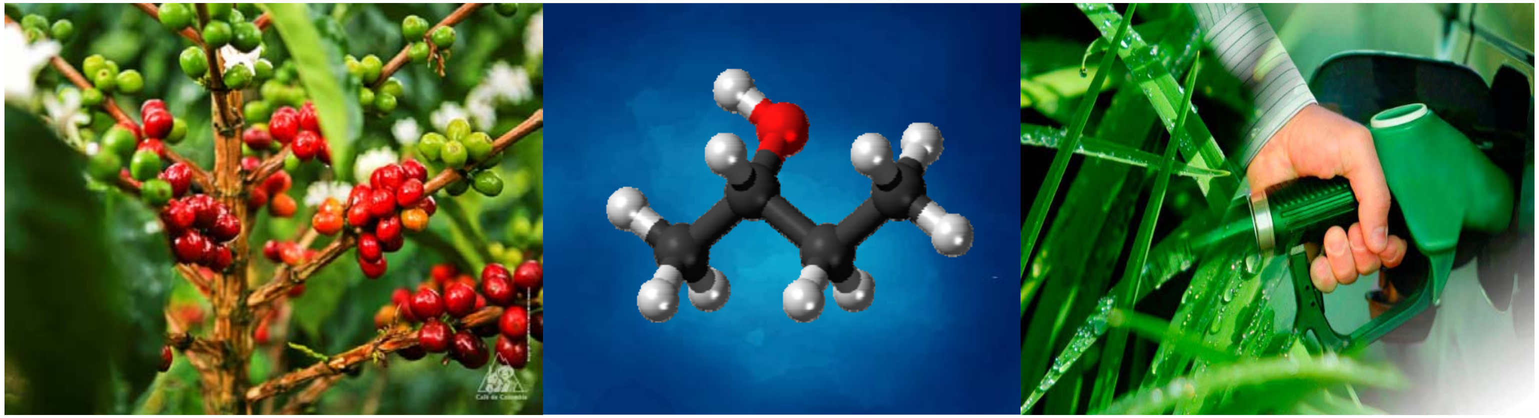
Evaluation and analysis of the coffee cut stems as raw material for the production of sugars for ABE fermentation

Estefanny Carmona Garcia, Mariana Ortiz Sanchez, Carlos Ariel Cardona Alzate.



Universidad Nacional de Colombia sede Manizales,
Instituto de Biotecnología y Agroindustria.
Manizales, Colombia

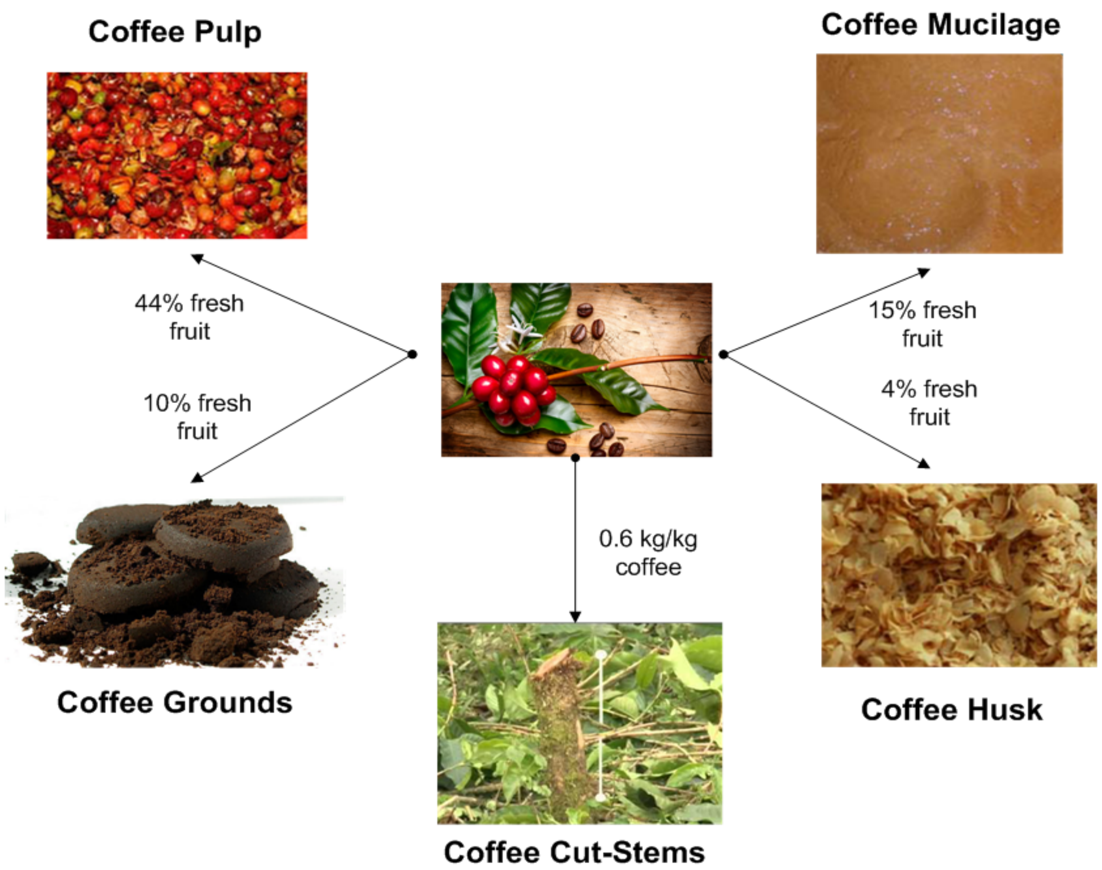
UNIVERSIDAD NACIONAL DE COLOMBIA SEDE MANIZALES

