Thermochemical and Biochemical routes to produce energy from residues: The case of Pinus patula as raw material for direct bioenergy and ethanol production

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Outline

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

Global problem

Population growth

Food and water shortages

GHG emissionsand fossil fuel consumption

Social and environmental problems

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The implementation of new technologies is urgent as they help to ensure long-term economic growth and sustainability

An option is produce renewable and sustainable energy from biomass such as biofuels

Pinus patula

Pinus patula is a lignocellulosic rich source which is widely distributed in Colombia and is classified as softwood.

Cultivation yield: 12-22 $m^3 Ha^{-1} year^{-1}$. The generation of waste during the wood processing of *Pinus patula* is a commercial interest for obtaining value-added products

The use of organic waste for biofuel production plays an important role in reducing CO_2 emissions. Different products such as biogas, syngas, biobutanol, biodiesel, bioethanol can be obtained [2].

Biomass valorization – *Pinus patula*

Ethanol production

The high polysaccharide content in Pinus patula can be hydrolyzed by different physicochemical pre-treatments (acid or base), followed by enzymatic hydrolysis (saccharification) [3]–[5]

Gasification

Allows the transformation of biomass at high temperatures into a gas (syngas) with high energy content. Mainly composed of CO, H_2, CH_4, CO_2 and N_2, where hydrogen is the main product with the highest added value [6].

Research objective

To evaluate the potential of *Pinus patula* for the production of ethanol an experimental and simulation component was carried out

Experimental

Pine was pretreated by dilute acid and enzymatic saccharification, the sugars obtained were fermented by *Saccharomyces cerevisiae* to obtain ethanol.

Simulation

1. Production of ethanol was simulated, including the separation stage and then an economic analysis .
2. A comparison was made between the biochemical route (fermentation) and the thermochemical (gasification). in order to determine the efficiency of each process

Methodology: Experimental procedure

Paticle size reduction

Dilute acid hydrolysis: H2SO4 2% v/v, 121 °C, 90 minutes, 15 psi

Enzymatic saccharification: Celluclast 1.5L and Viscozymes (1%-3%), 50°C, 15 g/l of biomass [7]

Fermentation: *Saccharomyces cerevisiae,* 32°C, 150 rpm, pH 4.

