Potential of Small scale Biorefineries in tropical countries

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Small-scale integrated Biorefineries for Rural Development in Latin America and Europe Workshop

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Outline

- Context- Introduction
- Definition of scale
- Biorefinery based on plantain
    - Plantain Pseudostem Biorefinery
    - Plantain Peel Biorefinery
- Definition of scale. A more technical approach
    - Cocoyam
    - Andes Berry
- Conclusions

Context

1) Fossil-based economies → Bio-economies

Taken from: goo.gl/4cy5Yh

Taken from: goo.gl/huUYvt

2) "Promoters" for the establishment of bio-economies (De Jong et al., 2012):

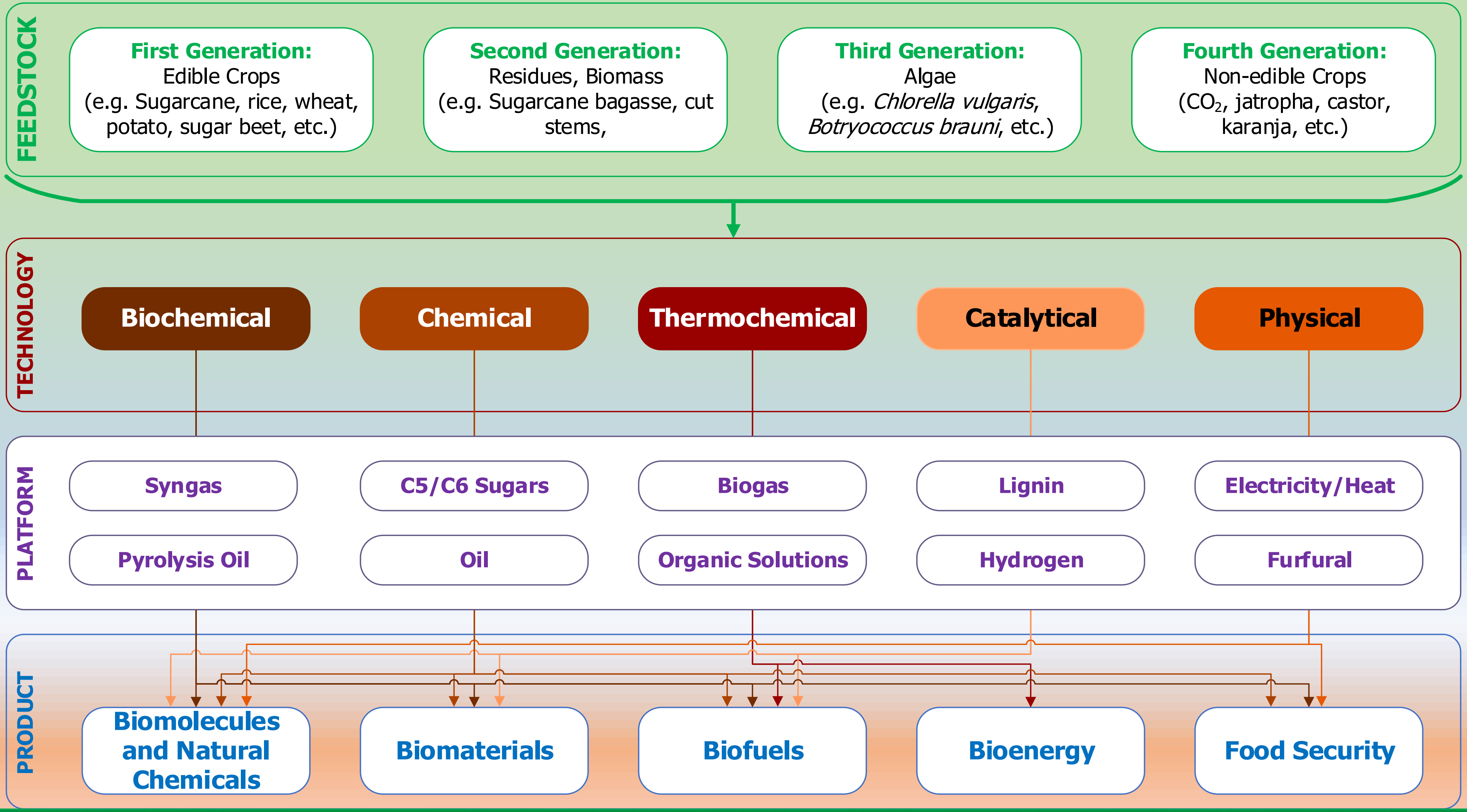
- Dependence on fossil fuels
- Reduction of green-house gases emissions
- Boosting regional/rural development
- More intensive use/exploitation of raw materials

Context

The Biorefinery Concept.

- The biorefinery concept is analogous to that of oil refinery, fractionating biomass into a family of products including biofuels and bioenergy, biomolecules and natural chemical products, biomaterials and food products that preserve food security. All this as a result of a very deep and comprehensive design to avoid what happened with the oil refineries in the past (Dermibas 2009, Cardona 2011, 2017).

Context


FEEDSTOCK
First Generation:
Edible Crops
(e.g. Sugarcane, rice, wheat, potato, sugar beet, etc.)
Second Generation:
Residues, Biomass
(e.g. Sugarcane bagasse, cut stems,
Third Generation:
Algae
(e.g. *Chlorella vulgaris*, *Botryococcus brauni*, etc.)
Fourth Generation:
Non-edible Crops
(CO_2, jatropha, castor, karanja, etc.)
TECHNOLOGY
Biochemical
Chemical
Thermochemical
Catalytical
Physical
PLATFORM
Syngas
C5/C6 Sugars
Biogas
Lignin
Electricity/Heat
Pyrolysis Oil
Oil
Organic Solutions
Hydrogen
Furfural
PRODUCT
Biomolecules and Natural Chemicals
Biomaterials
Biofuels
Bioenergy
Food Security

Context

Looking for potential biorefineries = Sustainable Biorefineries.

Many questions appear….

First Level: Feedstocks

A modern biorefinery must integrate first, second and third generation (even 4th) feedstocks with products in order to ensure sustainability.

- What is the best distribution?.
- What is the Economic, Environmental, Social Impact? i.e. Can sustainability be reached
- TAKE DECISIONS, EVALUATE AND ANALYZE.

Context

Sustainable Biorefineries.

- Include objetives for analysis or optimization, evaluating and analyzing impacts:

- **Environmental:** Liquid, Solid, Gas Emissions. Using tools like WAR Algorithm, Life Cycle Analysis, GHG and Carbon Balance.

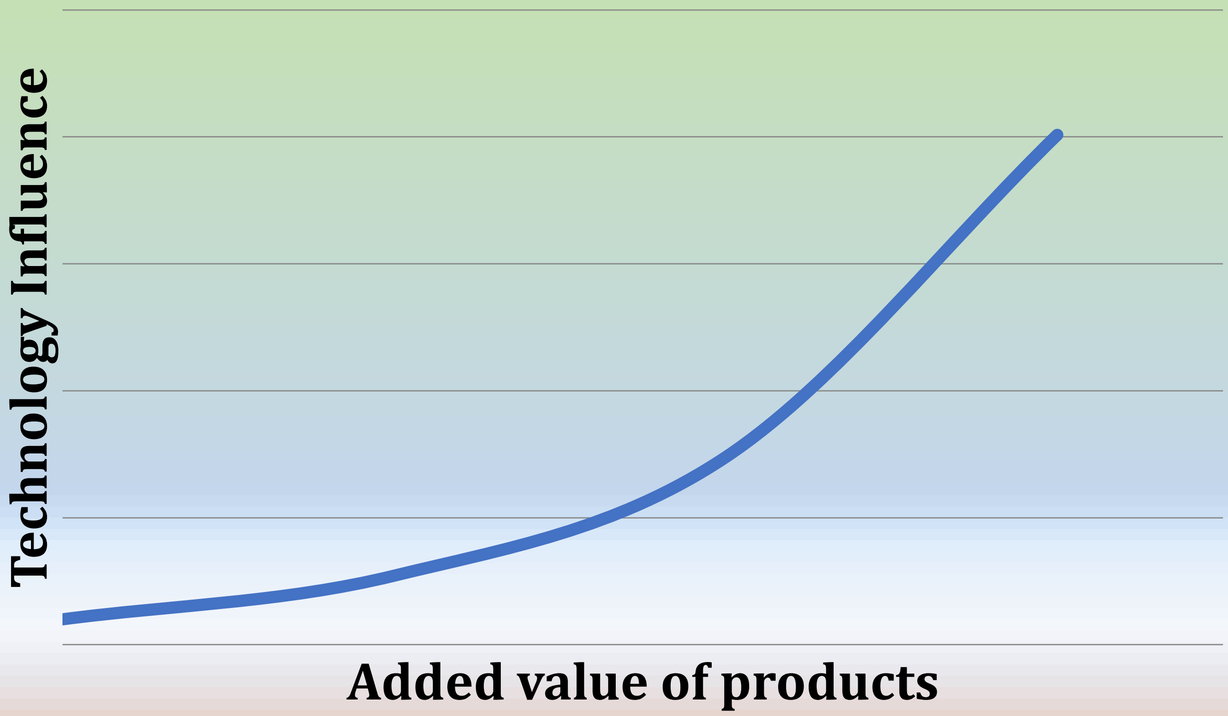
- **Economical:** Rentability of process, feedstocks charges including Logistics, Locations, Supply Chain, Disponibility of raw materials, Operating Charges among others.