NAXOS2018 13-16 June 2018

Outline

- Introduction
- Research objective
- Methodology
- Results and discussions
- Conclusions

Coffee-Processing Residues



Annual coffee production has increased from 140 to 152 million bags of 60 kg since 2010 [1]

Alternatives for the use of by-products should be investigated

Coffee cut stems is not considered in the studies

Coffee cut stems (CCS)

CCS are considered an abundant waste resulting either by cutting or by coffee crop renewal.

17 tonnes of dry Wood per Hectare can be obtained [2]

Studies have shown that the CCS is a potential raw material for gasification and biorefinery schemes [2] [3].

In both the authors concluded that CCS can be an interesting raw material

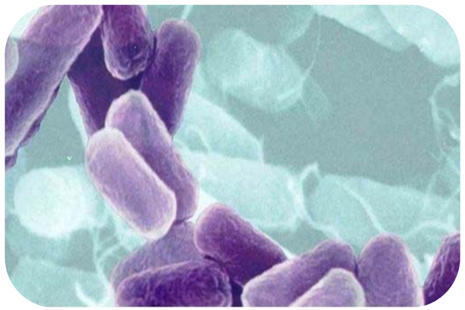
Butanol production

-Precursor of paints and plastics.
-Pharmaceutical industry and cosmetics for extraction process
-Solvent and chemical intermediary

It is also a substitute for fossil fuels or additive

BUTANOL = BIOFUEL

Butanol is currently industrially produced from petroleum or fermentation of corn, cassava or molasses as substrate using several *Clostridium* strains [4].



Clostridium **sp**

Tomada de: https://goo.gl/PpHKGZ

20-25 g/l → **Acetone** / **Butanol** / **Etanol**

Coffee cut stems are a potential raw material for butanol production due its availability

Research objective

The aim of this work is to conceptually design the production of biobutanol using process engineering tools and stoichiometric approaches.

ABE fermentation was simulated using the commercial software Aspen Plus® to obtain the mass and energy balances.

The economic analysis was carried out based on the methodology proposed by Peters et al. [5].

Finally, environmental evaluation of the process was performed using the software WAR GUI (Chemical Process Simulation for Waste Reduction) developed by United States environmental Protection Agency (EPA).

Methodology

The process simulation consists of three main steps: pretreatment of raw material in order to extract the sugars, ABE fermentation and separation of the product.

