Renewable Diesel

Hydrotreatment of Vegetable Oils (HVO)

Hydrotreatment of vegetable oils (HVO) is a relatively new method of producing renewable transportation fuels, predominantly diesel and jet fuel. It is similar to transesterification, which uses the same feedstock and produces conventional biodiesel, but HVO is generally considered to produce superior diesel fuel with better stability and a higher cetane number. Whilst transesterification involves reacting oils with methanol, producing Fatty Acid Methyl Esters (FAME) as the main product and glycerol as low value byproduct, hydrotreatment reacts the feedstock with hydrogen, yielding mainly n-paraffins as the main product and propane as a high value byproduct. Most importantly, perhaps, HVO can utilise existing infrastructure at refineries, which already perform hydrotreatment as part of the refinery process, albeit with different feedstocks and objectives, such as desulphurisation of fossil crude. Existing refineries are therefore uniquely positioned to use existing skills, technology and expertise as a means of transitioning from fossil to renewable fuels.

Although both HVO and FAME are classified as renewable fuels, their environmental and humanitarian footprint is largely determined by the sustainability of the feedstock. Various organisations, including ICCT have determined that only waste products, such as waste cooking oil, should be used, whereas virgin oils should be avoided. Growing demand for the latter could firstly negatively impact food supply chains. It could also drive deforestation and peat drainage through changing land use, as already experienced with increased global demand for palm oil, thus indirectly leading to increased carbon emissions and reduction of biodiversity. Too much emphasis on this technology also risks detracting investment from alternative, perhaps more scalable and sustainable, clean technologies.

Ai generated of a HVO plant

Hydrotreatment Process overview

Hydrotreatment involves reacting triglyceride feedstock, that is vegetable oils (or indeed animal fats such as lard), with hydrogen in at least one, but often multiple reaction steps. Depending on catalysts and reaction conditions, various byproducts are generated which require separating from the process flows. The main reactions predominantly produce saturated linear aliphatic hydrocarbons (or n-paraffins), which may need further processing to optimise their cold flow properties. Although existing refineries are ideally set up to carry out HVO, conventional hydrotreatment on fossil feedstock is mostly carried out to remove impurities, such as sulphur and nitrogen. Due to different feedstocks and end products in the HVO process, there may be a requirement to change reaction conditions and catalysts.

Although the single term hydrotreatment may imply a single reaction step, this process involves numerous process units, generally including more than one conversion reactor and several separation steps. The exact nature of the units, operating conditions and catalysts involved is highly dependent on feedstock and desired product. Various reactions, including some undesirable, can also take place during the hydrotreatment reactions and under the process conditions. These include hydrodeoxygenation, decarboxylation and decarbonylation as the main fuel producing reactions, as well as (reverse) water gas shift and methanation as undesirable side reactions.