- **Technical:** Evaluation of Productivity, Mass and heat balance.

- **Social:** Employment generation capacity at agronomical, industrial and distribution phase.

Context

Biorefineries.
Second Level: Technologies.



Generally the influence of technology depends on the added value of products. For this it is important to include a term that emphasize the influence of different stages of production in order to include integrated analysis of technologies.

Context

Sustainable Biorefineries.

- Process Integration Strategies.

- Level of Integration. Generation of Different Scenarios using mass, heat, separation-reaction, reaction-reaction integration.

Context

Sustainable Biorefineries.
Third Level: Food Security.

Is it feasible to ensure food security through biorefineries?

Aspects to take into account for food security implications.

- Energy Consumption.
- Land use
- High production cost due to source transportation and quality.
- Use of conventional technology that dont follow the green principles.
- The impact of biorefineries emlployment on the quality of life

Context

Biorefineries are designed under specific conditions:
- The typical location for the production of feedstocks is in rural regions and the processing location in other regions with adequate infrastructure in urban zones (Black et al., 2016)

Since the processing facilities have different capacities of production, the operating and capital costs depend on the capacity of the plants.

Context

Processing facilities are established mainly in two schemes (Palmeros Parada et al., 2017; Santibañez-Aguilar et al., 2015):

Secondary processing facilities

> Typically small facilities to reduce transportation costs

Centralized processing industries

> Typically large scales to take advantage of the economies of scale

Context

Economic performance

Production cost

Strong dependence on the scale

Energy consumption and equipment cost increase at different rates compared to production scale

Context

This context shows the importance of a comprehensive analysis of the scale, given the inherent features that will determine the economic performance of a biorefinery if it is operated at a small or a large scale (Kolfschoten et al., 2014)

!

However, there is not a common definition of large or small scale, or which flow determines a large or a small-scale process.

Definitions of scale

According to the supply of raw material

Processing scale: Amount of raw material processed in a period.

Examples:

A biorefinery that processes raw materials as sugarcane, palm, corn and their respective wastes could be considered as large scale, because the amount of feedstock that is available is very high.

Definitions of scale

According to the obtainment of product:

Production scale: Amount of product obtained in a period.

Examples:

A biorefinery that produces bulk chemicals as ethanol, sugar, butanol, biodiesel could be considered as large scale and one that produces lactic acid, PHB, citric acid could be considered as small/medium scale. However a biorefinery producing antioxidants, flavors, FOS, GOS and antibiotics are mainly small production scale

Definitions of scale

Ambiguities in the definitions of scale…

Consider a process to obtain a given metabolite from the peel of a fruit.

- Given the amount of the product in the peel, the production volume will be low because it is a fine or specialty (small scale).
- Given the low concentration of the product in the peel, it is necessary to process a considerable high amount of raw material. In that case, the scale of the process would be higher.

Therefore, it could be argued that the process has two different scales.

The main problem is that the term "scale" is used indistinctly to refer for the amount of raw material or product.(Serna Loaiza et al., 2017)

Definitions of scale

Small-Scale Biorefineries

The small-scale biorefineries are the new trend in design because these operations sometimes are unfeasible in large scale due to its production cost or market restrictions in quantity.

Small-scale biorefineries are affected by external factors such as:

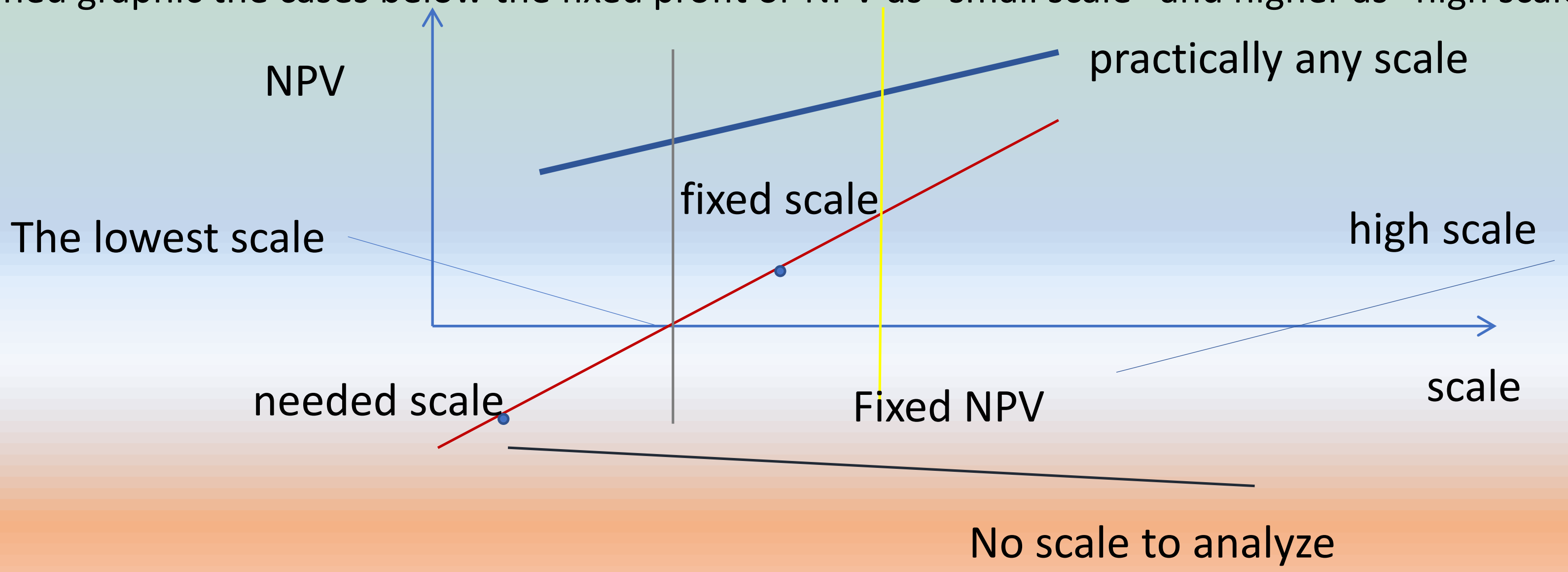
- ✓Government policies.
- ✓Environmental considerations.
- ✓Market conditions.
- ✓Transportation and Distribution costs.

Definitions of scale

How to define the small or high scale biorefinery. A technical approach.

Algorithm

1. Calculate your desired biorefinery at any scale.
2. Analyze the production costs, profit and net present value (NPV)
3. Develop the point 2 at different scales and fix the profit or NPV you want.
4. Define in the obtained graphic the cases below the fixed profit or NPV as “small scale” and higher as “high scale”.



Definitions of scale

How to define the small or high scale biorefinery. A technical approach.

Algorithm (cont)

5. Based on conceptual design, transform the lower profit or NPV for small scale biorefineries as a challenge for your design: How can we make these small scale cases as profitable?:

- Integration
- Increase the number or fraction of high value added products
- Technology changes

6. Redefine your problem or target as needed and repeat points 1-4.

Definitions of scale

Overall Methodology

Raw material selection

Experimental section

Process design according to the raw material POTENTIAL

Technical simulation using Aspen

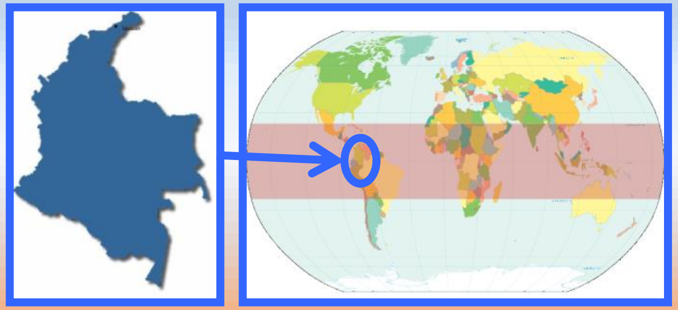
Economic assessment using Aspen Process Economic Analyzer

Environmental assessment using WAR GUI software

POTENTIAL

Some of the thousands of Agricultural Residues in a tropical country as Colombia

Crop	Residue	Residues Generated [ton/year]
Coffee	Coffee Pulp	301.848
	Spent Coffee	257.962
Cocoa	Cocoa Husks	59.756.000
Rice	Rice Husks	562.964
Plantain	**Plantain Pseudostem**	**1.699.137**
Cassava	Cassava stem	91.335



CASE 1. PLANTAIN

Example 1 Plantain Pseudostem (PP)

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

7.3 million tons of plantain pseudostem was produced in 2014

Plantain Pseudostem is used for nutrient assistance of new plants. But also in the paper fabrication and currently, 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

