Techno-economic and environmental assessment of an integrated biorefinery from two plantain processing residues: Pseudostem and Peel

CARLOS ARIEL CARDONA ÁLZATE M.Sc. PhD.

RESEARCH GROUP OF CHEMICAL, CATALYTIC AND BIOTECHNOLOGICAL PROCESSES

UNIVERSIDAD NACIONAL DE COLOMBIA SEDE MANIZALES

Project Partners

UNIVERSIDAD NACIONAL DE COLOMBIA
SEDE MANIZALES

GOBIERNO DE ESPAÑA
MINISTERIO DE ECONOMÍA Y COMPETITIVIDAD
Ciemat
Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

LNEG

Colsnacks
Fritos y Precocidos de Colombia

INTA

PONTIFICIA UNIVERSIDAD CATOLICA DE VALPARAISO
CHILE

STRADALUX
systems

Instituto de Biotecnología
UNIVERSIDAD NACIONAL AUTONOMA DE MEXICO

WIP

·C·A·D·O·V·A·
Cooperativa Agrícola do Vale de Arraiolos, CRL

Outline

- Bioenergy in Colombia
  - Residues from the Plantain crop
- Integrated Biorefinery
  - Plantain Pseudostem Biorefinery
  - Plantain Peel Biorefinery
- Results
- Final Remarks

Bioenergy in Colombia

Figure 1. Bioenergy in Colombia

Colombia has been gaining ground in the production of liquid first-generation biofuels, and it is starting to bet on the development of projects that encourage the use of organic waste for bioenergy.

Ethanol

The production of ethanol in Colombia was 456.4 million of Liters in 2015.

Biogas

Most of the biogas in Colombia is produced from wastewater treatment sludge which is a useful raw material for biogas production.

Plantain Pseudostem (PP)

The plantain pseudostem is the non-edible part of the plantain plant, it represents 50 % of total biomass.

7.3 million tons of plantain pseudostem produced in 2014.

Plantain Pseudostem is used for nutrient assistance of new plants. But also in the paper fabrication at very low scales and in this project, as raw material for the production of sugars to obtain other added-value products

Figure 2. Plantain Pseudostem

Table 1. Chemical Composition PP

Component	% dry basis
Cellulose	43.46
Hemicellulose	33.77
Lignin	20.14
Extractives	2.5
Ash	0.14

Plantain Peel

Figure 3. Plantain Peel

Represents between 30% and 40% of the total fruit weight.

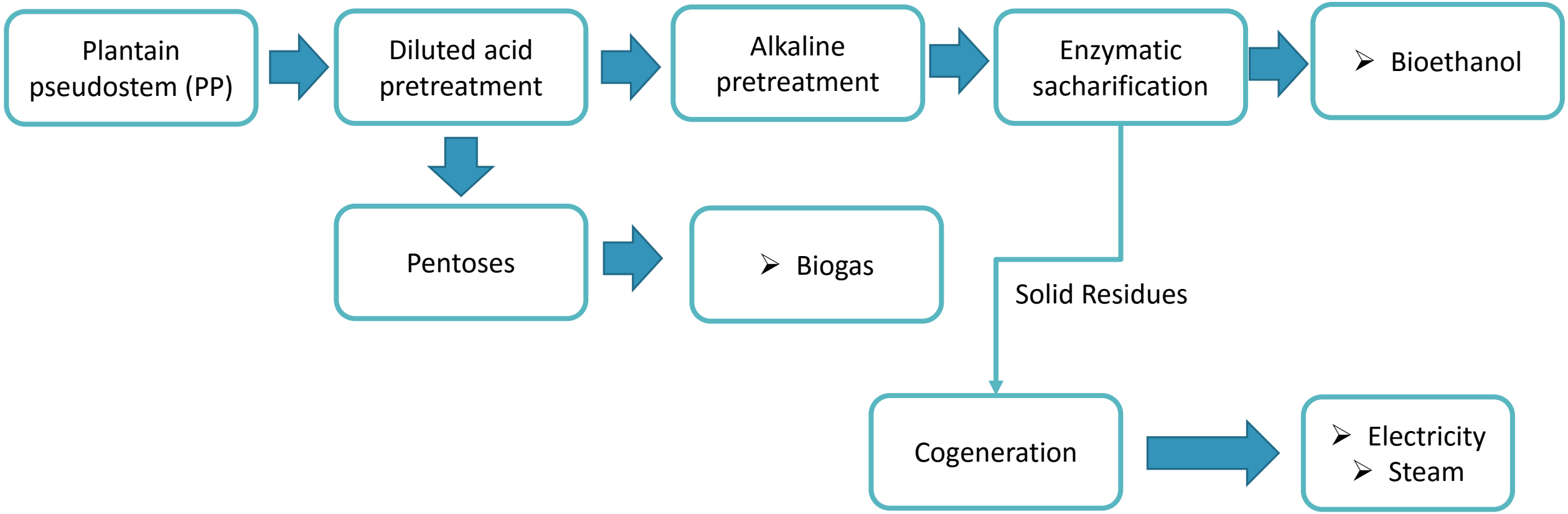
Approximately 1 kilogram of plantain bunches produces 360 grams of plantain peel.

Main Applications → Starch extraction for the food industry, extraction of phenolic compounds and antioxidants

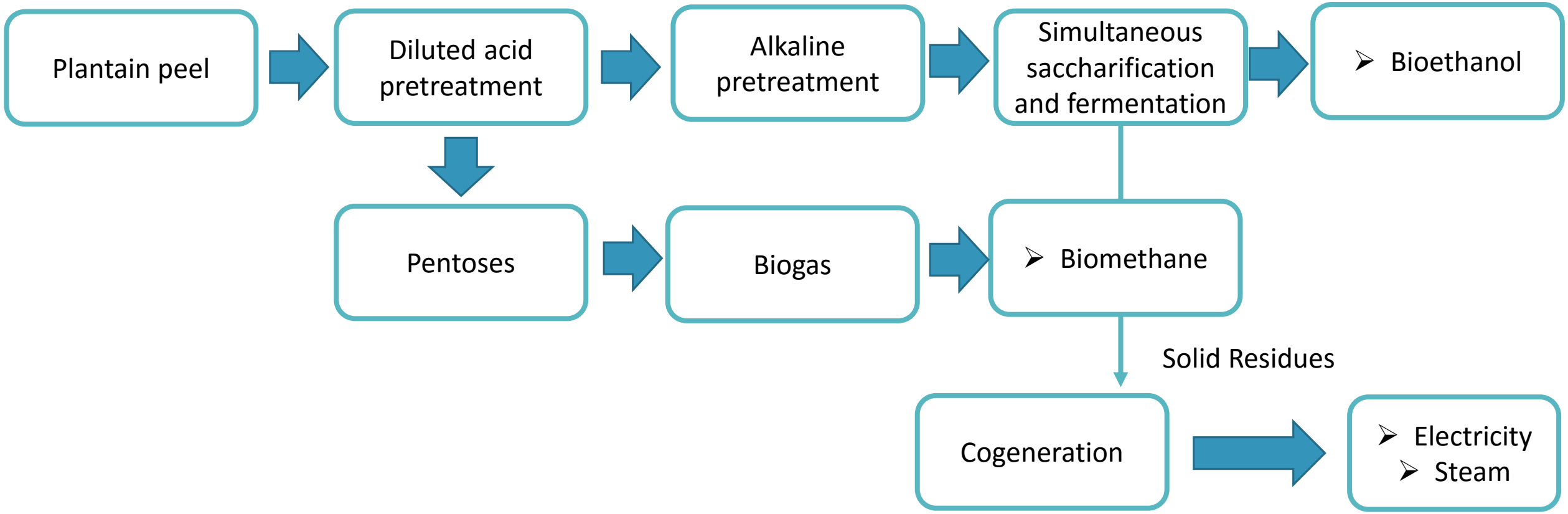
Table 2. Normalized Chemical Composition of Plantain Peel not accounting starch and water. (5.7% and 81% on wet basis)