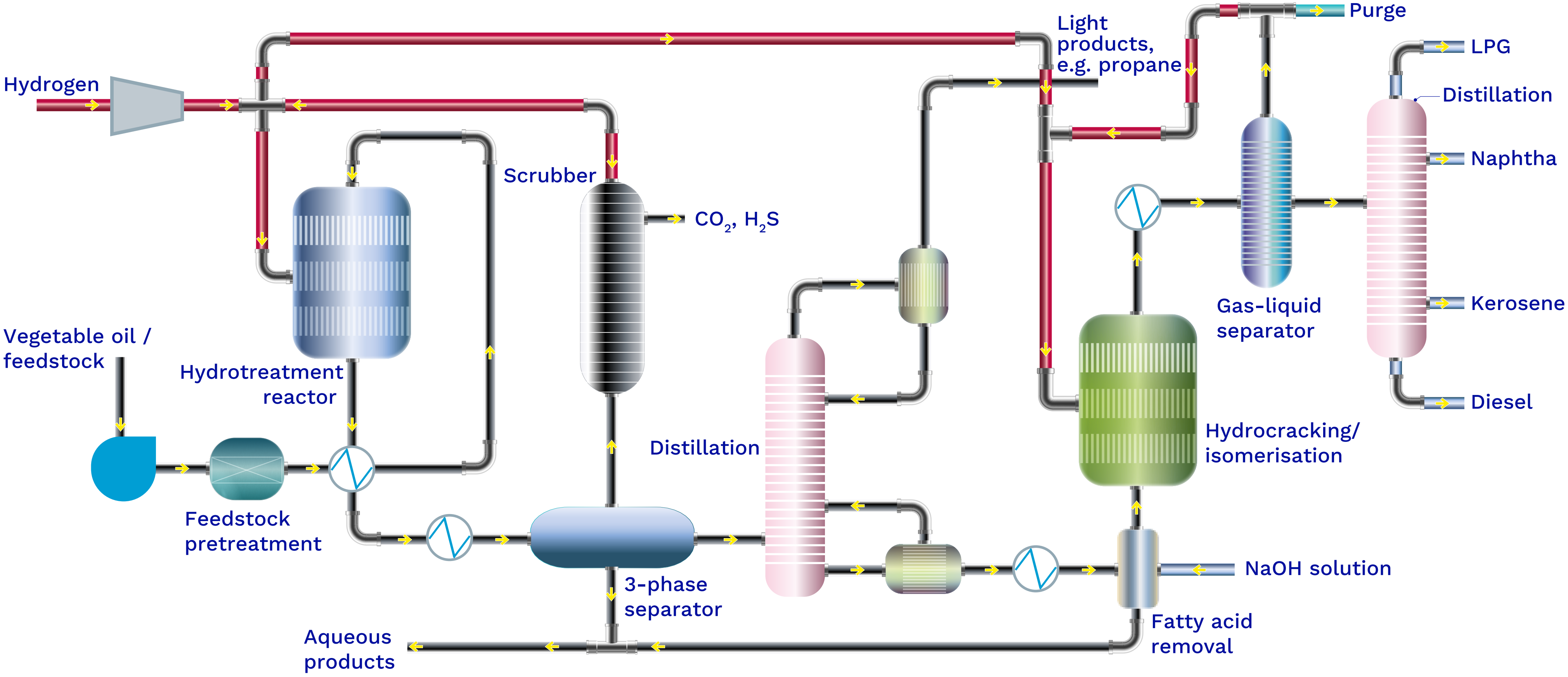
During the main hydrotreatment process, a number of reactions can occur, resulting in different end products. The first conversion step is saturation of unsaturated triglycerides. The second conversion step runs in parallel and involves hydrogenolysis of the glycerol ester bonds, producing fatty acids and propane. The final step converts the remaining fatty acids into straight paraffins. This can be achieved through 3 distinct pathways:

1. hydrodeoxygenation, where hydrogen combines with bonded oxygen producing n-paraffins and water
2. decarboxylation where the fatty acid group decomposes into CO_2, leaving shorter (n–1)-paraffin molecules, or
3. decarbonylation, producing CO, water and (n–1)-paraffin.

Importantly, pathways 1 and 3 consume hydrogen, whereas pathway 2 does not. From a carbon balance perspective, pathway 1 is generally preferred but at the cost of having a significantly higher hydrogen demand. Undesirable side reactions include methanation and Water Gas Shift reactions. Optimum product selectivity can be achieved through careful selection and control of reaction conditions and catalysts. Research is also ongoing in finding alternative reaction pathways and catalysts to reduce dependence on external hydrogen input, such as internal glycerol reforming. Hydrotreating operating conditions are typically 300 - 400°C and 20 - 40 bar hydrogen for typical HVO purposes.

Ai generated of a HVO reactor

HVO Generic Production
Process Diagram



HVO – feedstock

Vegetable oil feedstock

Feedstock is expected to be dominated by waste cooking oils. Pretreatment is necessary to protect downstream equipment and catalysts. This usually involves degumming, bleaching and neutralisation. Degumming removes phosphorous compounds (mostly in the form of phospholipids) and soap from the oils. Phosphorous contaminants form glassy phases at elevated temperatures, leading to deactivation of catalysts downstream as well as excessive pressure drops across reactors. Free fatty acids are removed by neutralisation, reducing the acidity of the process streams, which may otherwise lead to corrosion of process equipment. Bleaching aims to remove any remaining phosphatides and other contaminants, such as chlorine and trace metals, as required to avoid deactivation of catalysts in downstream reactors.

Hydrogen

Hydrotreatment requires significant amounts of pure hydrogen, free of contaminants, including moisture and hydrocarbons. Some of this hydrogen supply (typically 15-30%) will be produced internally within the refinery, for instance during catalytic reforming of naphtha, but the majority will have to be sourced externally. For the fuels to be truly renewable with small environmental footprints, hydrotreatment should involve a source of low carbon hydrogen, such as electrolysis from renewable electricity. Low carbon production routes to hydrogen are described in other fact sheets. Hydrogen can either be produced onsite or externally supplied, although security of a continual supply is essential to perform the hydrotreatment processes, so pipeline connection is desirable whilst buffer storage is essential. Onsite production may offer the potential for process integration, reducing overall energy consumption and making the process economically more competitive with fossil fuel production.

