

# Fischer-Tropsch Alternative Fuels Production

## Production overview

Alternative/sustainable fuels comprise a wide range of fuels that are sustainable analogues of their fossil counterparts, such as diesel, methanol or kerosene. There are a variety of methods of producing alternative fuels but certain pathways involve combining renewable and sustainable sources of hydrogen and carbon, thereby avoiding fossil feedstocks and providing a sustainable route to carbon-based fuels. This fact sheet focusses on fuels produced through the Fischer Tropsch process, which uses syngas as its feedstock, a mixture of CO and H<sub>2</sub>. Renewable syngas can be produced in a myriad of ways, from biomass gasification to combining captured CO<sub>2</sub> and H<sub>2</sub> from water electrolysis. As the final product is heavily dependent on the feedstock composition, controlling this feedstock is key to an economically viable process. Finally, economies of scale will be important for Fischer-Tropsch Alternative Fuels to become a viable commodity.

One broad subset of Alternative Fuel is Sustainable Aviation Fuel (SAF) which is expected to be a key fuel to de-fossilise the hard to abate aviation sector, requiring minimal changes to supply chains, infrastructure and aviation technology. Many Fischer-Tropsch plants are therefore mostly designed to yield SAF as well as other alternative fuels, such as synthetic naphtha and synthetic diesel as by-products. Further refining is required after the FT process to yield a product that is suitable for use as jet fuel, much like fossil derived kerosene. Approved pathways to producing SAF only allow blending with petroleum derived jet fuel up to 50%. R&D is ongoing to synthetically produce jet fuel that could be used without blending. Legislation and standardisation will also require updating to allow faster and more widespread adoption of SAF.



# Fischer-Tropsch reaction

Fischer Tropsch is a mature process, originally developed to produce liquid fuels from coal in the mid-1900s. The Fischer-Tropsch reaction is typically carried out by reacting syngas between 200 - 350°C and pressures of 40-80 bar over a catalytic bed. Fischer-Tropsch typically yields a wide range of products including saturated, unsaturated and oxygenated hydrocarbons with varying molecular mass. Reaction conditions and catalysts should be chosen such as to yield a desirable mixture of hydrocarbon compounds. For Alternative Fuels this usually means heavier, non-oxygenated, saturated alkanes, and, to a limited degree aromatics. For one of the most relevant Alternative Fuels, SAF this means a typical carbon number of C8-C16, to comply with jet fuel standards, such as ASTM D1655. Molecular configuration is critical too, e.g. linear, vs. branched and cyclic. Formation of short chain molecules in particular methane must be suppressed which can be achieved by avoiding higher reaction temperatures and the use of Ni-based catalysts.

The FT reaction is highly exothermic and care must be taken to remove excess heat in order to keep reaction temperatures within an acceptable range (increase in temperature may lead to undesirable side reactions such as methanation). Thermal management is therefore typically integrated with the reactors, for instance through a shell & tube heat exchange configuration. Many of the products in FT are also viscous liquids, which can cause mass transfer limitations, which should be taken into account.

