You can buy HVO in a 20-litre plastic container, but is it sustainable?

Biodiesel without bugs?

On the CA forums in October a member asked about using HVO (hydrotreated vegetable oil) in a marine engine. Malcolm Denham, who once ran a programme testing vegetable oils in diesel engines, investigates this new type of bio-fuel and compares it with standard diesel and other synthetic fuels

*I try to run my boat in as environmentally sensitive a way as possible. I don't use masses of diesel each year and am considering if I could change to use 100% bio-diesel. It would also help with red diesel problems when visiting the EU. The new form of bio-diesel (**HVO – Hydrotreated Vegetable Oil**) seems to be compatible with any diesel engines according to some specifications, but not others. It doesn't have any of the first generation (FAME) bio-diesel problems like attracting water, gumming up and allowing diesel bug infestations, removing all worries of water in your diesel etc. ...The fuel I have in mind can be delivered in 20L boxes and isn't stupidly expensive. Has anyone converted to this sort of fuel and has it all been a seamless switchover?* ***Andrew Guppy***

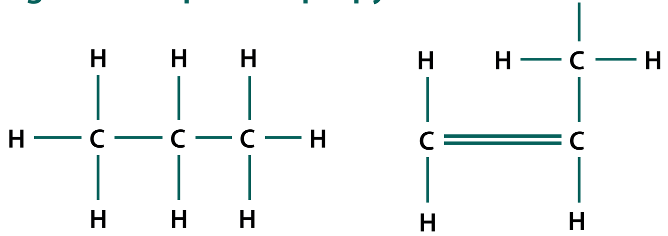
The question above was raised in the CA forums on the potential use of HVO in yacht engines. A short answer was provided in the forum and this article gives a more in depth look at HVO in a marine context.

When discussing fuels it is important to understand a few terms, so it's back to O-level chemistry for a moment. **Saturation** is used when referring to fuels, just as it is in diet with butter or cooking oils. Figure 1 shows two simple molecules, propane and propene/propylene. Propane, C_6H_8, is saturated and is an alkane or paraffin; propylene, C_6H_6, is unsaturated and is an alkene or olefin.

The **calorific value** (CV) of a fuel is the heat produced when a given mass of fuel is burned, again familiar from energy and calories in food. There are two measures, *Lower CV* where the steam produced in combustion is not condensed, as in an engine, and *Higher CV* where the latent heat from the steam is recovered, as in a domestic condensing boiler. The lower calorific value of hydrogen is 3.6 times that of carbon, so any reduction in carbon to hydrogen ratio will increase the calorific value of a fuel, but it will also reduce the density.

Probably the most important property of a diesel fuel is **cetane number** which is a measure of the fuel's propensity to self ignite. The higher the cetane number the more easily the fuel ignites. Paraffinic fuels have a higher cetane number than olefinic fuels.

Figure 1: Propane vs propylene



Propane C:H ratio 4.5:1
HCV 50.4 MJ/kg

Propylene C:H ratio 6:1
HCV 45.8 MJ/kg

Diesel fuel has changed a lot over the years. In the early days when diesel was produced from simple distillation, fuels tended to be more paraffinic with high cetane but very waxy, so they would block filters in cold weather. As refinery processes became more severe, to try to match the supply/demand for each type of product, diesel became more olefinic with lower cetane number and poorer storage stability.

Raw vegetable oils were looked at in the 1980s as supplements to diesel; the lower viscosity oils tend to be unsaturated and the saturated oils have high pour points. In a cold bottle of olive oil, wax crystals start to grow; coconut and palm oil are solid at room temperature. When used as a fuel, raw vegetable oils are not very stable, oxidise in fuel systems and produce carbon deposits and trumpets on fuel injectors, leading to poor combustion and more carbon deposits. They were never really used commercially. Many of the problems of gumming, cold flow performance and carbon build up were solved by **esterifing** raw vegetable oils; we found rapeseed methyl ester to be one of the best and most economic back in mid 1980s. Diesel meeting the current EN 590 standard has up to 7% FAME which is a mixture of fatty acids, all of which contain oxygen and hence reduce the calorific value of a given volume of fuel. Fatty acids also increase the diversity of potential bacteria and yeasts in the fuel and can lead to diesel bug problems.

