Economic viability of biomass to liquid via Fisher-Tropsch

When the Fisher-Tropsch process is coupled with a biomass gasification facility, sustainable liquid fuels can be produced for aviation and marine propulsion

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Global warming prompts limiting the Earth's average temperature rise to less than 2°C. To achieve this goal, greenhouse gas emissions must be reduced. Notably, the anthropogenic carbon dioxide (CO_2) emissions from burning fuels of fossil origin must be reduced to achieve carbon neutrality by 2050. The transportation sector is a major source of CO_2 emissions to the atmosphere, and aviation fuels are one of the more difficult transport modes to decarbonise. Despite the efforts being made to find alternative fuels for aircraft and vessels propulsion, liquid fuels remain the most practical solution. Producing synthetic liquid fuels from biomass via Fisher-Tropsch technology (BTL-FT) is a way to decarbonise the transport sector. This article discusses the fundamentals of this technology and spotlights the conditions under which the economic viability of BTL-FT investment is assured.

Fischer-Tropsch process

The Fischer-Tropsch synthesis process (FT) involves the non-selective polymerisation of carbon monoxide (CO) under reductive conditions. The polymerisation is catalysed by most Group VIII metals, notably iron or cobalt-based catalysts, typically supported on SiO_2, TiO_2, or Al_2O_3.

Due to the lack of selectivity, a wide variety of side reactions occur; hence, the synthesis products include alkanes and alkenes with a very broad composition, along with oxygen-containing compounds, mainly alcohols, carbonyl compounds, acids, and esters. The product distribution depends on the H_2/CO in the syngas, the catalyst employed, the reactor design, and the operating conditions, most notably the operating temperature.

Cobalt-based catalysts give a higher yield of middle distillate products with much less oxygenated relative to the use of iron-based catalysts. They show higher selectivity for paraffinic derivatives at low temperatures; hence, they can be used to produce sustainable aviation fuel (SAF). At high temperatures, however, an undesired quantity of methane forms. Thus, this type of catalyst is not suitable for high-temperature FT processes.

Iron-based catalysts are relatively inexpensive, tolerate flexible operation conditions, and are suitable for synthesis with low H_2/CO ratio syngas – typically derived from low-quality feedstock such as biomass – although it produces a significant quantity of non-paraffinic derivatives as byproducts.

As the FT reactions are highly exothermic, the accuracy of the reactor temperature control significantly impacts the products (paraffins and/or olefins).

In principle, syngas can be produced from any carbonaceous feedstock, including biomass and organic wastes. The FT process architecture may be either an open loop or a closed loop, depending on the feedstock to be processed.

In an open-loop scheme, the light ends are separated from the cooled reactor outlet and used to generate electric power for the FT process and export to the grid. In a closed loop, part of the light ends can be recycled back for further conversion to synthetic liquid fuel, while the remaining part is used for power generation.

The product from an FT plant is a synthetic crude analogous to crude oil of fossil origin, albeit syncrude components are different for different FT technologies and catalysts.

An FT operated at high temperature yields a syncrude containing light gases, LPG, naphtha, distillate, and aqueous products. Residue/wax, distillate, and naphtha are the major components yielded by a low-temperature FT plant. For both cases, an upgrade or a syncrude refining is needed to produce a more valuable product slate.

The waste energy related to the generation of syngas with the heat produced in the FT synthesis is generally recovered as steam and converted into electric power for internal use and export. Thus, electric power is typically a by-product of the current FT processes. The energy adds to the product slate and contributes a source of revenue.

Economics

The economics of an FT plant are strongly affected by the cost of the carbon-bearing feedstock, the cost of CO_2 emissions, the product pricing, and the facility's capital cost.

The cost of feedstock is a sizable component of operating costs, yet its price cannot be controlled because it is source dependent and on the distance from the production and harvesting (or collection and separation of biowaste) sites to the FT facility: the greater the distance, the higher the feedstock transportation costs. The latter is part of the key to biomass price at the fence of the FT plant and, ultimately, to its profitability.

It is worth noting that the SAFs produced by an FT plant are rich in alkanes and may command a price premium depending upon the end users. For example, an extra price is paid for FT-naphtha when used in the petrochemical industry because it gives a higher yield of ethylene than that derived from petroleum. Russian refineries typically blend diesel with an additive to adjust the cetane number. As FT-diesels have a cetane number of 73, compared to 51 in diesel that meets the EN-590 standard, it can command an extra premium on account of the additive savings it delivers when FT-diesel is blended in the diesel pool.

Analysis of the existing FT plant shows that these facilities are capital expensive. Indeed, the capital expenditure for industrial running natural gas FT plants, which benefit from the most favourable technical and economic conditions, ranges from \$100,000 bbl/d to \$146,000 bbl/d. The capital-intensive character of these industrial installations calls for large-scale production to achieve the economy of scale. In fact, today's commercial plant capacity spans from 15,000 bbl/d to 146,000 bbl/d. For the case study below, the total cost of the investment was estimated at 174,320 \$/bbl/d.