Biomass concentration

Dry weight method

Sugar concentration

Dinitrosalicylic acid (DNS) method

Ethanol concentration

Gas Chromatography (GC) using a GC-2014 (Shimadzu) gas chromatograph

Methodology: Simulation procedure

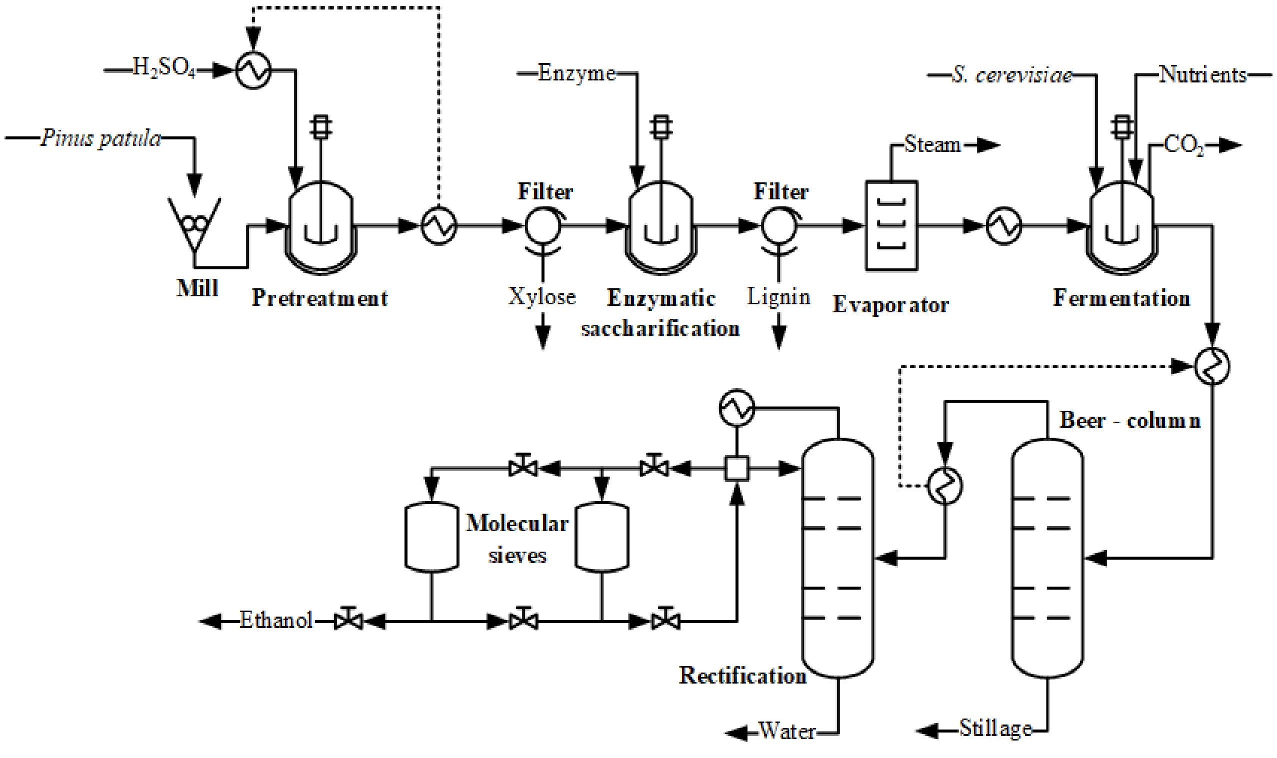

Fig. 1 Scheme of bioethanol production from *Pinus patula*

The simulation of bioethanol production consists in four stages: **pretreatment, enzymatic hydrolysis, fermentation and separation**

The beer column is either a stripper with a bottoms reboiler or a direct steam injection column that takes the product from the fermenters and strips out the ethanol overhead.

Methodology: Economic analysis

RAW MATERIALS	COST
Pinus patula	40 USD/ton
Cooling water	0.33 USD/ m^3
Sulfuric acid	94 USD/ton
Enzyme	700 USD/ton
UTILITIES	COST
Electricity	0.1 USD/kWh
Low pressure steam (LPS)	7.56 USD/ton
Medium pressure steam (MPS)	8.18 USD/ton
PRODUCT	COST
Ethanol	0.9 USD/kg

Table 1. Prices used in the economic evaluation

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., [7] and using the equipment cost estimated in Aspen Economic Analyzer

The production cost of ethanol was determined and the influence of the process scale

Methodology: Gasification

Table 2. Typical composition of gas during gasification biomass [9].