No matter what the base stock, whether animal fat, vegetable oil or fossil fuel, **treating with hydrogen**, with the right catalyst, temperature and pressure and then selectively distilling, will produce a paraffinic fuel which is very stable with a high calorific value. Another way to produce paraffinic fuels is **from natural gas**, via the Fischer Tropsch process, where the fuel is created "bottom up" from small molecules. Shell GTL (Gas to Liquids) is one that is commercially available. Hydrotreated Vegetable Oil has similar properties to GTL but has the distinct advantage of coming from a renewable source. It bears no resemblance to raw vegetable oils or FAME. Many engine manufacturers have approved HVO for use in trucks and passenger cars. A relatively new standard, BS EN 15940, has been developed for paraffinic diesel fuels. Table 1 has a comparison of the key properties of EN 590, EN 15940 and typical HVO.

What engine performance will HVO offer?

The technical paper *Evaluation of a Hydrotreated Vegetable Oil* (see Reference, below) compares performance of conventional EN 590 diesel with HVO in a modern Euro 5 diesel engine. It is used as the basis for many of the discussion points below. For simplicity I have superimposed a propeller power curve on the

Crown Oils is one of the largest UK suppliers of HVOs. It runs its fleet on HVO fuels, which reduces the fossil fuel impact of deliveries

results to describe what would be expected in a marine engine. Similar results would probably be achieved in other engines but this will depend somewhat on engine technology.

Most EN 590 diesel uses ignition improver additives to meet the cetane specification and the **cetane index** is a reasonable approximation of the cetane number before improvers are added. HVO has a very high natural cetane number of around 75, with no ignition improver.

Diesel combustion occurs in two main phases. Injection starts and there is a delay before the fuel starts to ignite; the fuel already injected burns, which is *pre-mix combustion*. Fuel continues to be fed into the flame which is termed the diffusion or *controlled combustion* phase. A high cetane number leads to a shorter ignition delay and shorter pre-mix combustion phase. Lower cetane fuels lead to a longer ignition delay, which is what makes the harsh "crack" sound you often hear from older diesel engines when idling, particular when the engine is cold. A high cetane number should lead to a quieter engine, although to get the most benefit it would be best to use new injector nozzles or clean nozzles. The benefits of high cetane will be less noticeable on new common rail injection engines. Cold starting will be improved because the fuel ignites more easily, with a potential reduction in cranking time, and the difference will be more noticeable on engines without glowplugs. It is also likely there will be less smoke on start up.

Calorific value of HVO is higher *by mass* than standard diesel because of the lower carbon to hydrogen ratio, but diesel engines meter *by volume*, so we need to account for the lower density. The research paper showed a calorific value 4% lower by volume than conventional diesel, so one would expect this increase in fuel consumption and a similar decrease in maximum power. Test results showed an increased consumption of 2-8% depending on load and speed, which would equate to increased consumption of 3 to 4% over the propeller curve range. Maximum power could be restored by adjusting the maximum fuel stop.

Property	*Unit*	BS EN 590	BS EN 15940	Typical HVO
Density	*kg/l*	0.82 - 0.845	0.77 - 0.79	0.78
Viscosity @ 40ºC	*mm²/s*	2.0 - 4.5	2.0 - 4.0	2.8
Sulphur	*mg/kg*	<10	<5	<5
Water	*mg/kg*	<200	<200	20 - 40
Cetane Number		51	70 min	75
Cetane Index		46	70 min	75
Nett HV (LCV)	*MJ/kg*	NS	42 min	44
Oxidation stability	*mg/kg*	<25	<25	5
FAME	*%v/v*	7	0	0
Lubricity HFRR	*µm*	460	<400	350
Distillation IBP	*ºC*	NS	>180	>180
Vol @ 250ºC	*%vol*	<65	<65	<20
Vol @ 350ºC	*% vol*	>85	>85	>98
95% recovered @	*ºC*	360	360	<350

Distillation parameters are hard to interpret to the untrained eye. An EN 590 diesel could have as little as 20% of the distilled volume recovered between 250°C and 350°C and 15% of heavier compounds recovered above 350°, although in practice this is unlikely. Typical HVO has a narrower distillation range with 75 to 80% recovered in the 250° to 350° range and very little boiling above 350°. The lack of heavier "back end" components contributes to the lower density and higher calorific value and is likely to lead to less smoke at full load engine conditions. The results in the paper over the propeller curve suggest a soot reduction of 55 to 65%.

