GREEN FLASH

HVO AND BIOFUEL PRIMER

version 1.0

May 2024

Oil is not a scientific term.

It is a generic word for *mixtures* that share the same properties: they don’t mix with water, they are slippery, and they all burn - to a degree.

All components that make up oil consists of long chains of carbon, with hydrogen atoms attached to it (hence: hydrocarbons).

Sometimes, there are a few scattered oxygens and other elements attached somewhere too, but not too many.

This primer explains what oils really are, how they are created and what they mean for our energy-hungry civilization.

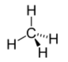
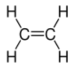
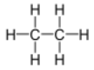
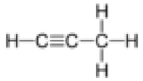
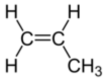
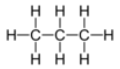
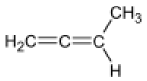
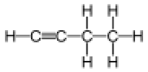
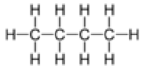
Nature's building blocks

Imagine a construction toy set with only a couple of pieces that connect in limited ways. There is only so much you can make from such a set – you quickly run out of configurations. This gets boring fast.

Now imagine a set of pieces that can be clicked together to create an almost infinite number of larger objects, with almost no limits. Blocks of different colors and shapes, all with little connectors. Like Lego.

Lego bricks not only connect to other kinds of bricks, but can also connect to each other, linking up to form long clusters or chains of the same bricks.

You can build chains with arms branching off to the side, each arm branching off into even more arms – or even create loops and weird shapes.

FORMULA	NAME	STRUCTURAL FORMULA	CHEMICAL CLASSIFICATION
CH_4	Methane		Alkane
C_2H_2	Acetylene		Alkyne
C_2H_4	Ethylene		Alkene
C_2H_6	Ethane		Alkane
C_3H_4	Propyne		Alkyne
C_3H_6	Propene		Alkene
C_3H_8	Propane		Alkane
C_4H_6	1,2-Butadiene		Diene
C_4H_6	1-Butyne		Alkyne
C_4H_{10}	Butane		Alkane

Magical carbon

Carbon is the Lego brick of chemistry. It has the unique ability to connect to other carbon atoms, forming long chains and complex structures.

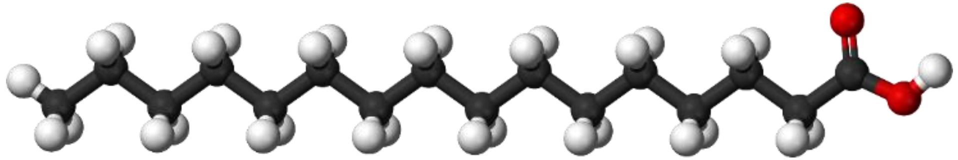
Think of a carbon atom as a ball with four arms sticking out. These arms ("bonds") connect to other carbon atoms, or other elements like hydrogen or oxygen.

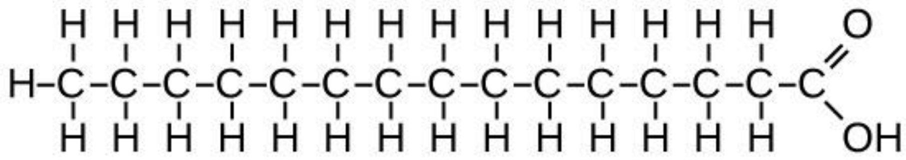
Carbon *always* has four arms. It can connect to its neighbor carbon with either one, two or three of these arms. These are called **single, double or triple bonds.**

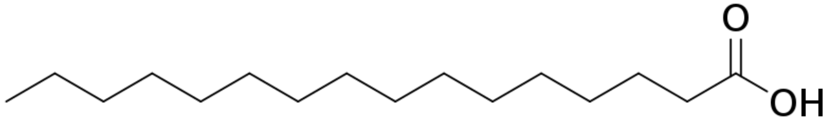
The length and shape of the carbon chain determines much of the properties, but so does whatever is dangling from the arms.

We know about 10 million different carbon-based compound. The actual number of possible compounds is billions of times bigger: more than there are stars in the universe.

A clearer visualization







With all these long chains, things tend to get cluttered.

The most common attachment for a carbon atom is either another carbon, or a hydrogen atom. As you can see from the ball-and-stick model to the left, things can get crowded.

An easier and clearer way to draw this molecule is the flat, black-and-white version below it, which is still a bit cumbersome.

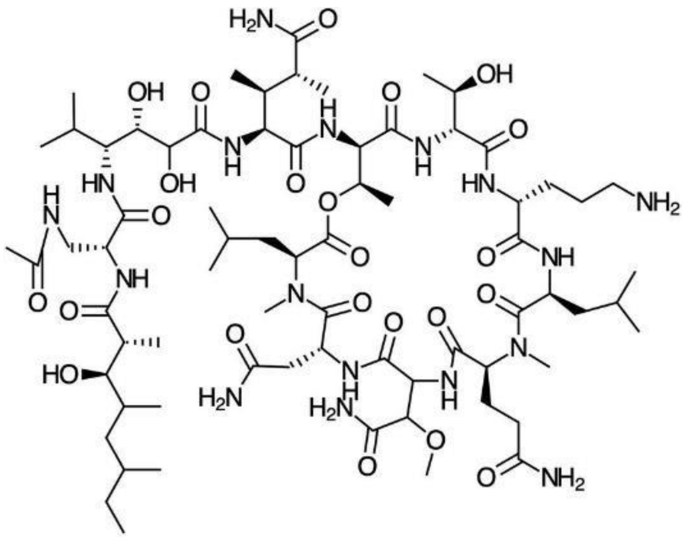
A general shortcut that you will encounter a lot is the version at the bottom. It just shows the arms connecting the carbons, assuming a carbon atom at each junction. The side arms with the hydrogen atoms are left out completely.

Why?

Because these have very few influence on the chemical properties. What matters most are the *length of the chain* and the clump of *other stuff* at the end. They mostly determine what the chemical does.

1

2



What does “organic” really mean?

A long time ago, scientist were convinced that only living creatures could create complex carbon compounds. They – quite arbitrarily – divided chemistry into inorganic and organic.

