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# A virtual Bio refinery evaluation of the value added separation of different components from Residual Biomass for food and Biofuel applications

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**Abstract**

Brewers' spent grain (BSG) and palm kernel meal (PKM) can be used to integrate protein extraction and ethanol production into a conceptual biorefinery process. The conceptual procedure is intended for an industrial-scale biorefinery that annually processes 8000 production hours of 20 kt dry weight BSG and 50 kt dry weight PKM for techno-economic performance analysis.

The techno-financial investigation showed that the biorefinery of BSG has a high monetary potential with an inside pace of return of 24 %. However, the PKM biorefinery maintains a positive internal rate of return of 12% despite the high costs of raw materials [1].

By combining the production of a valuable product, like protein powder for food applications, with the production of biofuel, like ethanol, from the remaining biomass, the presented virtual biorefinery demonstrated the economic potential of valorizing a larger portion of the biomass at the same cost of raw materials.

**Keywords:** Protein; Ethanol; Biorefinery; Techno-economic analysis; Brewers' spent grain; Palm kernel meal

## Introduction

Over 90 million tons of waste is produced annually in the EU as a result of worldwide agriculture and uncontrolled food production, which has a significant impact on the environment and contributes to global warming. Additionally, as the world's population continues to grow at an exponential rate, so will the demand for biomass—not just for food but also for fuel, fibers, and feed [2]. As a result, there will be intense competition for biomass, land, and other natural resources. A sustainable framework that takes into account all of these factors will be absolutely necessary due to their inherent interconnectedness. Because it is a reliable strategy for better valorizing and creating value from resources, the circularity approach has been adopted in the EU and other nations worldwide [3].

There are a number of components in biomass that can be put to use in a variety of ways. A portion of the biomass that is converted into biofuel is wasted, preventing the valorization of other important components like proteins. Additionally, utilizing a greater proportion of biomass for a variety of products can reduce the costs of raw materials, which typically make up a sizable portion of manufacturing expenses [4]. As a result, using the integrated biorefinery method to turn biomass into a high-value product (like food protein) and produce biofuel (like ethanol) will increase both the circular use of biomass and the economic potential of the products.

## Methodology

The conceptual process design is used to estimate the production process's operational expenditure (OPEX) and capital expenditure (CAPEX or fixed capital) in the techno-economic analysis. The quality of the parameters and assumptions determines the techno-economic analysis's accuracy. Additionally, the accuracy of a techno-economic analysis that is based on extremely speculative assumptions ranges from 50% to +100%. A techno-economic analysis with a 30% accuracy level is based on parameters and assumptions that are more specific and precise [5].

The major unit operations and their process parameters are chosen in the conceptual process design based on experimental data or the literature. The size and composition of the input, intermediate, and output streams are then determined, which determines the flow sizes, equipment size that is required, and energy consumption.

By estimating the costs of production, the conceptual process's economic viability can be determined. The method and parameters described by (Sinnott and Towler, 2009) serve as the foundation for the subsequent costs. Based on the literature, expertise, and industry, case-specific parameters are modified as necessary [6].

The case definition specifies the raw material specification and the product or products, as well as the appropriate annual production capacity. Either existing processing chains or experimental data from pilot or laboratory-scale processes serve as the basis for the process design. A translation of pilot or lab-scale data to industrial-scale processes is typically required when the design is based on pilot or lab-scale processes. The estimated costs of the equipment are calculated using the flow size and equipment size [7]. Cost data from literature, handbooks, the equipment cost database of flow sheeting software SuperPro Designer, quotations, and/or Wageningen Research (WR) expert knowledge are used to calculate the costs of the purchased equipment. The chemical engineering plant cost index (CEPCI) of 572, which represents the average from 2008 to 2020, and the dollar-to-euro rate of 0.87 are used to correct the costs of purchased equipment. The decent capital, otherwise called venture costs, is assessed by increasing the bought hardware costs by a multiplier, the Lang factor. For new plants (grass roots or green field) in this study, a Lang factor of 5.24 is utilized.

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### Process plan and unit tasks

The improved on process stream chart of the virtual biorefinery is displayed. The process of producing ethanol is depicted at the bottom, while the process of producing protein is depicted at the top. SuperPro Designer is used to create the flow diagram, which makes it possible to calculate mass balances. For the production of ethanol and protein powder, respectively, assumptions and estimates regarding unit operations are provided. The two cycles are associated by an incorporated succession of unit tasks that reach from biomass pre-treatment the entire way to the recuperation of the final result [8].

