Biorefinery model for the production of biofuels and bioproducts from lignocellulosic biomass

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Abstract This work studies advanced biofuel and biomaterials production using lignocellulosic biomass from poplar crops. In this sense, lignocellulosic biomass transformation into biojet fuel, bioLPG, green diesel and High-Density Polyethylene (HPDE) was studied through an exhaustive evaluation, including a techno-economic analysis, a life cycle assessment and physico-chemical and thermodynamical analyses. Biorefinery models were simulated using the chemical engineering software AspenPlus® v.12. In all cases, the NRTL thermodynamical method was employed, except for the HDPE production, where the Polymer method was used for the mass and energy balances. All biorefineries were fed with 77 t/h of feedstock. On the one hand, in the biojet fuel set-up, the biorefinery produced 92,400 t/year of biojet fuel and 39,917 t/year of green diesel. On the other hand, in the HDPE configuration, 103,000 t/year of HPDE were obtained. The life cycle analysis (LCA), carried out using the simulation software SimaPro® and the Ecoinvent® database, measured the environmental impact generated, kg of CO_2-eq/MJ biofuel and kg of CO_2-eq/kg of HDPE, at each process. Techno-economic results evaluated the relation between fixed and variable costs through a cash flow to obtain the products' minimum selling price (MSP). Even though economic competitiveness is barely achieved, when the processes by-products such as lignin are considered, the MSP drops enough to be competitive with their conventional counterparts. Besides, a sensitivity analysis was performed to evaluate different scenarios where the simulated biorefineries were competitive, demonstrating the potential of poplar biomass residues as feedstock. In all cases, the CO_2-eq footprint was compared with European standards, obtaining encouraging results compared to the Renewable Energy Directive II, which means the produced biofuels are eligible for financial support by public authorities. Finally, biofuels properties were compared to the American Society for Testing and Materials (ASTM) standards, where the specifications of road transport fuels and aviation turbine fuels are shown (consisting of a conventional and synthetic mixture). All biofuels met the standards.

Keywords: biojet fuel, biomass valorization, bioenergy, bioplastic, biorrefinery

1. Introduction

One of the more promising strategies to close the material and energy loop in recent years is biomass valorization for developing a circular economy and meeting sustainable development goals. This work studies advanced biofuel and biomaterials production using lignocellulosic residues from poplar crops as a feedstock. In this sense, biojet fuel, bioLPG, green diesel and High-Density Polyethylene (HPDE) processing were evaluated through an exhaustive evaluation, including a techno-economic analysis, a life cycle assessment (LCA) and physico-chemical and thermodynamical analyses, as shown in Figure 1.

2. Methodology

Biorefinery models were simulated using the chemical engineering software AspenPlus® v.12. In all cases, the NRTL thermodynamical method was employed, except for the HDPE production, where the Polymer method was used for the mass and energy balances and equilibria phase equilibrium calculations. All biorefineries were fed with 77 t/h of feedstock. On the one hand, in the biojet fuel set-up, the biorefinery produced 92,400 t/year and 39,917 t/year of green diesel. On the other hand, in the HDPE configuration, 103,000 t/year were obtained [1].

The LCA was carried out using the simulation software SimaPro® and the Ecoinvent® database.

3. Results

Techno-economic results evaluated the relation between fixed (equipment cost and salaries) and variable costs (feedstocks and resources) through a cash flow to obtain the products' minimum selling price (MSP). Biojet fuel MSP was 0.95 €/L while green diesel´s 0.83 €/L. In the case of bioLPG 0.99 €/L was achieved and 0.75 €/kg for the HDPE production. In each case, 11%, 8%, 2% and -9%

of a potential economic benefit was obtained. Even though economic competitiveness is barely achieved, when the processes by-products such as lignin are considered, the MSP drops enough to be competitive with their conventional counterparts [2], [3]. Besides, a sensitivity analysis was performed to evaluate different scenarios where the simulated biorefineries were competitive, demonstrating the potential of poplar biomass residues as feedstock. For all the processes, the biomass pretreatment stage was the most significant variable regarding operating costs and materials (e.g., sulfuric acid in thermal hydrolysis).

On the other hand, biojet fuel, bioLPG, green diesel and HPDE production contribute to the reduction of CO_2 emissions. In this study, the equivalent CO_2 emissions were analyzed through their LCA, considering all these products were obtained from the same raw material; poplar residues [2]. Other types of impacts generated on the environment were also analyzed. The LCA is an environmental management process or tool that allowed methodical, systematic, scientific and objective analyze the environmental impact caused by a certain process or product during its life cycle. In all cases, the CO_2-eq footprint was compared with European standards, obtaining encouraging results compared to the Renewable Energy Directive II, which means the produced biofuels are eligible for financial support by public authorities. Results showed for the biojet fuel process a significant reduction (52%) compared to its conventional counterpart (94 gCO_2-eq/MJ), which is in excellent agreement with similar studies [4], [5]. For the green diesel, bio LPG and HDPE a GHG footprint of 61 gCO_2-eq/MJ, 39 gCO_2-eq/MJ, and 89 gCO_2-eq/MJ was achieved respectively.