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HVO Feedstock components

Organic Feedstock - Reactors/Vessels*

- Steam stripper
- High speed separators or centrifuges
- Adsorption beds for physical degumming
- Heat exchangers
- Liquid pumps
- Mixing devices e.g. stirrers

* For all organic feedstock components corrosion resistant stainless steel e.g. series 300 stainless steel would be a suitable material

Hydrogen supply

- Hydrogen storage and buffer tanks
- Pipeline connection - see factsheet on compression, storage and distribution of gaseous hydrogen
- Compressors
- High pressure pipework and fittings suitable for hydrogen (E.g. Stainless steel AISI 316L or 304L)
- Gauges
- Pressure control system
- Manifolding
- Temperature control/sensing
- Mass flow control
- Actuated shut off valves
- Non-return valves
- Isolation valves
- For trailered supply - flexible tubes (Braided stainless steel for hydrogen transfer and quick release couplers or similar)

Hydrotreatment reactor internals

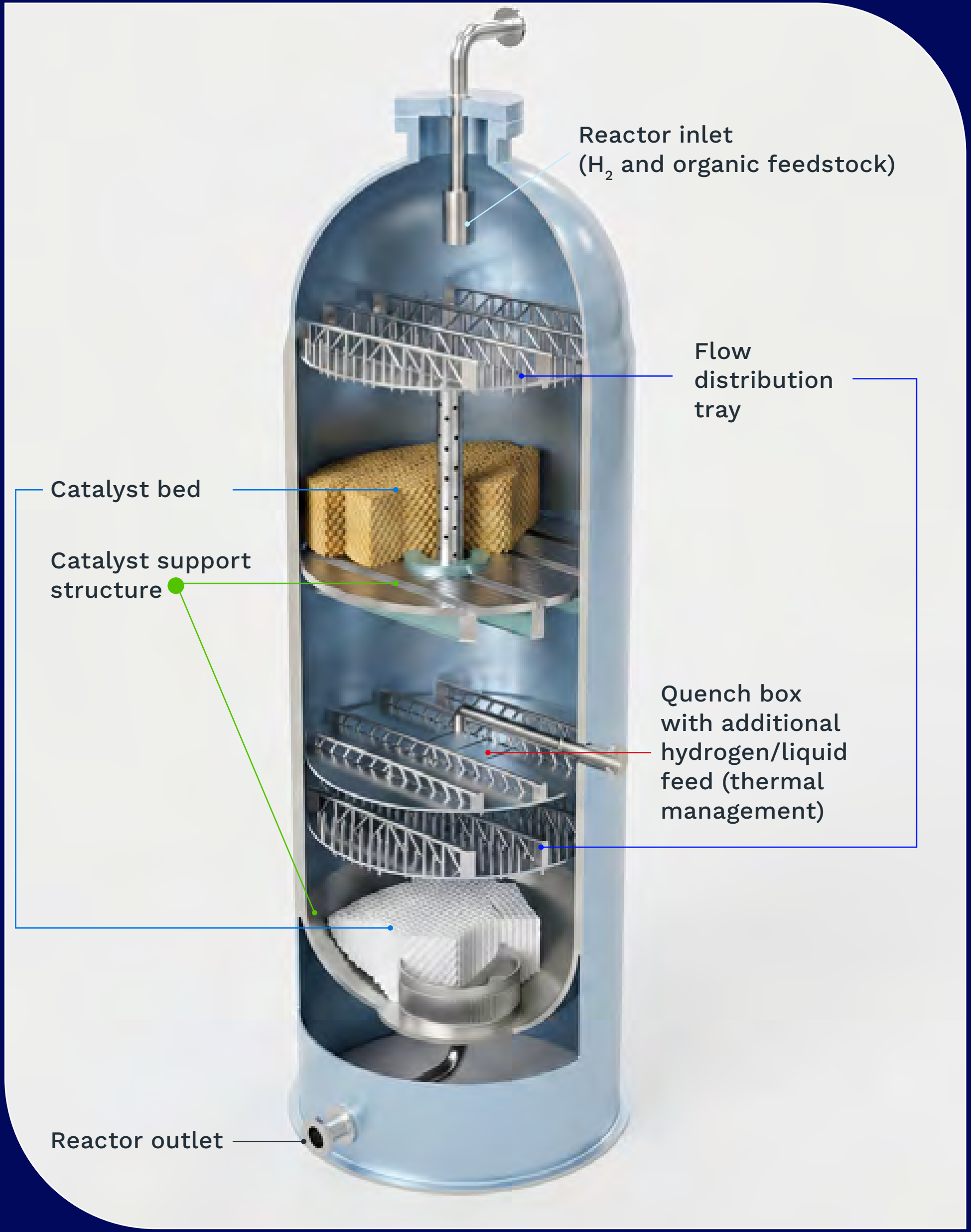
Reactor configuration

Multiple reactor configurations are utilised for hydrotreatment reactions, but a multistage Fixed Bed Reactor in trickle bed mode is most commonly deployed, particularly in existing refineries. In this configuration both gas (hydrogen feed and light hydrocarbon reaction products) and liquid (heavier hydrocarbons) phases trickle downward in co-current flow through multiple catalytic beds. Due to mass transfer limitations, flows are kept at low velocity to optimise contacting time between gas, liquid and solid (catalyst bed) phases. Separating the reactor in multiple catalytic beds allows for introducing thermal management features in between beds to avoid excess temperature build up due to the reactions' exothermicity. Flow distribution features are also essential to avoid creating 'dead zones' of unutilised catalyst. Finally, a multiple bed configuration allows for fine tuning reaction pathways by using different catalyst along the reactor axis. FBR are popular due to their relatively simple design, flexibility and ease of operation. Other than non-ideal flow distribution, their main drawback is that they require shutting down periodically to replace the catalyst beds, due to deactivation or excess pressure drop, typically every 1 – 2 years.

Other reactor designs and configurations can be used to address some of the Fixed Bed Reactor challenges. These configurations include Moving Bed Reactor, Ebullated Bed Reactor and Slurry Phase Reactor, which all share continual replacement of catalyst.