Inorganic referred mostly to the less glamorous, lifeless chemicals that do not have complex chemical structures, such as salt, sand, rust or gold.

In practice, the line is blurry. Inorganic table salt plays an important role in biology. Organic compounds like urea can be created out of inorganic ammonia and water.

To add to the confusion, we use “organic” to signify “natural”, “healthy” or “without pesticides” .

“Organic” in chemistry simply means “made up of interconnected carbon chains and loops”

Love is in the air

Sure, carbon loves hydrogen – it connects to it all the time. But you know what carbon loves even more? Oxygen. So does hydrogen, by the way. They both just love oxygen.

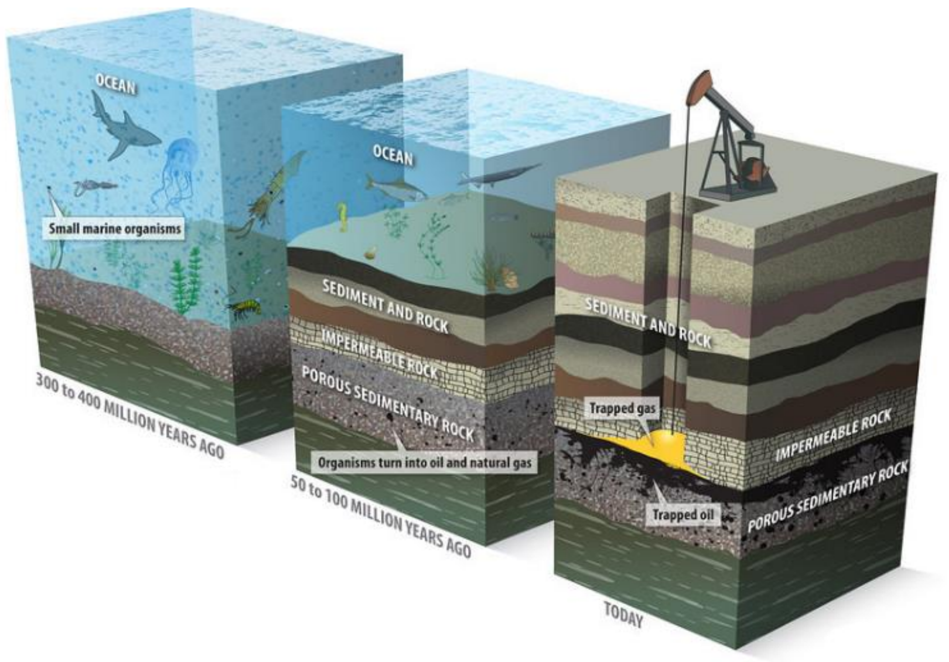
So when you take a hydrocarbon (yes, that is what they are called), add some oxygen and some energy (heat) to get the love going, you got yourself a fire: the chains fall apart and all the carbon and hydrogen rush to connect with the oxygen, yielding a lot of heat in the process.

The result is water (H_2O) and carbon dioxide (CO_2).

In practice, this process can get messy. Not all carbon breaks apart in neat separate little atoms. Some chunks of carbon and hydrogen stay connected, forming new compounds (which is why a car exhaust smells), or floating chunks of carbon (soot and smoke).

If there is not enough oxygen, like in an enclosed garage, the eager-to-connect carbon atoms will settle for one oxygen instead of two, forming the dangerous carbon monoxide (CO).

Where does oil come from?



Where does oil come from?

The energy we get from the oil that we pump out of the ground comes mainly from hundred-million-year-old trapped sunlight – with a bit of Big Bang residual heat and nuclear power thrown in.

Millions of years ago, all kinds of organisms on Earth used sunlight and water to make babies (procreation) and bigger versions of themselves (growing).

Billions of tons of biomass, consisting of algae, plankton, plants, trees and animals from before the age of the dinosaurs, settled down into swamps, or drifted to the ocean's bottoms, and were eventually crushed under millions of tons of sedimental rock forming on top of it.

This biomass was then heated by Earth's internal temperature, left over from the formation of the planet. A bit of extra heat was generated by the natural decay of trace amounts of radioactive materials trapped in the Earth's crust and mantle.

After millions of years of slow-cooking, most of this biomass has broken apart and been converted to coal, brown coal, crude oil and natural gas.

What is mineral oil made of?
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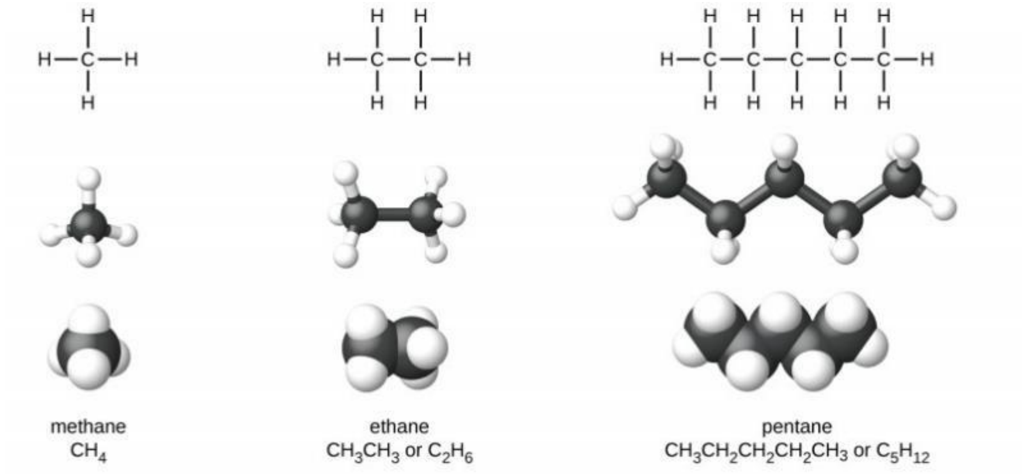
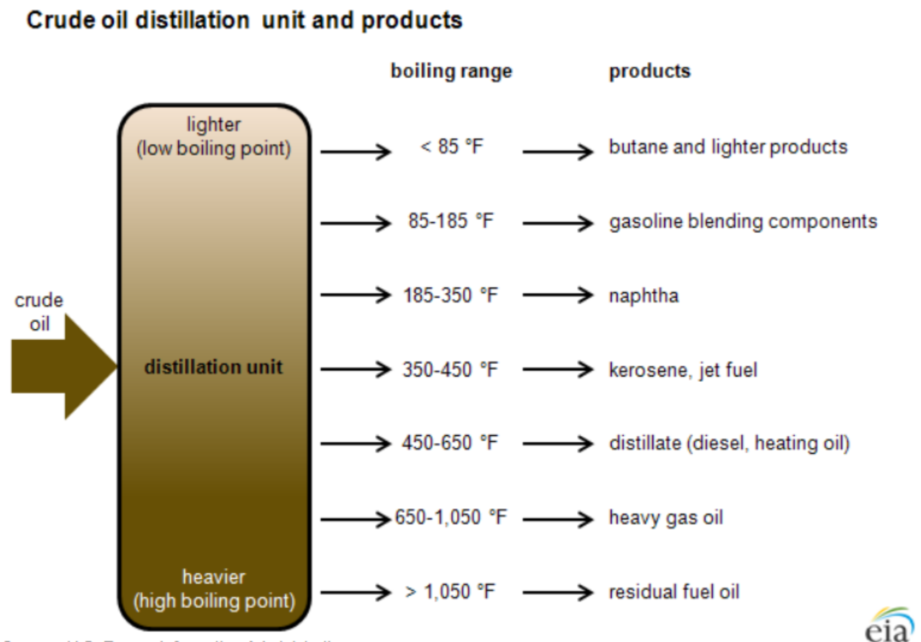