The total cost of investment for a biomass FT plant might be significantly higher relative to the current FT plants because biomass impacts several parts of the line-up of the syngas production and FT synthesis system. More specifically, biomass requires:

- More extensive feedstock handling and preparation
- Application of a slagging entrained flow gasifier, which includes all solids handling, is typically 50% more expensive than a natural gas reformer
- About 50% higher oxygen demand, i.e. 50% larger ASU capacity is required
- Need for pre-combustion carbon capture to remove the higher load of CO_2.

Therefore, robust R&D programmes are needed – in addition to selecting the optimal site location – to reduce the investment cost and open the window of the economic viability of BTL-FT technology for supplying sustainable fuels to the transport sector. That is the objective of the GLycerol to Aviation and Marine products with sustainable Recycling (GLAMOUR) project. The project has received funding from the European

Proximate analysis						Ultimate analysis (wt%, dry basis)					
Fixed carbon (wt%)	Volatile matter (wt%)	Ash (wt%)	Moisture (wt%)	LHV (MJ/kg)	HHV (MK/kg)	Carbon	Hydrogen	Oxygen	Nitrogen	Sulphur	Ash
18.1	61.6	5.30	15.0	14.5	15,935	47	5.72	40.2	0.86	0.09	6.19

Table 1 Biomass main properties

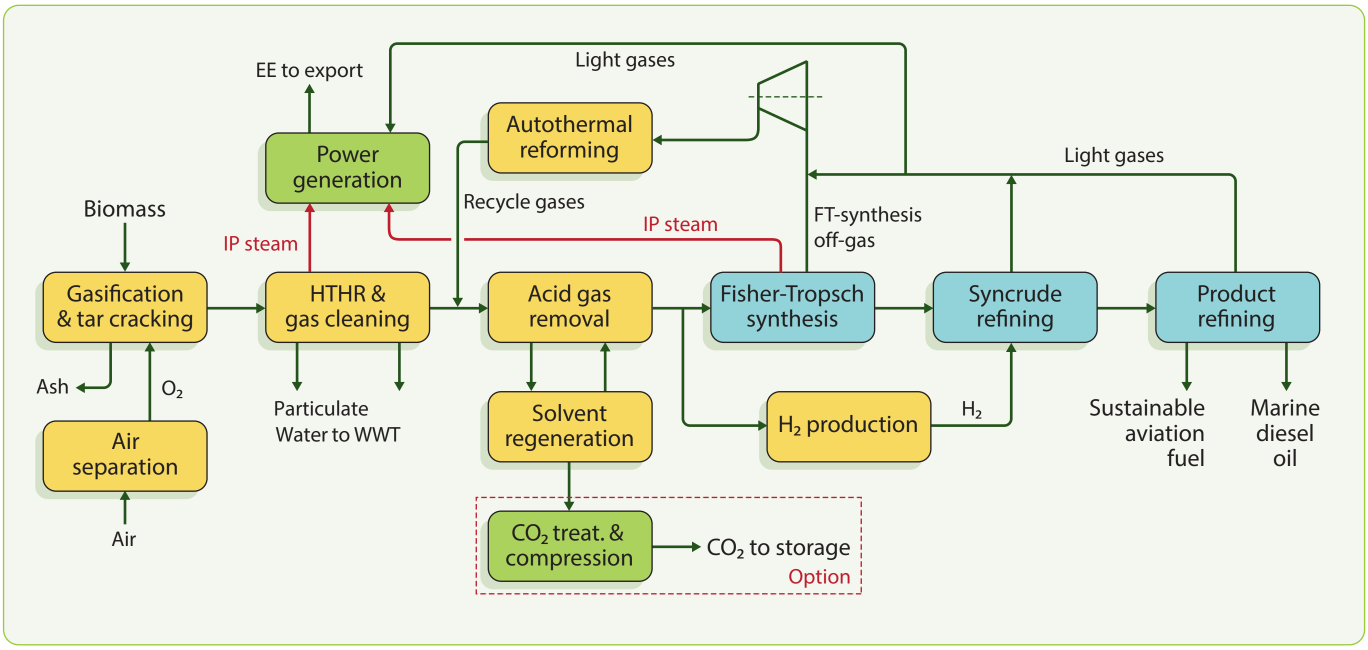

Figure 1 Biomass to liquid process setup

Union's Horizon 2020 research and innovation programme under grant agreement N° 884197.

Case study

In the context of the GLAMOUR project, Siirtec Nigi developed the benchmark against which to compare the new technology. In order to find out the conditions for the economic viability of investments in BTL-FT processes, the case for the production of 1.5 MMbbl/y of middle distillates from 149.2 t/h of herbaceous biomass was modelled. **Table 1** shows the main properties of the biomass fed to the plant.

The plant setup is shown in **Figure 1**. The plant front-end consists of the chopping of herbaceous feedstock followed by feeding via lock-hoppers. The syngas from biomass is produced by a dry-fed, oxygen/steam-blown fluidised bed gasifier operating at 30 bar. An on-site air separation unit provides the O_2.