Component	% dry basis
Cellulose	27.7
Hemicellulose	22.7
Lignin	27.9
Crude Protein	7.4
Extractives	7.9
Ash	6.4

Plantain Pseudostem Biorefinery



Plantain Peel Biorefinery



Plantain Pseudostem Biorefinery

Acid Hydrolysis
Sulfuric Acid 2%w/w
Temperature = 122°C
Water to Solid Ratio (WSR) = 8g/g

Detoxification
Overliming with Lime
Temperature = 60°C

Alkaline treatment
NaOH 2 %w/v
Temperature = 120°C
Water to Solid Ratio = 10 g/g

Enzymatic Saccharification
Celluclast 1.5L
Temperature = 45°C
Biomass to Enzyme Ratio = 2% w/v

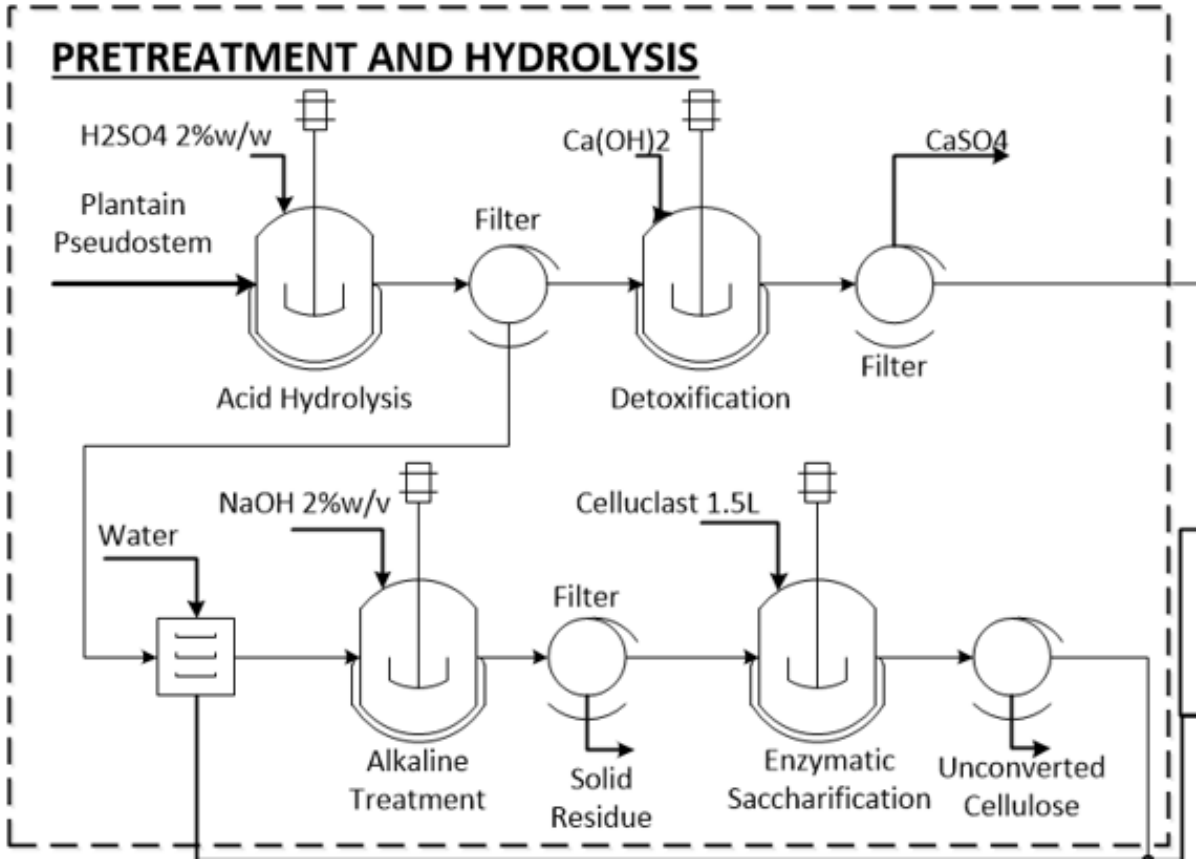


Figure 4. Pretreatment Process Scheme

Plantain Pseudostem Biorefinery

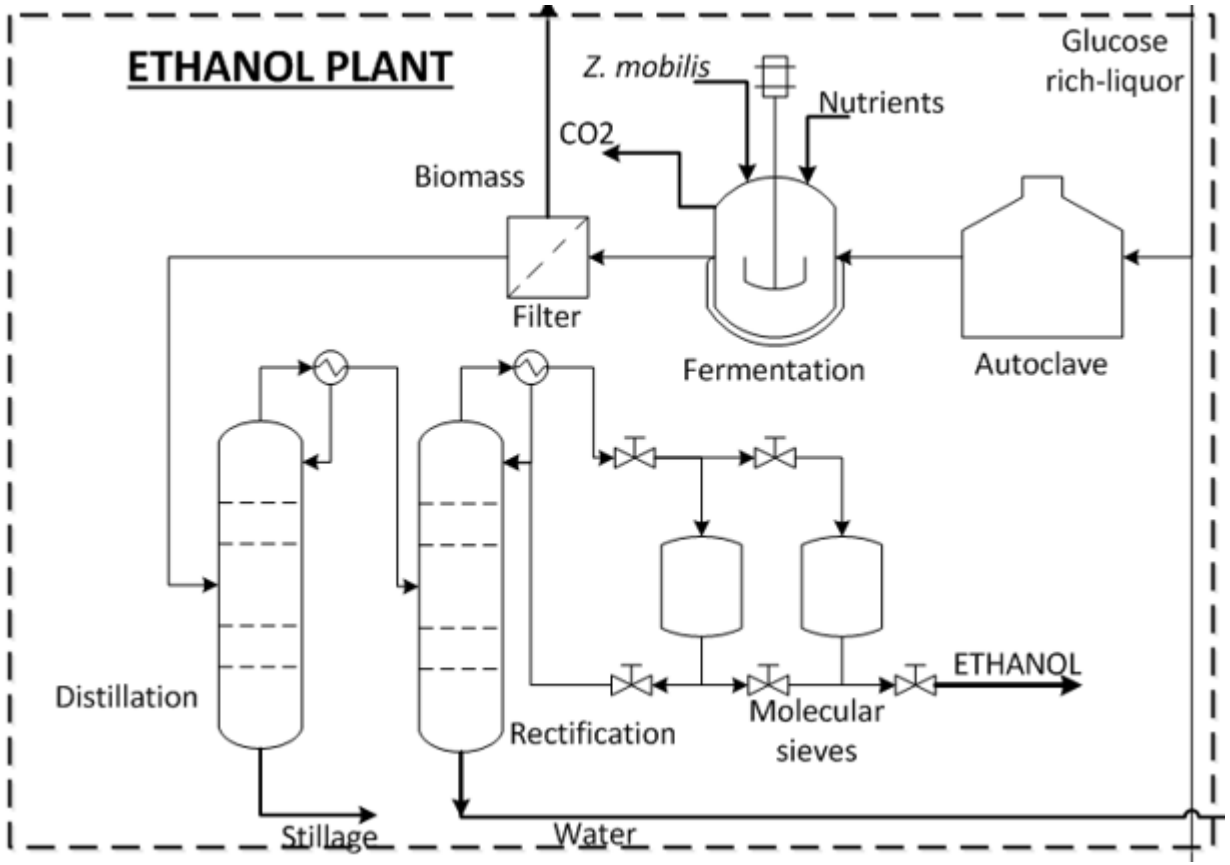


Figure 5. Ethanol Process Scheme

Fermentation

Microorganism = *Z. mobilis as the best technology option*

Temperature = 30°C

Downstream

Distillation column = Ethanol 50-55%wt.

