3-PLATFORM (BIOCRUDE, SYNTHESIS GAS, ELECTRICITY&HEAT) BIOREFINERY USING WOOD BIOMASS FOR GASOLINE, REFINERY GAS, PROPYLENE, ELECTRICITY & HEAT WAXES WITH ENTRAINED FLOW GASIFICATION AND METHANOL 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 producer gas which contains a mixture of compounds. The producer gas must be cleaned and conditioned to get a mixture of CO and H_2 – the synthesis gas - which is then converted to methanol/DME via a catalytic reaction system (methanol/DME synthesis). The final quality of the transportation synthetic biofuels is reached in the refinery upgrading. Butane, propane & polypropylene are valuable side products.

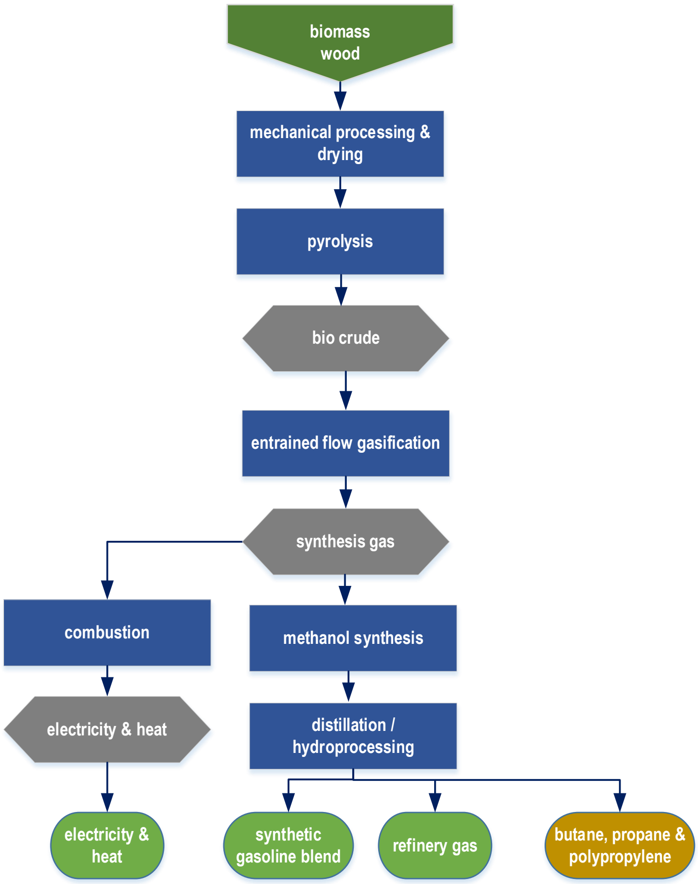


Figure 1: Basic flow chart of Methanol/Dimethoxymethane (DME) processes for high-quality gasoline blend

PART A: BIOREFINERY PLANT

MtG

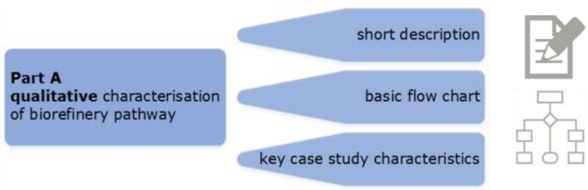


Figure 1 shows the inputs and outputs of the system as well as energy inputs in form of biomass and the energy contained in intermediates and final products. With a biomass consumption of 1,061,934 t a tenfold input is processed compared to the 100 kt of product obtained. This can be interpreted as an increase in energy density from educt to product, as the overall energy efficiency is 87 %. Without utilities like steam or electricity the product efficiency ($\eta_{products}$) is 43.2 %. This lies within the range of 46-48 % via simulation results reported in other assessments. The efficiency only for the synthetic gasoline is at 28.9 %. A detailed overview on in- and outputs is listed in Table 1 and illustrated in Figure 2a & b.

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

Inputs		Outputs	
Biomass	*1,061,934*	*Synthetic gasoline*	*100,000*
Oxygen	*364,653*	*Butane*	*31,722*
		Propylene	*906*
		Propane	*13,293*
Energy Inputs		**Energy Outputs**	
Biomass	*14.73*	*Steam*	*3.9*
		District Heat	*0.14*
		Electricity	*0.04*
		C3-C4 products	*2.10*
		Refinery gas	*2.35*
		Synthetic gasoline	*4.26*
Overall efficiency	***86.69 %***		
Product efficiency	***43.22 %***		
Gasoline efficiency	***28.94 %***		