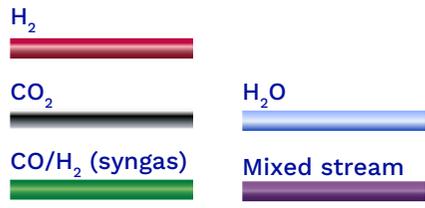
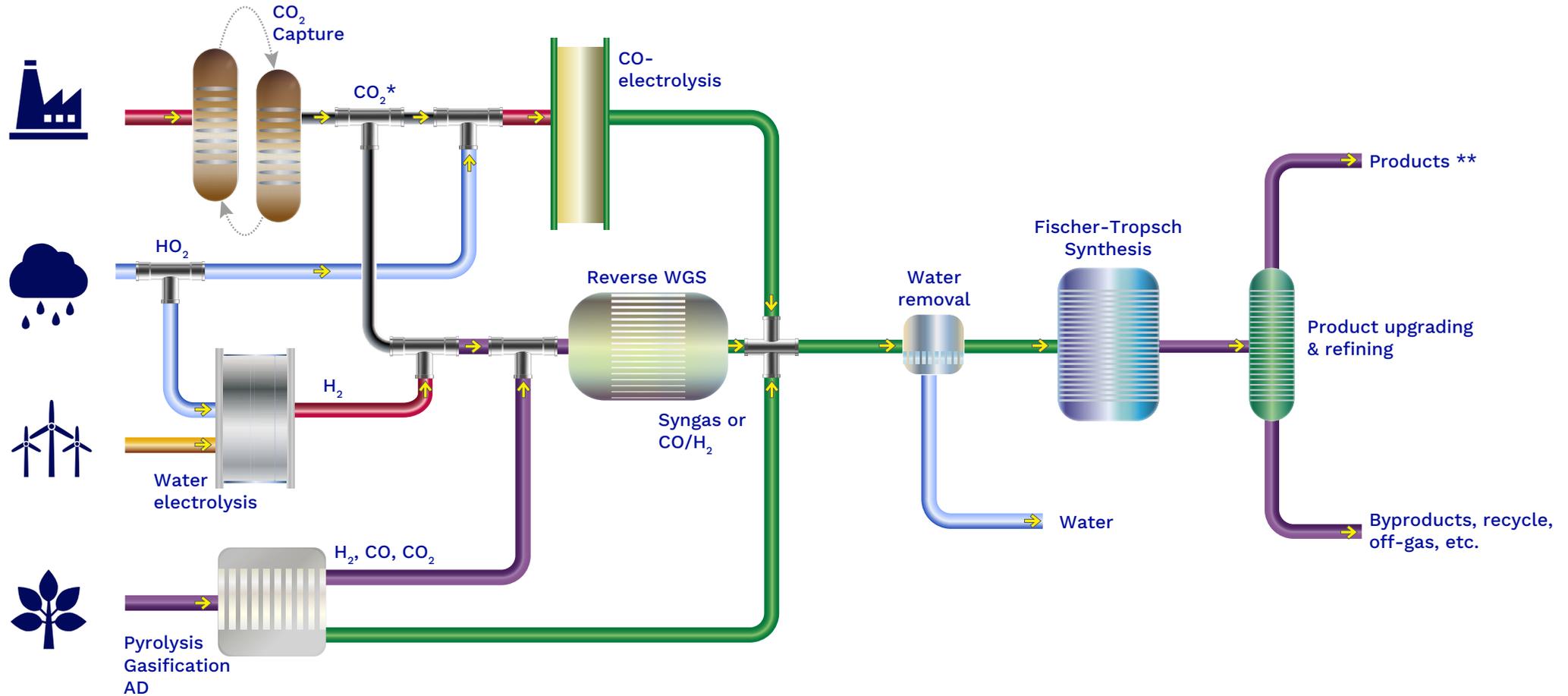
Specialist catalyst and support materials are required. Typically Iron (Fe) or Cobalt (Co) based (Co based catalysts are better suited for longer chain alkanes) - supported on materials such as Aluminium Oxide ( $\text{Al}_2\text{O}_3$ ), (mesoporous) Silicon Dioxide ( $\text{SiO}_2$ ), Zirconium Dioxide ( $\text{ZrO}_2$ ) or Titanium Dioxide ( $\text{TiO}_2$ ). And promoters such as Potassium Oxide ( $\text{K}_2\text{O}$ ) and Manganese (II) Oxide ( $\text{MnO}$ ).

Various configurations or reactors can be used, usually integrating catalyst bed and thermal management e.g. multi-tubular cooled reactor in tube-shell arrangement, gas or water cooled, slurry bubble or fluidised bed. Typically low carbon chromium steels are needed for reactor vessels. Also molybdenum-chromium (Mo-Cr) low carbon alloys are needed for reactor tubes.