Rectification column = 96%wt.

Molecular Sieves = 99.7%wt.

Plantain Pseudostem Biorefinery

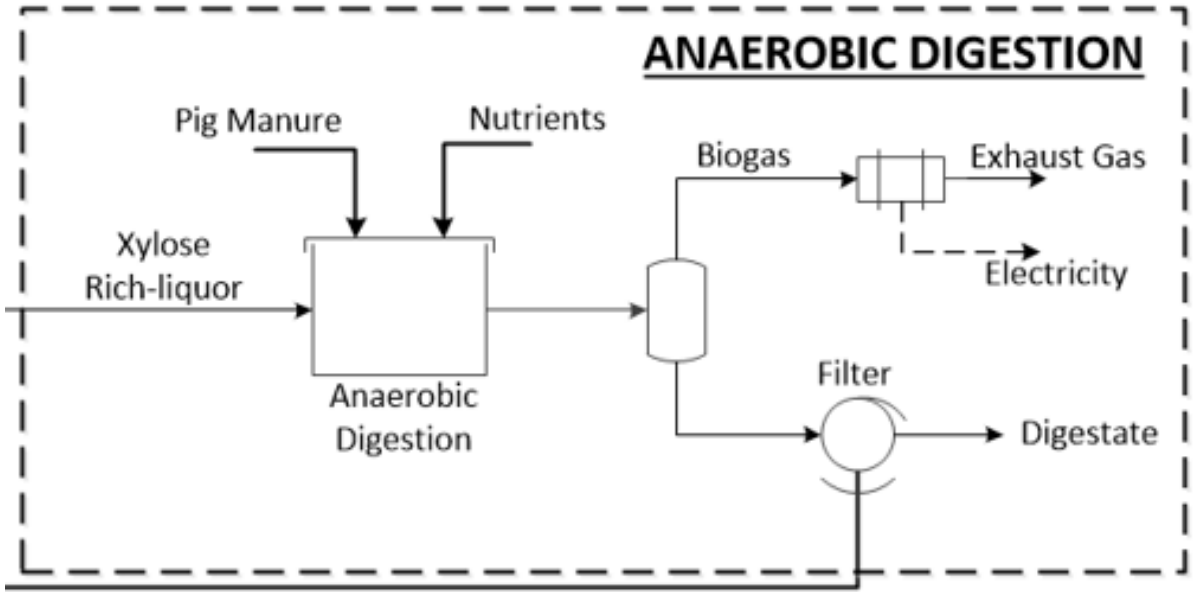


Figure 6. Anaerobic Digestion Process Scheme

Anaerobic Digestion

Inoculum = Pig Manure
Substrate to Inoculum Ratio = 1:2
Temperature = 37°C
Electricity generation from biogas = 1.7 kWh/cum biogas

Plantain Peel Biorefinery

Acid Hydrolysis
Sulfuric Acid 2%w/w
Temperature = 122°C
Water to Solid Ratio (WSR) = 10 g/g

Detoxification
Overliming with Lime
Temperature = 60°C

Alkaline treatment
NaOH 1 %w/v
Temperature = 121 °C
Water to Solid Ratio (WSR) = 8 g/g