Example 2. 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

Applications studies

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

Table 2. Chemical Composition Plantain Peel

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

2. PROCESS DESCRIPTION

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

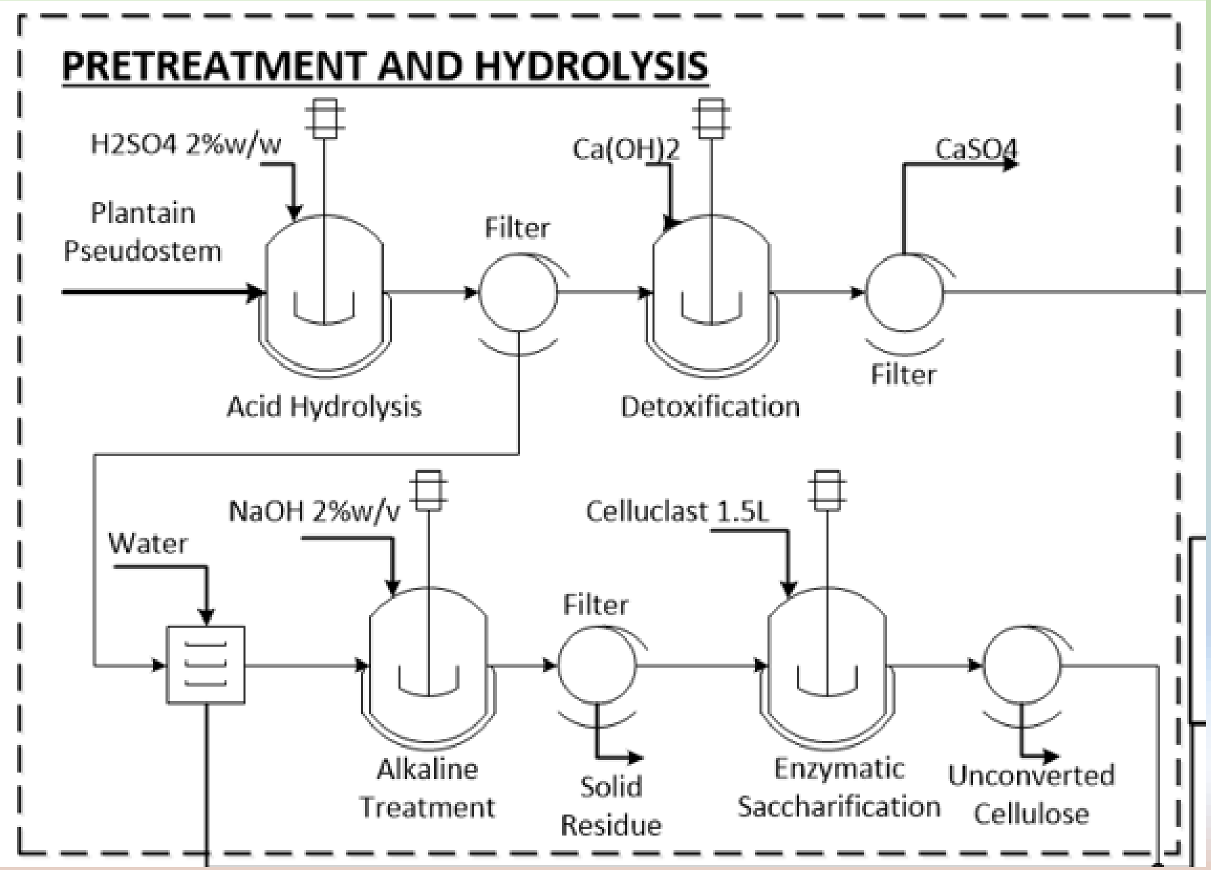


Figure 4. Pretreatment Process Scheme

2. PROCESS DESCRIPTION

Plantain Pseudostem Biorefinery

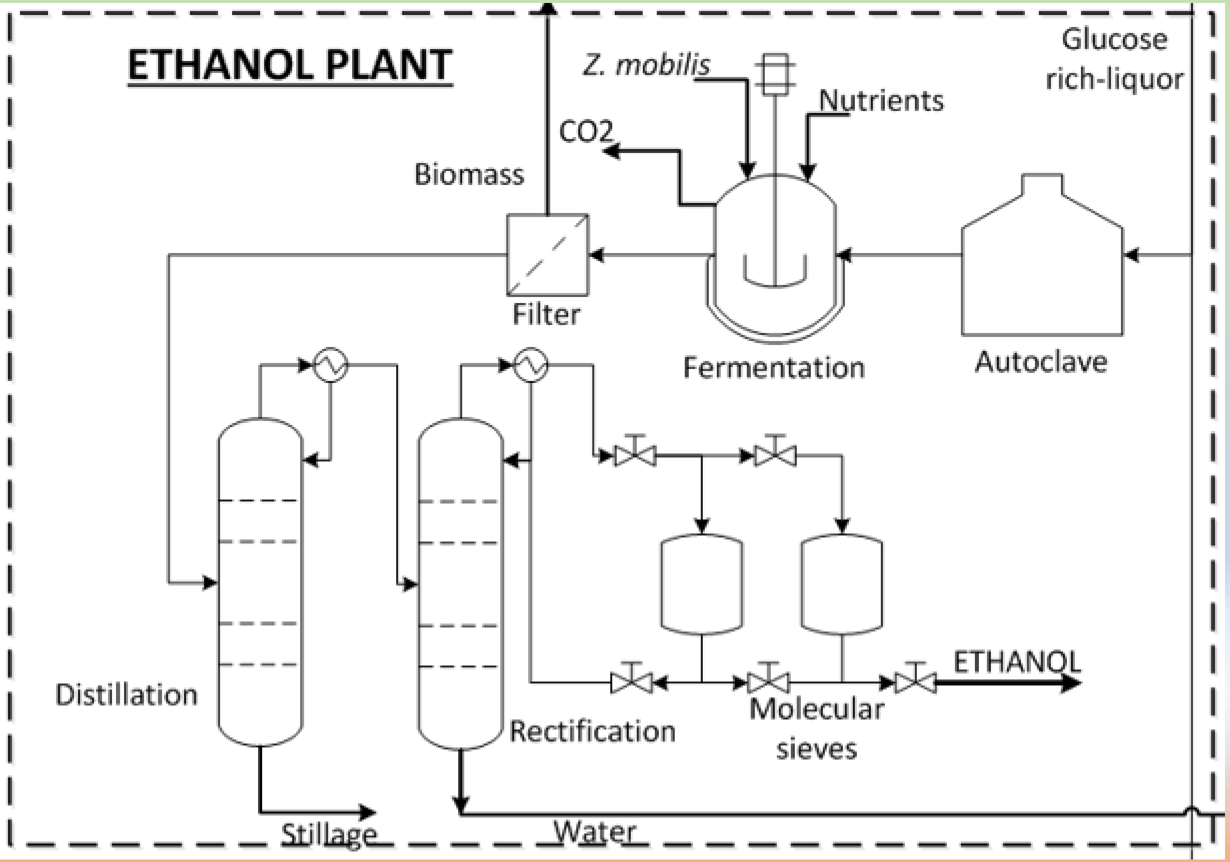


Figure 5. Ethanol Process Scheme

Fermentation
Microorganism = *Z. mobilis*
Temperature = 30°C

Downstream
Distillation column = Ethanol 50-55%wt.
Rectification column = 96%wt.
Molecular Sieves = 99.7%wt.