Finally, biofuel properties were compared to the American Society for Testing and Materials (ASTM) standards, where the specifications of road transport fuels and aviation turbine fuels are shown (consisting of a conventional and synthetic mixture). All biofuels met the standards except for the density requirement for biojet fuel processing (724 kg/m^3), which was expected; however, this issue could be sorted by recalculating the blending ratio with petroleum-derived kerosene when it will be used [5].

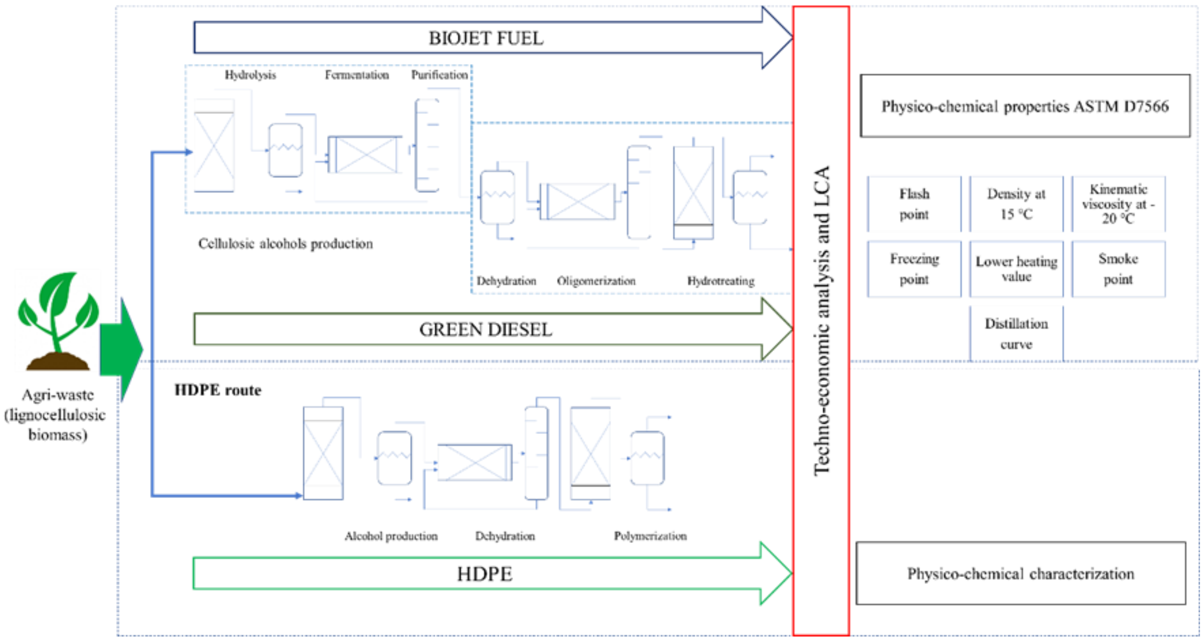

Figure 1. Schematic process for poplar biomass valorization.

References

[1] N. Vela-García, D. Bolonio, M. J. García-Martínez, M. F. Ortega, and L. Canoira, "Thermochemical conversion of agricultural waste to biojet fuel," Sustainable Alternatives for Aviation Fuels, pp. 27–48, Jan. 2022, doi: 10.1016/B978-0-323-85715-4.00002-1.

[2] N. Vela-García, D. Bolonio, M.-J. García-Martínez, M. F. Ortega, D. Almeida Streitwieser, and L. Canoira, "Biojet fuel production from oleaginous crop residues: thermoeconomic, life cycle and flight performance analysis," Energy Convers Manag, vol. 244, p. 114534, Sep. 2021, doi: 10.1016/j.enconman.2021.114534.

[3] E. Martinez-Hernandez, L. F. Ramírez-Verduzco, M. A. Amezcua-Allieri, and J. Aburto, "Process simulation and techno-economic analysis of bio-jet fuel and green diesel production — Minimum selling prices," Chemical Engineering Research and Design, vol. 146, pp. 60–70, Jun. 2019, doi: 10.1016/J.CHERD.2019.03.042.

[4] N. Vela-García, D. Bolonio, A. M. Mosquera, M. F. Ortega, M.-J. García-Martínez, and L. Canoira, "Techno-economic and life cycle assessment of triisobutane production and its suitability as biojet fuel," Appl Energy, vol. 268, p. 114897, Jun. 2020, doi: 10.1016/j.apenergy.2020.114897.

[5] D. Bolonio Martín, M. F. Ortega Romero, M. J. García Martínez, J. Rodríguez Fernández, M. Lapuerta, and J. L.

Canoira López, "Biofuels for aviation: from bio-iso-butanol to synthetic paraffinic kerosene," Prague: PRES, 2018.Aguado J., Arsuaga J.M., Arencibia A., Lindo M. and Gascón V. (2009), Aqueous heavy metals removal by adsorption on amine-functionalized mesoporous silica, *Journal of Hazardous Materials*, **163**, 213-221.