

# Economic Analysis of a No Centrifugal Sugarcane (*Panela*) and Bioethanol Production Plant Located in Villeta Cundinamarca, Colombia

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The energy sector remains globally concerned about the escalating energy demand driven by swift population growth and industrial progress. Biomass plays a fundamental role in this transition because it is composed of biodegradable organic matter that contributes to the reduction in environmental impact. Among the various sources of biomass for biofuel production is sugarcane (*Saccharum officinarum*), which, in addition to being used to produce sweeteners such as sugar and panela, stands out as one of the main raw materials for bioethanol production. The fermentation of sugarcane juice with the yeast *Sacharomyses cerevisiae*, one of the most studied microorganisms for bioethanol production. Furthermore, the Department of Cundinamarca is the municipality of Villeta, known as Panela city, for its extensive cultivation of sugarcane to produce Panela. In this region, traditional methods are used to produce panela, which leads to the generation of tons of carbon dioxide. In addition, compared with the sugar industry, panela production processes, which are artisanal, present a great disadvantage. This project presents a feasible alternative for sugarcane production processes to be carried out in a more efficient way and with energy and therefore economic gains, using ASPEN PLUS. With a feed rate of 1,000 kg/h of sugarcane, a production rate of 20 kg/h of anhydrous ethanol was obtained: 60.32 kg/h of char, 103.29 kg/h of noncondensable gases, and 113.21 kg/h of bio-oil. The economic analysis evaluated obtaining income represented by a net present value of \$US\$ 2'155,076; in addition, it has a profitability of 29%, which is above the internal rate of opportunity established at 20%.

## 1. Introduction

The growing demand for energy due to rapid population growth and industrial advances continues to be a global concern in the energy sector (Prasad et al., 2024). Therefore, the use of renewable and sustainable energy sources has been proposed as a solution to this problem (Deshmukh & Pathan, 2024). Despite efforts to make this change, statistics show that 21.3 billion tons of CO<sub>2</sub> are produced annually because of the burning of fossil fuels, of which only half can be processed naturally (Prasad et al., 2024).

Biomass performs a fundamental role in this transition because it is composed of biodegradable organic matter that contributes to the reduction of environmental impact, and according to the international energy association, this represents 53% of renewable energy, much more than solar, wind and hydro combined (Kumar et al., 2020). Biomass is classified as a renewable energy source and is efficient in its use since it can be cultivated, harvested and stored and has properties very similar to those of renewable energy sources; thus, it has a fundamental role in the energy transition process (Li et al., 2024). It can be subjected to thermochemical transformation processes, generating heat, electrical power (Rezaei et al., 2024), synthesis gas (Gómez-González et al., 2024), and zeolite (for biomedical uses) (Samanta et al., 2022). Biofuels, as an essential part of this range of products, have gained worldwide recognition as alternatives to fossil fuels. However, biofuels offer significant advantages from an environmental point of view, as they are eco-friendly energy sources that are produced from biomass without sulphur and help reduce the emission of greenhouse gases, including nitrogen oxide (NO<sub>x</sub>), carbon

dioxide (CO<sub>2</sub>) and sulphur dioxide (SO<sub>2</sub>) (Jayakumar et al., 2023). Among the various sources of biomass for biofuel production is sugarcane (*Saccharum officinarum*), which, in addition to being used to produce sweeteners such as sugar and panela, stands out as one of the main raw materials for bioethanol production (Kyriakou et al., 2023). The fermentation of sugarcane juice with the yeast *Sacharomys cerevisiae*, one of the most studied microorganisms for bioethanol production, is promising as an alternative to fossil fuels (Alalwan et al., 2019). In Colombia, bioethanol production is focused on the sugar agro-industrial sector, especially in sugarcane mills located in Valle del Cauca, where they are integrated into the supply chain of this raw material (Ortegón et al., 2016). The Colombian Agricultural Research Corporation (CORPOICA) has encouraged the diversification and use of sugarcane crops for bioethanol production. However, this transition generates a gap between the panela and sugar sectors, since the large distilleries are financed and belong to the sugar mills located in Cauca, Caldas and Valle del Cauca (Ramírez et al., 2018).

