3-PLATFORM (BIOCRUDE, SYNTHESIS GAS, ELECTRICITY&HEAT) BIOREFINERY USING WOOD BIOMASS FOR FT-DIESEL, FT-GASOLINE, REFINERY GAS, PROPYLENE, ELECTRICITY&HEAT WITH ENTRAINED FLOW GASIFICATION AND HYDROCRACKER REACTION SYSTEM (HG) FISCHER-TROPSCH SYNTHESIS

The case study analyses possibilities for integration of gasification systems into conventional oil refineries for the production of synthetic bio-fuels. The wood biomass feedstock is gasified with steam to produce synthesis gas containing CO and H_2, which is then converted to raw FT-biofuels via a catalytic reaction system (FT-synthesis). The final quality of the transportation FT-biofuels (diesel & gasoline) is reached in the refinery upgrading. Refinery gas and propylene are valuable side products.

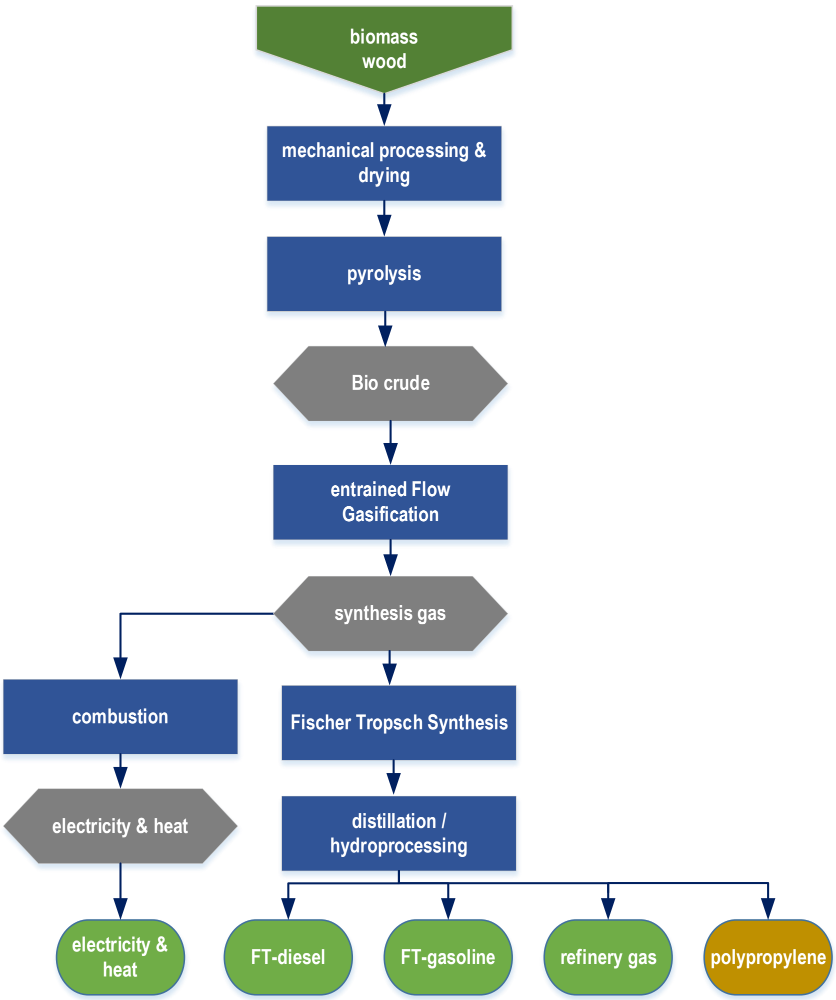
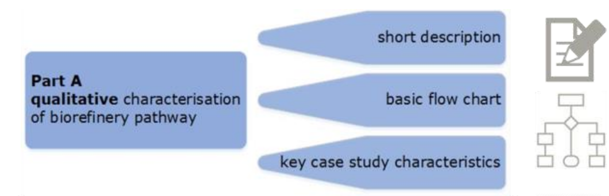


Figure 1: Basic flow chart of FT-synthesis processes for high quality FT-diesel, FT-gasoline, refinery gas, propylene, electricity&heat

PART A: BIOREFINERY PLANT

The gasification under study features an approach in which biomass is gasified, followed by an MtG-process which then finishes with a FT conversion into fuels. The energy and mass balances are taken from [1] and scaled to 100,000 tons of synthetic fuel per anno. The scope in the original study was 50 t/h with a runtime of 8,600 h/a marking an annual production almost fourfold in volume.