COMPONENT	%
H_2	12-20
CO_2	9-15
CH_4	2-3
CO	17-22
N2	50-54

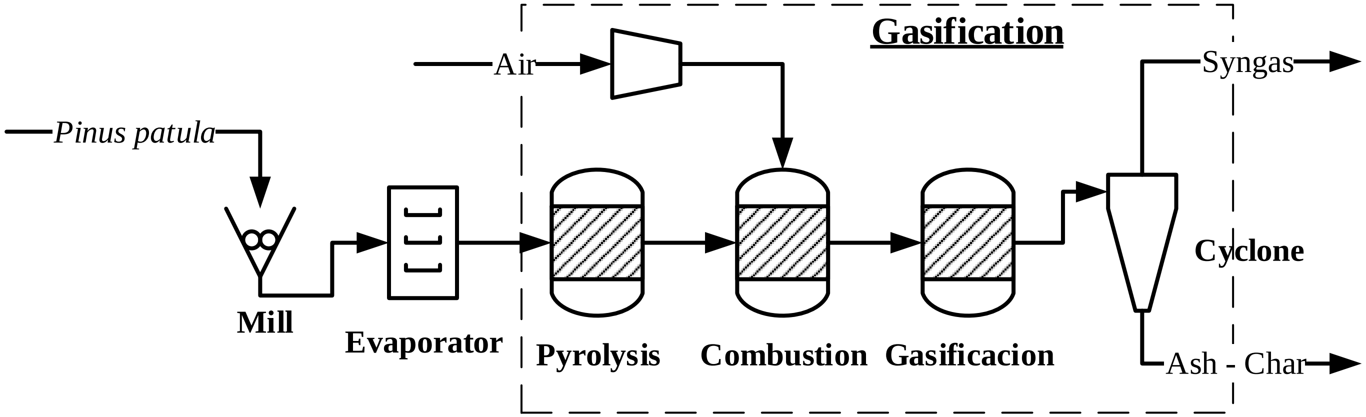

Fig. 2 Biomass integrated gasification with cogeneration system scheme

Stages in gasification

Dried. **Pyrolysis:** 700 °C. **Combustion:** 1000 °C. **Gasification 800 °C**

RESULTS

Pretreatment stage

Concentration of reducing sugars of 31 g / L was obtained

Enzymatic hydrolysis

13.5 g/L, due to the high amount of water used in the enzymatic hydrolysis

Fermentation

A substrate consumption of 6.29 g/L was obtained. The final concentration of sugars was 50% of the initial concentration, which suggests that it should be inoculated with a higher concentration of biomass. For the other hand the concentration of **biomass in the concentrated hydrolysate was 3.7g/L**