Component	%
Moisture	4
Cellulose	38.88
Hemicellulose	32.61
Lignin	9.71
Extracts	13.59
Ash	1.21

Table 1. Composition of the CCS used as substrate for ABE fermentation [16]

Pretreatment

Acid Hydrolysis
Sulfuric Acid 2.4%wt.
Temperature = 100°C
Products = Pentose-rich liquor
Solid residue (mainly cellulose and lignin)
Kinetic model [7]

Enzymatic Saccharification
Celluclast 1.5L and Viscozymes (1%-3%)
Temperature = 50°C
15 g/l of biomass [8]
Products = Hexose-rich liquor
Solid residue (mainly, lignin)

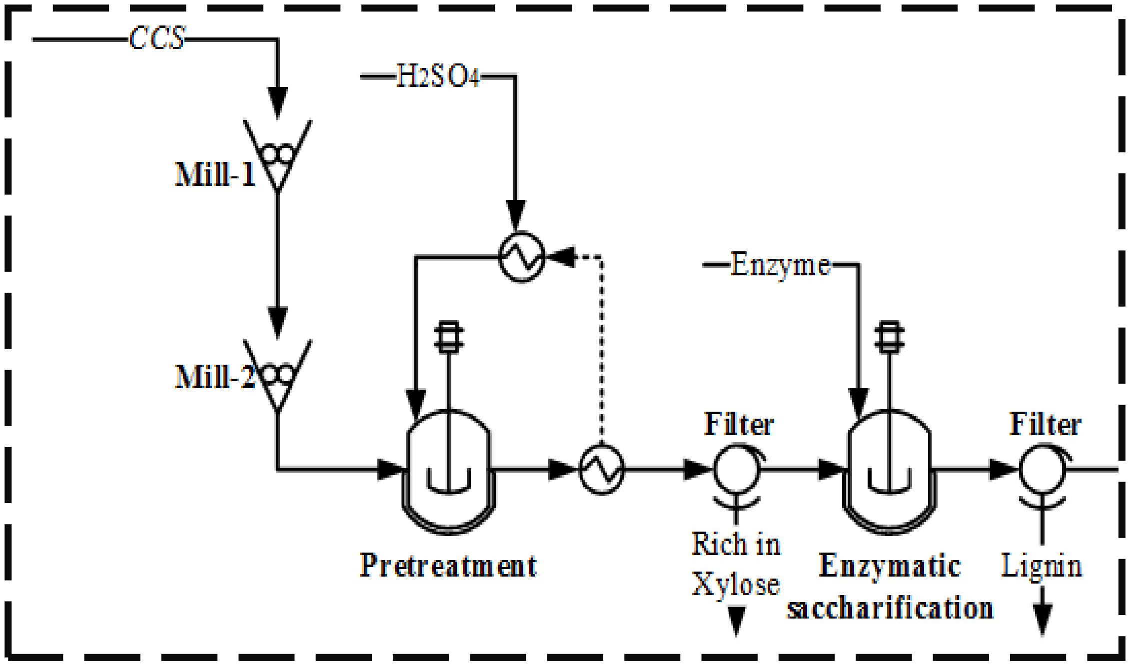
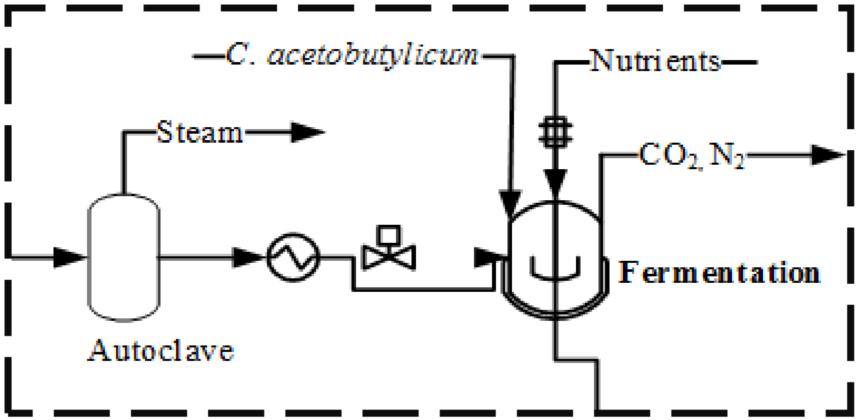