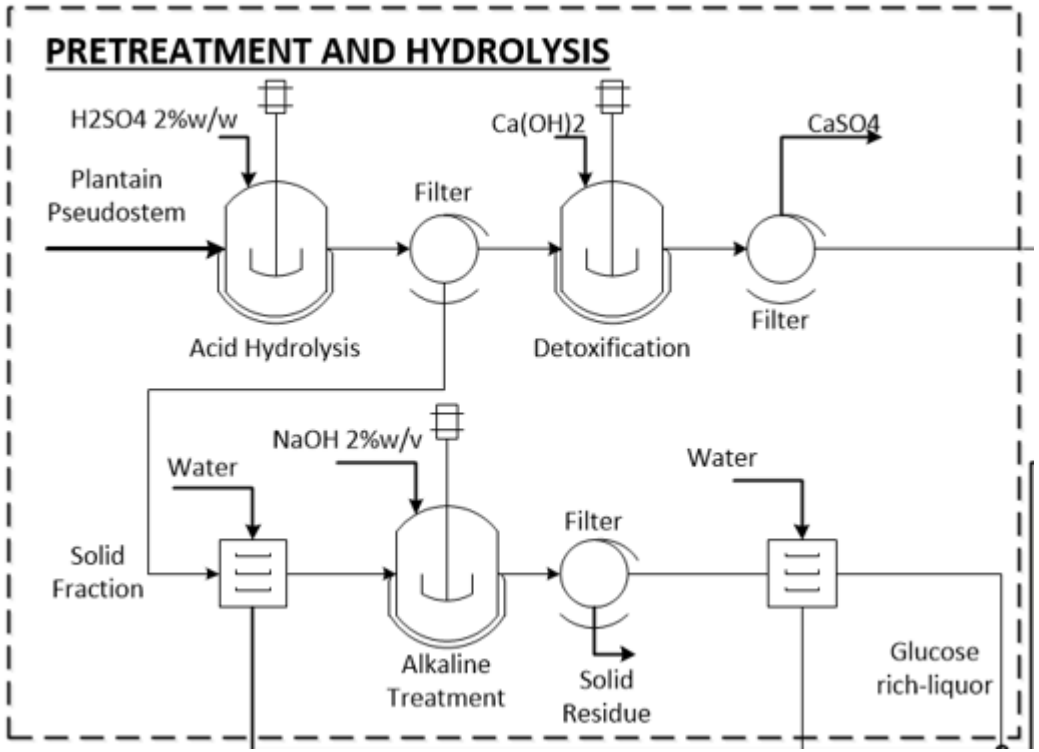


Figure 7. Pretreatment Process Scheme

Plantain Peel Biorefinery

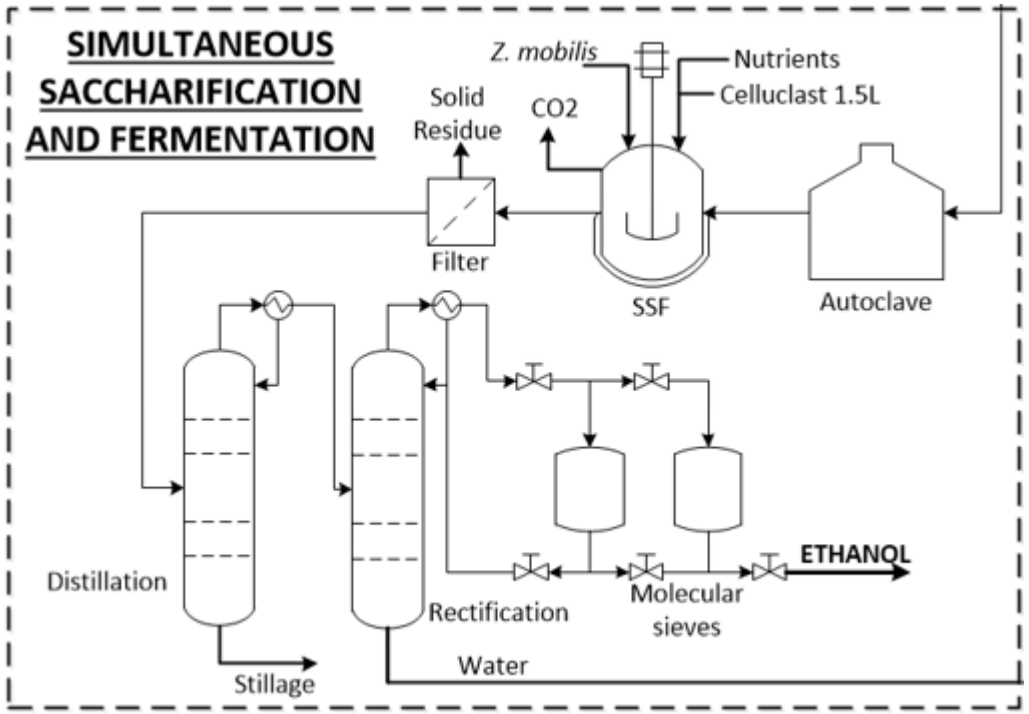


Figure 8. Simultaneous saccharification and fermentation Process Scheme

Simultaneous saccharification and fermentation

Enzyme = Celluclast 1.5L

Temperature = 40°C

Biomass to Enzyme Ratio = 2% w/v

Microorganism (ethanol) = Saccharomyces Cerevisiae

Plantain Peel Biorefinery

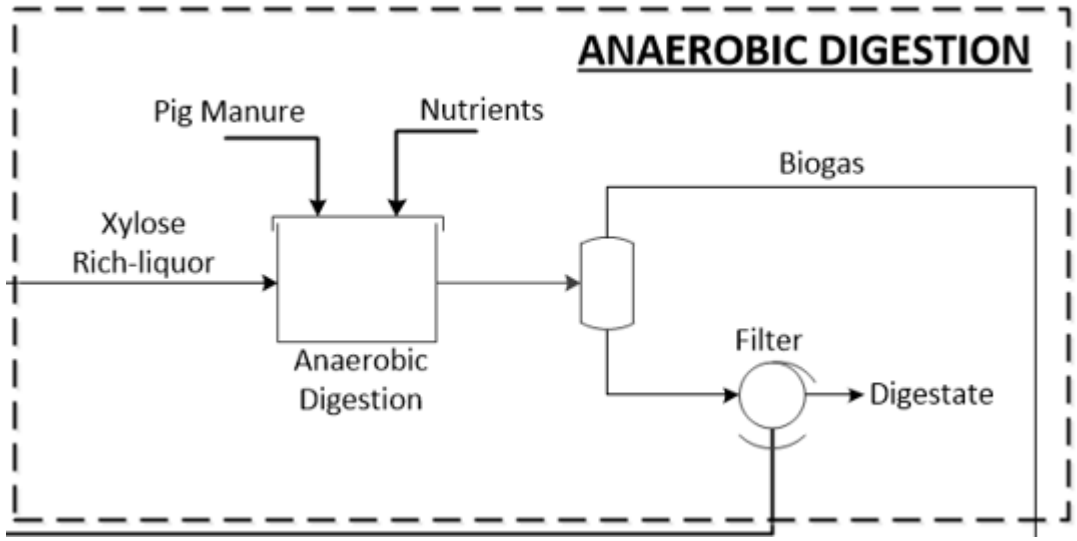


Figure 9. Anaerobic Digestion Process Scheme

Anaerobic Digestion
Inoculum = Pig Manure
Substrate to Inoculum Ratio = 1:2
Temperature = 37°C
Electricity generation from biogas = 1.7 kWh/cum biogas

Plantain Peel Biorefinery

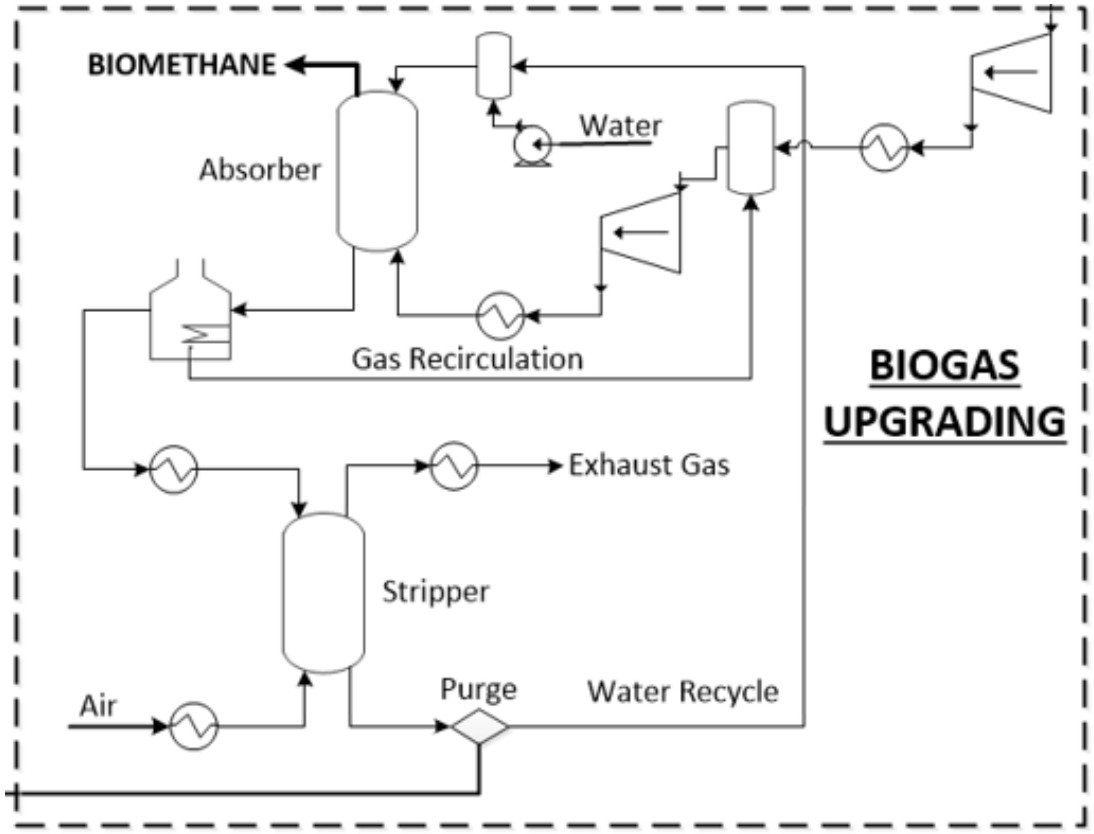


Figure 10. Biomethane Process Scheme

Biogas Upgrading (Absorption and Stripping)

Absorber
Pressure = 10 bar
Temperature = 20°C
Absorption agent = Water

Stripper
Pressure = 1 bar
Temperature = 20°C
Stripping Agent = Air

Biomass integrated gasification combined cycle (BIGCC)

Biomass dryer, gasification chamber, gas turbine and heat steam recovery generator (HRSG)