# Fischer Tropsch Alternative Fuels Production

## Process Diagram

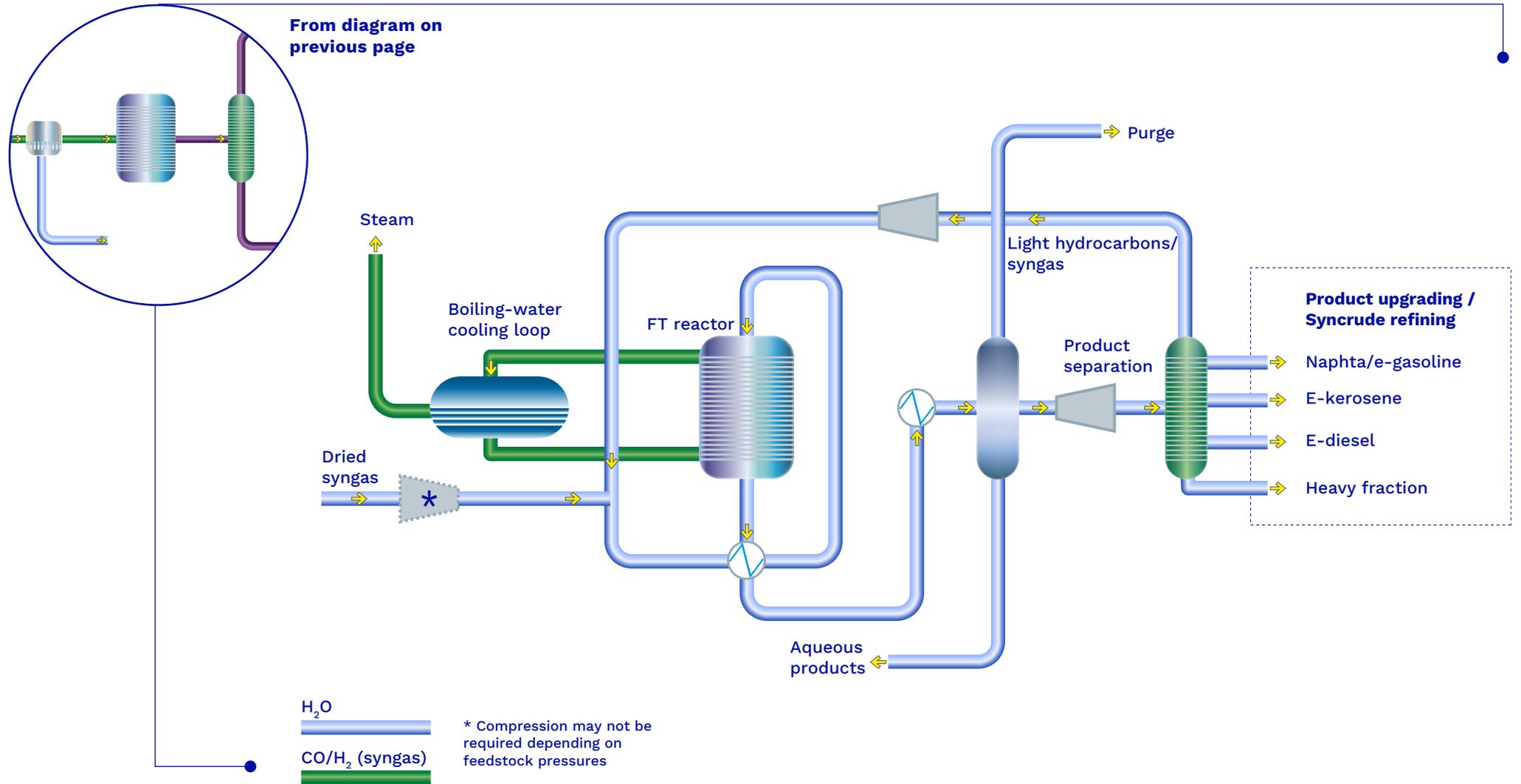


\* CO<sub>2</sub> ideally from renewable, non-fossil sources

\*\* E.g. E-kerosene (SAF), E-diesel and E-gasoline

# Fischer Tropsch Alternative Fuels Production

## Process Diagram (continued)



# Fischer Tropsch Alternative Fuels – feedstock

Fischer-Tropsch can utilise many different feedstocks. Syngas can be produced directly from biogenic (or even Municipal Solid Waste) feedstock through e.g. gasification. Co-electrolysis using Solid Oxide technology is an alternative means to producing syngas, but this requires water and CO<sub>2</sub> as feedstock. Hydrogen and CO can also be produced separately, through routes described in other hydrogen fact sheets, combined with reverse Water Gas Shift (WGS) reaction to convert CO<sub>2</sub> into CO. A combination of any of the above may be required to achieve the right feedstock Hydrogen/Carbon composition for the downstream Fischer-Tropsch process. If applicable, hydrogen can either be produced onsite as part of the overall process, or externally supplied. Although security of a continual supply is essential to optimally run the Fischer-Tropsch production process, so a dedicated pipeline connection with buffer storage would be desirable. Onsite production offers the potential for extensive process integration, reducing overall energy consumption and making the process economically more competitive with fossil-based production.

## CO<sub>2</sub> reduction – Reverse Water Gas Shift

CO is produced by reduction of CO<sub>2</sub> and this can be achieved through the reverse WGS reaction (r-WGS) in a thermo-catalytic reactor. The r-WGS reaction is not an industrially mature process. Due to its endothermic nature and equilibrium conditions, the reaction would be favoured at high temperatures. The reactor could be an adiabatic fixed bed reactor, possibly multi-tubular, and is expected to be operated at temperatures of over 600°C to achieve sufficient conversion and several 10s of bar.

### Component list

Hydrogen and/or CO <sub>2</sub> storage tanks	Mass flow control
Buffer tanks	Actuated shut off valves
Compressors	Non-return valves