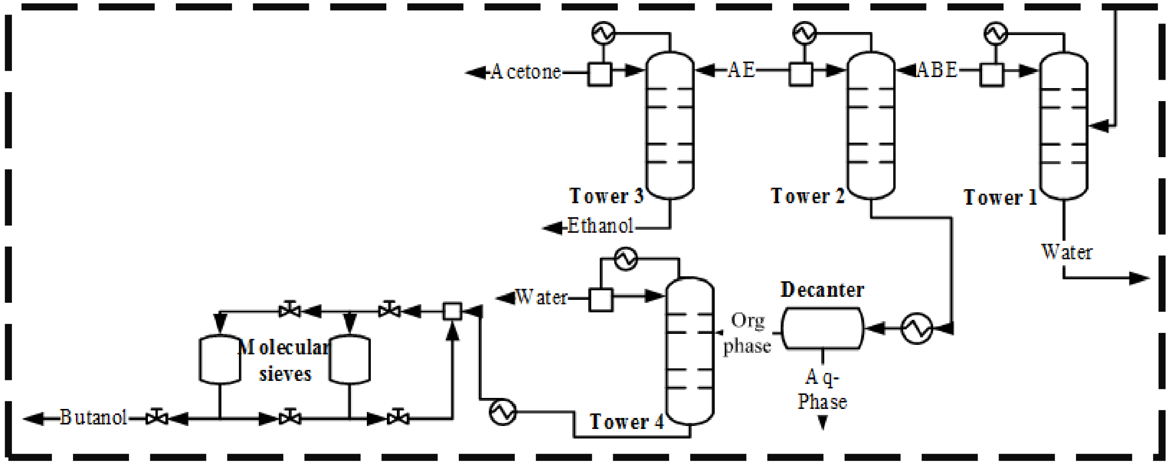
Figure 1. Pretreatment Process Scheme

ABE fermentation

Fermentation
Substrate = Hexose-rich liquor (50 g/l)
Microorganism = *C. acetobutylicum*
Temperature = 37 °C
Limit ABE 20-30 g/l

Dowstream
This stage consists of four distillation columns due to the mixture of ABE solvents is highly diluted and one decanter for azeotropic system





Economic and environmental analysis

Economic analysis

It is estimated based on the information obtained in the simulation process. It is developed taking into account the methodology reported by Peters et al., [5] and using the equipment cost estimated in Aspen Economic Analyzer.

Environmental analysis

Calculation of environmental indicators, stipulated by the Environmental Protection Agency (EPA), related to liquid-solid stream discharges and gaseous emissions.

Results

Base case of 80 ton / h (1920 ton/day)

Acetone
2.8 ton/h

Butanol
6.08 ton/h

Etanol
1.52 ton/h

75% of the produced ABE is being recovered as final product.

Energy requirements

This study: 21.50 MJ / kg butanol
Kurkijärvi et al.,: 20.6 MJ/kg [9]
Kraemer et al., with 18.4 MJ/kg butanol [10]