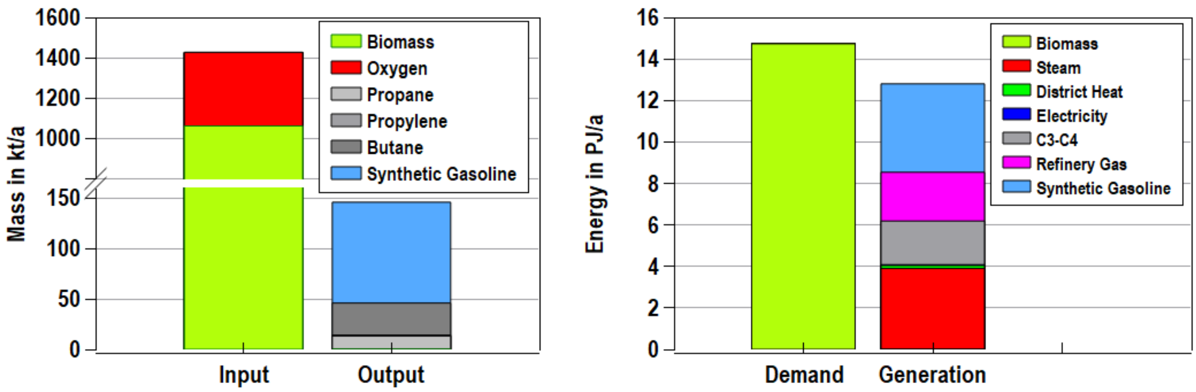
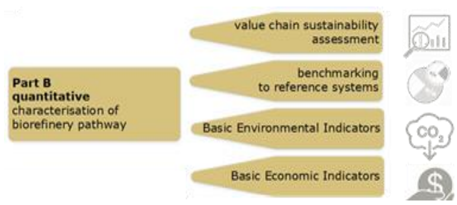


Figure 2a & b: 2a (left) displays the mass balances of the MtG system. 9b (right) shows the energy input in form of biomass compared with the energy content of the products and energy carriers obtained in the transformation.

PART B: VALUE CHAIN ASSESSMENT



For the economic evaluation Rauch and Koroveshi [1] assumed OPEX of 0.23 € per litre and CAPEX of 0.52 € per litre of product. Moreover, a propylene price of 800 €/t, a butane/propane price of 0.586 €/t and a gasoline price of 844 €/t was assumed. The results are shown in Figure 3a & Figure 4 3b.

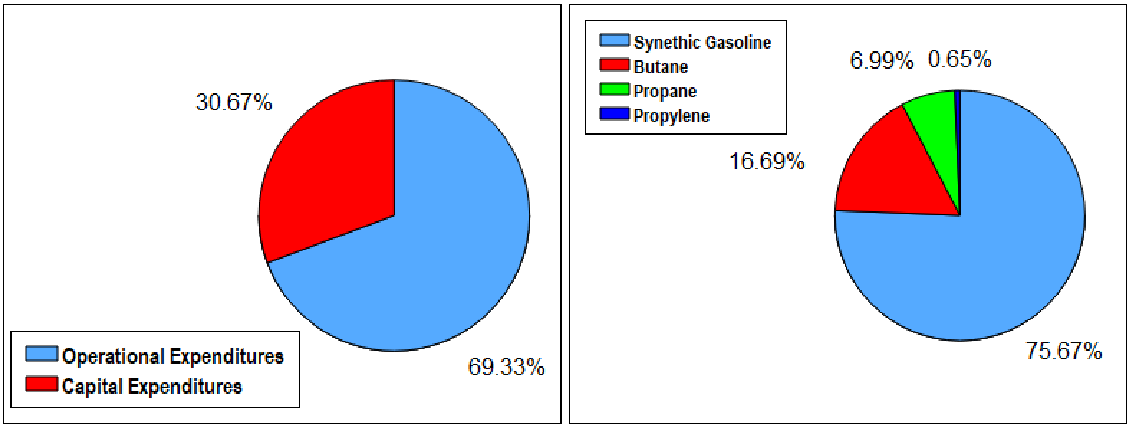


Figure 3a & 3b: 3a (left) shows the share of total costs between CAPEX and OPEX. 3b (right) shows the share of revenues generated by the products types.