Thermal management

Multiple quench boxes can be positioned within a reactor to remove excess heat from the reactor and prevent excess heating. Excess heating can cause damage to catalysts and reactor internals as well as the production of undesirable side products due to operation out with optimum reaction conditions. Hydrogen gas is typically used as quench fluids and this is usually in the form of adding multiple hydrogen feeds along the height of the reactor, with the added benefit of replenishing consumed hydrogen, keeping partial hydrogen pressures high for optimum product selectivity. Liquid feed quenching or heat exchange with external coolant can be used as an alternative.



Ai generated of a hydrotreatment reactor

Hydrotreatment Components

Catalysts

Typically Nickel–Molybdenum (Ni-Mo), Nickel-Tungsten (Ni-W) or Cobalt–Molybdenum (Co-Mo), supported on Aluminium oxide (Al_2O_3), zeolite of mesoporous silica e.g. MCM-24 or SBA-15.

Precious metal-based catalysts - Platinum (Pt), Palladium (Pd) on Aluminium oxide (Al_2O_3), carbon, zeolite.

Reactor - multi-stage fixed bed reactor in trickle bed mode

External - typically Chromium-Molybdenum (Cr-Mo) steels, grade 41xx/ASTM A387

Internal - typically 300 series stainless teel, suitable for reaction conditions and resistant to hydrogen embrittlement e.g. grades 321 and 347. Acidic corrosion resistance is also advantageous e.g. grades 316 or 317.

Hydrotreatment Reactor – Internals*

Quench box - fluid collection tray, quench fluid injection system, plate-fin or tube shell heat exchange configuration

Hydrogen and/or liquid feeds

Flow distribution features e.g. bubble cap or sieve tray

Catalyst support structure

* For all internal components - 300 series stainless steel such as 321 and 347, combining strength and resistance to embrittlement. For added resistance to acid corrosion grades 361 or 317

Product upgrading

Isomerisation

This step is generally added after the first hydrotreatment reaction. Straight n-paraffins have a high cetane number which is desirable in diesel fuel, but also high cloud points, the minimum temperature at which precipitation occurs, which affects cold flow properties. Isomerisation is an effective way to reduce the cloud point, making the fuel more suitable for low temperature operation, an important aspect for both diesel and jet fuels. Typical operating conditions for this step would be 300-400°C, 20-40 bar hydrogen.

