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Analysis of the improvement of biorefineries based on sugarcane through the sugarcane bagasse inclusion as raw material

VALENTINA ARISTIZÁBAL M., **CHRISTIAN D. BOTERO G.**, JUAN C. SOLARTE T., CARLOS A. TAIMBU, CARLOS A. CARDONA A*

INSTITUTO DE BIOTECNOLOGÍA Y AGROINDUSTRIA. CHEMICAL ENGINEERING DEPARMENT. UNIVERSIDAD NACIONAL DE COLOMBIA SEDE MANIZALES

Introduction

Bioprocesses: Main topic in the industry

Renewable feedstock

For example!

Sugarcane (SC)

Juice

Sugar

Molasses

Ethanol

Bagasse - SCB

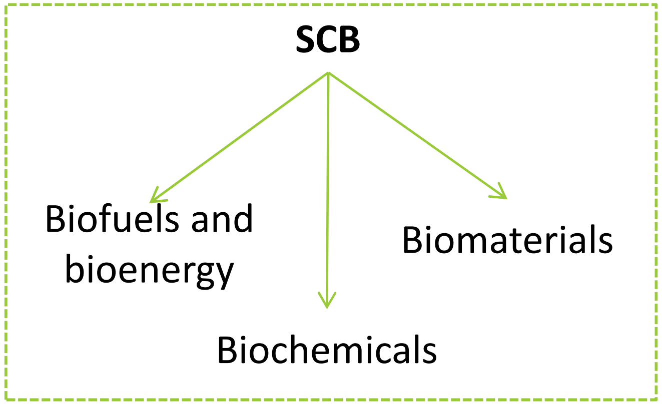
Electricity

High availability: From 1 ton of SC processed 280 kg of SCB is obtained

High content of cellulose (40-45%) and hemicellulose (30-35%)

Good characteristics to obtain added-value products

Introduction



BIOREFINERY CONCEPT

This concept promotes an integral use of feedstocks and generates economic and environmental advantages when the use of sugarcane bagasse is integrated into the process

- The selection of feedstocks , technologies and products are a fundamental issue for the design of biorefineries with the best characteristics.
- This selection is not easy and it is necessary to apply tools to guide and simplify the process.
- The characterization indexes allow reducing the working time and simplifies the calculations in the design of the biorefineries

Methodology

1. Raw material: Sugarcane

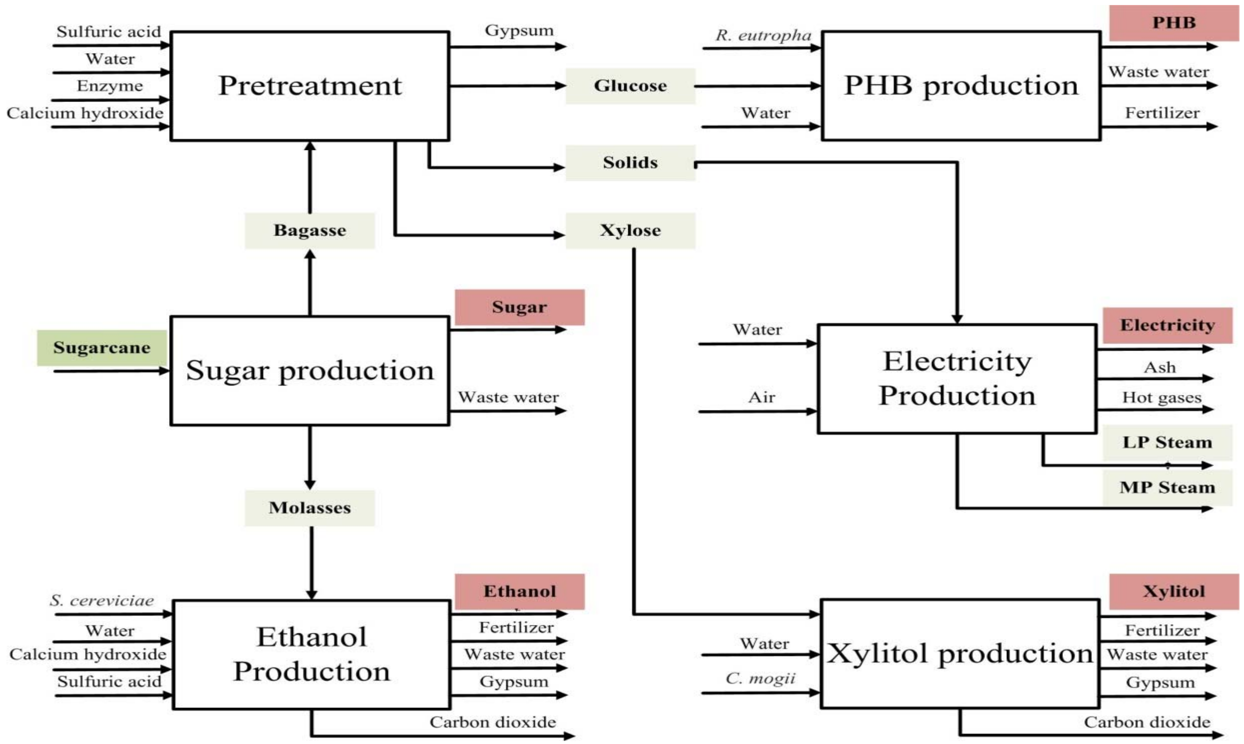
Composition (%w/w)
Cellulose 6.55, Hemicellulose 5.45, lignin 1.43, Sucrose 13.64 and moisture 70.40