Mineral crude oil – the black goop we pump out of the ground - is a rich mixture of many different compounds. Many of them are simple carbon-based chains of carbon and hydrogen, ranging from very short to very long. These simple, chain-like compounds are called **alkanes**. The shortest alkanes are gasses; as the chains get longer (and heavier), they become liquids and eventually solids.

Methane (one carbon) is a gas, as is ethane (2) . Pentane (five carbon atoms) up to octane (8) are liquids and can be found in gasoline. Kerosine has chains from 9 to 16 long, diesel 9 to 25 carbon atoms in a long chain.

Even longer alkanes are found in heavy fuel oil, asphalt and tar (semi-solids).

Crude oil was formed from long-boiled organic plant and animal goop, so it contains a lot of “other” stuff as well: water, sulfur, metal compounds, weirdly complex carbon loops (called “aromatics” because they often, well… smell).



Source: U.S. Energy Information Administration.

Separating the crude oil mixture (oil refining)

Separating these components from crude oil is a simple process, in theory at least, called **fractional distillation**: by gently raising the temperature of the crude oil, the most volatile components evaporate first, followed by the longer chains. These are then captured and syphoned off separately.

In practice, shorter chains (like found in gasoline and kerosene) are in higher demand and therefore more valuable than the very long ones (like tar and asphalt).

Cracking, Hydrocracking, Hydrotreating

Humans realized long ago that they liked the volatile gasoline stuff more than the gooey black residue. They came up with a way to turn longer carbon chains into shorter ones.

By using complex chemical high-temperature processes, it is possible to break the longer carbon chains up into shorter ones and then attach hydrogen or other groups of atoms to the loose ends. A bit like shaking up the construction set to get smaller pieces.

These processes create shorter (more volatile) compounds but can also ber used to manufacture more complex chemicals.

Biofuels

We don’t need to rely on plants and animals that lived millions of years ago for our energy.

Modern-day plants and animals have the same magical ability to rearrange carbon from the air and water from the soil to produce fats and oils that, in many cases, contain just as much energy as mineral oil. When we burn these substances, the solar energy that was stored in the chemicals is released, producing water, carbon dioxide and a host of other compounds - and heat.

While fats and oils from plants share some properties with mineral oil (they don’t mix with water, they are slippery, and they all burn), they are chemically very different in structure from those found in mineral oil.

turning oil and fat into fuel

Fats and oils from plants, algae and animals are chemically different from the oil we get from under the ground.

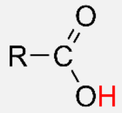
The term “lipids” is often used for biological fats and oils, but lipids are in fact a much broader group of chemical compounds that includes fats and oils, but also waxes, sterols, and even vitamins such as A, D, E and K.

The plant and animal fats we all know and love so well – olive oil, bacon fat, whale blubber and sunflower oil - are a subgroup of lipids called **triglycerides.**

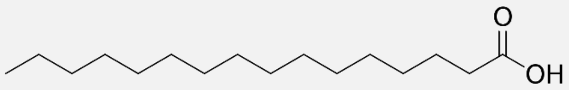
These triglycerides are a type of chemical called an **ester**. Think of an ester as a marriage between an alcohol (any alcohol – there are many different types) and an acid.

Keep in mind that “acid” does not have to mean “burn-through-the-floor” acid, and “alcohol” does not have mean “party time liquid”.

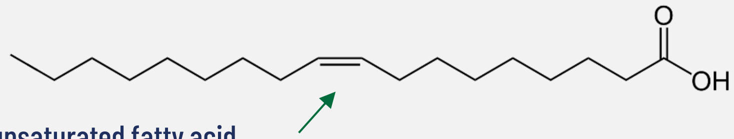
Regular fat (Triglycerides) is an ester, which is made by combining an alcohol and an acid.