2. PROCESS DESCRIPTION

Plantain Pseudostem Biorefinery

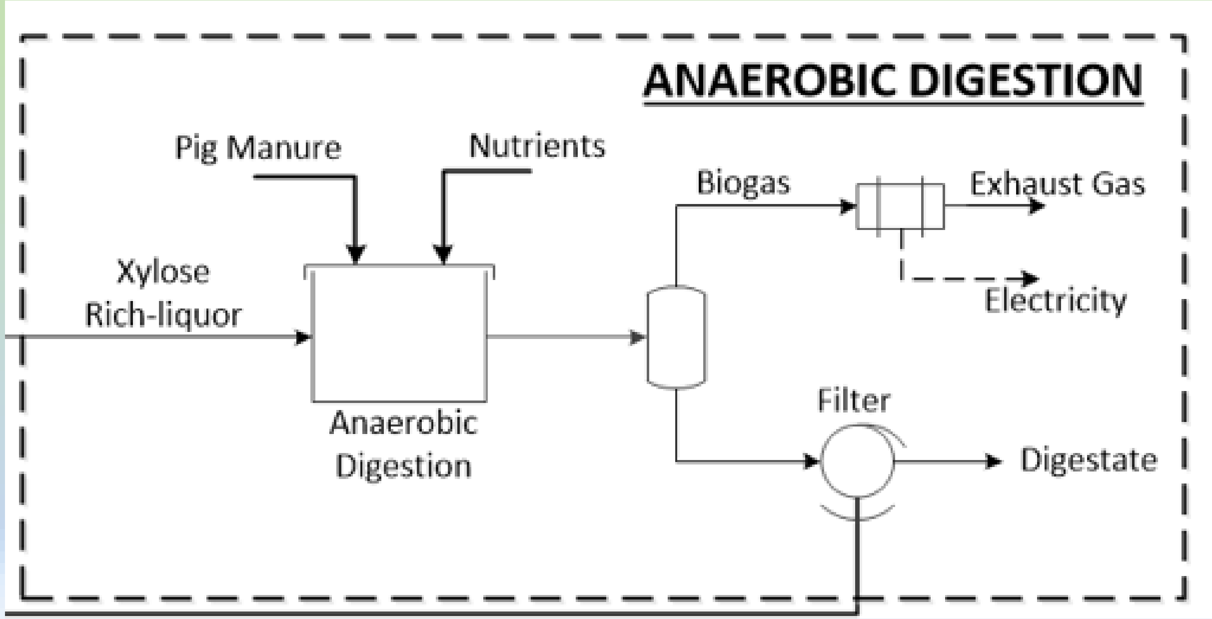


Figure 6. Anaerobic Digestion Process Scheme

Anaerobic Digestion

Inoculum = Pig Manure

Substrate to Inoculum Ratio = 1:2

Temperature = 37°C

Electricity generation from biogas = 1.7 kWh/cum biogas

2. PROCESS DESCRIPTION

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

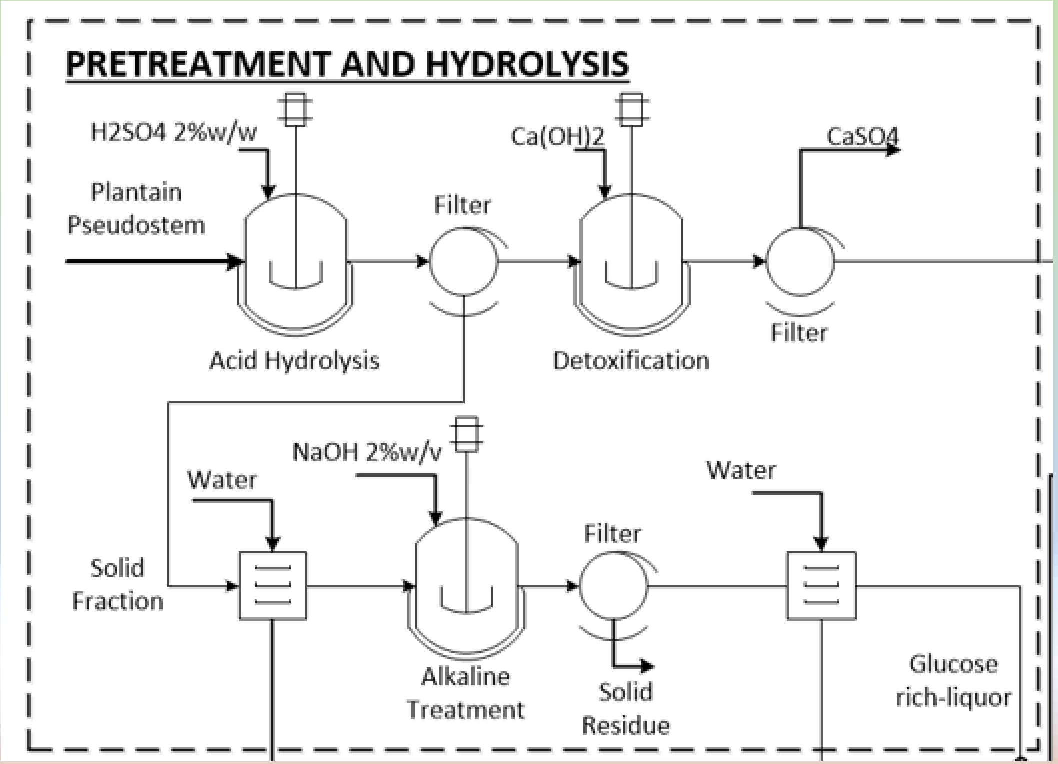


Figure 7. Pretreatment Process Scheme

2. PROCESS DESCRIPTION

Plantain Peel Biorefinery

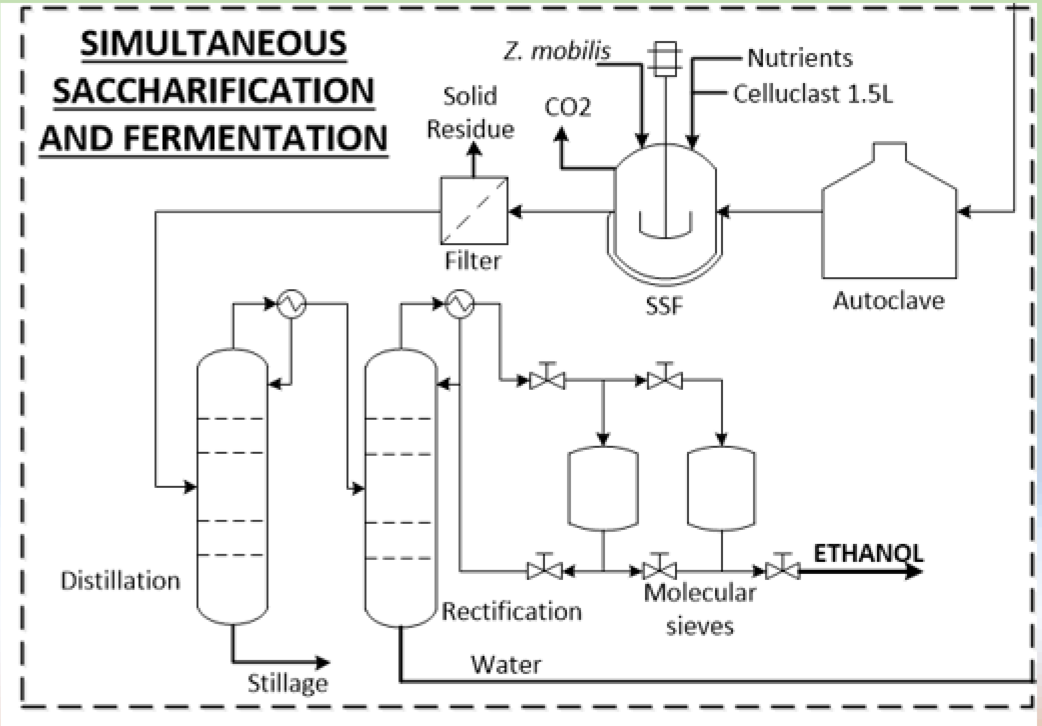


Figure 8. Simultaneous saccharification and fermentation Process Scheme

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

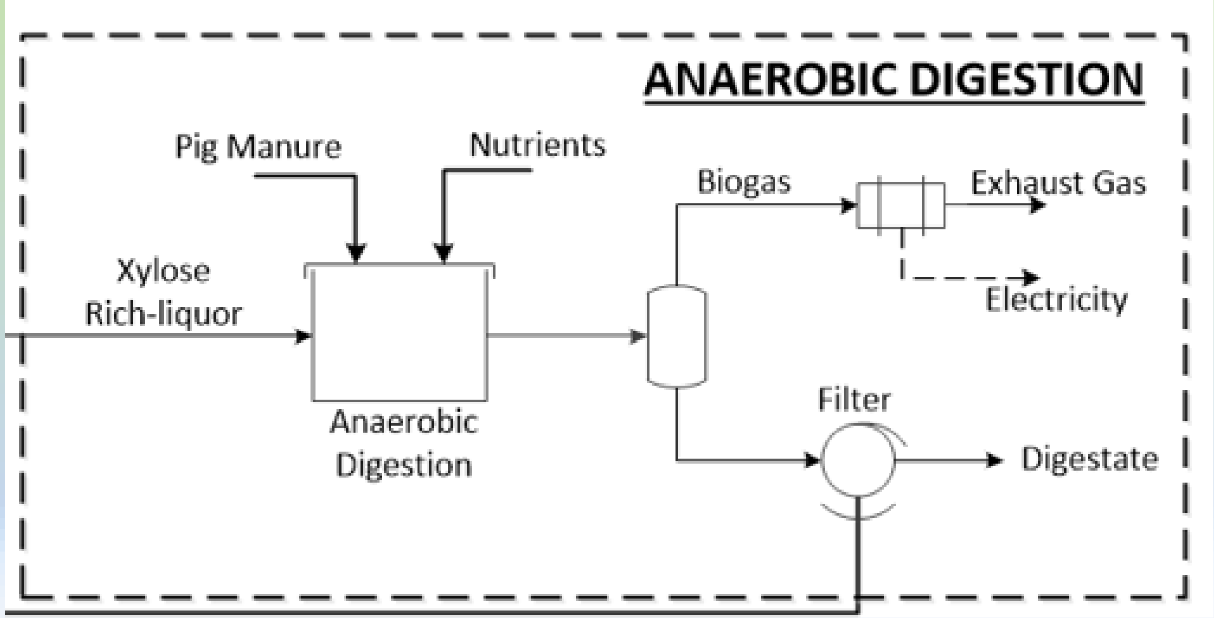


Figure 9. Anaerobic Digestion Process Scheme

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