High pressure pipework and fittings <sup>1</sup>	Isolation valves
Gauges	Quick release couplers (or similar) for external supply interfacing
Pressure control system	Flexible tubes for hydrogen transfer from tube trailer <sup>2</sup>
Manifolding	Specialist catalyst <sup>3</sup>
Temperature control/sensing	Reactor for reverse water gas shift <sup>4</sup>

1. E.g. Stainless steel AISI 316L or 304L

2. E.g. braided stainless steel

3. including transition metals e.g. Copper (Cu), Nickel (Ni) and Iron (Fe) supported on oxide materials such as CeO<sub>2</sub>, ZrO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub> and SiO<sub>2</sub> or alumina-silicates. Also precious metals Platinum, Rhodium, and Palladium (Pt, Rh and Pd) finely dispersed on support materials. Mixed metal oxides in R&D stages e.g. doped barium zirconates

4. Fixed bed adiabatic, possibly multi-tubular - likely Nickel-Chromium (Ni-Cr) steels or specialist alloy (e.g. Inconel - suitable for reactor conditions)

## Biogenic feedstock – gasification

Where biogenic feedstocks, or even Municipal Solid Waste are considered as feedstock, gasification is generally considered the most reliable process to convert these into syngas. During this process, the feedstock is mixed with small quantities of air/oxygen and/or steam at high temperatures, typically 800 – 1,200°C, to produce a mixture of H<sub>2</sub>, CO, CO<sub>2</sub> and methane under autothermal conditions. Several gasification technologies exist, and suitability will depend on feedstock. Fixed or fluidised bed gasification are mature technologies and suitable for most biomass feedstocks.

Gasifying biomass will require some pre-processing of the feedstock, including mechanical treatment (chipping, crushing, grinding, etc.). Thermal and chemical treatments may be required too. These include drying to control moisture levels and acid washes to reduce alkali and silicon levels which cause slagging.

Gasifying biogenic feedstock will generate impurities, including sulphurous and halide compounds, which can poison catalyst beds that are utilised downstream. These impurities will require removal, as also discussed in the low carbon hydrogen production through methane reforming fact sheet.