2. Scenarios

Scenario	Products	Description
1	Sugar, ethanol and electricity	Current Colombian base case. Sugar production from cane juice, ethanol production from molassess and electricity generation from sugarcane bagasse.
2	Sugar, ethanol, xylitol and electricity	Xylitol production from xylose obtained in the acid hydrolysis of sugarcane bagasse and electricity generation from remaining solids of acid hydrolysis.
3	Sugar, ethanol, xylitol, PHB and electricity	PHB production from glucose obtained in the enzymatic hydrolysis of sugarcane bagasse and electricity generation from remaining solids of enzymatic hydrolysis.

Methodology

3. Process description



Feedstock
Platforms
Products

Maximum plant processing capacity of 10 ton SC h^{-1}

Figure 1. Global schematic description of the processes involved in the sugar, ethanol, xylitol, PHB and electricity production (Scenario 3).

Methodology

4. Characterization indices

BIOREFINERY COMPLEXITY INDEX

A biorefinery has features as feedstock, platforms, products and processes. The BCI is estimated for each feature through a Feature Complexity Index (FCI)

The FCI is determined as the product of Number of Features (NF) and Feature Complexity (FC)

The FC considers the Technology Readiness Level (TRL) for each feature. The TRL has a range of 1 (basic research) to 9 (system proven and ready for full commercial deployment)

$$BCI = \sum_{j=1}^{m} FCI_i \longrightarrow FCI_i = \sum_{j=1}^{m} NF_i * FC_i \longrightarrow FC_i = 10 - TRL_i$$

$$BCP = BCI(FCI_{platforms}/FCI_{feedstocks}/FCI_{products}/FCI_{processes})$$

Where:
FCI: Feature Complexity Index; NF: Number of Features; FC: Feature Complexity; TRL: Technology Readiness Level; BCP: Biorefinery Complexity Profile

Methodology

4. Characterization indices

MASS INDICES

Index	Equation
Biorefinery mass index (MI_B)	$MI_B = \frac{\sum_{i=1}^{n} m_i^p}{\sum_{j=1}^{n} m_j^f}$
Biorefinery water-mass index(MI_B^w)	$MI_B^w = \frac{\sum_{i=1}^{n} m_i^p}{\sum_{j=1}^{n} m_j^w + \sum_{j=1}^{n} m_j^f}$
Biorefinery reagents-mass index (MI_B^r)	$MI_B^r = \frac{\sum_{i=1}^{n} m_i^p}{\sum_{j=1}^{n} m_j^r + \sum_{j=1}^{n} m_j^f}$
Biorefinery co-products and by-products-mass index ($MI_B^{cop-byp}$)	$MI_B^{cop-byp} = \frac{\sum_{i=1}^{n} m_i^{cop} + \sum_{i=1}^{n} m_i^{byp}}{\sum_{j=1}^{n} m_j^f}$

Where:
i: Denotes the species i, referring to products, co-products and by-products.
j: Denotes the species j, referring to feedstock, water and reagents.
m: Denotes the mass flow rate of feedstock, water, reagents, products, co-products and by-products, and superscripts f, w, r, p, cop and byp denote feedstock, water, reagents, products, co-products and by-products, respectively.

Methodology

4. Characterization indices

ENERGY INDEX

Biorefinery energy index by equipment ($EnI_{B-equip}$)

$$\mathrm{EnI_{B-equip}} = \frac{\sum_{j=1}^{n} \mathrm{En}_j^{\mathrm{equip}}}{\sum_{j=1}^{n} \mathrm{m}_j^{\mathrm{f}}}$$

Where:
En: Denotes the heat duty required by equipment.