2. PROCESS DESCRIPTION

Plantain Peel Biorefinery

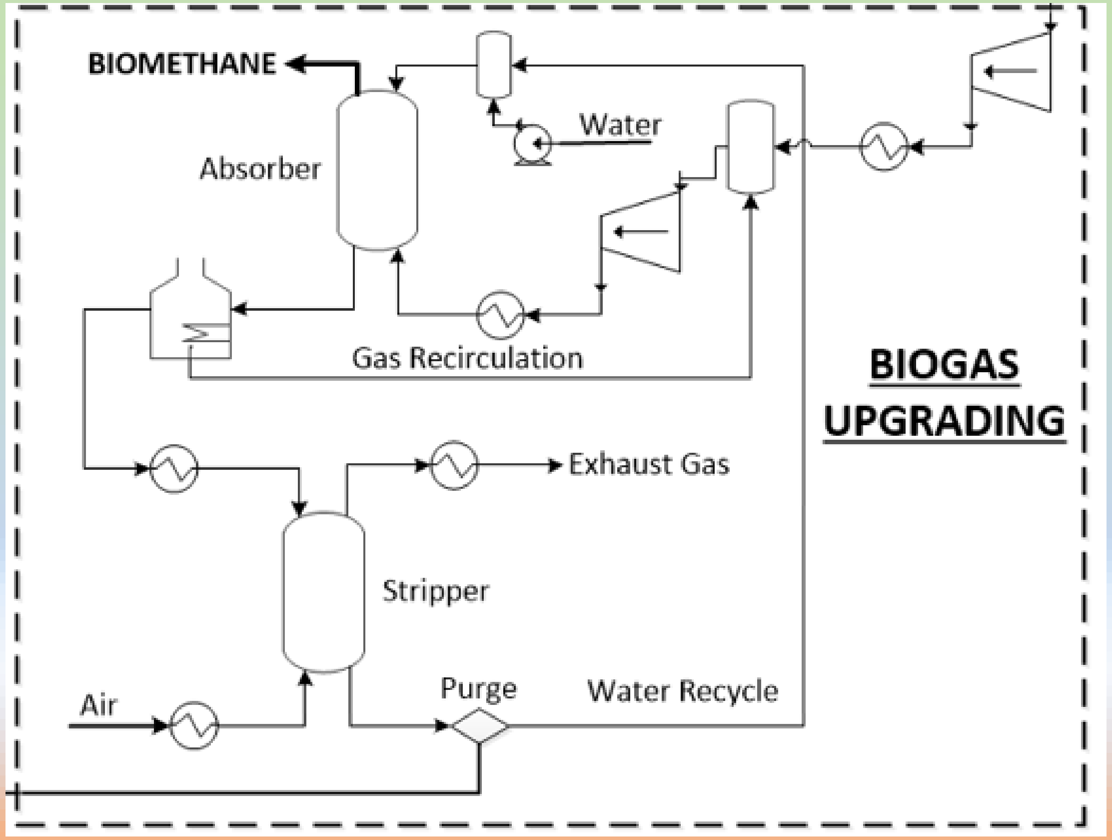


Figure 10. Biomethane Process Scheme

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

2. PROCESS DESCRIPTION

Biomass integrated gasification combined cycle (BIGCC)

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

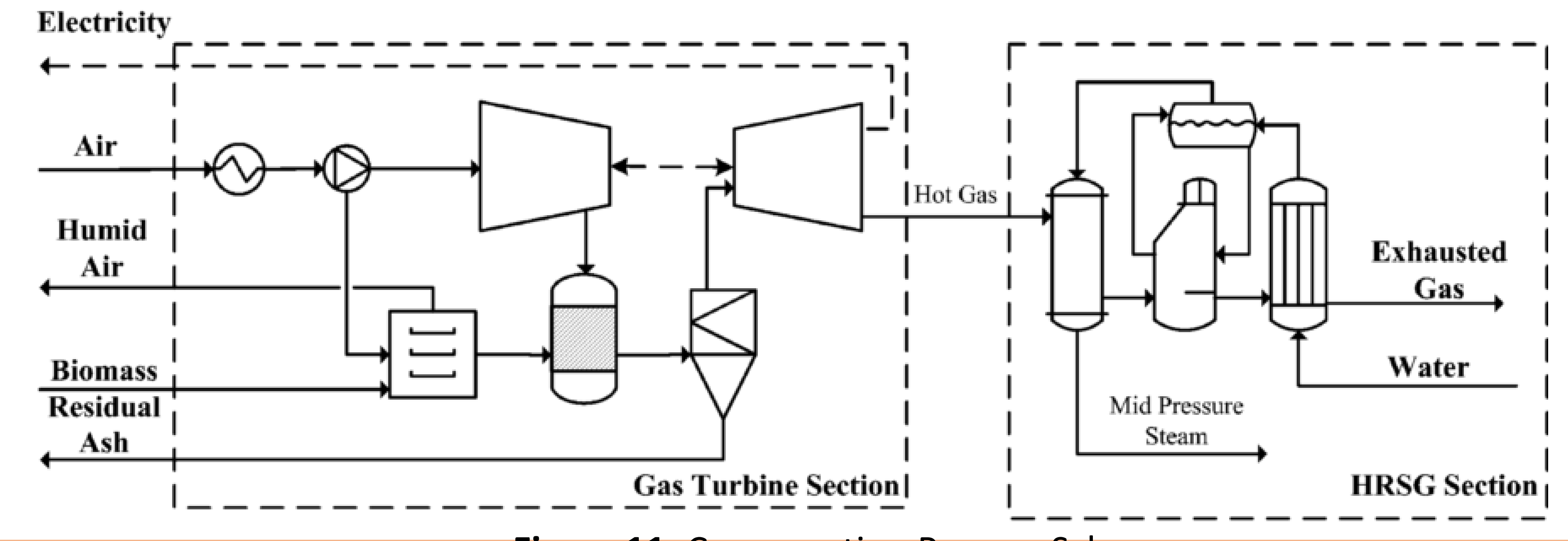


Figure 11. Cogeneration Process Scheme

3. RESULTS

Process Simulation for plantain

Table 3. Bioethanol productivity and yield of the integrated biorefinery

Products	Productivity		Yield	
	Value	Unit	Value	Unit
Plantain Pseudostem	148.31	m^3/day	102.85	L/ton
Plantain Peel	17.62	m^3/day	0.29	L/ton

3. RESULTS

Economic Assessment

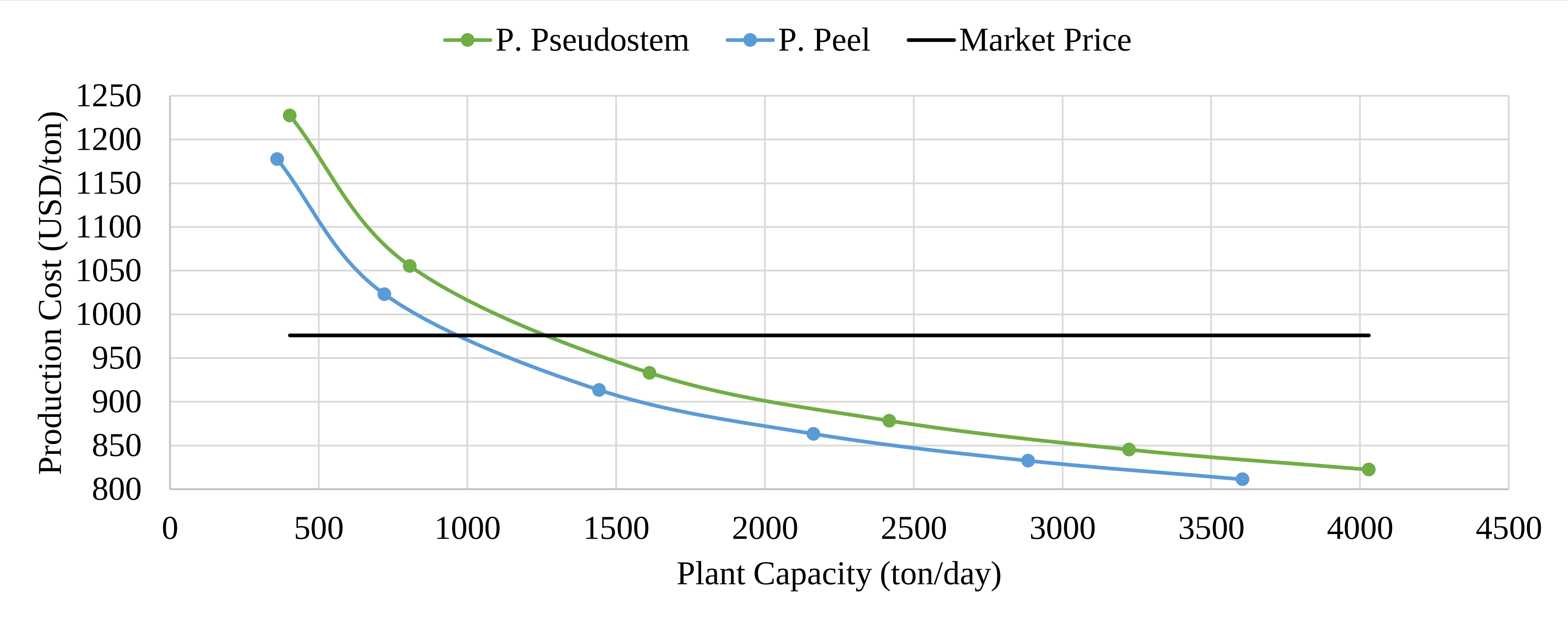


Figure 12. Effect of each plant processing capacity in the production cost of the bioethanol.