### Component list

Grinding, crushing and pelletising equipment	Air compressor
Dryers	Air separation unit if using pure oxygen (see Ammonia factsheet)
Acid and water washing	Steam generator
Hydrothermal treatment	Absorption units for sulphur, halides and heavy metals etc. (see low carbon hydrogen production through methane reforming factsheet)
Gasifier reactor - fixed or fluidised bed	



# Product upgrading – Syncrude refining

The mixture of hydrocarbons leaving the FT reactor is called syncrude and mainly consists of n-alkanes, some alkenes and oxygenates, critically lacking in some key jet fuel components (e.g. cyclic and branched alkanes) and thus needs to be further treated to yield the products with the desired fuel properties. A number of process steps can be performed and indeed can use conventional refinery infrastructure already used for fossil crude. These include hydro- or catalytic cracking, isomerisation and fractional distillation, as well as aromatisation. When the FT process predominantly yields larger hydrocarbons, hydrocracking and isomerisation may be performed to yield a fuel with optimal properties. This is already an approved route to SAF. Refining the syncrude and isolating a fraction with the desired properties, as is done for fossil crudes, is another route to producing SAF, but is yet to be approved for use in aviation.

ASTM D7566 details certified refining pathways to synthetic jet fuels or SAF in the US. So although a synthetic fuel may have all the relevant properties of jet fuel, its refining pathway will have to be specifically approved through ASTM D4054/D7566.

## Distillation

After separating an aqueous fraction and gaseous species, syncrude firstly needs separating by fractional distillation, as determined by their boiling point ranges. The different fractions correspond to different molecular weights and in turn different transport applications i.e. lighter fractions for gasoline and heavier for kerosene and diesel. Distillation is typically performed under atmospheric pressures.

## Hydro treatment

The middle distillate which has the desired molecular weight range for SAF, still requires further treatment for use as jet fuel. During hydro treatment, any unsaturated alkenes are converted to alkanes by reacting with hydrogen gas. Hydro-treating operating conditions are typically 300 – 400°C and 20 - 40 bar hydrogen for relevant fractions.

## Cracking

Hydrocracking or catalytic cracking converts hydrocarbons that are too heavy for kerosene into lighter ones whilst retaining saturation and concomitantly adding branching. Cyclic molecules can also be produced. Light fractions can be sent for oligomerisation or isolated as naphtha. This step could be combined with aromatisation in a single conversion depending on catalyst and operating conditions. Typical operating conditions: 300 - 450°C, 35 - 200 bar hydrogen.

## Product upgrading – Syncrude refining (continued)

### Isomerisation/oligomerisation and alkylation

These processes combine lighter alkenes to produce heavier and branched alkanes within the kerosene range, whilst also production cyclic molecules. Branched aromatics with desired molecular weights can also be produced during this step through Friedel Craft type reactions.