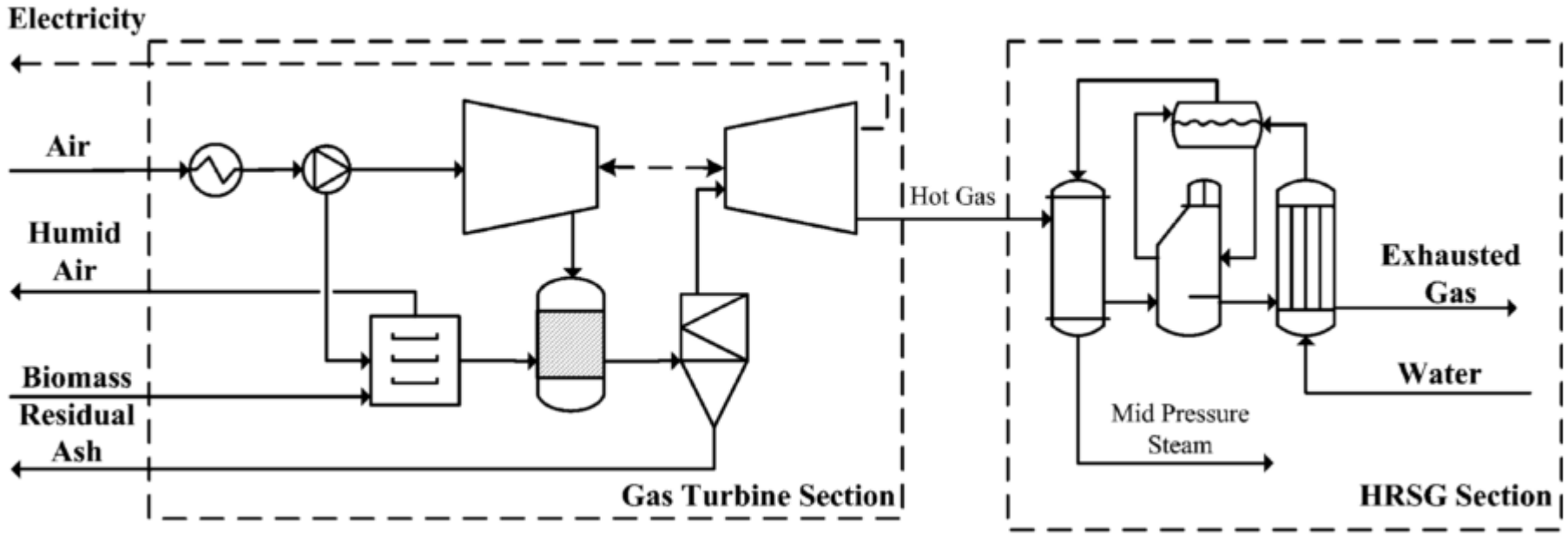


Figure 11. Cogeneration Process Scheme

Process Simulation

Table 3. Bioethanol productivity and yield of the integrated biorefinery

Raw Material	Productivity		Yield	
	Value	Unit	Value	Unit
Plantain Pseudostem	66.4	m^3/day	102.9	L/ton
Plantain Peel	44.0	m^3/day	68.4	L/ton

Table 4. Electricity generation from the Pseudostem Biorefinery

Products	Productivity		Yield	
	Value	Unit	Value	Unit
Electricity	4.0	MW	15.1	kWh/ton

Table 5. Biomethane production from the Peel Biorefinery

Products	Productivity		Yield	
	Value	Unit	Value	Unit
Biomethane	9.3	MW	34.9	kWh/ton

Economic Assessment

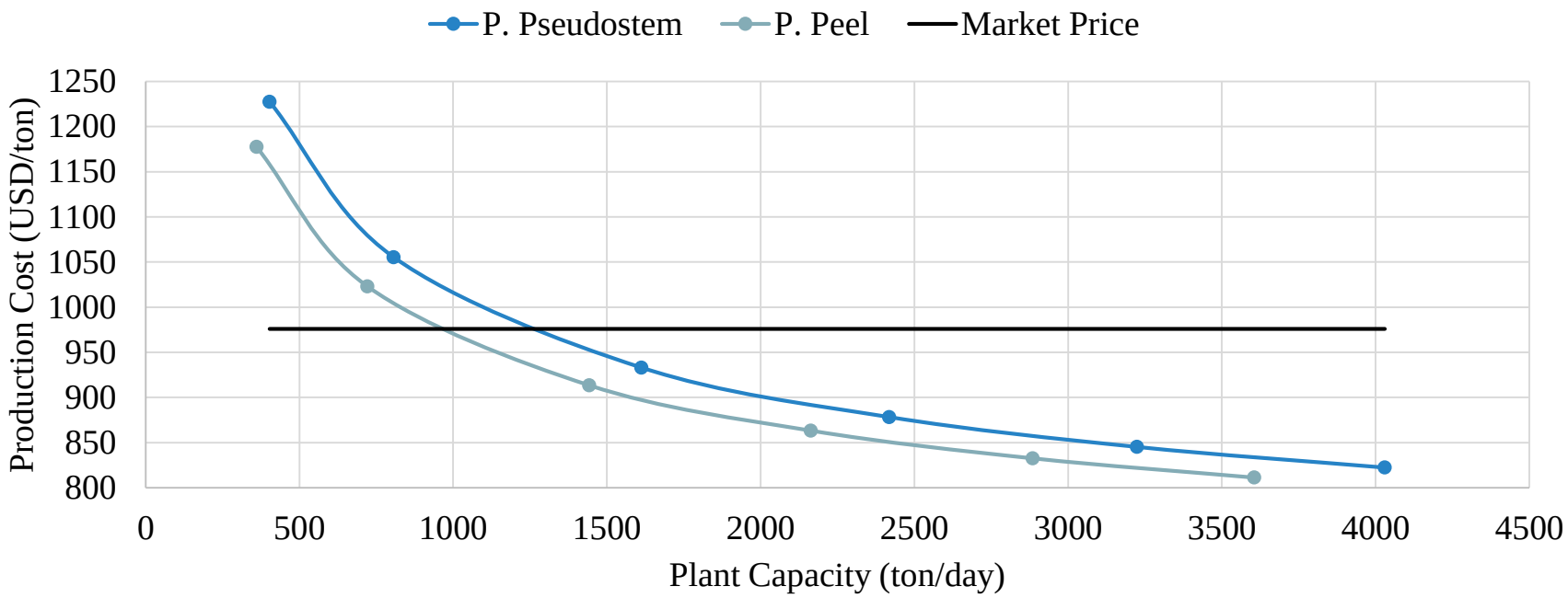


Figure 12. Effect of each plant processing capacity in the production cost of the bioethanol.

Economic Assessment

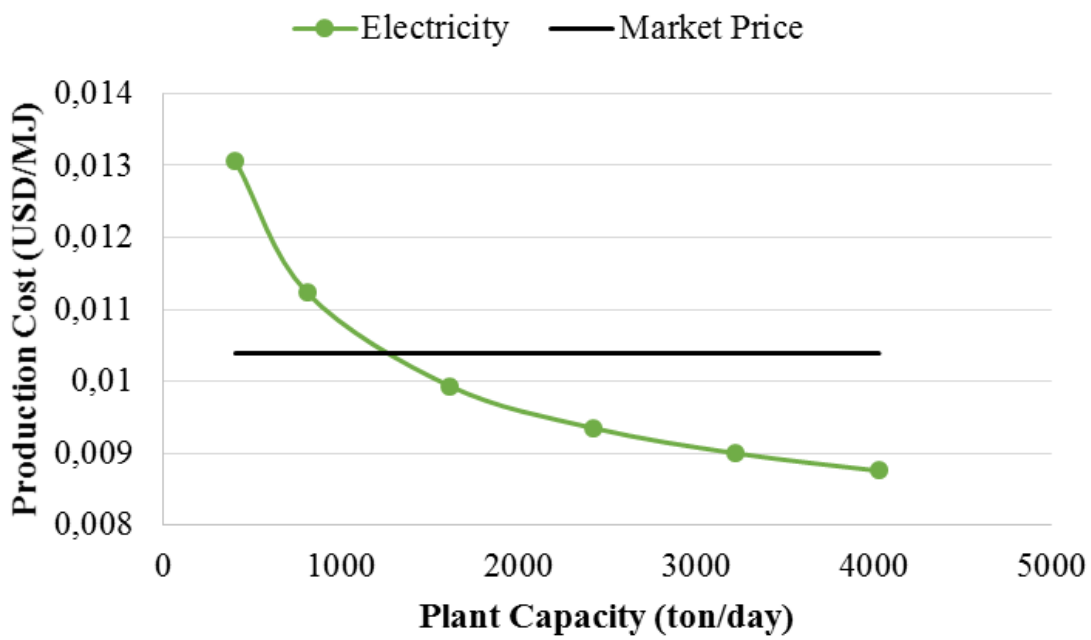


Figure 13. Effect of the plant processing capacity in the electricity production cost