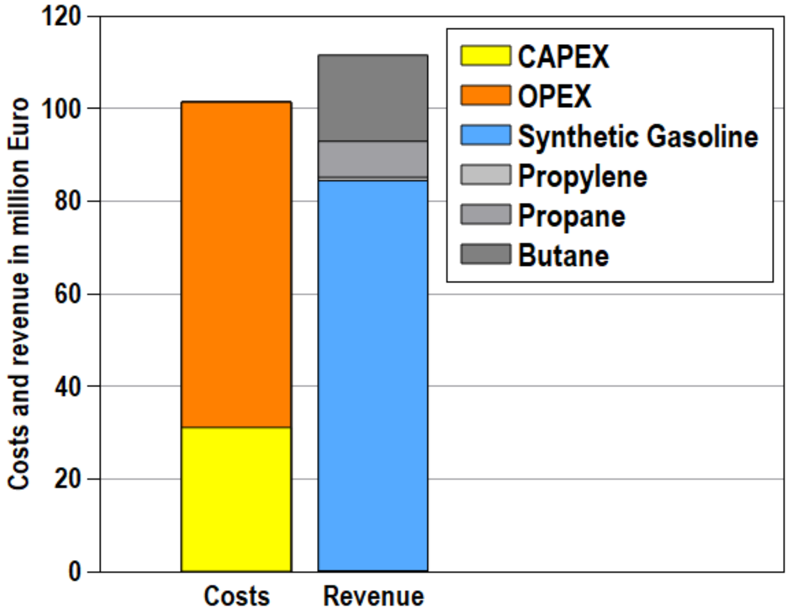


Figure 4: Costs and revenues and their detailed composition for the specific reference case.

The comparison or the shares of OPEX and CAPEX in total expenses are relevant, as mostly high initial investment costs are a big challenge for biorefineries as it is reported that these can hinder implementation, due to the fact that they often make up the biggest share of costs in a challenging market thus marking a big factor of insecurity for potential investors. [2],[3] This can be interpreted as a hint that a high level of maturity is reached within the technology, however, widespread application and roll-out depend very much on the specific economic framework conditions. Another specific finding is that, synthetic gasoline yields more than ¾ of the total revenue, while only making up for 68.5 % of product mass. With the cost of 0.75 €/l fuel a price of 25 €/GJ was calculated with an estimated energy density of 30 MJ/l for the synthetic gasoline, which is within the literature values presented, but lower figures have been reported before. This assumption is of course also highly sensitive to current subsidies and legal framework conditions for advanced biofuels.

All results of the simplified economic assessment are displayed again in Table 1 & Table 3.

Table 2: CAPEX and OPEX of the gasification plant.

CAPEX (€/l) & (€/kg)	**0.23**	**0.31**
in %	30.67	30.67
OPEX (€/l) & (€/kg)	0.52	0.70

Table 3: Costs and revenue of the gasification plant, in Million €/a.

	Cost	Revenue
CAPEX	31.08	0
OPEX	70.27	0
Synthetic Gasoline	0	84.37
Propylene	0	0.73
Propane	0	7.80
Butane	0	18.60
Total	***101.35***	***111.50***

Ultimately, Fossil Primary Energy Demand (PED) and Greenhouse Gas Emissions were also compared for the reference scenario and the biorefinery in Figure 5a & 5b for a comparative product portfolio.

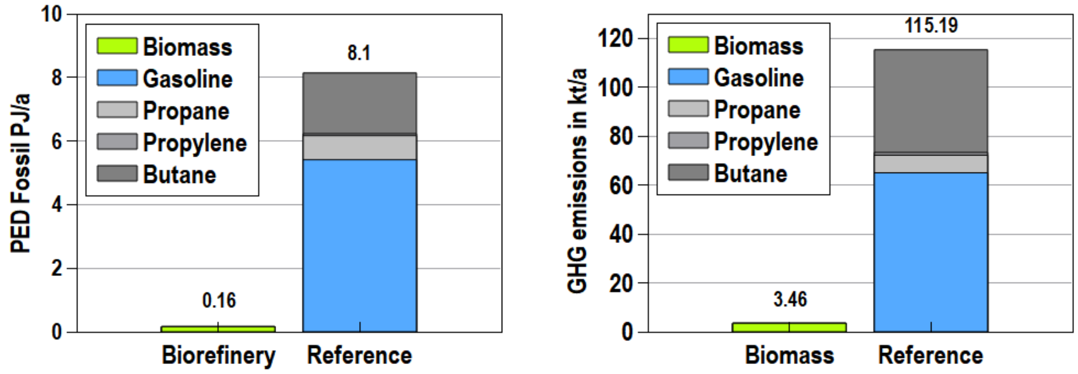


Figure 5a & 5b: Figure 5a (left) shows the fossil primary energy demand and Figure 5b the GHG emissions of the reference products compared to the biorefinery case.

According to the RED [4] energy from renewable energy should carry no burden, therefore in this comparison bioenergy is far superior to the fossil references. Figure 5b highlights that replacing more refined products such as butane bring considerable advantages from an environmental perspective. Figure 6 shows that the total primary energy consumption is much higher for the biorefinery. This is in accordance to previously discussed points as it was concluded that the biorefinery turns low-energy-density materials into high-energy-density materials. Figure 7 shows a graphical abstract of the two systems compared and Table 4 summarizes results for energy and GHG emission savings.