Cost distribution

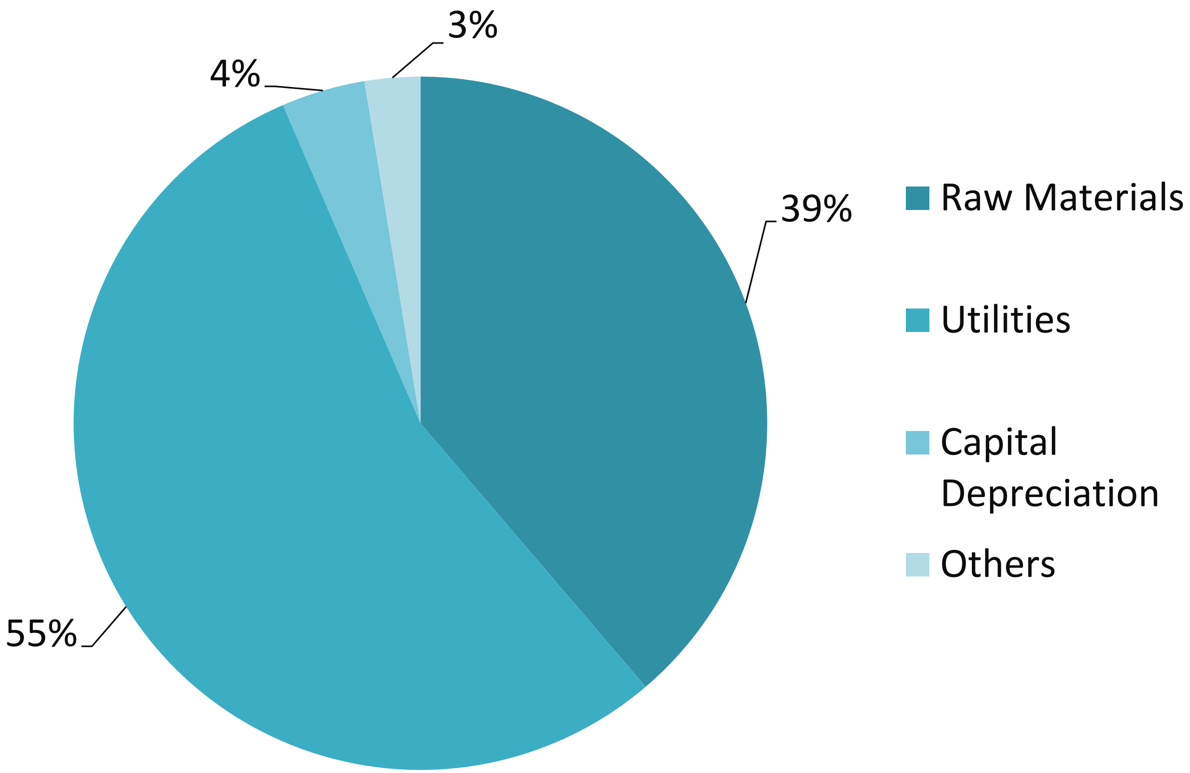


Fig. 4 Cost contribution for the base case *Others corresponds to: maintenance (1.14%), labor (0.09%), fixed and general (0.71%) and plant overhead (0.64%)

Of the cost of raw materials, 30% corresponds to cost of CCS, 41% represents the enzyme cellulase added for the enzymatic hydrolysis, 25% corresponds to the sulfuric acid used in dilute acid hydrolysis and 4% for process water.

Production cost

Product	Income [mUSD/year]	Allocation Factor (Economic)	Allocated Cost [mUSD/year]	Production Cost USD/kg
Butanol	76.20	0.68	73.90	1.39
Acetone	35.61	0.32	34.53	1.41
Ethanol	6.01	0.05	5.83	0.44

Table 2. Revenue from sales and cost production of ABE solvents

Sale price

Butanol → 1.43 USD/kg

Acetone → 1.45 USD/kg

Ethanol → 0.45 USD/kg

Three production costs are lower than the commercial reported sales price, which is an initial indicator of a good economic performance of the process for the base case.

Neet present value

The NPV is the difference between the present value of the cash inflows and the present value of the cash outflows (including the initial cost) over a period of time. For a period of 10 years it would be counted with an accumulated cash flow of 19.59 mUSD and payback period of 4 years.