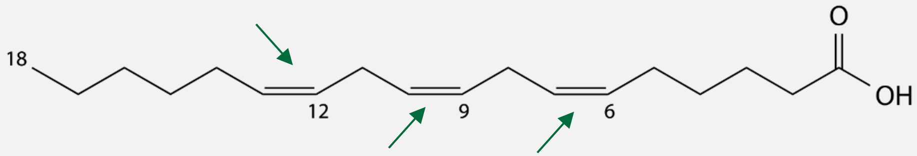
acid group



fatty acid



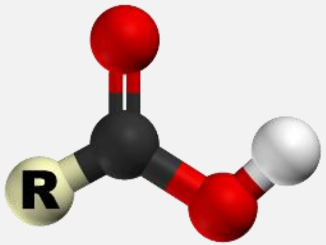
unsaturated fatty acid



polyunsaturated fatty acid

Acids and fatty acids

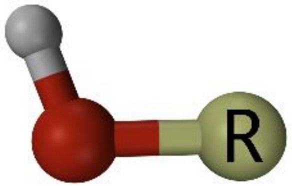
An **organic acid** is a chemical that has a string of carbons (R), a carbon with one oxygen attached to it with a double bond, and another oxygen with a single bond, which has a hydrogen attached to it:



Fatty acids are organic acids with a long, straight chain (no side branches or rings). Note that some of the bonds in these long carbon chain can be double bonds. These double carbon-carbon bonds can be forced open, creating room for an extra hydrogen to attach to. If a long chain has a double bond in it, the fatty acid is called **unsaturated**. If the chain has more than one available double bond, it is called **polyunsaturated**.

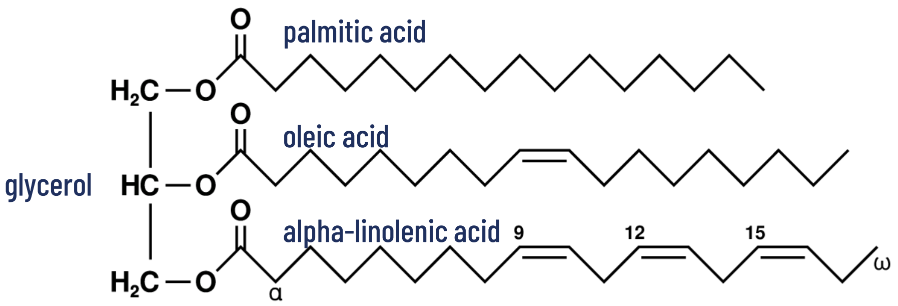
Alcohols

“Alcohol” is a name for a huge family of chemical compounds that all have two things in common: they are made up of some carbon chain (represented by the letter “R” below), and they all have a group sticking out, consisting of an oxygen (red) with a hydrogen (grey) attached to it:



There is only one “fun” alcohol: ethanol. All other alcohols no effect on the mind (glycerin) or are poisonous (ethanol/antifreeze)

Alcohols can have more than one of these groups in their structural formula. For example: the simple household product glycerin is a triple alcohol (triol), with three of these groups.



The fats we know and love

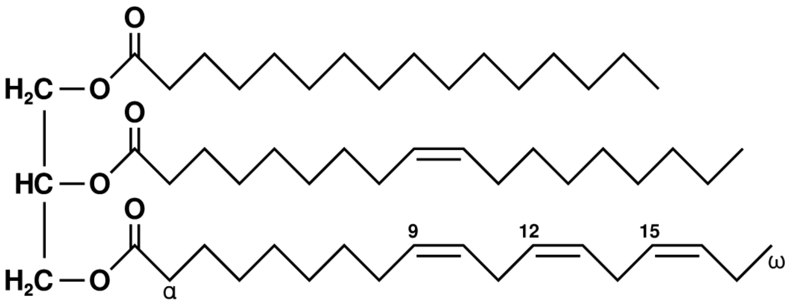
Most fats and oils are a particular group of esters called triglycerides.

They are made from a triple alcohol called glycerol (old name: glycerin) and three fatty acids (hence: tri).

Triglycerides are the main constituents of body fat in humans and other vertebrates, as well as vegetable fat.

Here is a “polygamy wedding picture” of an ester that was created by uniting glycerol with three fatty acids. To the left is the glycerol part, to the right the three long chains of fatty acids. Note the double bonds.

Oil versus oil



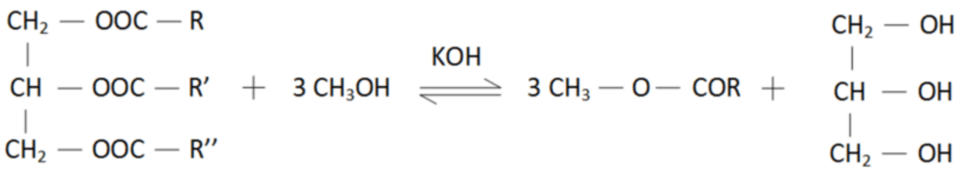
plant-based oil

mineral oil

Plant- and animal-based fats and oils (triglycerides) are esters: long, straight chains of carbon with a cluster of other stuff at the end, where the acid part fused with the alcohol part.

Mineral oil consists mainly of aliphatic compounds: just the straight chains, with no fancy rings or subgroups. They are fundamentally different, even through they look the same (oily liquid) and both burn pretty well.

Burning pure triglycerides has some downsides. It reverts some of the triglycerides back to fatty acids, which – although not very aggressively – can cause corrosion over time. Also: most plant-based organic oils are too viscous for use in engines. Another downside is shelf life: plant oils can attract water and are susceptible to contamination by bacteria and fungi.