3. RESULTS

Economic Assessment

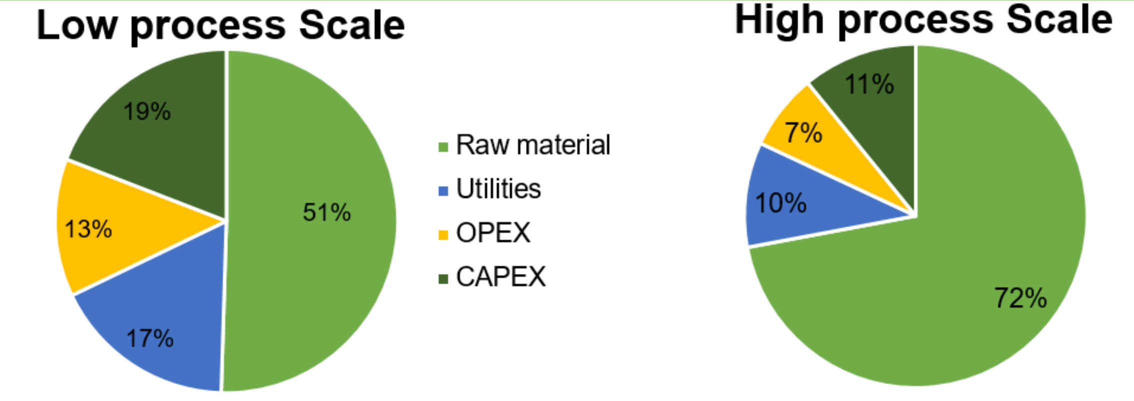


Figure 13. Effect of the process scale in the contribution of the main economic parameters of the pseudostem biorefinery

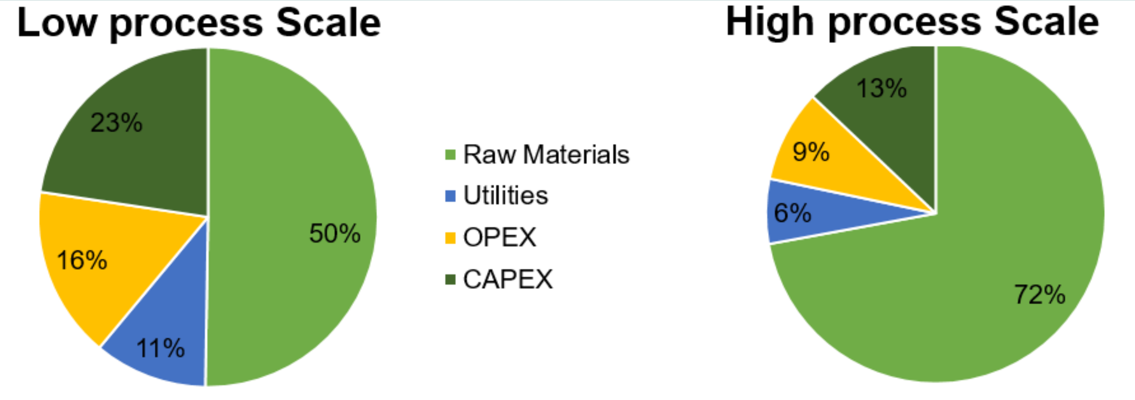


Figure 14. Effect of the process scale in the contribution of the main economic parameters of the plantain peel biorefinery

3. RESULTS

Economic Assessment

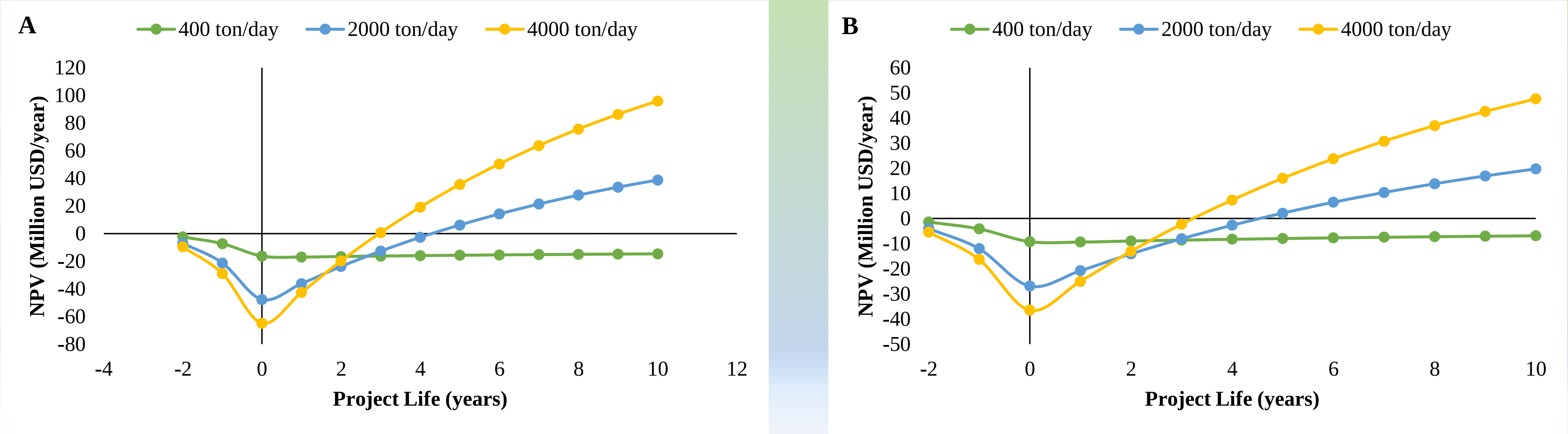


Figure 15. Effect of the plant capacity in the economic profitability of the biorefinery. A. Plantain Pseudostem. B. Plantain Peel

3. RESULTS

Market Price Sensibility Analysis: Pseudostem

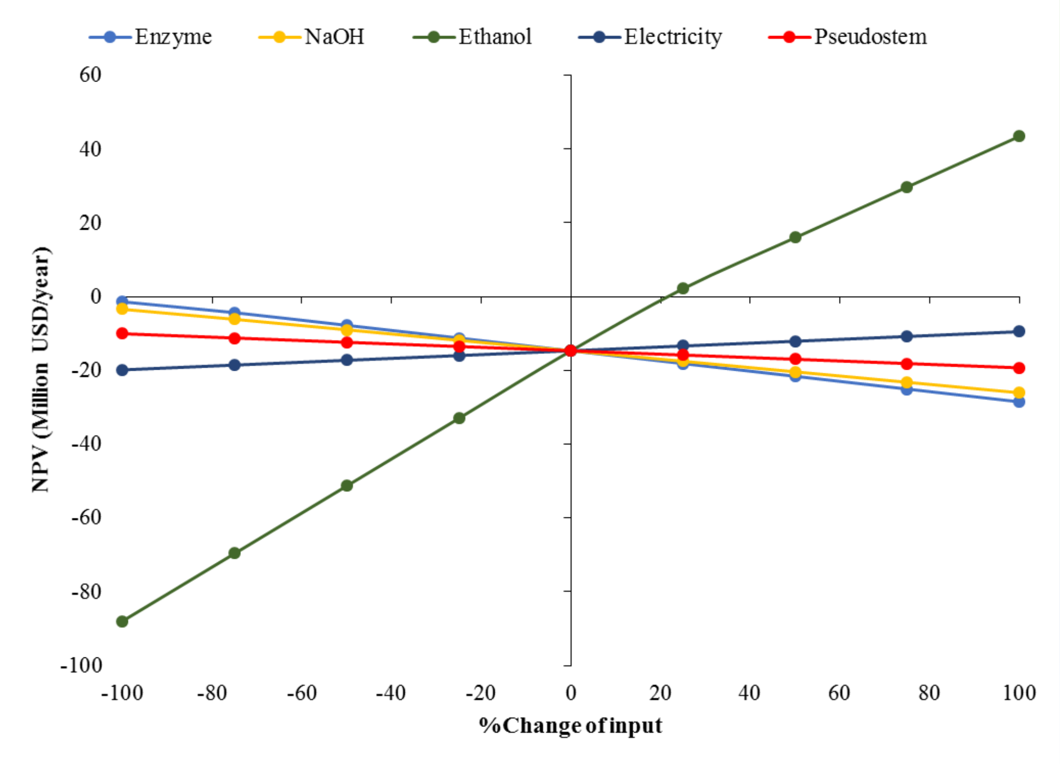


Figure 16. Market Price Variations of low-scale biorefinery (200 ton/day)

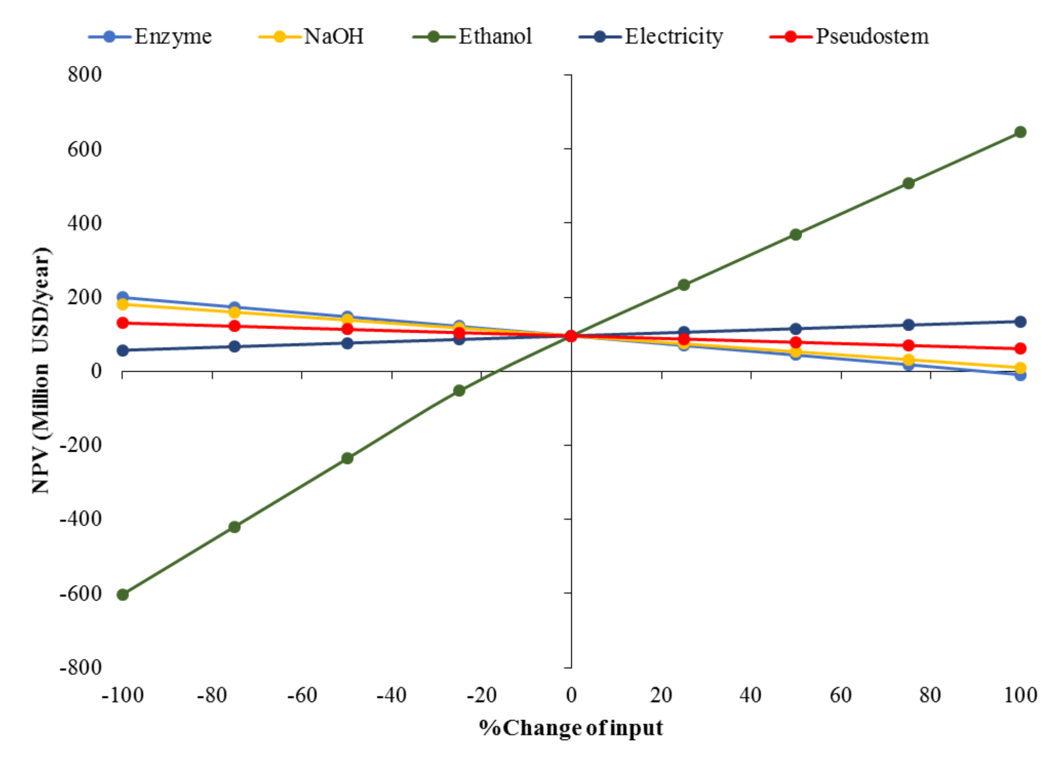


Figure 17. Market Price Variations of high-scale biorefinery (2,000 ton/day)

