Biofuel mailing list](#), 15 Mar 2003

Oil spill remediation -- CytoCulture's CytoSol Process

<http://www.cytoculture.com/process.html>

"Cleaning Oiled Shorelines with a Vegetable Oil Biosolvent", Port Technology International, 1998, London, UK

<http://www.cytoculture.com/cytosolarticle.htm>

Appropriate transport

>> ****Renewable Energy Online Newsletter****

>> August 24, 2001

>> Environment News Service:

>> European Government Support Growing for Biofuels

>
> <snip>
>> Since biofuels release none of the greenhouse gas carbon dioxide,
>
> Interesting... Perhaps a silicon-based fuel? With sand for exhaust?
> Tom
> New Mexico, USA

Silicon and sand? Whatever makes you think that? Bit primitive aren't you? We do it this way. Of course we use only the most advanced techniques to make our biodiesel, from whatever feedstock, and then use it in the normal way, giving a thorough application to all the exposed woodwork on the wagon, the wheel hubs, the front axle steering bolt, the canvas tarp cover, and all the leatherwork, harnesses, etc. Then we add the glycerine to the yak-dung in the biogas generator, which powers a small motor with an elbow crank connected to a long forward-mounted bamboo shaft on an offset fulcrum, causing it to waggle, shaking the carrot tied to the end of the shaft enticingly at some suitable point between the yaks' noses and our destination. No carbon emissions, just a bit of odd methane escaping when the yaks fart, but you get used to it. We only use organically grown carrots, of course.

Keith Addison
Journey to Forever

For an explanation of "carbon neutral" fuels, see [Greenhouse gases and global warming](#)

Identifying plastics

What is this "HDPE" plastic that people use for mixing chemicals, and how do you identify it? What sorts of plastics can withstand what sorts of chemicals?

Identifying different kinds of plastic and their properties, American Plastics Council:

http://www.americanplasticscouncil.org/benefits/about_plastics/resin_codes/resin.html



This helps even more: **Plastics Identification** -- Society of Plastics Engineers, Mid-Michigan Section

<http://www.midmichiganspe.org/education/identification.pdf>

Chemical compatability -- Chemical Resistance Database, Cole-Parmer:

To search, select at least one of three criteria to search on, Chemical, Material, Compatibility Level. If you wish to search by compatability level, you must specify a chemical or material.

<http://www.coleparmer.com/techinfo/ChemComp.asp>