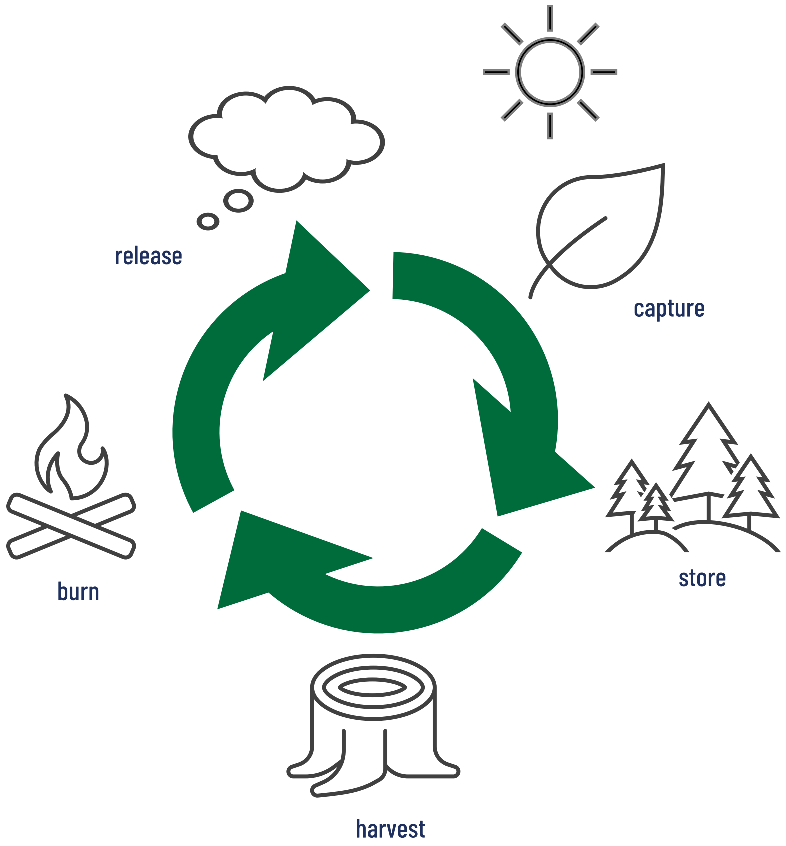
triglycerides | methanol | biodiesel | glycerol

Transesterification: the road to FAME

A solution to turn organic oil into a biofuel is **transesterification**. This is simply a process that turns one kind of ester into another kind of (simpler) ester by replacing the alcohol-part with another alcohol.

The most common method of transesterification is the reaction of the organic oil or fat with methanol in the presence of a catalyst. Any remaining free fatty acids in the mixture are also converted to the new ester. Note that the end results contain glycerol, the original alcohol.

The result is a new ester called FAME: fatty acid (m)ethyl esters. Still an ester, but less viscous and less corrosive.

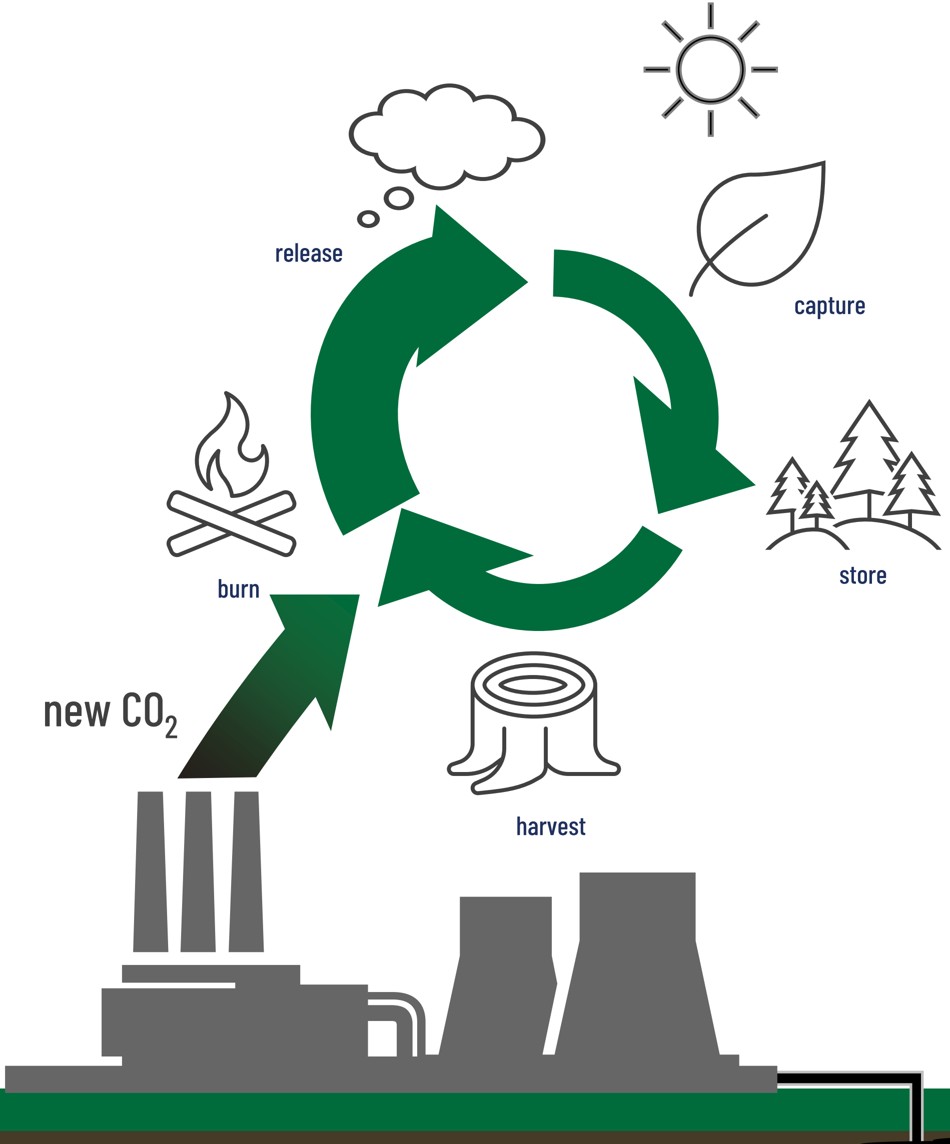


The cycle of life

The carbon cycle at its most simple is just a matter of give-and-take: energy from sunlight is used by organisms to click together hydrogen (from water) and carbon (from CO_2 in the air) and turn them into wood, sugars, starch, seeds and oils, releasing oxygen in the process.

Humans and animals take in this organic materials as food or fuel. We break those carbohydrates apart again inside our bodies, connecting them with oxygen from the air in our lungs to generate CO_2, (breath), water (urine and breath) and energy. Or we burn them in a fireplace, creating the same waste products.

This delicate balance between plants taking CO_2 out of the air and people and animals putting CO_2 back into the air is disrupted when we suddenly add a whole new bunch of new carbon to the cycle: carbon that was previously stored underground and was not part of the cycle, like oil, coal and gas.