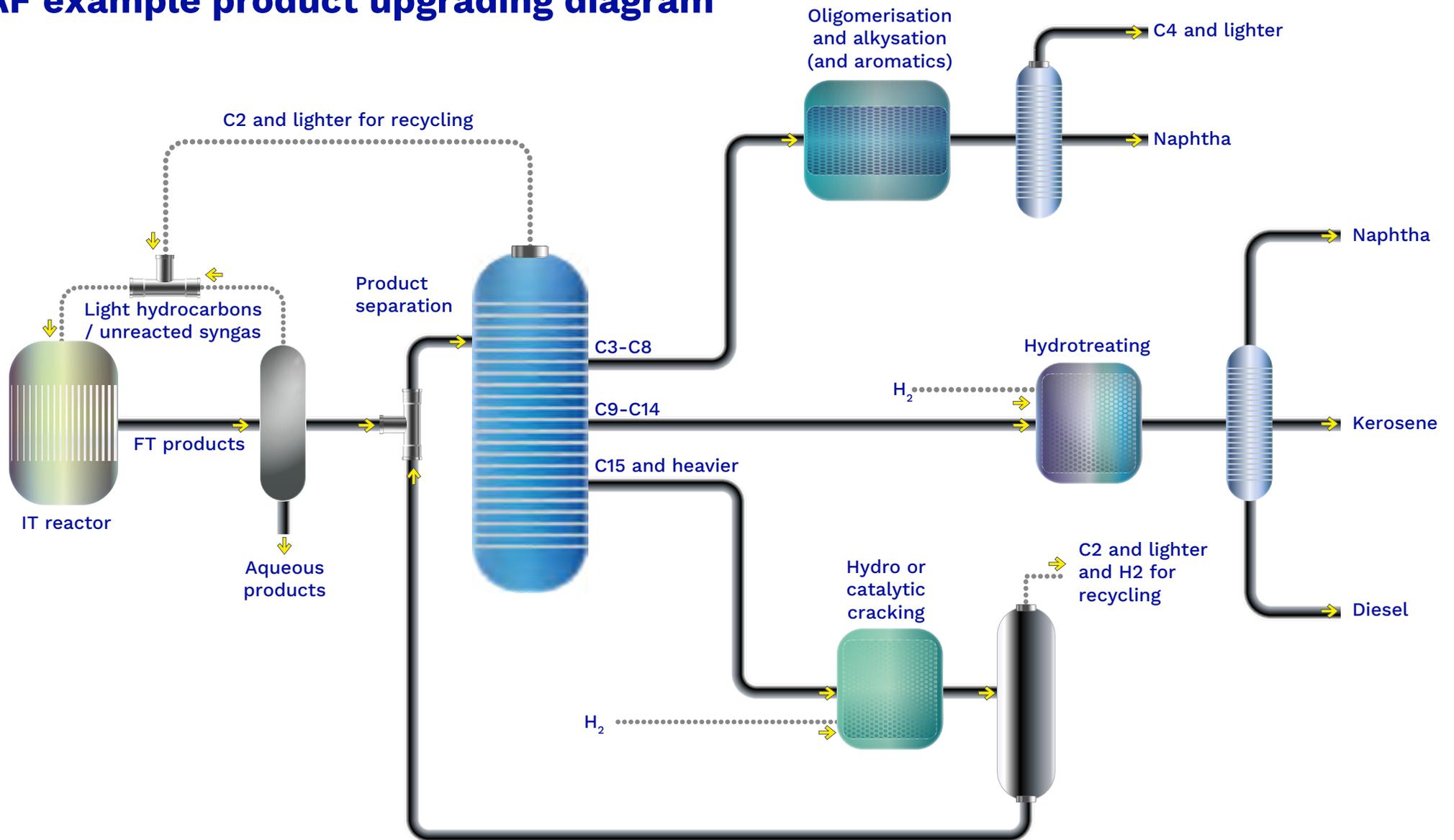
### Recycle loops and purge

For process efficiency, various reactor outlets are recycled, possibly first requiring separation. Hydrogen for hydrotreating and hydrocracking for instance is typically added in large excess and unreacted hydrogen is typically separated from the volatile hydrocarbon fractions to be recycled into the treating or cracking units, whereas the lighter hydrocarbons can be sent back to the FT reactor. Recompression is also typically needed to make up for consumed gas (see hydrogen compression fact sheet). A purge needs to be included to avoid build-up of inert components.

### Component list

Fractional distillation unit	Typically carbon steels
Reboilers	Typically carbon steels
Reflux condenser	Typically carbon steels
Compressors for recycled streams	Typically carbon steels
Hydrotreatment reactor	Typically fixed bed reactors, preferably low carbon steel or stainless steel 316L Molybdenum (Mo) or Tungsten (W) based catalysts, promoted by Nickel/Cobalt (Ni/Co) on Alumina support
Catalytic or hydrocracking unit - typically fixed bed	Typically fixed bed reactors, preferably low carbon steel or stainless steel 316L Catalysts - Platinum (Pt) on chlorinated alumina or Nickel on zeolitic supports e.g. Hydrogen Zeolite catalyst H-ZSM-5
Fixed bed reactor for isomerisation/oligomerisation	
Acidic aluminosilicate for isomerisation/oligomerisation	E.g. Hydrogen Zeolite catalyst H-ZSM-5

## SAF example product upgrading diagram



## Balance of Plant

Balance of plant and plant/process safety will largely be identical for Fischer-Tropsch Alternative Fuels production as for production of hydrogen or other hydrogen products. One key difference is the presence of many liquid phase compounds, requiring special consideration, e.g. liquid pumps and seals, etc.

## Process safety

Process safety is integrated with process control. Pressure relief and shutdown valves are linked to pressure and temperature monitoring. Burst valves can be also 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 leak detection and linked to process control system allows for process shutdown. Periodic maintenance and inspections, both invasive and non-invasive, should be carried out to spot defects and replace process critical equipment.