Cracking

Depending on the feedstock or the desired fuel (kerosene vs. diesel), a hydrocracking step can be added to convert heavy hydrocarbons into lighter ones whilst retaining saturation. This step may be combined with isomerisation, concomitantly adding branching, although operation conditions and catalysts need to be carefully considered. Cyclic molecules, can also be produced, for instance for jet fuel. Light fractions can be sent for oligomerisation or isolated as naphtha through recycle streams. This step could be combined with aromatisation in a single conversion depending on catalyst and operating conditions. Crackers usually operate at higher temperatures and pressures than other hydrotreatment reactors with typical operating conditions being 300 - 450°C, 35 - 200 bar.

Recycle loops and purge

For process efficiency, various reactor outlets are recycled, possibly first requiring separation. Hydrogen for isomerisation and hydrocracking is typically added in large excess and unreacted hydrogen is separated from the volatile hydrocarbon fractions to be recycled and combined with make up gas. The lighter hydrocarbons can be sent back for oligomerisation or isolated and sent to e.g. naphtha. Recompression is also typically needed to make up for consumed gas (see fact sheet on Hydrogen compression, storage and distribution). A purge is usually required to prevent build-up of inerts.

Product Upgrading Components

Multi-stage fixed bed reactor in trickle bed mode (see page 8)

Crackers - typically operate at elevated hydrogen pressures c.200 bar so need high strength Chromium–Molybdenum (Cr-Mo) steel for outer reactor wall to withstand pressure.

Isomerisation/oligomerisation catalysts – Acidic aluminosilicate catalyst e.g. H-ZSM-5 and Platinum (Pt), Ruthenium (Ru) or Nickel–Molybdenum (Ni-Mo) based catalyst supported on zeolite e.g. ZSM-5.

Catalytic or hydrocracking unit catalyst – Platinum (Pt) on chlorinated aluminia or Nickel (Ni) on zeolitic supports e.g. H-ZSM-5. Also Ruthenium (Ru) on ZSM-5. Acidic supports to promote cracking reactions.

Product separation

The HVO production process involves a number of separation steps to enhance overall process efficiency and improve product quality, purity and recovery whilst optimising unit sizing downstream of separation processes. The main hydrotreatment reactor outputs a mixture of desirable products, as well excess H_2, water, CO_2, and various undesirable hydrocarbons. A three-phase separator separates aqueous products, and light products (typically < C3) from the liquid hydrocarbon phase. H_2 from this separation step is recycled by further separating from the light hydrocarbons, which could be done by acid scrubbing.

The liquid hydrocarbon leaving the three-phase separator is usually first distilled to remove any valuable light fractions that are unsuited for the final fuel product, such as butane and propane. The heavier fraction is further processed.

Excess fatty acid content from the first hydrotreatment reaction may need to be separated first to prevent acid corrosion downstream which can be through treatment with an alkaline solution, e.g. NaOH and subsequent liquid-liquid separation of the aqueous phase.

More Gas-Liquid separation, e.g. by flashing, is required after the isomerisation and cracking steps to enable hydrogen recycling and purging; a final distillation step is usually performed to separate and retrieve the desired products, e.g. diesel, naphtha or kerosene.

Product Separation Components

- Stainless steel (e.g. 316) horizontal or vertical separator vessels - typically operating up to 200°C - 30-40 bar hydrogen
- Liquid level controllers
- Liquid control valves (oil and water)
- Inlet diverters
- Baffles
- Mist extractors
- Pressure transducer and control valve
- Amine absorber and stripper columns (see methane reforming)
- Amine solution e.g. Diethanolamine
- Fluid pumps
- Heat exchangers
- Compressors
- Vacuum systems
- Reflux and condenser drums
- Bubble or sieve trays
- Distillation column
- Reboiler
- Condenser

Balance of Plant

Balance of plant and plant/process safety is covered in detail in other fact sheets and will largely be identical for HVO fuel production. As discussed for other processes, thermal and process integration is key to operating at optimum energy efficiency, for instance utilising heat generated during the hydrotreatment steps to heat up inlet process streams. Integration with other adjacent processes is also common practice in a refinery set up. Process monitoring and control is also critical for operating at optimum conditions for reactions and separations, requiring accurate sensing of process parameters (pressure, temperature, mass flow) and fast feedback loops to e.g. compressors and mass flow controllers.