The tar-free gas from the gasification unit is then cooled in the high-temperature heat recovery (HTHR), where high-pressure steam is raised to be sent to the power generation section. For this case study, the gasification was designed to deliver syngas with an H_2:CO ratio of about 2.

114 t/h of CO_2 is removed in an acid gas removal process and vented in the base case. Alternatively, this CO_2 is compressed, dehydrated, and delivered to an underground storage facility.

The FT design is based on the slurry-phase reactor, which enables a high heat transfer, resulting in the high conversion of feed gas to liquids in a relatively small reactor volume without excessive temperature rise. The syncrude is distilled to split naphtha, distillate, and wax. The naphtha stream is first hydrotreated, resulting in the production of hydrogen-saturated liquids (primarily paraffins). The distillate stream and the wax fraction are also hydrotreated, resulting directly in the finished products.

A slipstream of the light gases (C_1-C_4) separated from the syncrude is used as fuel gas in the power generation block, while most of them are mixed with unconverted syngas and the off-gas from the H_2 production section and recycled back to the FT synthesis through the autothermal reformer to maximise the liquid fuel production.

About 66 MW of electric power is being generated in the power generation, with two-thirds of this power being used to meet internal power demand, while the balance is delivered to the electric grid as a by-product.

For this case study, the economic viability has been assessed by:

- Fixing a preset rate of return (RR) on investment and the CO_2 price ($80/tons as per the average January 2022 ETS)
- Varying the price of the synfuels products expressed in terms of barrel of oil (Brent) equivalent (BBE) or crude oil equivalent (CEO)

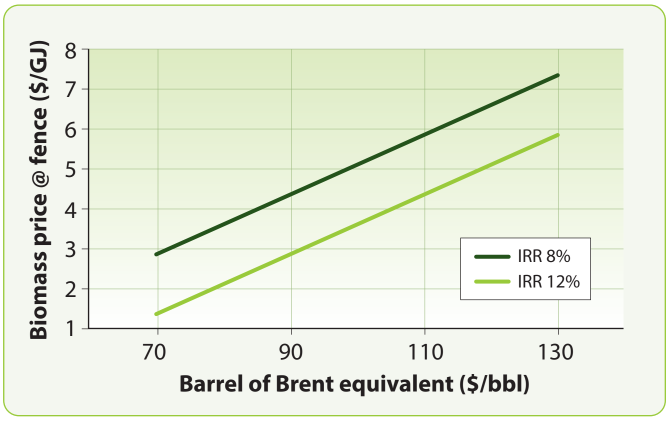

Figure 2 Economic viability chart for the BTL-FT-CCS case

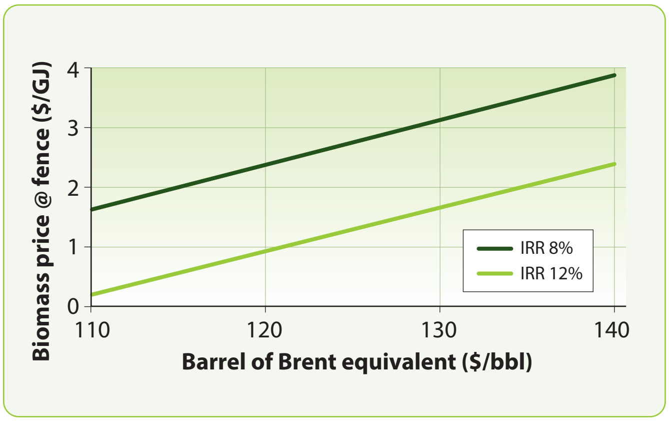

Figure 3 Economic viability chart for the BTL-FT- CO_2 vent case

- Computing the maximum feedstock prices that set the gross profit equation to zero
- Assuming the electric energy is quoted at $42 per MWh.

Figure 2 shows the results of the algorithm described above for 8% and 12% rates of return. The BTL-FT plant operates at a loss to the left of the 8% or 12% RR lines in the chart, while it operates at a profit to the right.

It is worth mentioning that for the case without a carbon capture and storage facility integrated into the plant line-up to attain the carbon balance negative, the above equilibrium lines move downward and to the right, so a BTL-FT-CO_2 vent project is going to be feasible for higher BBE and lower biomass prices, as shown in **Figure 3.**

Takeaway

The Fischer-Tropsch process is the catalytic, non-selective polymerisation of CO and H_2, which can produce a wide variety of liquid hydrocarbons. The actual product mix is strictly related to the selected operating conditions, the type of catalyst, and the reactor design.

When an FT process is coupled with a biomass gasification facility, sustainable liquid fuels can be produced for aviation and marine propulsion without upsetting the existing distribution infrastructures.

Since these products are crude oil derivative analogues, they are subject to the same market dynamic of crude oil and its derivatives. Hence, the economic viability of a BTL-FT is linked to the expected oil price actions, which set the maximum feedstock price for the investment to be profitable.

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