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

NÍCOLÁS VELA-GARCÍA¹, DAVID BOLONÍO²*, CHRISTOPHER J. CHUCK³, MARÍA-JESÚS GARCÍA-MARTÍNEZ²

¹Department of Environmental Engineering, Universidad San Francisco de Quito, Diego de Robles s/n, 170901 Quito, Ecuador
²Department of Energy and Fuels, Escuela Técnica Superior de Ingenieros de Minas y Energía, Universidad Politécnica de Madrid, Calle Ríos Rosas 21 28003, Madrid
³Department of Chemical Engineering, University of Bath, Bath BA2 7AY, UK

*corresponding author:
e-mail: david.bolonio@upm.es

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 biofuel 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 HPDE configuration, 103,000 t/year of HDPE 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 CO₂-eq/MJ biofuel and kg of CO₂-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 CO₂-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, biorefinery

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, biofuel 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 equilibrium calculations. All biorefineries were fed with 77 t/h of feedstock. On the one hand, in the biofuel 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). Biofuel 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 HDPE production contribute to the reduction of CO₂ emissions. In this study, the equivalent CO₂ 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 CO₂-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 gCO₂-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 gCO₂-eq/MJ, 39 gCO₂-eq/MJ, and 89 gCO₂-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/m³), 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