Furthermore, the department of Cundinamarca is the municipality of Villeta, which is known as the panela city for its extensive cultivation of sugarcane to produce panela (Ubaque González, 2013). In this region, traditional methods are used to produce panela, which leads to the generation of tons of carbon dioxide, thus contributing to atmospheric pollution via the release of compounds (Requier-Desjardins & Rodriguez Borray, 2004). In addition, compared with the sugar industry, panela production processes, which are artisanal, present a great disadvantage. Despite this, the volume of panela production in Colombia represents 14.9% of world statistics, making it one of the main agricultural activities of the national economy (Alarcón et al., 2021). To maximize the use of sugarcane, the implementation of circular economy processes has been promoted. In this context, the design of a panel and bioethanol production plant generates a product such as bagasse, which can be used for energy generation (Ayala et al., 2022). Raising new process designs at the industrial level that can apply circular supply management schemes will help mitigate the anthropogenic impact and the problem of waste management (Awasthi et al., 2021). The aim of this study is to research the conceptual design for the implementation of circular economy processes, using Aspen Plus, and evaluate economic analysis.

## 2. Methodology

The simulation process to produce panela and ethanol is carried out via Aspen Plus software, and this process involves the following considerations:

### 2.1 Biomass

The cultivation of sugarcane is now a great alternative to carry out processes that are environmentally friendly, thus becoming a source of biomass, in which the solid content is 28% considering the average solid content found in 6 varieties and the liquid content is 72% (Valderrama et al., 2020). The 28% that corresponds to the solid, bagasse, is modeled as a nonconventional solid component. For this reason, it is necessary to define it by its proximate and ultimate analysis. Table 1 presents information compiled from different authors regarding these parameters. Table 2 shows the information corresponding to the proportion of sugars found in sugarcane juice.

Table 1: Ultimate (C, H, O, N, S, HHV) and proximate analysis of sugarcane bagasse

Characteristic	(Marx et al., 2023)	(Rodrigues et al., 2007)	(Michailos et al., 2017)
Moisture	6.3	-	5
Volatile matter	69.7	-	83.65
Ash	10.9	4	3.2
Fixed carbon	13.1	-	13.15
C	49.79	46.3	45.38
H	6.92	6.4	5.96
O	42.78	43.3	45.21
N	0.42	-	0.15
S	0.08	-	0.1
HHV (MJ/kg)	15.8	17.5	19

Table 2: Chemical composition of sugars present in sugarcane juice.

Characteristic	(Thai & Doherty, 2011)	(Alarcón et al., 2021)
Glucose	2.8	2.9
Fructose	2.35	1.6
Sucrose	81.24	91.9

## 2.1 Production process

Figure 1 shows a schematic representation of the process design of the panela, bioethanol and energy production plants.