The gasification models were based on stoichiometries and efficiencies previously known by the Karlsruhe Institute for Technology (KIT). Wood was the feedstock in this model. The MtG step of the synthesis was performed with the help of commercial software ASPEN™ Plus V10, based upon laboratory data and confirmed with literature. [2], [3]

The FT-step is based on the Anderson-Schulz-Flory (ASF) distribution model with value of 0.9 for α. This value translates to diesel of the highest quality. The processing of the syncrude was performed with internal simulation software. Moreover, produced diesel does not need further refining after the distillation step. The waxes included in the syncrude were cracked in the hydrocracker (HG).

Table 1: Detailed overview over in- and outputs (in kt/a), energy inputs and outputs in (PJ/a) and efficiencies.

Inputs	HG	Outputs	HG
Biomass	*687.050*	*Synthetic gasoline*	*34.053*
Oxygen	*235.971*	*Synthetic diesel*	*65.947*
		Propylene	*0*
Energy Inputs		**Energy Outputs**	
Biomass	*9.53*	*Steam*	2.79
		District Heat	*0*
		Electricity	0.29
		C3-C4 products	0.06
		Synthetic gasoline	*2.91*
		Synthetic diesel	*1.50*
Overall	***79.22%***		
Product	***46.97%***		
Fuel efficiency	***46.29%***		

FCC…catalytic cracker
HG … hydrocracker

The results on mass and energy balances are presented in Figure 2. Evidently, HG is an efficient case, irrelevant if mass efficiency or energetic efficiency is regarded. Considerably smaller amount of input materials is used in the HG case while the output stays nearly identical with the exception of a small amount of propylene compared to FCC which is documented in another fact sheet.

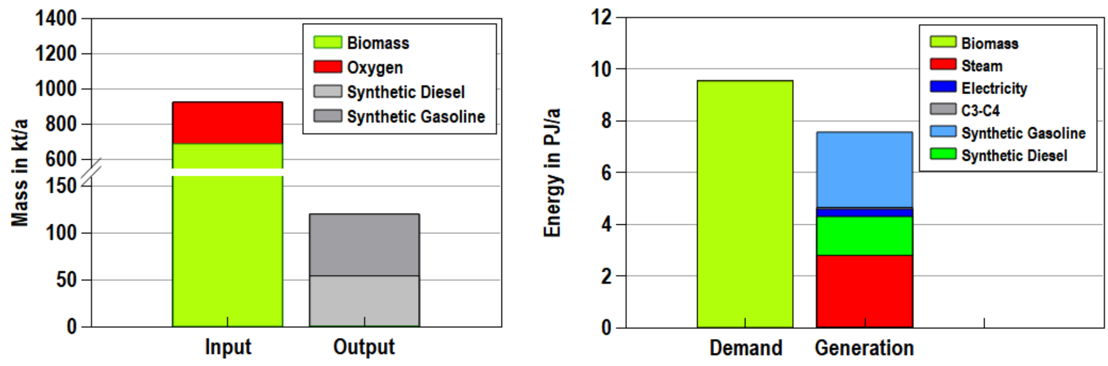
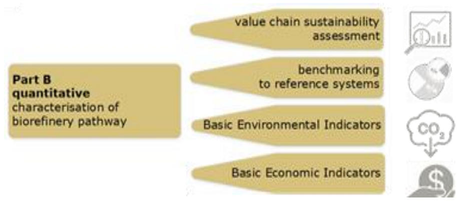


Figure 2 displays the mass and energy balances for the FT HG model.

PART B: VALUE CHAIN ASSESSMENT



Economic data is presented in Table 2 and Table 3 & Figure 3 and Figure 4.