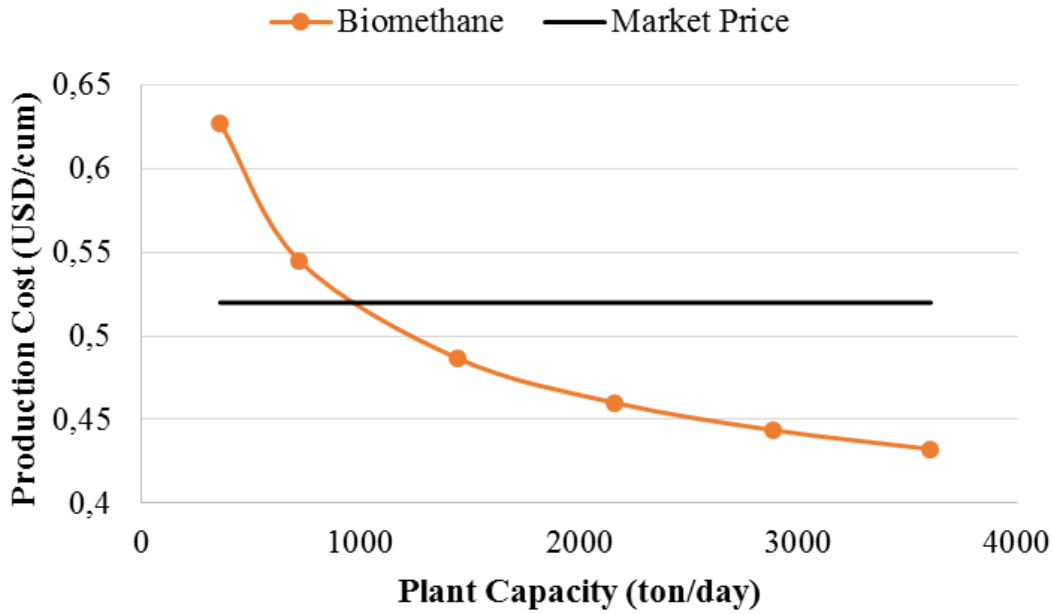


Figure 14. Effect of the plant processing capacity in the biomethane production cost

Economic Assessment

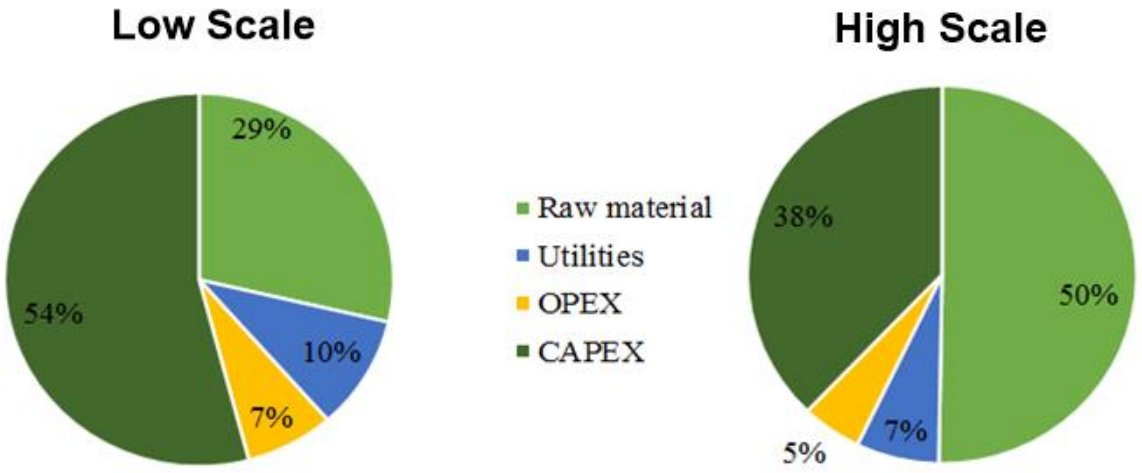


Figure 15. Effect of the process scale in the contribution of the main economic parameters of the pseudostem biorefinery

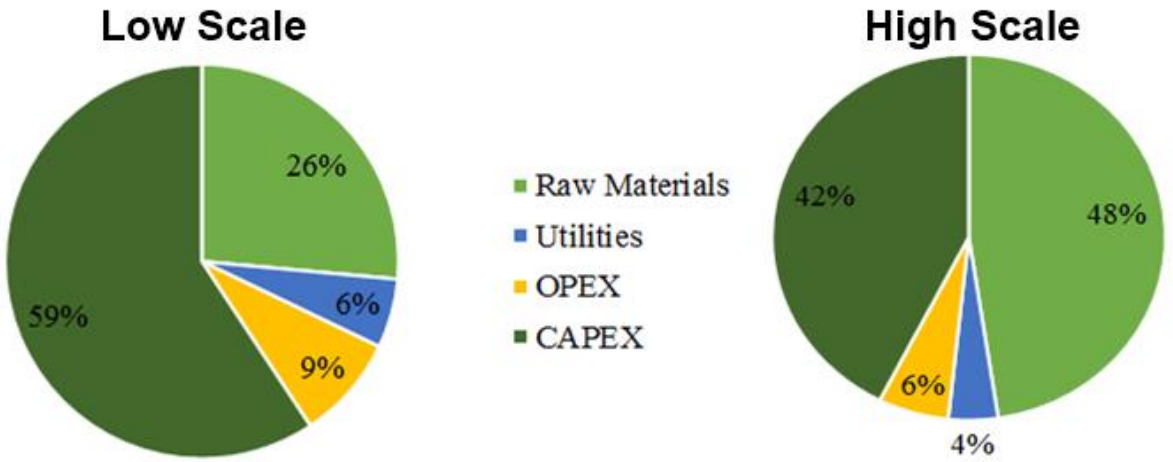


Figure 16. Effect of the process scale in the contribution of the main economic parameters of the plantain peel biorefinery