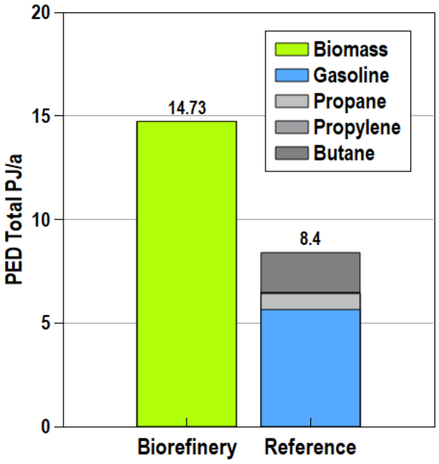


Figure 6: The total primary energy demand including renewable energy is compared between the benchmark and the biorefinery.

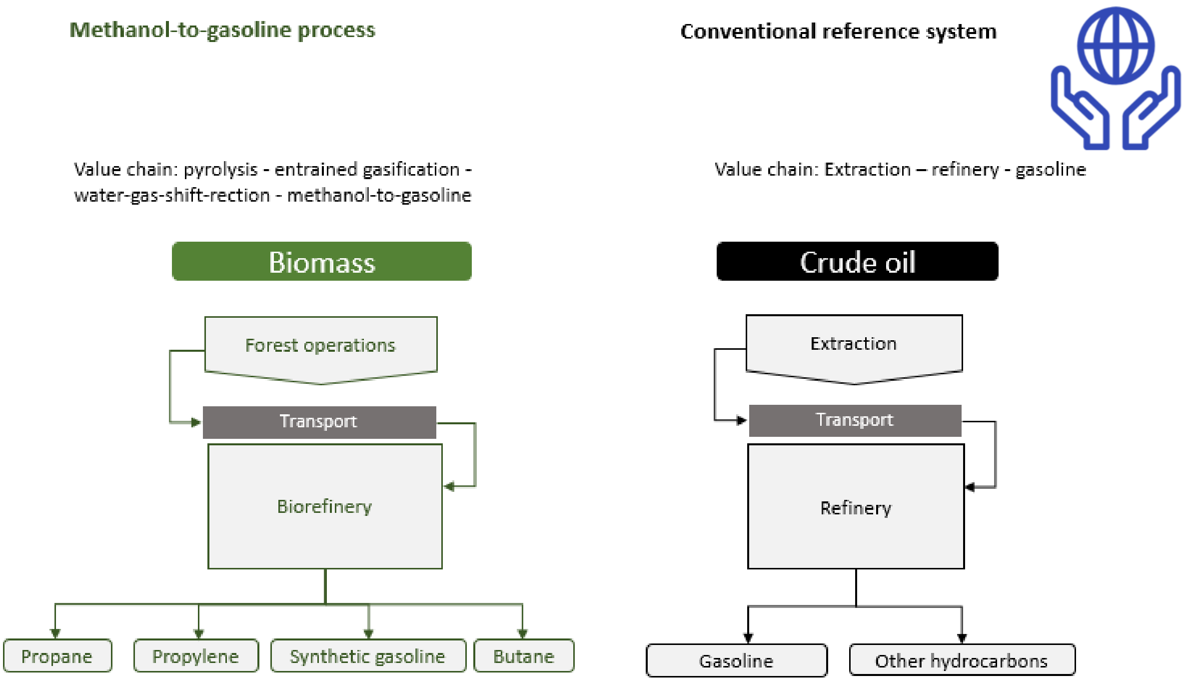


Figure 7: Biorefinery and reference system - value chain (cradle to gate)

Table 4: Accumulated results for the MtG system.

Greenhouse gas emissions		
Biomass	0	kt CO_2-eq/a
Biorefinery auxiliary materials and supplies	3.46	kt CO_2-eq/a
Crude oil refinery reference system	115.19	kt CO_2-eq/a
Savings	-111.73	kt CO_2-eq/a
Cumulated (total) Primary energy demand		
Fossil Reference system	8.4	PJ/a
Biomass	14.73	PJ/a
Reference system versus biorefinery total primary energy demand	+6.33	PJ/a
Reference system versus biorefinery fossil primary energy demand savings	-7.94	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] R. Lundmark *et al.*, 'Large-scale implementation of biorefineries: New value chains, products and efficient biomass feedstock utilisation', 2018, Accessed: Jun. 30, 2022. [Online]. Available: https://pure.iiasa.ac.at/id/eprint/15350/1/Briefing%20Notes%20(Tryck).pdf

[3] Y. V. Palgan and K. McCormick, 'Biorefineries in Sweden: Perspectives on the opportunities, challenges and future: Biorefineries in Sweden', *Biofuels Bioprod. Biorefining*, vol. 10, no. 5, pp. 523–533, Sep. 2016, doi: 10.1002/bbb.1672.

[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/