Like E-fuel production, fuel production through HVO involves processing many liquid phase compounds, requiring special consideration as compared to gas phase processing, e.g. liquid pumps, liquid phase separators, seals, etc. Mass and heat transfer will also be slower and potentially less uniform than typical gas phase processes, requiring alternative engineering solutions, as for instance discussed in the reactor configuration section.

Process safety

Process safety is integrated with process control. Check valves prevent process streams flowing in undesirable directions, whilst pressure relief and shutdown valves linked to pressure and temperature monitoring provide critical process safety. Burst valves can also be installed in case of critical pressure increases, avoiding catastrophic damage to equipment or even explosions. Sudden drops in gas (differential) pressure may indicate a major leak from e.g. equipment failure, loose connections. Gas monitoring equipment allows for gas leak detection and linked to process control system allows for process shutdown if this is the case.

Periodic maintenance and inspections, both invasive and non-invasive carried out to spot defects and replace process critical equipment.

Balance of Plant Components

Balance of Plant	
Heat network and heat exchangers - plate fin and/or tube shell	Compression fittings or orbital welded
Compressors - centrifugal and reciprocating for hydrogen streams depending on required pressures and volumetric flows	Process control systems
Blowers	Electrical supplies to various componentry
Liquid/water pumps	Electrical heating elements
Liquid level gauges, controllers and control valves	Electrical signalling (control systems and sensors)
Pressure monitoring and control for multiple pressure ranges	Electrical switchboard and electronics cabinets
Back pressure regulators	Electrical safety and interlocks
Temperature monitoring and control - thermocouples and thermistors	Carbon steel construction frames and gantries
Coriolis or Ultrasonic or Thermal Conductivity based mass flow controllers	Stairways, handrails and safety barriers
Control valves - solenoid (actuated)	Concrete foundations and plinths
Multidirectional valves and no-return valves	Earthing and drainage
Ball valves	Steel skids
Pressure relief valves	Gas detection - stationary and mobile - of various technologies (Ultrasonic, Electrochemical, Catalytic bead)
Burst valves	Warning signs (Illuminated, traffic light, yellow flashing lights)
Stainless steel ASTM 316/304 pipework	General signage

HVO fuel storage

Green diesel produced through HVO is essentially a ‘drop in’ substitute for diesel (see standards EN 590 and EN 15940), with the benefits of using existing supply chain infrastructure, such as fuel storage and distribution (e.g. bunkering, bulk transport and fuelling of depots). Biodiesels, such as FAME have been allowed (and since 2020 required) in transport fuel for at least two decades and as such codes and standards that cover handling and transport already exist or have been updated in case of fossil fuel with biofuel additions. FAME is limited to 7 vol.% in transport diesel, whereas HVO meeting EN 15940 can be used up to 100%.

Fuel storage and distribution is classified depending on the risk they pose. The most relevant HVO fuels, that is diesel or kerosene, are classified as Class 3, and Packing Group III, meaning relatively low risk.

Relevant codes are API 650 (diesel, kerosene) or API 620 (lighter fuels)

HVO Fuel Storage Components
Tanks*
Pressure relief valves
Pressure gauges
Thermometer
Sunshield
Coatings e.g. zinc
Filling and draining valves
Water drain sump and valve
Earthing connections

Ai generated of a HVO storage tank

* Double walled construction with a stainless steel, aluminium or carbon steel with epoxy lining inner wall. External wall requires corrosion protection in the form of coatings or anodic passivation may be required on particularly corrosive environments e.g. offshore or coastal storage

HVO Fuel distribution

Distribution of green diesel, like conventional diesel, will primarily be by shipping, rail and road.

HVO diesel is a Class 3 flammable liquid under UN regulations and due to its relatively high flash point, comes under packing group III. For lighter fuels, such as petrol, packing group II would apply.

The safety of transporting HVO fuels is regulated by the respective regulations of the mode of transport, i.e.