Economic Assessment

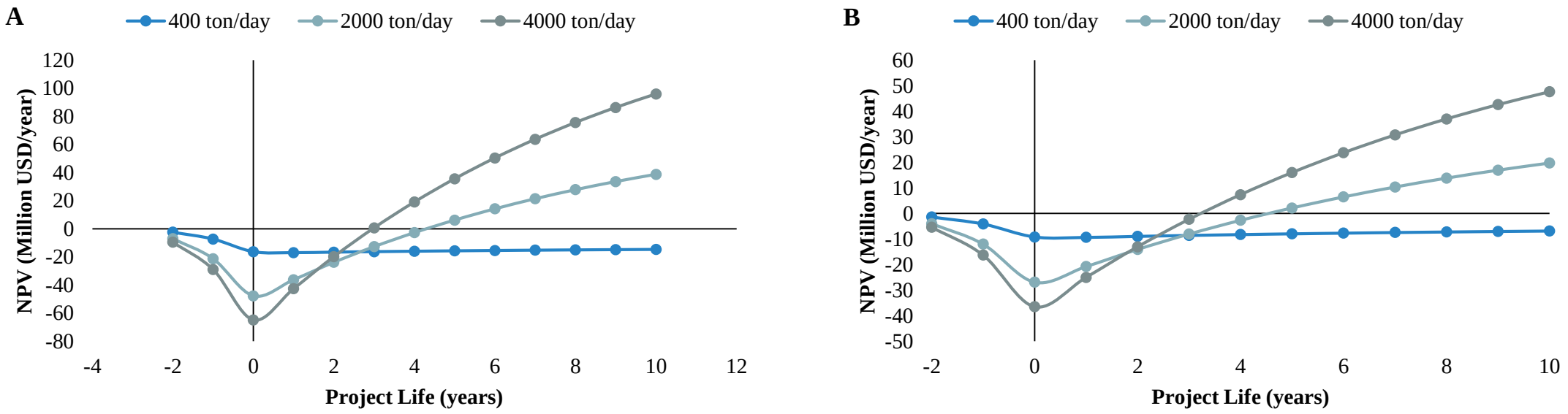


Figure 17. Effect of the plant capacity in the economic profitability of the biorefinery. A. Plantain Pseudostem. B. Plantain Peel

Market Price Sensibility Analysis: Pseudosetm

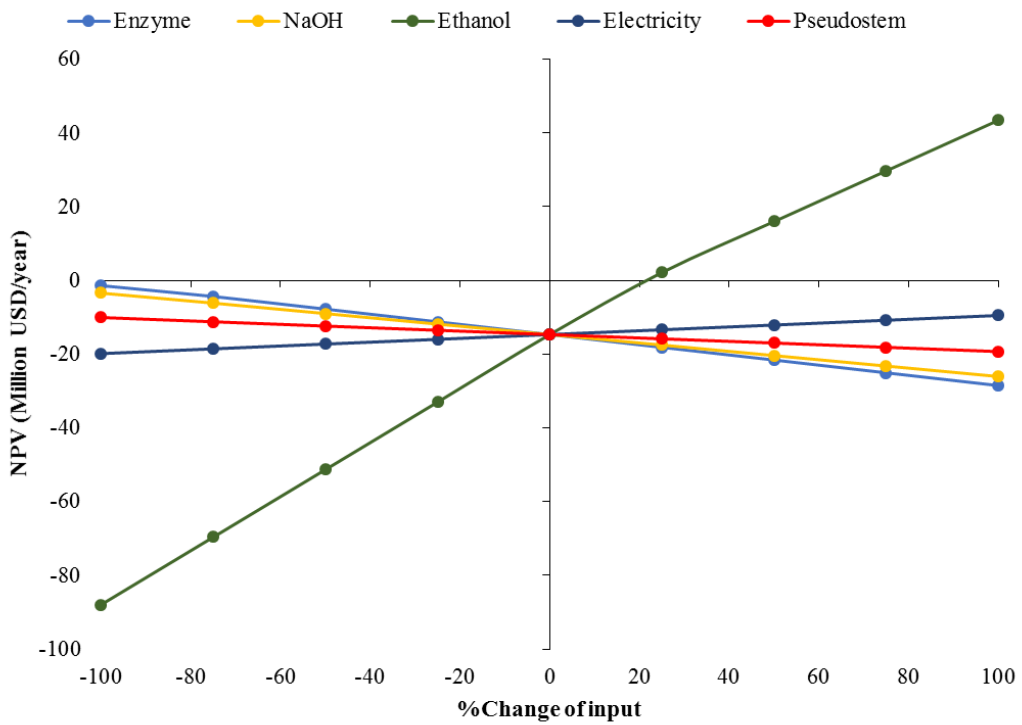


Figure 18. Market Price Variations of low-scale biorefinery (400 ton/day)

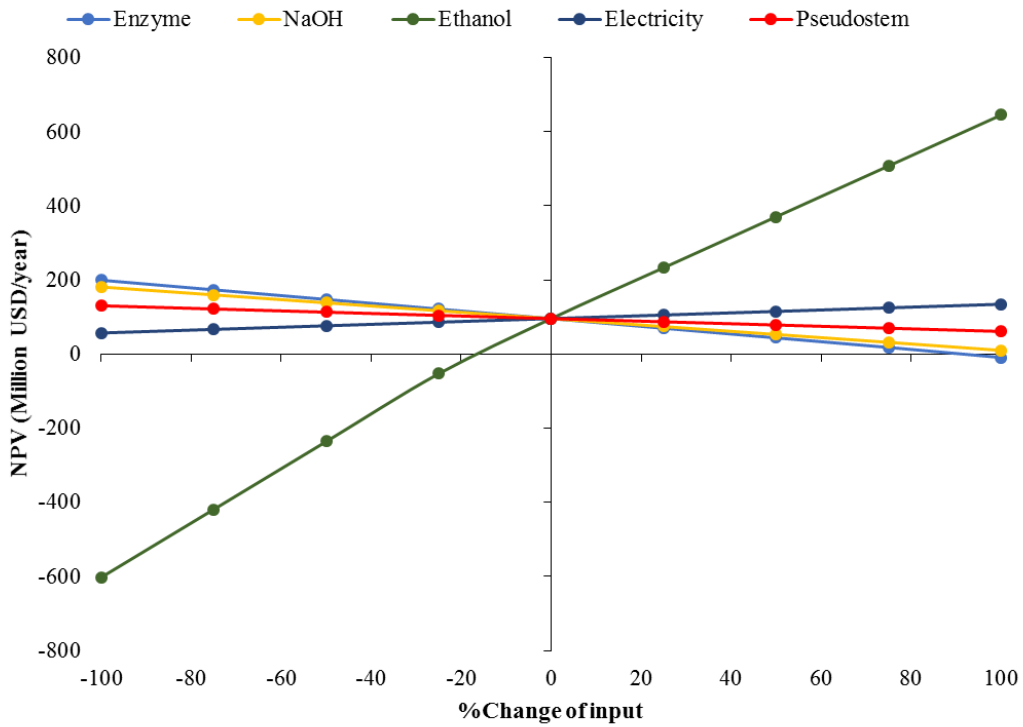


Figure 19. Market Price Variations of high-scale biorefinery (4,000 ton/day)