### Bought hardware costs and fixed capital

In view of the mass offset with the stream measures, the hardware size and the bought gear costs are assessed, utilizing scaling factors. The costs of purchasing the equipment are based on Humbird et al. 2017 for Alcalase hydrolysis fermenters; Maroulis and Saravacos (2007) for the filter press and centrifugation; expert knowledge of WR for reverse osmosis; Towler and Sinnott (2013) for spray drying; and SuperPro Designer for ethanol production [9]. The derived fixed capital costs and the estimated costs of purchasing equipment Material-related costs. The prices of raw materials were previously determined to be €125 per ton DW for BSG and €200 per ton DW for PKM. Electricity rates are set at €0.10 per kWh, and steam rates are set at €25 per ton (thermal energy).

The enzymes are the consumables that significantly increase production costs. The expected Alcalase expansion is assessed on 2 kg Alcalase per ton DW (0.2%) [10]. Alcalase is expected to cost €25 per kilogram. Based on an estimate of 3 kg of hydrolase per ton DW, the amount of hydrolase that needs to be added is 0.3%. The assumed cost of Hydrolase per kilogram is €25. The packing of dehydration columns and the replacement of reverse osmosis membranes have negligible costs.

## Results and Discussion

Mass balances are calculated using unit operations assumptions and estimates. A summary of the mass balance, including product revenues and material costs, is presented [11]. In addition, the enzymatic protease treatment is crucial to the process's success, particularly in terms of the amount of protein produced in the supernatant. As a result, considering the enzymatic treatment with Alcalase, the majority of the proteins appeared to be soluble, with a final protein yield of 75% for PKM and 82% for BSG, respectively [12]. This suggests that the enzymatic treatment was successful in solubilizing not only the soluble proteins but also the non-soluble proteins that are covalently linked to non-soluble polysaccharides, rendering them insoluble in water. In comparison to a prior study by Treimo et al., the performance of protein hydrolysation with Alcalase was superior in terms of yield and incubation time [13]. In addition, considering that BSG contains more protein than PKM, its annual protein powder production is nearly as high as that of PKM, despite the fact that BSG's raw material input in terms of dry weight is 2.5 times lower (Table 3). 2008), where the final yield of 77 percent protein was obtained after 4 hours of incubation with Alcalase instead of 2 hours. However, the higher carbohydrate content of the BSG-derived composition results in a protein purity of 59 percent, which is significantly lower than the 75 percent purity of the PKM-derived protein powder [14].

Techno-economic and business case analysis The BSG and PKM receive €1.8 and €2.3, respectively, for each kilogram of protein powder, respectively, when the powder's revenue is adjusted for protein purity. When compared to the production costs, which are estimated at €1.2 per kg protein powder and €0.68 per kg ethanol, the revenue from the biorefinery of BSG is higher for the protein powder and lower for the ethanol (€0.60 per kg). The production costs of protein powder in the biorefinery of PKM are €2.2 per kilogram, which is just below the revenue (€2.3 per kilogram) [15]. However, the ethanol production margin is substantial, with estimated production costs of €0.41.

## Conclusion

Protein extraction and ethanol production from BSG and PKM can be combined in a conceptual biorefinery process. With 8000 production hours per year, the conceptual process is intended for an industrial-scale biorefinery that processes 20 kt DW of BSG and 50 kt DW of PKM. The performance is analyzed techno-economically with the help of the virtual biorefinery.

According to the techno-economic analysis, the biorefinery of BSG generates more revenue from protein powder than it does from ethanol when production costs are taken into account. With an internal rate of return of 24%, the BSG biorefinery has a significant economic potential. The protein powder's revenue in the PKM biorefinery is just higher than the costs of production. In any case, the income of the ethanol is a lot higher contrasted with the creation costs. The PKM biorefinery still has a positive internal rate of return of 12% despite the high costs of raw materials.

The economic potential of combining the production of a biofuel like ethanol from the remaining biomass with the production of a high-value product like protein powder for food applications was demonstrated by the virtual biorefineries that were presented. The biorefinery is profitable overall because the biorefining of a greater portion of the raw material's biomass into various products generates more revenue for the same amount of raw material.

### Acknowledgement

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### Conflict of Interest

None

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