3. RESULTS

Market Price Sensibility Analysis: Peel

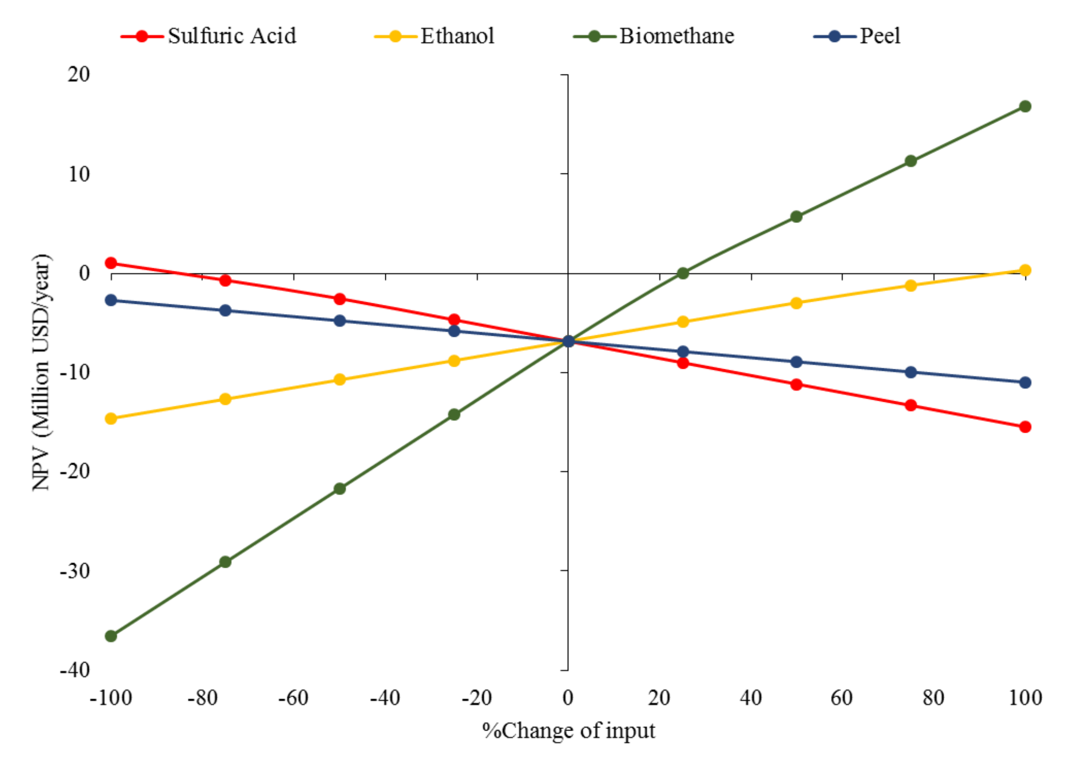


Figure 18. Market Price Variations of low-scale biorefinery (200 ton/day)

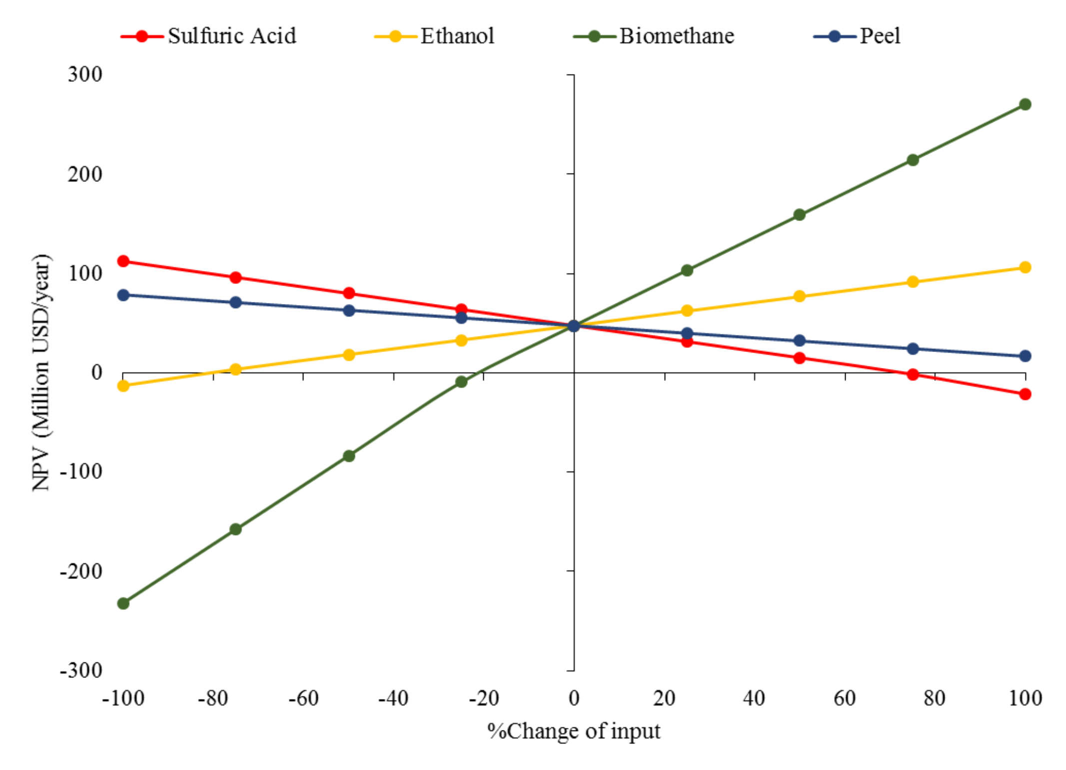


Figure 19. Market Price Variations of high-scale biorefinery (2,000 ton/day)

3. RESULTS

Environmental Assessment

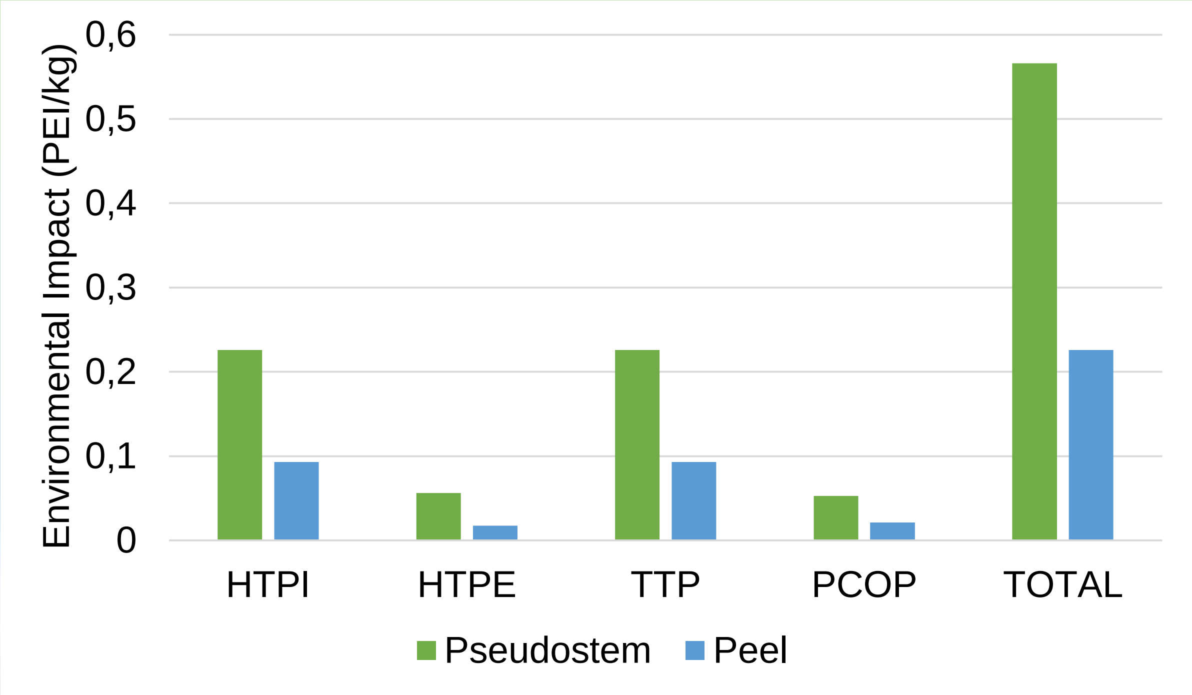


Figure 20. Potential Environmental Impact of the Integrated Biorefinery

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

Definitions of scale to analyze the potential of the biorefinery at different scales….proposing a more technical strategy

Processing scale: Amount of raw material processed in a period. → Ambiguities!