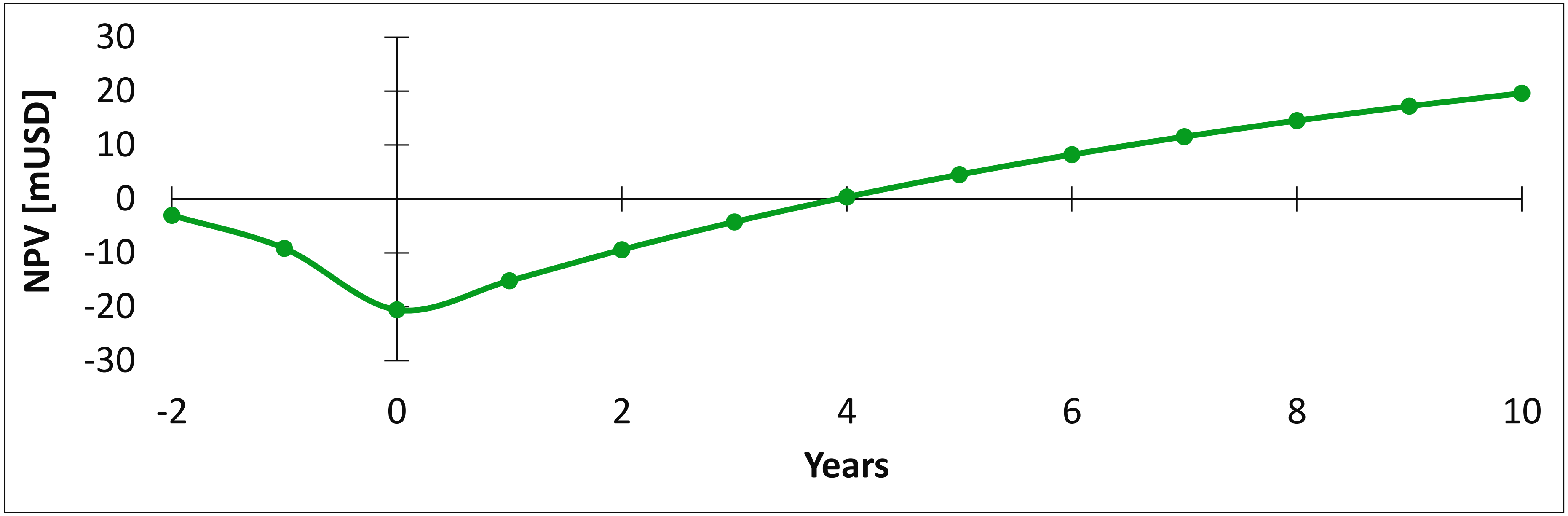
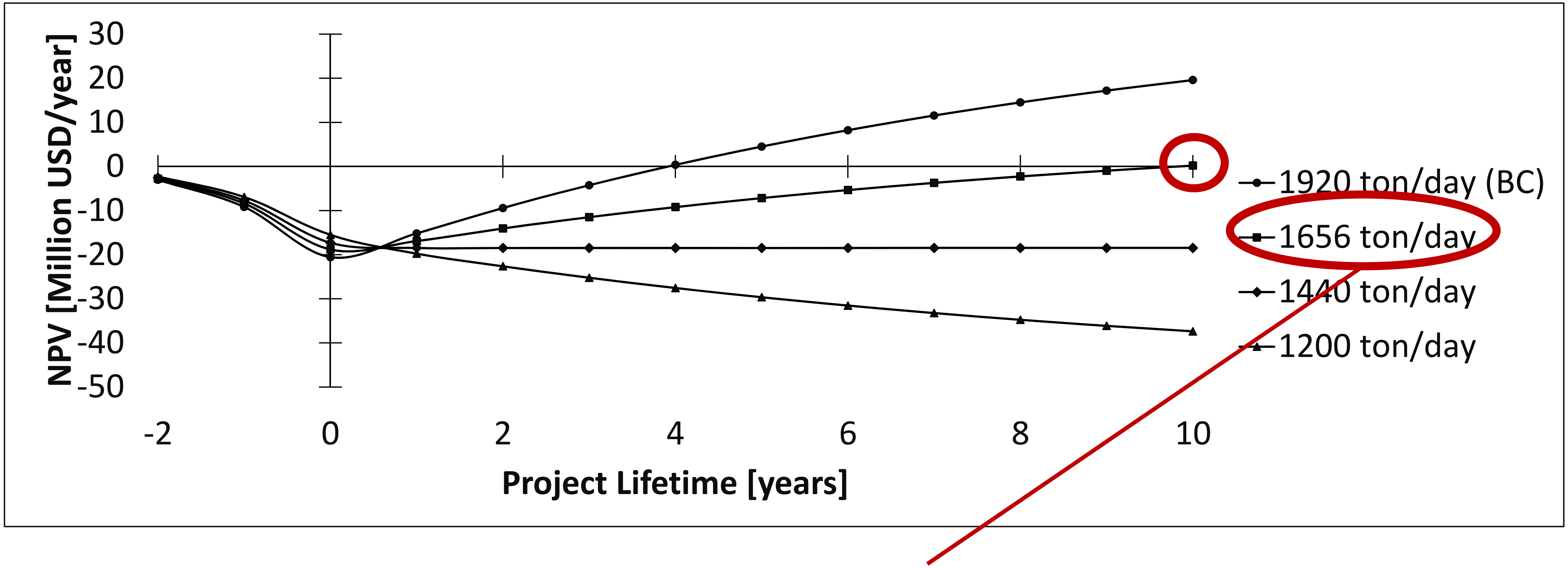