## Component list

Heat exchangers	Process control systems
Centrifugal/reciprocating compressors	Electrical supplies to various componentry
Blowers	Electrical heating elements
Liquid/water pumps	Electrical signalling (control systems and sensors)
Pressure gauges	Electrical switchboard and electronics cabinets
Pressure transducers - Multiple pressure range including vacuum for VPSA	Electrical safety and interlocks
Back pressure regulators	Shipping containers
Thermocouples/thermistors	Acoustic shielding
Mass flow controllers E.g. Coriolis or Ultrasonic or Thermal Conductivity based	Carbon steel construction frames and gantries
Solenoid (actuated) Control valves	Stairways, handrails and safety barriers
Multidirectional valves	Concrete foundations and plinths
Non-return valves	Earthing and drainage
Ball valves	Steel skids
Pressure relief valves	Stationary and mobile gas detection
Burst valves	Warning signs (Illuminated, traffic light, yellow flashing lights)
Stainless steel Pipework e.g. ASTM 316/304	General signage
Compression fittings (or orbital welded)	

## Alternative Fuels Storage

The attraction of Alternative Fuels is that they are essentially synthetic analogues of their fossil counterparts, minimally impacting on existing supply infrastructure, such as fuel storage and distribution (e.g. bunkering, bulk transport and fuelling of depots). This also means there is likely to be minimal change in codes and standards that cover their handling and transport, although amendments are likely required in cases where standards are too prescriptive or constraining, preventing their market penetration, as appears to be the case currently for SAF.

Fuel storage and distribution is classified depending on the risk the fuels pose. Most relevant Alternative Fuels are classified as Class 3, with SAF and synthetic diesel in transport group 3, meaning relatively low risk. Relevant codes are API 650 (diesel, kerosene) or API 620 (lighter fuels).

### Component list

Tanks*	Coatings (e.g. zinc)
Pressure relief valves	Filling and draining valves
Pressure gauge	Water drain sump and valve
Thermometer	Earthing connections
Sunshield	

\* Double walled construction. Inner wall - stainless steel or aluminium (or carbon steel with epoxy lining) External corrosion protection in the form of coatings or anodic passivation may be required in particularly corrosive environments (e.g. offshore or coastal storage - port terminals and shipping)



# Alternative Fuels distribution

Distribution of Alternative Fuels is expected to be primarily by shipping, rail and road. SAF and synthetic diesel are Class 3 flammable liquids under UN regulations and, depending on flash point, can come under packing group I, II or III. The safety of transporting Alternative 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



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## Component list

Tanks and tankers	Pressure relief valves
Transport frames	Non-return valves
Drain and fill valves	Differential pressure gauge
Liquid level gauge (e.g. gravimetric)	Water drain valve
ATEX rated liquid transfer pumps	ATEX rated heater for cold condition fuelling
Flexible hoses - suitable for hydrocarbon liquids (Typically synthetic rubbers (e.g. Nitrile), PVC, or composites)	Earth bonding
Fuel filtration system (API 1581)	Refuelling hoses and hose reel assembly (API 1529)

# Standards and Codes of Practice

Organisation	Standard	Details	Date of Publication
American Petroleum Institute	API 620 - Design and construction of large, welded, low-pressure storage tanks	This standard covers the design and construction of large field-assembled, welded, low-pressure carbon steel above ground storage tanks (including flat-bottom tanks) that have a single vertical axis of revolution, 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
SAE International	SAE Aerospace Specification (AS) 5751 - Design and operating requirements of the onboard aircraft refuelling system and associated ground refuelling equipment interface	This Aerospace Specification defines the minimum design and operating requirements for the aircraft refuelling interface. These requirements establish the minimum criteria for the aircraft design that provides practical standardised refuelling system requirements, provides minimum standardised criteria for the operation and performance of any aircraft refuelling equipment, and establishes an integrated minimum performance for aircraft refuelling operations.	Published 2023

# Regulations

Organisation	Standard	Details	Date of Publication
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

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## Guidance Documents

Organisation	Standard	Details	Date of Publication
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



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