RESULTS

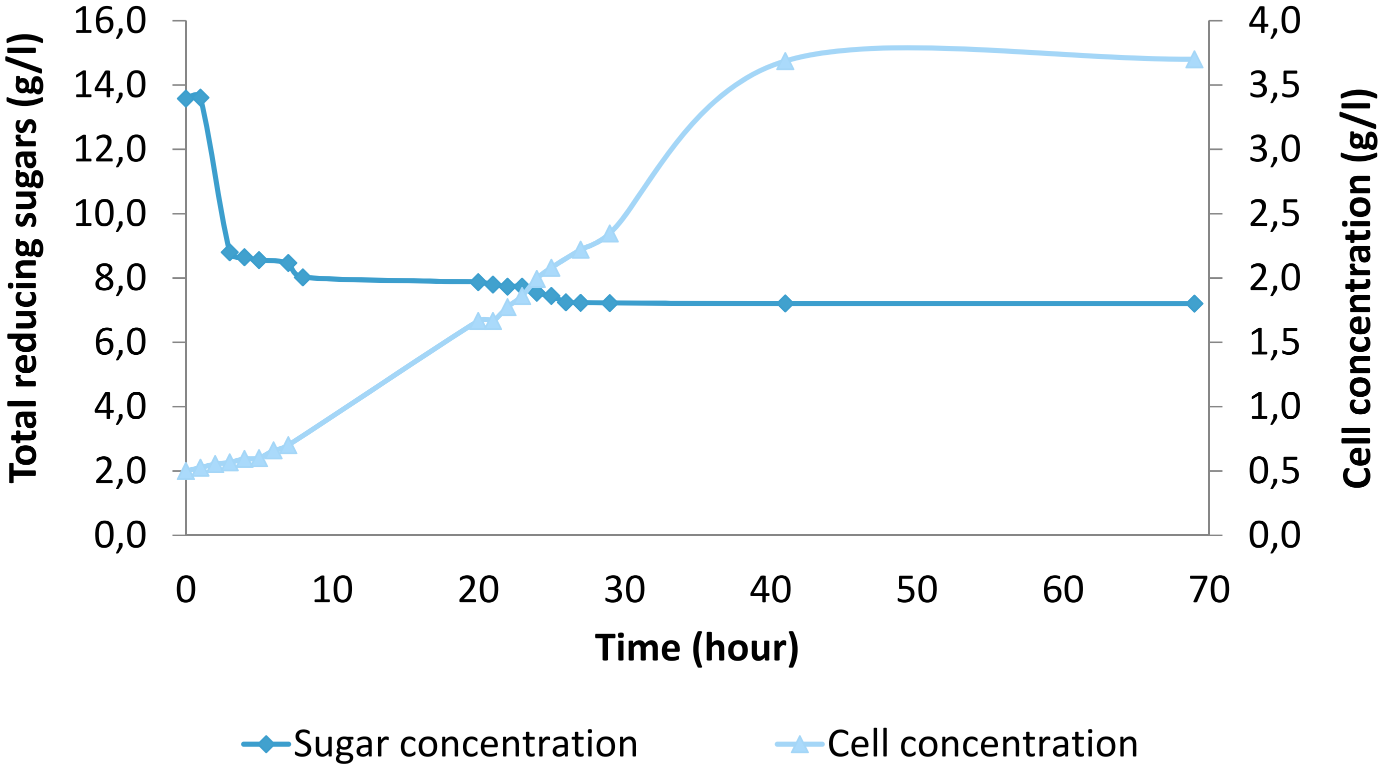

Fig. 3 Biomass growth and total reducing sugars concentration in the ethanol fermentation

The final ethanol concentration **was 4.79 g/L,** which corresponds to a yield of .035 g ethanol / g sugar (69% of the theorical)

If a higher ethanol concentration is required, the hydrolysate **must be concentrated** through evaporation until reaching a higher concentration of sugars

RESULTS

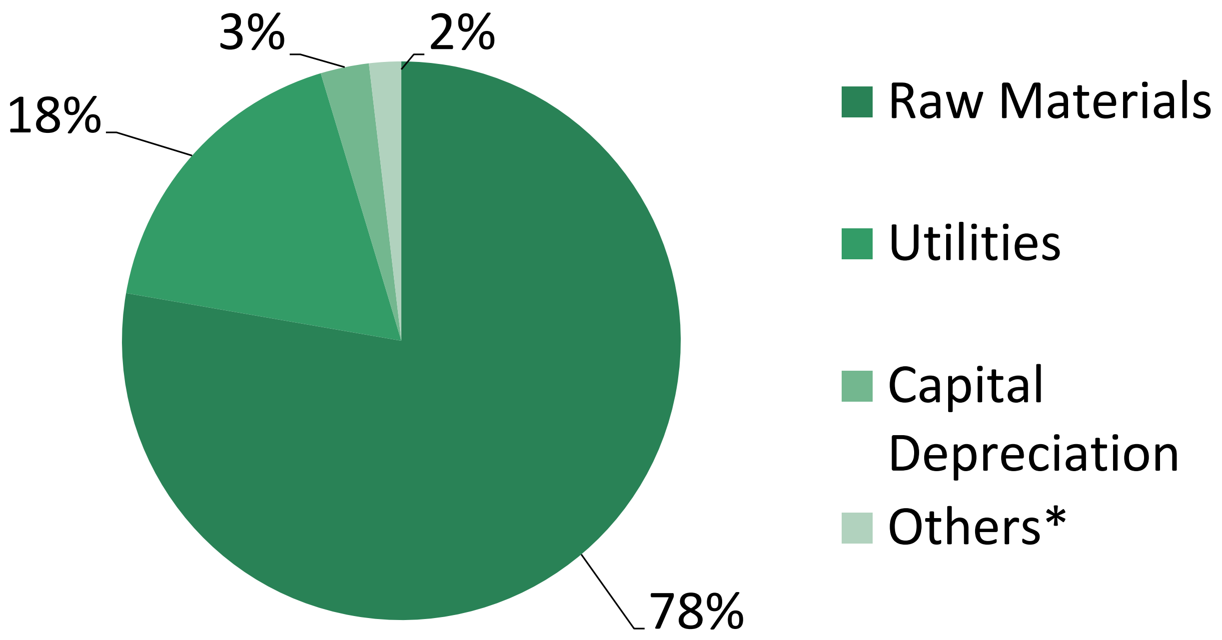

Fig. 4 Cost contribution for the base case (6000 ton/day). *Others corresponds to: maintenance (1.67%), labor (0.12%), fixed and general (1.04%) and plant overhead (0.94)

From the raw material cost, 55% corresponds to cost of ***Pinus patula*** (87 mUSD/year), 21% represents the **enzymes** added for the enzymatic hydrolysis (33 mUSD/year), 19% corresponds to the **sulfuric acid** used in dilute acid hydrolysis (29 mUSD/year) and 4% for process water (7 mUSD/year).