- Shipping – IMDG (The International Maritime Dangerous Goods code)
- Rail – RID (Regulations concerning the International Carriage of Dangerous Goods by Rail)
- Road – ADR (European Agreement concerning the International Carriage of Dangerous Goods by Road)
- Air – DGR (IATA) – International Air Transport Association's Dangerous Goods Regulations

HVO Fuel Distribution Components
Tanks (Inner wall should be stainless steel or aluminium (or carbon steel with epoxy lining)
Transport frames
Drain and fill valves
Liquid sump
Liquid level gauge (e.g. gravimetric type)
Liquid transfer pumps - ATEX rated
Flexible hoses suitable for hydrocarbon liquids (Typically synthetic rubbers e.g. nitrile, PVC, or composites)
Fuel (diesel) dispenser with metering system
Fuel pump
Fuel filtration system
Pressure relief valve
Non-return valve
Differential pressure gauge
Water drain valve
ATEX rated heater for cold condition fuelling
Earth bonding
Refuelling hoses and hose reel assembly

Relevant codes and standards (1/3)

Organisation	Standard	Details	Date of Publication
Standards and Codes of Practice			
American Petroleum Institute	API 620 - Design and construction of large, welded, low-pressure storage tanks	The API Downstream Segment has prepared this standard to cover large, field-assembled storage tanks of the type described in 1.2 that contain petroleum intermediates (gases or vapors) and finished products, as well as other liquid products commonly handled and stored by the various branches of the industry.	Published 2013 (updated 2025)
American Petroleum Institute	API 650 - Welded tanks for oil storage	This standard establishes minimum requirements for material, design, fabrication, erection, and inspection for vertical, cylindrical, aboveground, closed- and open-top, welded storage tanks in various sizes and capacities for internal pressures approximating atmospheric pressure (internal pressures not exceeding the weight of the roof plates), but a higher internal pressure is permitted when additional requirements are met.	Fourteenth Edition Published 2025
American Petroleum Institute	API Recommended Practice 941	Summarises the results of experimental tests and actual data acquired from operating plants to establish practical operating limits for carbon and low alloy steels in hydrogen service at elevated temperatures and pressures.	Eight Edition Published 2016
British Standards Institute	BS-EN 15940:2023	Describes requirements and test methods for paraffinic diesel fuel marketed and delivered as such, containing a level of up to 7,0 % (V/V) fatty acid methyl ester (FAME).	Published 2023
American Society of Mechanical Engineers	ASME B.31.3 - Process Piping	Contains requirements for piping typically found in petroleum refineries; chemical, pharmaceutical, hydrogen, textile, paper and pulp, power generation, semiconductor, and cryogenic plants; and related processing plants and terminals.	Published 2024
American Society of Mechanical Engineers	ASME Boiler and Pressure Vessel Code	A comprehensive set of engineering standards that governs the design, construction, inspection, and testing of boilers and pressure vessels.	Updated version published 2025

Relevant codes and standards (2/3)

Organisation	Standard	Details	Date of Publication
Regulations			
Health and Safety Executive	ATEX - 2014/34/EU	Two EU directives which describe the minimum safety requirements for workplaces and equipment used in explosive atmospheres - ATEX Workplace Directive and the ATEX Equipment Directive	Published in 2014 and applicable from 2016
Health and Safety Executive	Dangerous Substances and Explosive Atmospheres Regulations 2002 (DSEAR)	Require employers to control the risks to safety from fire, explosions and substances corrosive to metal	Published 2002
European Union	Pressure Equipment Directive - 2014/68/EU	Sets out the standards for the design and fabrication of pressure equipment (including steam boilers, pressure vessels, piping, safety calves and other components and assemblies subject to pressure loading) greater than one litre in volume and having a maximum pressure more than 0.5 bar gauge.	Published May 2014

Relevant codes and standards (3/3)

Organisation	Standard	Details	Date of Publication
Guidance Documents			
Health and Safety Executive	HSG176 - Storage of flammable liquids in tanks	This guidance applies to above and below ground fixed bulk storage tanks. It applies to premises where flammable liquids are stored in individual tanks or groups of tanks. It may also be applied to portable or skid-mounted vessels with capacities in excess of 1000 litres.	Published 2015
Health and Safety Executive	HSG51 - Storage of flammable liquids in containers	This guidance is for those responsible for the safe storage of flammable liquids in containers at the workplace. It applies to storage of flammable liquids in containers up to 1000 litres capacity.	Published 2015
Health and Safety Executive	HSG140 - Safe use and handling of flammable liquids	This guidance is for those responsible for the safe use and handling of flammable liquids in all general work activities, small-scale chemical processing and spraying processes. It explains the fire and explosion hazards associated with flammable liquids and will help you determine how to control the risks in your workplace.	Published 2015

Scottish Enterprise

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With thanks to: ESP

Scottish Enterprise

Atrium Court
50 Waterloo Street
Glasgow
G2 6HQ

www.scottish-enterprise.com