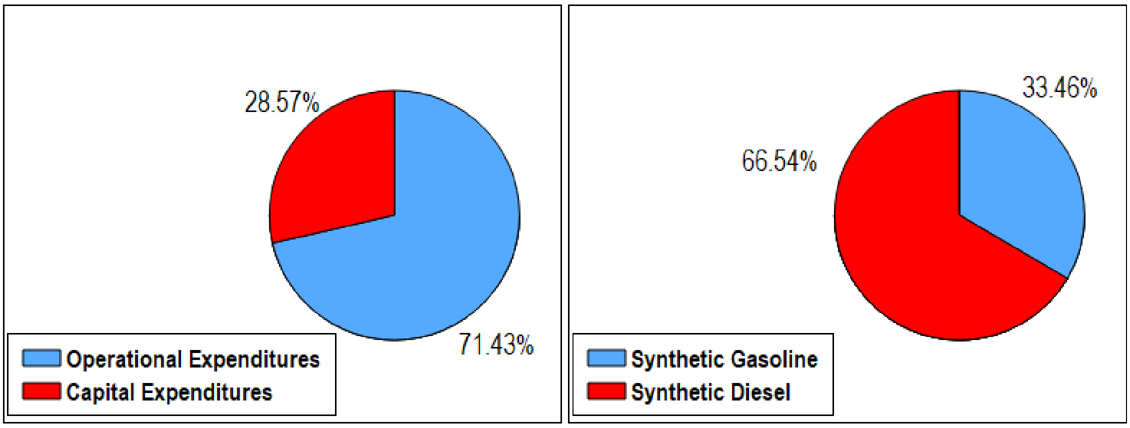


Figure 3 shows the share of total costs between CAPEX and OPEX and the revenue generated by different products for the HG process.

Table 2: CAPEX and OPEX of the respective Fischer Tropsch plants.

CAPEX (€/l) & (€/kg) & %	0.22	0.31	25.88
OPEX (€/l) & (€/kg) & %	0.63	0.70	74.12

Table 31: Costs and revenue of the FT plants, in Million €.

HG	Cost	Revenue
CAPEX	25.48	0
OPEX	63.69	0
Synthetic Gasoline	0	28.73
Synthetic Diesel	0	57.14
Propylene	0	0.00
Total	***89.17***	***85.87***

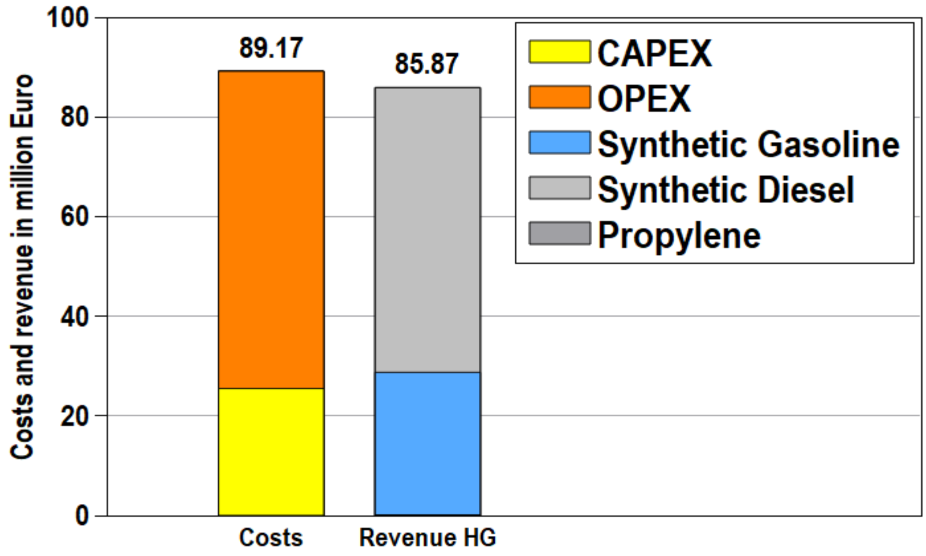


Figure 4: Costs and revenues and their detailed composition.