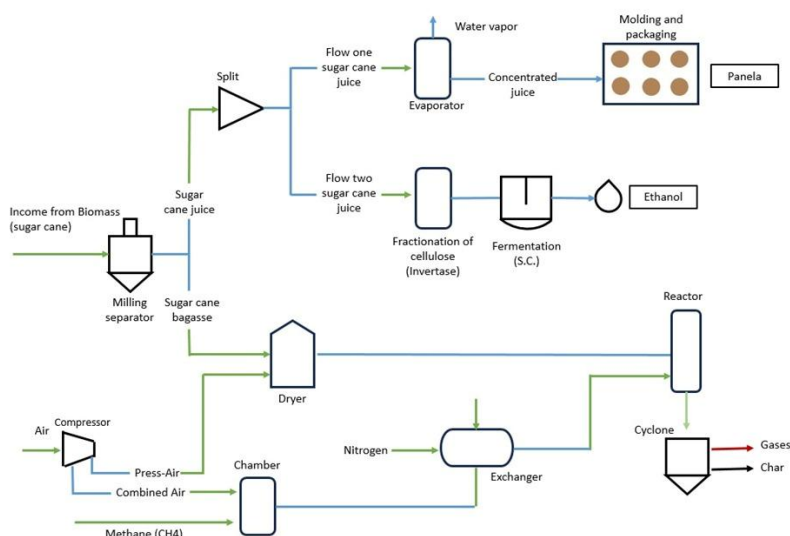


Figure 1: Schema for the bioethanol and Panela production plants.

In addition, a generalized description of the specifications given in each process that are established in articles on sugarcane fermentation to obtain ethanol and bagasse pyrolysis is shown. Table 3 presents a description of the components of the process.

Table 3: Description of the plant process.

Process	Description	Specification
Feedstock	Sugarcane reception	Raw material: Sugarcane cutting Ambient temperature of 28°C and humidity of 85% (Meteoblue, 2024)
Cyclone	Sugarcane juice and bagasse extraction	
Cyclone 2	Sugarcane Fraction of sugarcane juice for panela production and fraction for ethanol production	Initially, 50% for panela and 50% ethanol.
Reactor	Enzymatic hydrolysis process is carried out with immobilized invertase.	Reactor temperature: 30°C - 40°C - 45°C - 45°C and 1 atm (Martínez-Moreno et al., 2012)
Reactor 2	Sucrose is fermented with the yeast <i>Saccharomyces cerevisiae</i> to obtain ethanol. Bagasse	Reactor temperature: 40°C and 1 atm (Martínez-Moreno et al., 2012)
Drying	Bagasse is dried so that the moisture content is in the range of 5 - 6.5%.	Bagasse temperature: 28%. Ambient temperature 28% and humidity 85% (Meteoblue, 2024)
Reactor 3	Bagasse enters the reactor to start the pyrolysis process.	Reactor temperature: 600°C and 1 atm (Ahmed et al., 2018).
Cyclone 3	Separates condensable and noncondensable gases from the char	-
Condenser	Bio-oil is obtained. The noncondensable gases pass to the cooling tower.	Water temperature at 20°C and 1 atm.

### Aspen Plus simulation

The simulations were carried out in Aspen Plus according to the equipment reported in Table 3. A 1000 kg/h feed of the previously defined sugarcane was used. The NRTL thermodynamic model was used according to (Farzad et al., 2021).

### Economic model

To carry out the economic analysis of the pyrolysis plant, the economic analysis proposed by Aspen Plus (APEA) is used, obtaining the costs of the equipment used together with the installation costs and the heating, cooling, and electricity utilities. The Aspen Process Economic Analyzer (APEA) is a model integrated in the Aspen database, which makes it easier to determine operating costs and investment costs from the process model established in Aspen Plus. To determine economic sustainability, economic feasibility indicators such as the net present value (NPV), internal rate of return (IRR) and payback are used.

## 3. Results and discussion

### 3.1 Mass and energy balance

The mass and energy balance of the process in general is established in Table 4. The inputs of the system include the feed of sugarcane, air, nutrients, and yeast. The outputs of the process include valuable products such as anhydrous ethanol, char, noncondensable gases, and bio-oil. The ethanol plant has a production rate of 20 kg/h; in this way, it will have an annual production rate of 185.2 tons/year, which is equivalent to 234.7 liters/year. On the other hand, the following pyrolysis products were produced: char (60,32 kg/h), noncondensable gases (103.29) and bio-oil (113.21 kg/h).