ECONOMIC INDEX

Biorefinery economic index (EcI_{B1})

$$\mathrm{EcI_B} = \frac{\sum_{i=1}^{n} \mathrm{pc}_i^{\mathrm{p}}}{\sum_{j=1}^{n} \mathrm{sp}_j^{\mathrm{p}}}$$

Where:
pc: Denotes the production cost of products and superscript p denotes products.
sp: Denotes the sale price of products and superscripts p denotes products.

Results and discussion

Biorefinery complexity index

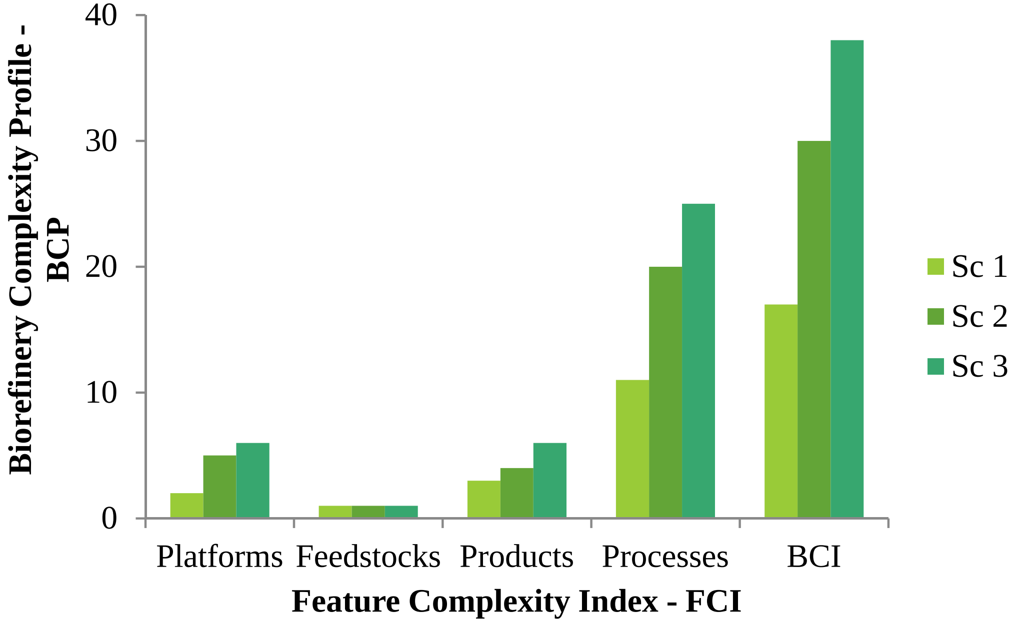


Figure 2. Biorefinery complexity profile of SC biorefineries.

$$\text{Sc. } 1 \rightarrow 17(2/1/3/11)$$
$$\text{Sc. } 2 \rightarrow 30(5/1/4/20)$$
$$\text{Sc. } 3 \rightarrow 38(6/1/6/25)$$

As it can be seen, the addition of new processes lines(xylitol and PHB) to the base scenario influences positively the BCP increasing their values, mainly the number of platforms and processes.

It means that the scenarios 2 and 3 have higher conversion capacity and are more complex than scenario 1.

Results and discussion

Mass indices

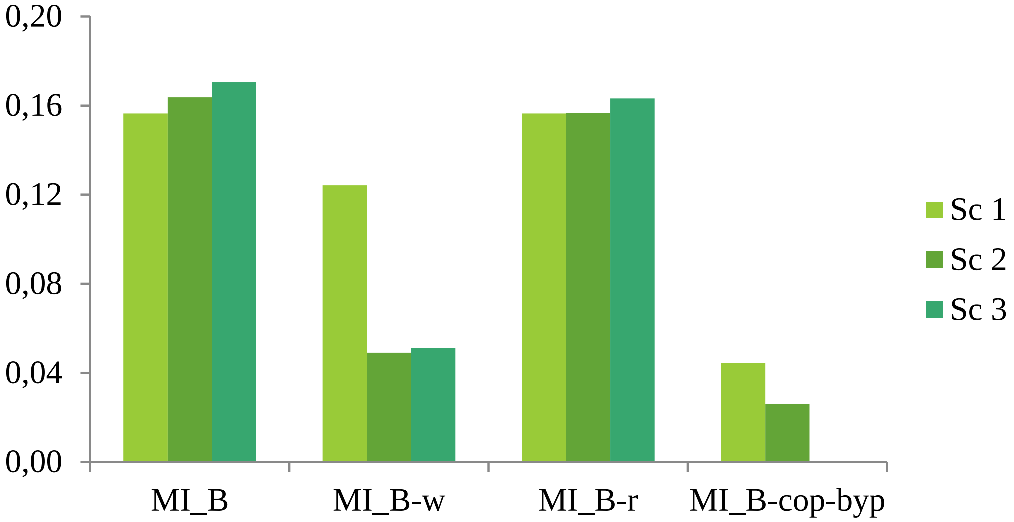


Figure 3. Mass indices for SC biorefineries.