Emissions, carbon and climate crisis

When we add new carbon to this cycle, it gets overloaded. We put in more CO_2 than the cycle can handle and as a result, the levels of CO_2 in the atmosphere rise.

CO_2 has a nasty side effect: it traps heat from the sun. All the extra CO_2 makes our planet warmer. Just a few degrees is enough to melt icecaps, disrupt the existing climate and change our world forever.



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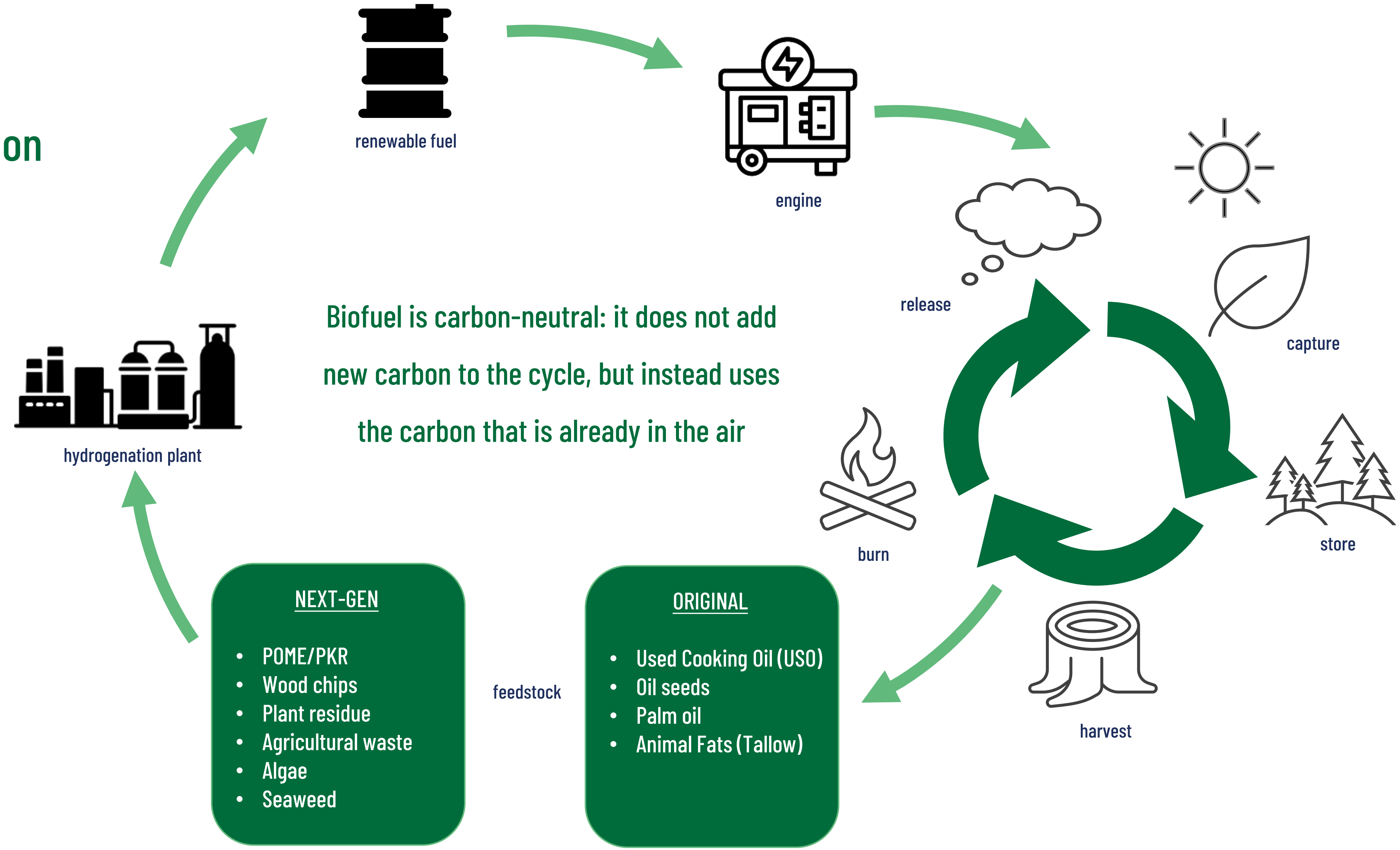
The biofuel solution








Biofuels – an introduction

Renewables is the term for energy sources that will not run out, such as solar, wind power, geothermal energy and wave power. **Biofuel**, also a renewable energy source, is any fuel that is derived from biomass (or feedstock).

One of the most widely used biofuels is wood. Burning wood has many disadvantages, from air pollution to logistical issues.

Liquid biofuels are of particular interest because of the vast infrastructure already in place to use them, especially for transportation.

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Biofuels – Ethanol

The liquid biofuel in greatest production is **ethanol** (ethyl alcohol), which is made by fermenting starch or sugar. Brazil and the United States are among the leading producers of ethanol.

In the United States ethanol biofuel is made primarily from corn (maize), and is typically blended with gasoline to produce “gasohol,” a fuel that is 10 percent ethanol. In Brazil, ethanol biofuel is made primarily from sugarcane, and it is commonly used as a 100-percent-ethanol fuel or in gasoline blends containing 85 percent ethanol.

Unlike the “first-generation” ethanol biofuel produced from food crops, “second-generation” cellulosic ethanol is derived from low-value biomass that possesses a high cellulose content.

Biofuels – Biodiesel

The second most common liquid biofuel is biodiesel, which we now know is made primarily from oily seeds (such as soybean or oil palm) and to a lesser extent from other sources (used cooking oil from restaurant deep-frying - UCO).

Biodiesel (B100), which has found the greatest acceptance in Europe, is used in dedicated diesel engines or usually blended with petroleum diesel fuel in low percentages. Higher percentages of biodiesel tend to cause mechanical problems and corrosion in standard diesel engines.

Biofuels – Biogas

Biogass is created by the decomposition of biomass in the absence of oxygen, but it can also be produced in chemical factories from organically sourced methanol, butanol, and dimethyl ether.

While important for industrial and domestic heating, it has limited applications for use in internal combustion engines.