Market Price Sensibility Analysis: Peel

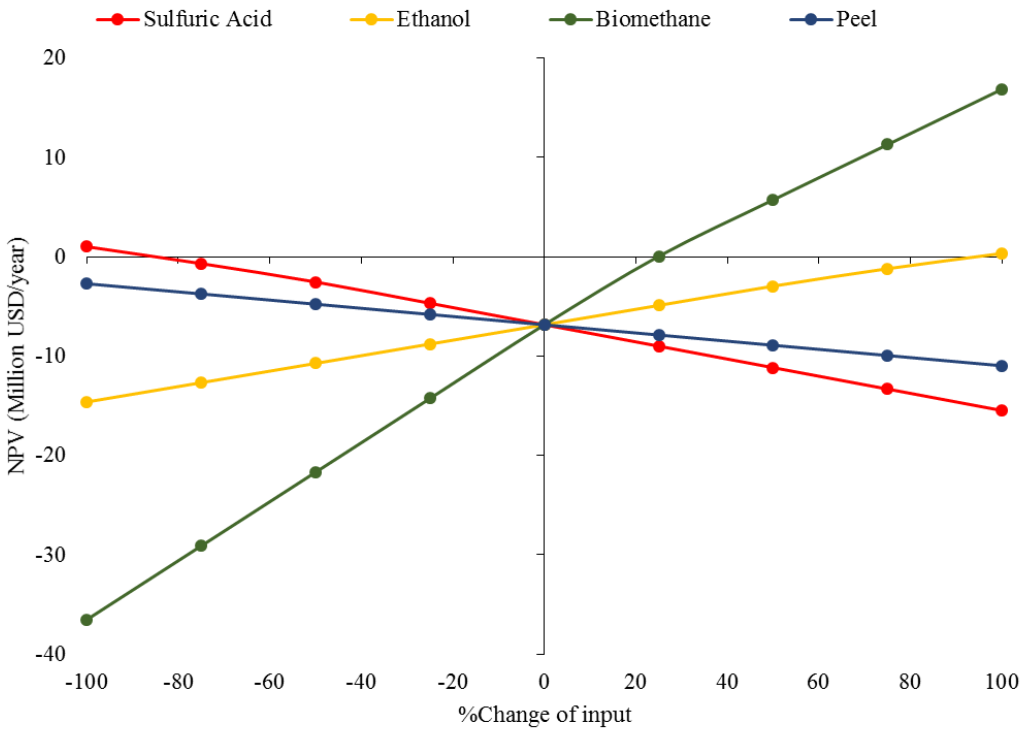


Figure 20. Market Price Variations of low-scale biorefinery (400 ton/day)

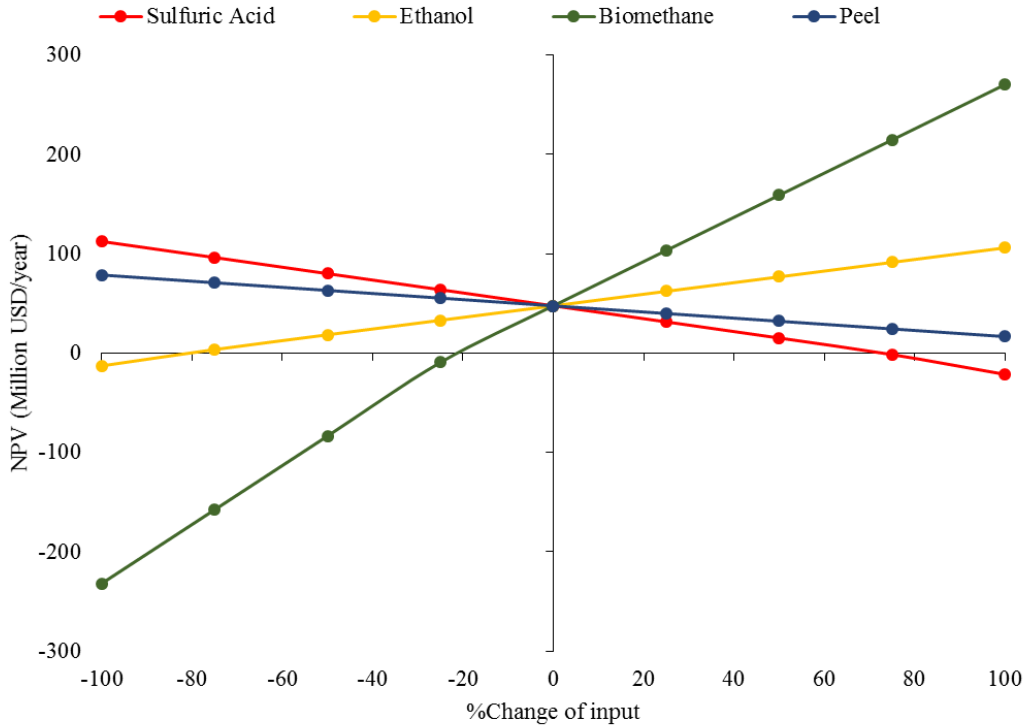


Figure 21. Market Price Variations of high-scale biorefinery (4,000 ton/day)

Environmental Assessment

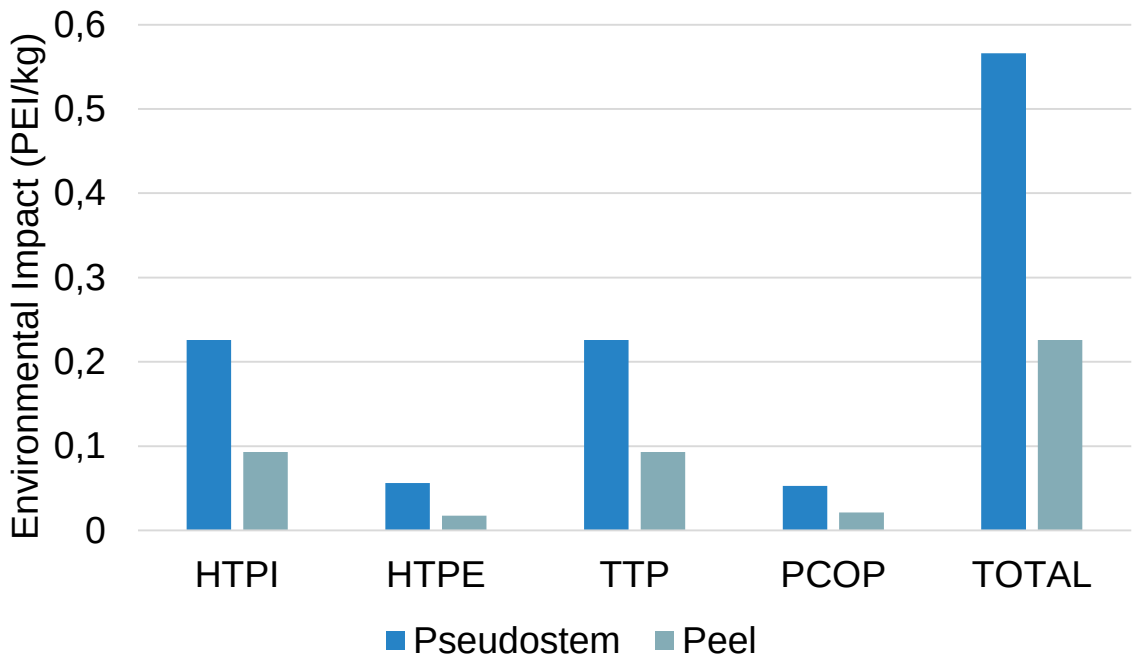


Figure 22. Potential Environmental Impact of the Integrated Biorefinery

High Contribution to PEI

Human Toxicity by Ingestion (HTPI) and Terrestrial Toxicity Potential (TPP)

LD_{50} (Lethal Dose)

Xylose = 23,000 mg/kg

Glucose = 25,800 mg/kg

Conclusions

- The use of residues form plantain allows the production of different types of bioenergy such as bioethanol, biomethane, electricity and steam. However the minimal scales in terms of raw materials needed shlold be considered as high. However the stand alone processes for energy supply in not interconnected zones together with starch and sugars production is an alternative to be analyzed at low scale.
- The production of high added-value products can compensate the productivity problems, such as in the case of the peel biorefinery, where the low ethanol productivity is compensated by biomethane production that actually is of high interest in Colombia.

Thanks for the attendance

Carlos Ariel Cardona Álzate M.Sc. Ph.D
E-mail: ccardonaal@unal.edu.co
Universidad Nacional de Colombia Sede Manizales