Table 4: Mass and energy balance of the plant process

Stream	Mass Balance		Energy Balance		
	Input (kg/h)	Output (kg/h)	Block	Input (kW)	Output (kW)
Scane	1,000		COLREC	5.89	6.64
AirIn	10,000.00		DESTIL	0.43	2.24
AMMO	0.00018		CAZETRO	74.29	59.49
Scerev	0.10		HEATER	21.49	
Glycerol	10		FERMENT A		13.04
Ncsc		360	INVERTAS	4.35	
Exgas		34.85	DRYER		105.31
Ethanhi		20.00	COMPRES	109.79	
W1		15.00	REACTOR	1,789.56	
S7		296.15	COOLER1	112.72	
S4		10,007.30	CONDG		6.71
Char		60.32	COOL1		0.53
Ncg		103.29			
Bio-oil		113.21			
TOTAL	11010.10	11010.10	TOTAL	2,118.52	193.96

### 3.2 Economic analysis

Financial analysis aims to evaluate the economic viability of a project by means of economic feasibility indicators, which determine investment and operating costs throughout the project evaluation period. In the first instance, a period of 5 years is set, taking the cash flow to 2030, considering that the average useful life of the plant is between 5 and 8 years (Doing, 2022). Figure 2 shows the cash flow obtained from the initial investment, together with the operating costs and annual incomes obtained from the sale of char, liquid, syngas and ethanol. For the development of the NPV, it is necessary to establish an opportunity rate that represents the expected return of the project, for which a percentage of 20% was established, a value determined from an average of the expected profitability rates of different Colombian companies that work under their own capital (Corporación Financiera Colombiana S.A, 2021). Under these conditions, a positive net present value of US\$ 2'155,076 was obtained, indicating that the project was viable for a period of 5 years. According to the internal rate of return obtained, which is 29%, the project is profitable for a period of 5 years, given that the reflected IRR is higher than the internal rate of opportunity stipulated in the net present value (NPV). The payback (year) is 2.4, and the payback (month) is 27.7.

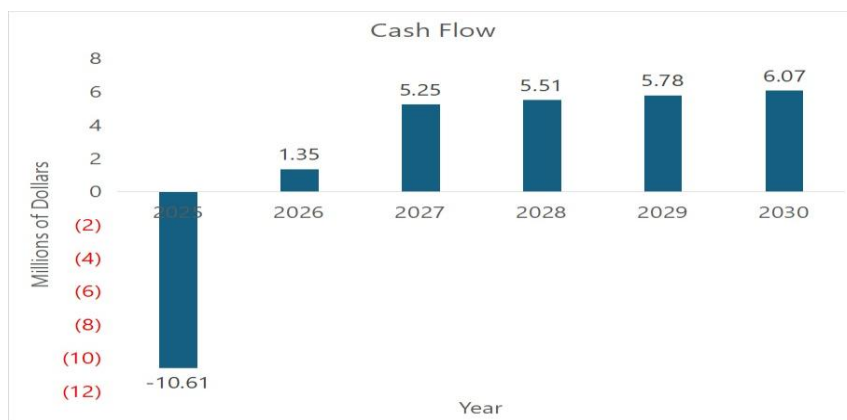


Figure 2 Cash flow of the pyrolysis plant (millions of dollars)

#### 4. Conclusions

For the process described above, with a feed of 1,000 kg/h of sugarcane, a production of 20 kg/h of anhydrous ethanol equivalent to 2% of the products obtained, 60.32 kg/h of char equivalent to 6%, 103.29 kg/h of noncondensable gases equivalent to 10.3%, mainly methane and CO<sub>2</sub>, and 113.21 kg/h of bio-oil equivalent to 11.3%. This implies that the integration of the anhydrous ethanol production process, together with the pyrolysis of sugarcane bagasse, takes advantage of nearly 28% of the sugarcane input. The economic analysis allows classifying the project as profitable in a period of 5 years, obtaining income represented by a net present value of \$US\$ 2'155,076; in addition, it has a profitability of 29%, which is above the internal rate of opportunity established at 20%. Importantly, the project will start its profits 2.4 years after the beginning of the investment, which represents a payback of 27.7 months. This indicates a great opportunity for the economic development of the sector and the region.

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