Biofuels – HVO

HVO stands for hydro-treated or hydrogenated vegetable oil, a bit of a misnomer, because it does not have to be produced from vegetables. Like biodiesel, HVO is a fuel for diesel engines only.

HVO is a next-generation biofuel. Its biggest advantage is that it uses the same kind of feedstock as biodiesel, but a different process. Instead of making light esters (FAME) out of oil, fat and alcohol, HVO uses pressure, heat, hydrogen gas and catalysts to turn these fatty acids into the same straight-chain alkanes found in regular diesel.

This means that HVO is chemically identical to regular diesel, without any of the disadvantages of biodiesel. It can be added to regular diesel in any amount, from 1 to 100%, without any side effects (fully miscible)

Since HVO is made from oils and fats, it does not contain the polluting byproducts that traditional diesel has, such as aromatics and sulfur.

Biofuels – feedstock issues

The use of feedstock such as corn and soybeans for the first generation of biofuels sparked a fierce "food versus fuel" debate.

If you take away arable land and feedstock from the human food chain for biofuel production, it will affect food prices. Poorer people could go hungry because of our appetite for fuel.

Even dedicated biofuel agriculture can have a negative impact; demand for palm oil is destroying ancient tropical forests to make way for monoculture plantations.

Loss of such natural habitat can change the hydrology, increase erosion, and generally reduce biodiversity of wildlife areas. The clearing of land can also result in the sudden release of a large amount of carbon dioxide as the plant matter that it contains is burned or allowed to decay.

Biofuels – new feedstocks

The biofuel industry is adapting to this challenge by exploring new feedstock sources such as used cooking oil (UCO). Advances in science and engineering also mean biofuels can now be produced from biomass that was considered unsuitable before, such as agricultural waste, forest residue, palm oil sludge and discarded oil seed husks.

Some algal species contain up to 40 percent lipids by weight, which can be converted into biodiesel or synthetic petroleum. Some estimates state that algae and cyanobacteria could yield between 10 and 100 times more fuel per unit area than second-generation biofuels.

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Energy transition

Great strides are being made in harnessing wind, solar and tidal power. This is great for industrial and domestic energy use – but more complicated for transportation.

Electric vehicles are on the rise, but they have their own issues. Battery production is neither a clean or low-energy process and batteries use a relatively scarce and hard to recycle element called lithium.

For heavy power users, battery capacity is a problem, and many existing diesel-powered machines would have to be completely replaced with their electric version, which is cost-prohibitive. In some cases, diesel engines are simply irreplicable, like backup generators.

While waiting for the technological dream solution to emerge, we should start saving the planet right now by switching to renewable fuels.

MATERIAL	EFFECT OF BIODIESEL RELATIVE TO DIESEL FUEL
Fluorosilicon	Hardness little change, swell +7%
Nitrile rubber	Hardness -20%, swell +18%, reduced tensile strength
Nylon 6/6	Decreased elongation, reduced tensile strength
High density polypropylene	Hardness -10%, swell +8 to 15%
Teflon	Little change
Viton 401-C	Little Change
Viton GFLT	Little change
Polyurethane	Hardness little change, swell +6%
Polyvinyl	Much worse
Tygon	Worse

NAME	BIODIESEL	FOSSIL DIESEL	CARBON REDUCTION
B7	7%	93%0	3%
B10	10%	90%	4%
B20	20%	20%	8%
B100	100%	0%	40%-60%

Practical problems with Biodiesel

Biodiesel (FAME) is a first-generation biofuel. Since it is chemically not identical to regular diesel, it can only be used as a drop-in fuel or in dedicated (modified) engines.

The main issues with biodiesel are:

1. The fuel deteriorates the plastic components and reduces their lifespan.
2. The carbon footprint reduction is low.

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HVO: the perfect transition fuel

HVO has all the convenience and reliability of traditional diesel, while offering a 94% reduction on carbon footprint and cleaner emissions.

Why not 100%? Because the entire production and transportation chain – from harvesting feedstock by the farmers to delivering HVO by sea – is not yet completely carbon-neutral.

94% is very high. An average electric car only offers around 25% reduction compared to its gasoline-powered equal. Switching to HVO also negates the need to purchase new equipment, an additional source of carbon emissions.

HVO burns cleaner, produces less soot and carbon monoxide, has the same or better performance as regular diesel and is recommended by almost every diesel engine manufacturer in the world.

It is also a drop-in fuel, meaning it can be added to any tank of regular diesel in any amount without changing any hardware.