Fig. 5 Net present value of the process over the project lifetime.

Scale analysis

Fig. 6 VPN behavior for different scales of raw material processing



Minimum Processing Scale for Economic Feasibility - MPSEF

MPESF

Minimum Processing Scale for Economic Feasibility (MPSEF) was 1656 ton/day of coffee cut stems. According to the definition given by Serna-Loaiza [11]:

…is the processing scale of raw material at which the process will recover the invested amount during the entire lifetime of the project

The determination of the MPSEF is very important because it shows the minimum processing scale at which the process will be economically feasible.

Environmental analysis

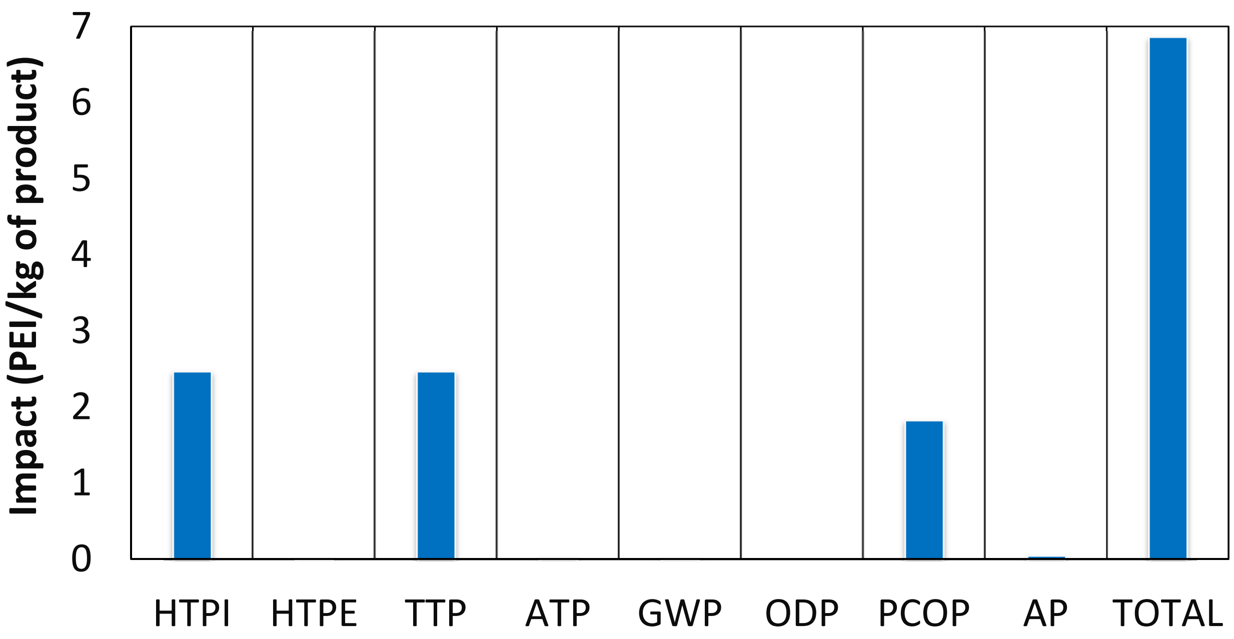


Fig. 7 Potential Environmental Impact (PEI) calculated for ABE production for the base case (80 ton/h)