The HG process specialises in the production of diesel making up roughly 2/3s of production. While this would normally lead to higher revenue, the additional propylene makes the process not fully feasible in this very approximate assessment & applied basic assumptions. However, as the difference is relatively similar in size market shifts and price changes may easily change the final result, as market prices tend to fluctuate and are also subject to influences from the outside E.g.:

- + 3 % revenue increase (+2.6 Mio €/a) completely changes the picture towards + NPV
- CO_2 emission certificates are at levels that can be considered tipping points to generate business cases (e.g. + 2.04 – 2.40 Mio.€/a at 50 €/ton CO_2eq)
- Expansion of the material product portfolio can bring additional value creation
- => Additional valorization of waste heat can bring additional value creation

Fossil Primary Energy Demand (PED) and the Greenhouse Gas (GHG) emissions for the reference substances are presented in Figure - Figure. Not only does the additional propylene add additional revenue, it also leads to higher primary energy demand in the reference system and thus to a higher possible reduction of GHGs. Due to the relatively low share of renewable energy the PED and the fossil PED behave alike for the reference systems. The amount of bioenergy needed is lower in the HG case due to the higher efficiency. Due to the fact that the mini LCA is of the scope “Cradle-to-Gate” HG yields lower savings due to the fact that the main product is diesel, which has a considerably lower footprint in production. If a combustion were to be included too the opposite could be expected.

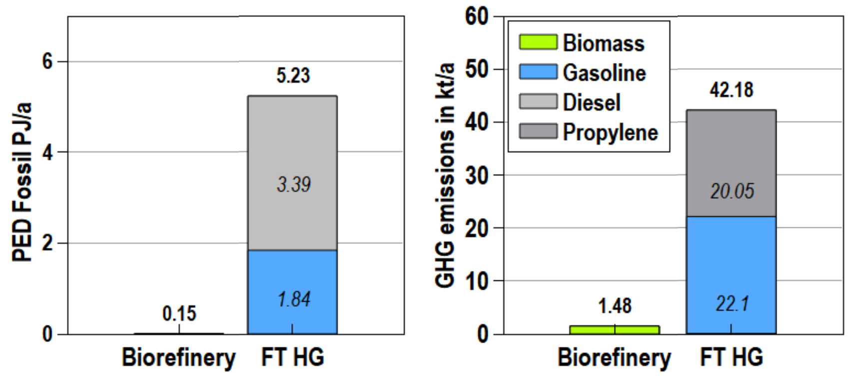


Figure 5: Figure 5a (left) shows the fossil primary energy demand and Figure 5b the GHG emissions of the reference products.

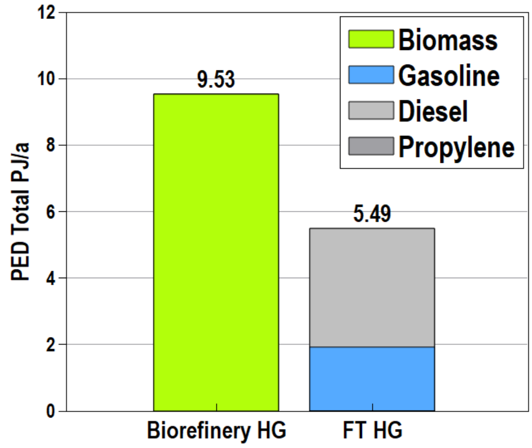


Figure 6: The total primary energy demand including renewable energy is compared between the benchmark and the biorefinery.