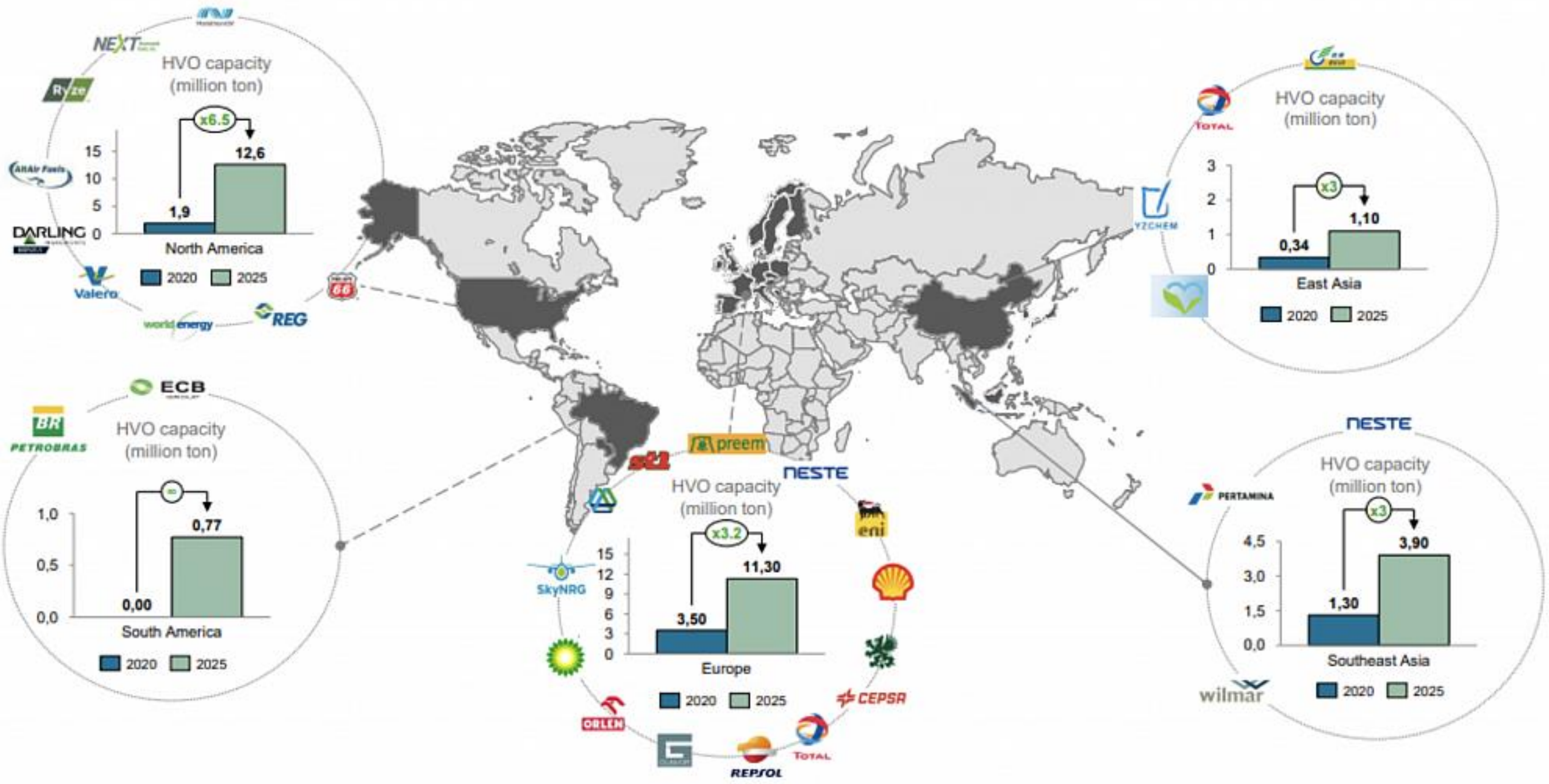
HVO around the world

Increase in HVO production capacity between 2020 and 2025:

Europe: 300%

USA: 600%

Asia: 300%



More production means lower prices, lower transportation costs and better fuel security

GREEN FLASH

Aliphatics	Simple carbon and hydrogen compounds made up of long strings of carbon, without rings or other complex structures. Main ingredient in gasoline, and diesel
Aromatics	Carbon and hydrogen compounds with loops or rings.
Biodiesel	A diesel-type fuel made from organic sources that is chemically different from regular diesel. It has to be blended with regular diesel or used in converted engines.
Catalyst	Anything that makes a chemical reaction happen faster or more efficiently. Catalysts help the reaction along, but do not participate in it and remain unchanged.
Cetane rating	Cetane rating, also known as the cetane number, is a measurement of the quality or performance of diesel fuel. The higher the number, the better the fuel burns within the engine of a vehicle. The cetane number is similar to the octane rating for gasoline. Mineral diesel has a cetane number of 51 and FAME biodiesel has a cetane number between 50 and 65 – whereas HVO has a cetane number between 70 and 90, means better starting performance, cleaner combustion and less chance of waxing in extremely cold weather.
Ethanol	A simple alcohol, found in wine, beer and distilled spirits. Common fuel additive.
FAME	Fatty Acid Methyl Esters, the main ingredient of biodiesel
Green Diesel	Also known as Renewable Diesel is a confusing term. Scientifically, it is defined as a a fuel of straight-chain and branched saturated hydrocarbons with 15–18 carbon atoms per molecule (C15 to C18), but in practice, people use it - confusingly – to indicate any kind of organic diesel fuel.
HEFA	Hydroprocessing of Esters of Fatty Acids, a process to make biodiesel
Hydrocracking	A process where heat, pressure, hydrogen gas and catalysts are used to fundamentally change the structure of a chemical compound. Similar to hydrogenation.
Hydrogenation	A process where heat, pressure, hydrogen gas and catalysts are used to fundamentally change the structure of a chemical compound. Can be used to make airplane fuel, HVO and margarine. Similar to hydrocracking.
Methanol	A poisonous alcohol used in anti-freeze. Fuel additive.
NOx	NO x is shorthand for nitric oxide (NO) and nitrogen dioxide (NO2), the nitrogen oxides that are most relevant for air pollution. Under normal circumstances, oxygen and nitrogen (both present in the atmosphere) do not react, but they can do so in the hot gas mixture in a combustion engine.
Particulate Matter	Particulate matter contains microscopic solids or liquid droplets that are so small that they can be inhaled and cause serious health problems. Thet are produced when burning things.
PKR	Palm Kernel Residue – a waste product from the palm oil industry, used as a feedstock for renewable fuels
POME	Palm oil mill effluent (POME) is a wastewater generated from palm oil milling activities which requires effective treatment before discharge into watercourses due to its highly polluting properties. Pome can be used as a source for biofuels
Red Diesel	In some countries, renewable fuels and blends are taxed differently, or are only allowed for some applications. Red dye is sometimes added to renewable diesels to make it easier to detect fraud.
Renewable diesel	Renewable diesel and biodiesel are often confused, but they are not the same. Renewable diesel is a pure hydrocarbon diesel fuel chemically very similar to fossil diesel, and is also known as Hydrotreated Vegetable Oil (HVO) fuel, whereas biodiesel is a Fatty Acid Methyl Ester (FAME) product which is not a hydrocarbon.
SAF	Sustainable Aviation Fuel – HVO’s cousin for the aviation industry. SAF has a slightly different chemical composition than HVO, but HVO can be processed into SAF.
soot	Informal name for very small particles of carbon, produced by incomplete burning of fuel.
UCO	Used Cooking Oil, a valuable feedstock for the renewable fuel industry.