- The MI_B presents an upward trend, as the products are added in each scenario this index increases in logic way, improving the global yield of biorefinery.

- The addition of products in the scenarios 2 and 3 affects the MI_B^w, reporting lower values than base scenario. Scenarios 2 and 3 consider the pretreatment stage of sugarcane bagasse, which demands large volumes of liquids in order to extract sugars from lignocellulosic material that are the substrate to obtain xylitol and PHB.

Results and discussion

Energy index

Scenario 1 → 8.16MJ/kg

Scenario 2 → 13.24MJ/kg

Scenario 3 → 15.76MJ/kg

The amount of required energy in each scenario is directly proportional to the addition of products.

The energy requirements by equipment increase with the number of products. As it can be seen, the values obtained for scenarios 2 and 3, the addition of pretreatment stage of SCB, xylitol and PHB production contribute significantly to energy demand of biorefineries affecting negatively the energy index. However, the cogeneration system considered in the biorefinery mitigates these requirements with the production of low and medium pressure steam.

Results and discussion

Analysis EcI_B vs processing capacity

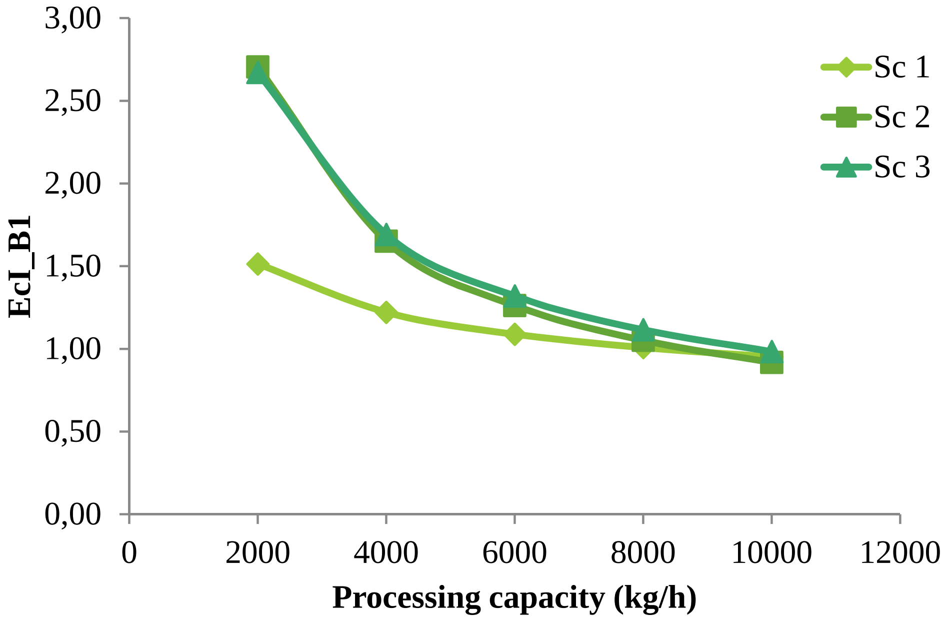


Figure 4. Economic index vs processing capacity for SC biorefineries.

The decreasing of processing capacity affects in negative way the economic index of all scenarios. The addition of xylitol and PHB to scenarios 2 and 3 increases the economic index making the systems unfeasible economically. However, if the biorefineries consider processing capacities higher than 10 ton h^{-1} exists the probability to obtain better economic results.

The biorefinery is not feasible from economic point of view if it is carried out to low scale.

Conclusions

- The characterization indices allowed doing an elemental analysis of technical and economic feasibility in the generation of a preliminary screen during the conceptual design of SC biorefineries. The characterization indices are presented as a practical tool that involves easy and understandable calculations.

- According to the obtained results, the use of SCB as additional platform in the sugar mills for the obtaining of added-value products present better economic opportunities in comparison to cases when only it is dedicated to the electricity generation, considering high processing scales.

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Thank you

ccardonaal@unal.edu.co

Questions