High Contribution to PEI

Human Toxicity by Ingestion (HTPI) and Terrestrial Toxicity Potential (TPP) Photochemical oxidation or smog potential (PCOP)

LD_{50} (Lethal Dose)

Xylose = 23,000 mg/kg

Glucose = 25,800 mg/kg

Conclusions

- This work demonstrates the production of biobutanol through a conventional ABE fermentation with a hydrolysate of lignocellulosic residue (CCS) as carbon source. The purification stage allows obtaining acetone and ethanol as co-product

- The economic assessment shows a good performance, achieving a payback period of 3.9 years and generating positive income margins for the base case (80 ton/h). The production cost achieved in this work remains within the reported ranges and above of market price.

- The analysis of the scale shows that this process has good economic performances at high-scales, given that the Minimum Processing Scale for Economic Feasibility corresponds to 69 ton/h (1656 ton/day), a value below to 10% of the Colombian production of CCS.

- Regarding the environmental analysis, it is observed that the waste streams that contain lignin, sugars and solvents generate negative environmental impacts. Therefore, the study should be complemented with an assessment of these streams.

ACKNOWLEDGEMENTS

The authors express their gratitude to the Universidad Nacional de Colombia at Manizales, the research project entitled ***"Small-Scale Integrated biorefineries to produce an optimal range of bio-products from a variety of rural agricultural and agro-industrial residues with a minimum consumption of fossil fuels energy"*** with HERMES code 30928 and the Sistema de Información de la Investigación de la Universidad Nacional de Colombia (HERMES) for the international mobility according to request HERMES 8402.

REFERENCES

[1] International Coffee Organization ICO, "Coffee production," 2017. http://www.ico.org/

[2] C. A. García, J. Moncada, V. Aristizábal, and C. A. Cardona, "Techno-economic and energetic assessment of hydrogen production through gasification in the Colombian context: Coffee Cut-Stems case," *Int. J. Hydrogen Energy*, vol. 42, no. 9, pp. 5849–5864, 2017.

[3] . Aristizábal M., Á. Gómez P., and C. A. Cardona A., "Biorefineries based on coffee cut-stems and sugarcane bagasse: Furan-based compounds and alkanes as interesting products," *Bioresour. Technol.*, vol. 196, pp. 480–489, Nov. 2015.

[4] G. Jouzani and M. Taherzadeh, "Advances in consolidated bioprocessing systems for bioethanol and butanol production from biomass: a comprehensive review," *Biofuel Res. J.*, vol. 5, pp. 152–195, 2015.

[5] M. Peters, K. Timmerhaus, and R. West, *Plant Design and Economics for Chemical Engineers*, Fifth ed. New York, 2003.

[6] C. A. García Velásquez, "HYDROGEN PRODUCTION THROUGH GASIFICATION AND DARK FERMENTATION Hydrogen production through gasification and dark fermentation," 2016.

[7] A. Torkkeli, "Droplet microfluidics on a planar surface," *VTT Publications*, vol. 54, no. 504. pp. 3–194, 2003.

[

REFERENCES

8] M. Selig, N. Weiss, and Y. Ji, "Enzymatic Saccharification of Lignocellulosic Biomass," *Natl. Renew. Energy Lab.*, no. March, pp. 1–5, 2008.

[9] K. Kraemer, A. Harwardt, R. Bronneberg, and W. Marquardt, "Separation of butanol from acetone–butanol–ethanol fermentation by a hybrid extraction–distillation process," *Comput. Chem. Eng.*, vol. 35, no. 5, pp. 949–963, May 2011.

[10] K. Kraemer, A. Harwardt, R. Bronneberg, and W. Marquardt, "Separation of butanol from acetone–butanol–ethanol fermentation by a hybrid extraction–distillation process," *Comput. Chem. Eng.*, vol. 35, no. 5, pp. 949–963, May 2011.

[11] S. Serna-Loaiza, "Design of Efficient Small-Scale Biorefineries: The Application of Thermodynamic-Topological Using Bore (Cocoyam) As Study Case," Universidad Nacional de Colombia - Sede Manizales, 2018.