Carbon monoxide and hydrocarbon **emissions** are relatively low on diesel engines anyway, but they showed a reduction of 25% over the propeller curve. Nitrogen oxides (NO_x) emissions are likely to be reduced because they are determined by combustion temperature and available oxygen. Shorter pre-mix combustion will lead to lower peak combustion temperature. The research used an automotive engine fitted with EGR (Exhaust Gas Recirculation) to reduce NO_x; it still showed a reduction of 0 to 5% over the propeller curve. I would expect NO_x reductions to be greater on an unregulated marine engine.

Actual **CO_2 reductions** from the engine will be a function of the carbon content for a given calorific value. With the lower carbon to hydrogen ratio, CO_2 will be reduced. The measured CO_2 reduction over the propeller curve was 5 to 6%.

The **claim for an overall 90% CO_2 reduction** can only be made when the base oil is from renewable and sustainable sources ("field to wheels"). The overall CO_2 footprint is highly dependent on many things such as transport of the bulky vegetable materials to produce the raw vegetable oil. I think it impossible to make these claims for HVO with a high animal fat content. Palm oil is also rather contentious. In a refinery or chemical plant hydrogen is normally produced from steam reforming of natural gas. The source of hydrogen for HVO needs to be considered in the overall carbon footprint.

Storage performance

The *water content* of typical HVO is very low, because there are fewer polar compounds and no oxygenated components which have an affinity for water. HVO will have better water separation in pre-filter bowls. HVO being more saturated means there are fewer components that will oxidise, so fuel stability will much better and typical HVO properties in Table 1 indicate significantly lower oxidation deposits. The diesel "bug" organisms prefer unsaturated fuels and live at the water/fuel interface. Their ability to thrive will be greatly reduced with a paraffinic fuel, with no fuel-bound oxygen, no FAME and

Neste fuels, the world's largest supplier of renewable diesel, is already selling its HVO from the pump in some Scandinavian locations, including its home location of Espoo in Finland. Photo © Neste

reduced water content. Good fuel management to remove water is still needed. While *cold flow* properties are not normally an issue for marine use, they will be better than conventional diesel even though it is a paraffinic fuel. The narrow distillation range removes some of the very waxy components.

Other considerations.

The **price** for a 25-litre box of GreenD+ HVO from Express Gas is £1.70/litre, excluding delivery. The supplier of GreenD+HVO in a box, New Era Fuels, says it is dyed and duty paid at the lower rate. Crown Oils gave a verbal quote for two 205-litre barrels of HVO delivered to the South Coast of £1.57/litre for rebated and £2.16/ litre for 100% duty paid. I suspect it would be difficult to agree a split duty and get a receipt to prove it from some of the small suppliers. Delivery in conventional diesel vehicles will increase the carbon footprint and the use of plastic containers contributes to plastic pollution. Consideration needs to be given to where fuel can be stored and how and where fuel can be transferred to the boat fuel tank. There are regulations for the **storage** of petrol at home, but nothing specific for diesel. Good practice is to store large quantities of fuel in a bund 10% greater than the container, so any leakage is contained and doesn't pollute ground and water courses. Some marinas do not allow the transfer of fuel from containers.

In summary

HVO is a high quality diesel with reduced emission levels for all pollutants, albeit with a small increase in volumetric fuel consumption. HVO offers some real advantages for the typical low-usage long storage time of most sailing yachts if supply, storage and transfer to the yacht fuel tank can be resolved. There are clear environment benefits of using HVO but some of the large CO_2 reduction claims should be viewed with caution.

Reference

Evaluation of a Hydrotreated Vegetable Oil (HVO) and Effects on Emissions of a Passenger Car Diesel Engine, Dimitriadis et al, 2018, published in *Frontiers in Mechanical Engineering*.
www.frontiersin.org/articles/10.3389/fmech.2018.00007

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