Potential of residues to biotechnological conversion. Case study: Detailed Economic Assessment of polylactic acid production used glucose platform from sugarcane bagasse, coffee cut steams and plantain

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The depletion of fossil resources has led to the search for new sources for the production of fuels and added-value products derived [1]. On the other hand, agriculture is increasingly linked to different economic sectors, which is generating the development of a biomass-based economy [2]. A raw material source of great scientific interest is either agricultural resources or waste generated during its transformation. These residues are divided into agricultural, agroindustrial, marketing, and domestic food waste [3]. Sugar cane bagasse, coffee cut steams and plantain are produced in large quantities. Different bioprocessing alternatives for the use of these wastes are reported in the open literature. The chemical composition of these residues allows obtaining fermentable sugars to be used as a platform for the production of added-value compounds. A product of great scientific and industrial reception is polylactic acid (PLA) [4]. PLA is a biopolymer obtained from the polymerization of lactide from lactic acid [5]. PLA biosynthesis has been considered an alternative for the production of plastics from renewable sources. In this sense, the fermentable sugar platform obtained from agro-industrial waste is an alternative for the generation of this important biopolymer encouraging the industrial production of bio-based products. Economic evaluation is a tool used for making investment decisions in a conceptual design process (i.e., optimize the energy demand or raw material demand) [6]. This analysis involves cost estimation to determining capital costs (CapEx) and operating costs (OpEx). Based on the above, this work focuses on the economic evaluation of PLA production considering fermentable sugars as a platform obtained from agro-industrial waste. For this purpose, a methodology was developed to make a detailed economic analysis in the conceptual design stage considering industrial aspects. An optimum accuracy in the detailed conceptual design depends on the robustness and clarity of the developed conceptual design.

The process simulation begins with the production of lactic acid by using glucose as a feedstock. The lactic acid process simulation was done considering the thermodynamic model NRTL (Non-Randon Two Liquid). The lactic acid production process was performed by fermentation using the strain *Lactobacillus cassei*. The kinetic model used in the simulation was the propoused by Lin et al. [7]. On the other hand, the PolyNRTL thermodynamic model was selected to simulate PLA production. PLA was obtained by using ring-opening polymerization (ROP) of lactide. Condensation of aqueous lactic acid produces low molecular weight PLA prepolymer [8]. The production scale was defined in 5 Ton/day as a case of study based on the potential market volume of a company producing polymers like ESENTTIA S.A., Colombian industry. The cost of PLA production involved estimates of raw materials, utilities, and financing costs. The economic analysis was carried out based on gross income. The costs associated during the construction phase, such as equipment, instrumentation, labor costs, piping supports, civil foundations, materials, installation, and preliminary and detailed engineering, were considered. Building and utility costs were not considered in the financial investment decision. For the study, multiple financial ratios were available. The depreciation of capital investment was calculated using the straight-line method.

The detailed economic assessment in the conceptual design involves industry practices of petrochemical processes. The detailed economic methodology shown in **Figure 1** was based on the design process alternatives from previous studies, available information and even access, and the petrochemical processes scope as starting points. This methodology allowed to identify critical parameters of the design basis in the equipment, piping, civil, electrical, and instrumentation specifications, define engineering workforces by phase and discipline in the planning and construction, identify preliminary the instrumentation and electrical requirements, and summarize overall components that belong to the process flowsheet to get a better estimation of costs. This definition allowed clarifying the piping connection points, piping routes, distance, storage needs, pumping systems, and the basic requirements for all engineering disciplines. The critical methodology step is to place the information obtained from the process flow diagram (PFD) by identifying the fluids and the preliminary quantification of equipment, instruments, and process lines. Although much of the details are unknown, frequently, those items are undervalued from an estimate. Finally, to determine the pre-feasibility of a process requires an evaluation of several different factors. In this context, financial viability can be conducted through financial analysis methods like NPV (Net Present Value), PBP (Payback Period), and DCF (Discounted Cash Flow Rate Of Return) [9].

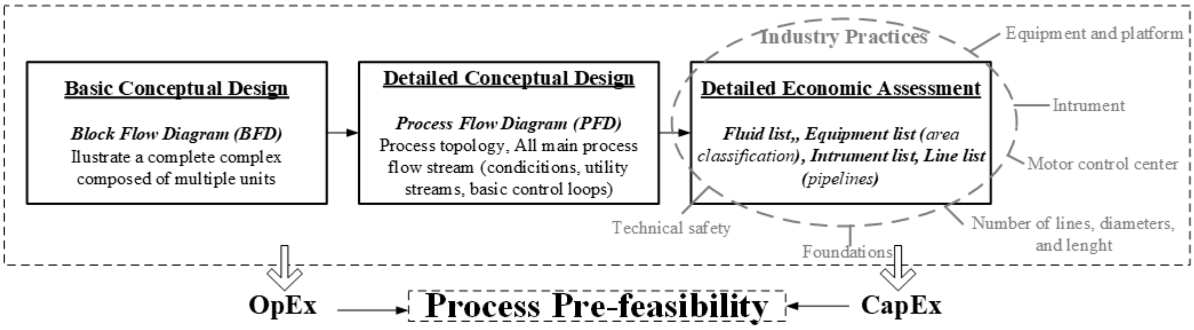

Figure 1. The methodology of the detailed economic assessment in the conceptual design stage.

The economic assessment goal was to evaluate the total capital costs (investment) by gross incomes. The distribution costs indicate that about 27% of the CapEx corresponds to equipment, 24% to extrusion, pelletizing, bagging infrastructure, and 13% to instrumentation. For the PLA process, depreciation, and amortization add a significant amount to profits under earnings before interest, taxes, depreciation, and amortization. The best scenario to reach the breakaway point for PLA production is with a gross income of USD 1400/MT and 9.5 years. An overall cost of USD 10.35 million was obtained for the CapEx project stages with its critical drivers process equipment, extrusion, pelletizing, and bagging areas, and the instrumentation with a cost-share of 27%, 24%, and 13% in that order. The best scenario to reach the project's breakaway point is with a gross income of USD 1400/MT in 9.5 years. The economic and financial analysis results indicated that the gross income is the largest driver for the pre-feasibility of PLA production inside existing facilities, which is highly influenced by the operating costs and the uncertainty in the raw material costs. The above-mentioned results allow elucidating the influence of more accurate information related to the economic analysis on the economic performance of a process. Thus, the development of a methodology to perform the detailed economic analysis of biotechnological processes provides more exact values of investment. This new methodological approach involving industrial aspects can be applied to any biomass upgrading process because the data required is independent of the type of process. As conclusion, the implementation of a new methodological approach to improve the quality of the economic analysis of biotechnological processes is a crucial step to reach real sustainable processes in a near future since if the quality of the information improves in early stages, better decisions and actions can be taken to make the implementation of a biotechnological processes more feasible.

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