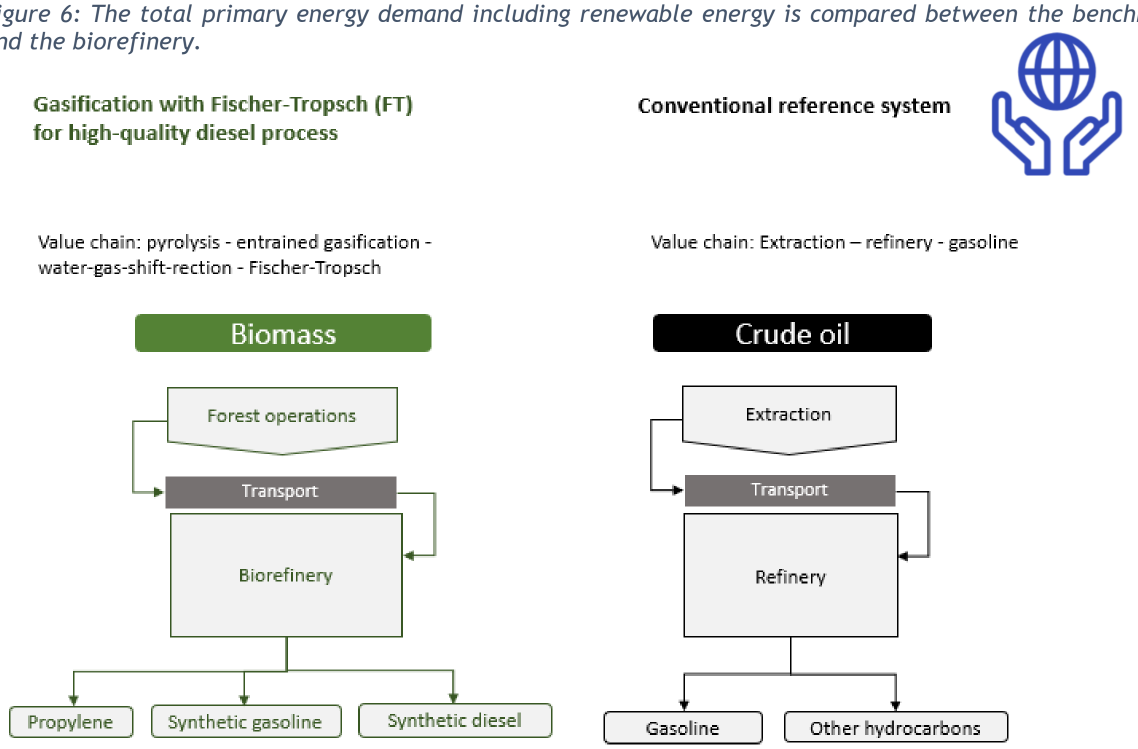


Figure 7: Biorefinery and reference system - value chain (cradle to gate)

Table 4: Accumulated results for the FT systems.

Greenhouse gas emissions	FT HG	
Biomass	0	kt CO_2-eq/a
Biorefinery auxiliary materials and supplies	1.48	kt CO_2-eq/a
Crude oil refinery reference system	42.18	kt CO_2-eq/a
Savings	40.70	kt CO_2-eq/a
Cumulated (total) Primary energy demand		
Fossil Reference system	5.23	PJ/a
Biomass	9.53	PJ/a
Reference system versus biorefinery total primary energy demand	+4.3	PJ/a
Reference system versus biorefinery fossil primary energy demand savings	-4.45	PJ/a

REFERENCES

[1] R. Rauch and X. Koroveshi, 'Gasification for the application in biorefineries', Karlsruher Institut für Technologie, https://www.ieabioenergy.com/wp-content/uploads/2022/01/Gasification_case_story_03.pdf. Feb. 2021.

[2] S. Lee, M. Gogate, and C. J. Kulik, 'Methanol-to-Gasoline vs. DME-to-Gasoline; Process comparison and analysis', *Fuel Sci. Technol. Int.*, vol. 13, no. 8, pp. 1039–1057, Aug. 1995, doi: 10.1080/08843759508947721.

[3] C. Chang, 'The conversion of methanol and other O-compounds to hydrocarbons over zeolite catalysts', *J. Catal.*, vol. 47, no. 2, pp. 249–259, May 1977, doi: 10.1016/0021-9517(77)90172-5

[4] Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources

MORE DETAILED INFORMATION ON THE DATA BASIS AND THE METHOD APPLIED ARE AVAILABLE IN THE ACCOMPANYING REPORT AT HTTPS://TASK42.IEABIOENERGY.COM/PUBLICATIONS/TEE-ASSESSMENT-GASIFICATION/