RESULTS

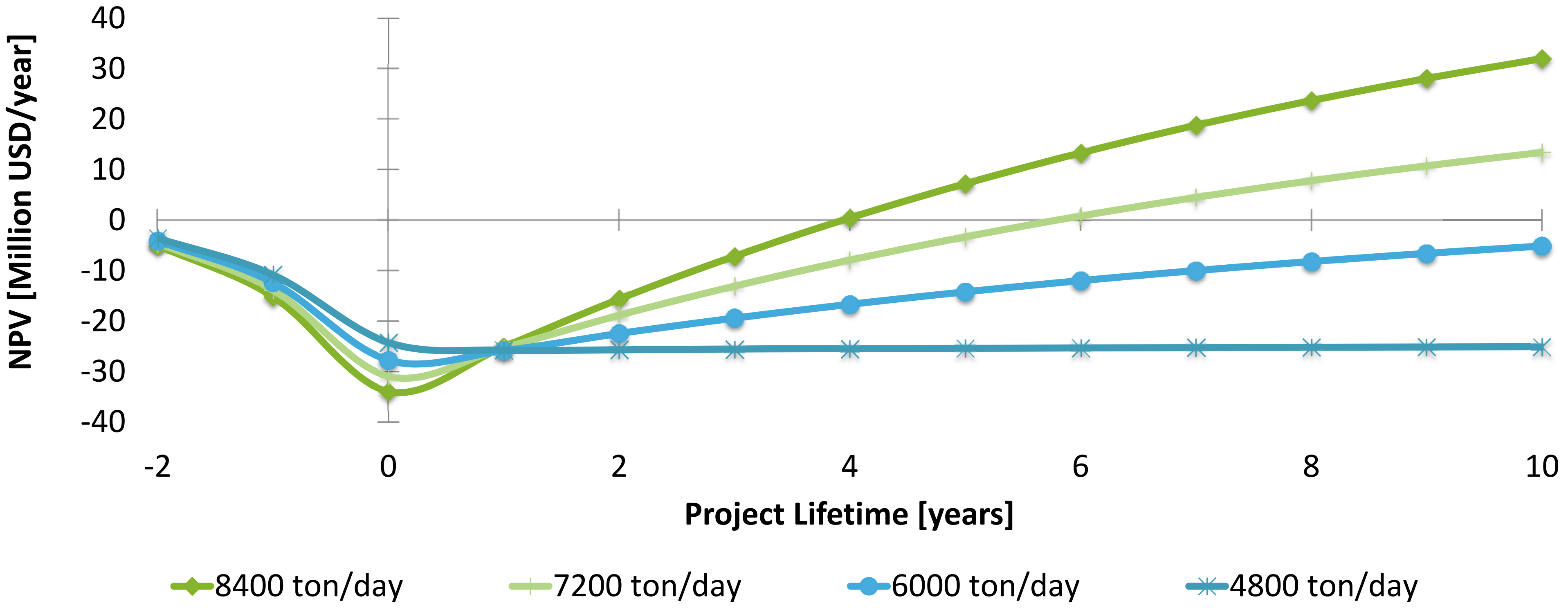

Fig. 5 Influence of process scale in NVP

RESULTS

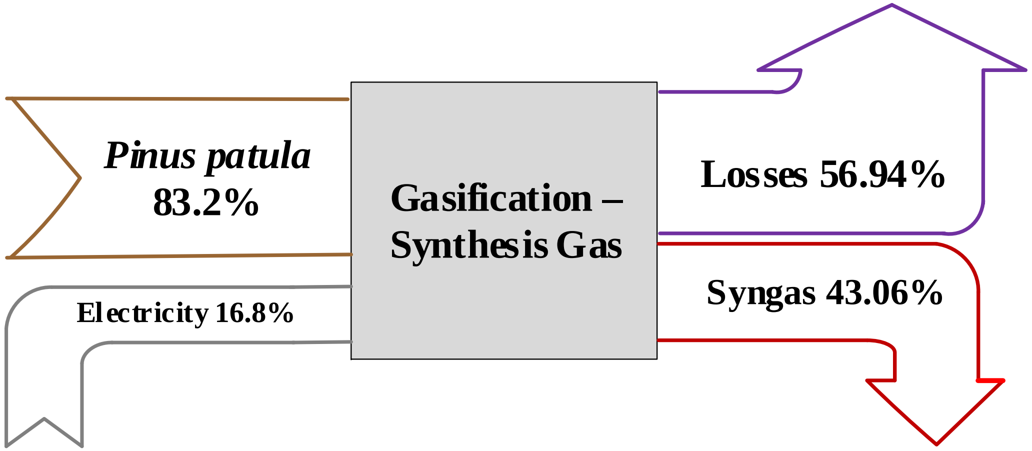

Fig. 6 Sankey diagram for gasification process

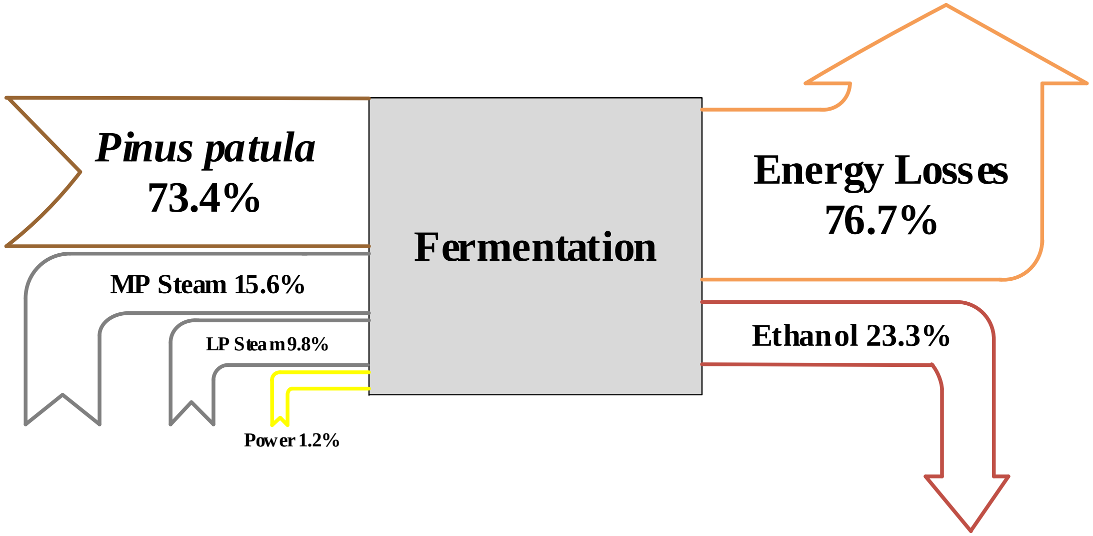

Fig. 7 Sankey diagram for fermentation process

Then according to the results from the energy balance of both process, the energy yield of the ethanolic fermentation is lower than the gasification of *Pinus patula*, with values of **4.11 MJ/kg and 7.16 MJ/kg,** respectively. As a result, the net energy efficiency of both processes is **23% for ethanol and 43%** for syngas production

CONCLUSIONS

- It is possible to produce ethanol from *Pinus patula* with average experimental yield 0.35 g ethanol/g glucose. From the simulation procedure, the fermentative process of *Pinus patula* has proven for higher capacities (> 6000 ton per day) generating lower production costs, even lower than the market price. Consequently, the process can provide positive NPV values.

- The energy analysis was focused in the comparison of the fermentation and gasification pathways for energy production. As a result, the net energy efficiency of both processes was 18% and 35%, respectively. Therefore, electricity from gasification cannot be considered an added-value product due to the low market price and the diversity of methods to produce it, especially in Colombia.

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