Production scale: Amount of product obtained in a period.

New definition…

(*Minimum Processing Scale for Economic Feasibility – MPSEF*):

Minimum scale of processing the raw material at which a process achieves a feasible economic performance (VPN=0 during the lifetime of the project). (Cardona, 2015)

Analysis of Scale

Objective: Determining the flow of raw material at which the biorefinery will have a positive economic performance, and determine the minimum feasible small-scale from this point

Processing scale **Vs.** NPV

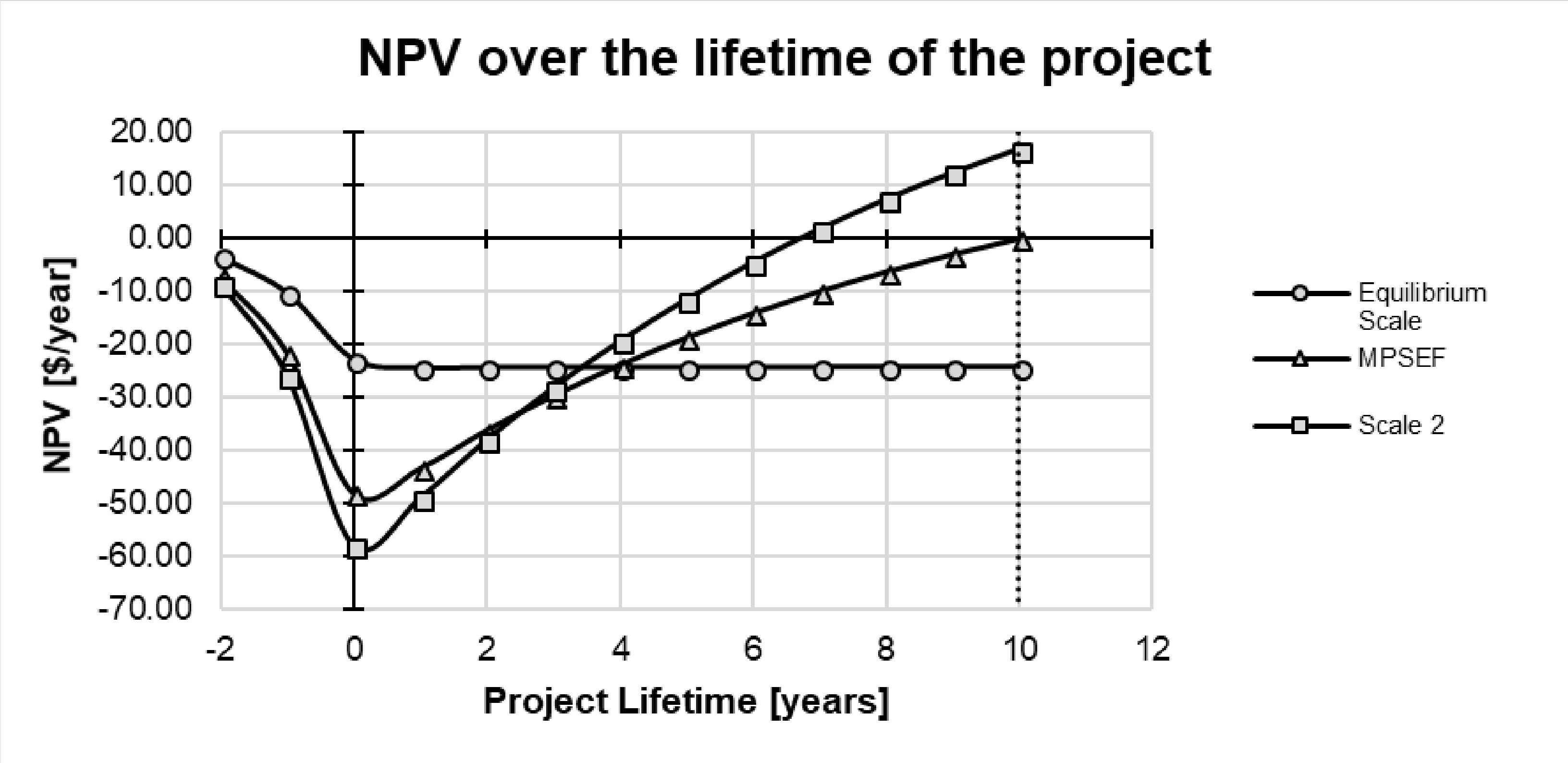
Variables to determine previous to the analysis of scale

- Upper limit
- Base case
- Lower limit

Based on the availability, production and specific conditions of the raw material

Analysis of Scale

Processing scale **Vs.** NPV



Analysis of Scale

Important scales to determine:

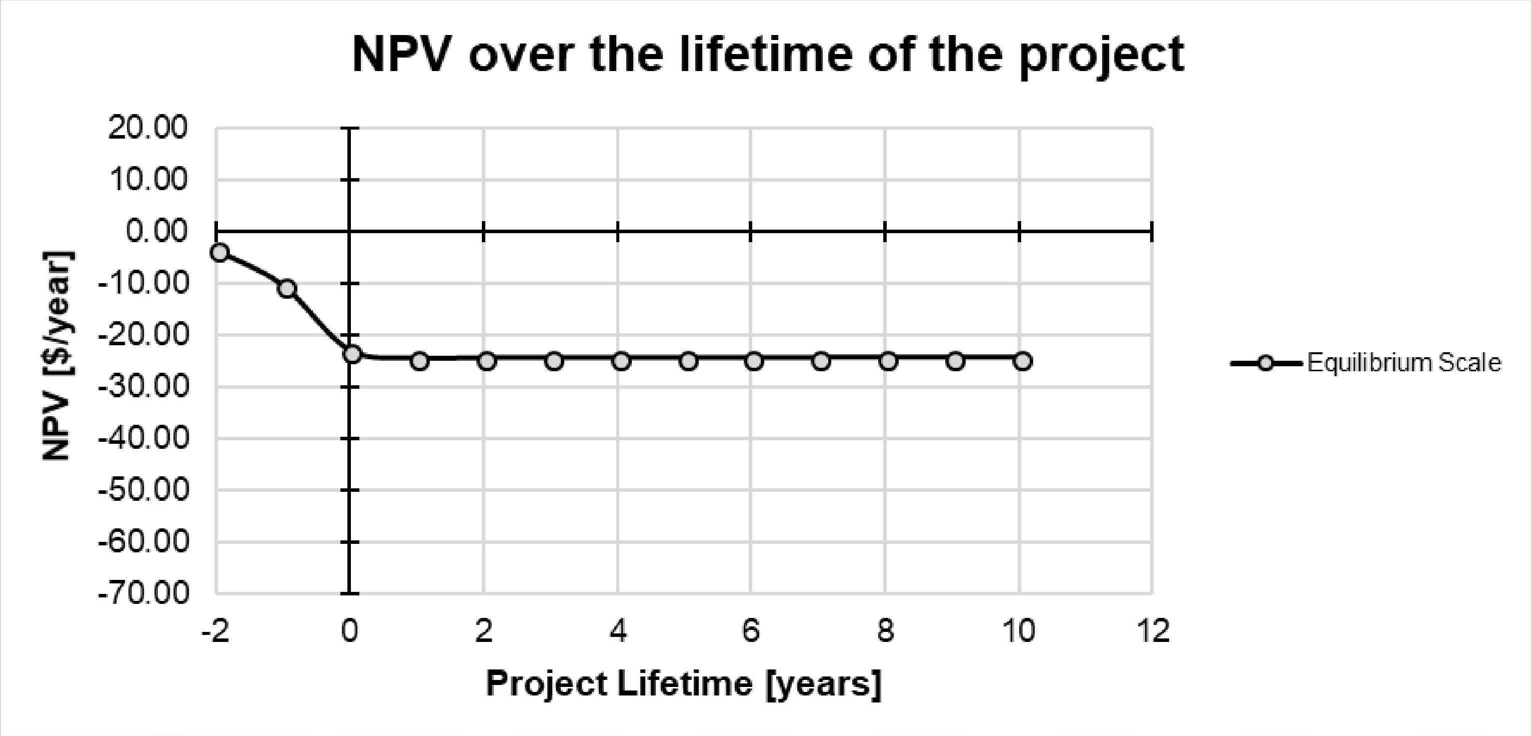
Equilibrium scale:

Processing scale at which the relationship between the incomes and the expenses become constant but usually negative. This scale will be named as the Equilibrium Scale and it shows that the process could be feasible only if some external factors provide economic benefits to the process (e.g. governmental subsidies to decrease given taxes or utilities cost) or new configuration of products should be applied

Analysis of Scale

Important scales to determine:

Equilibrium scale:



Analysis of Scale

Important scales to determine:

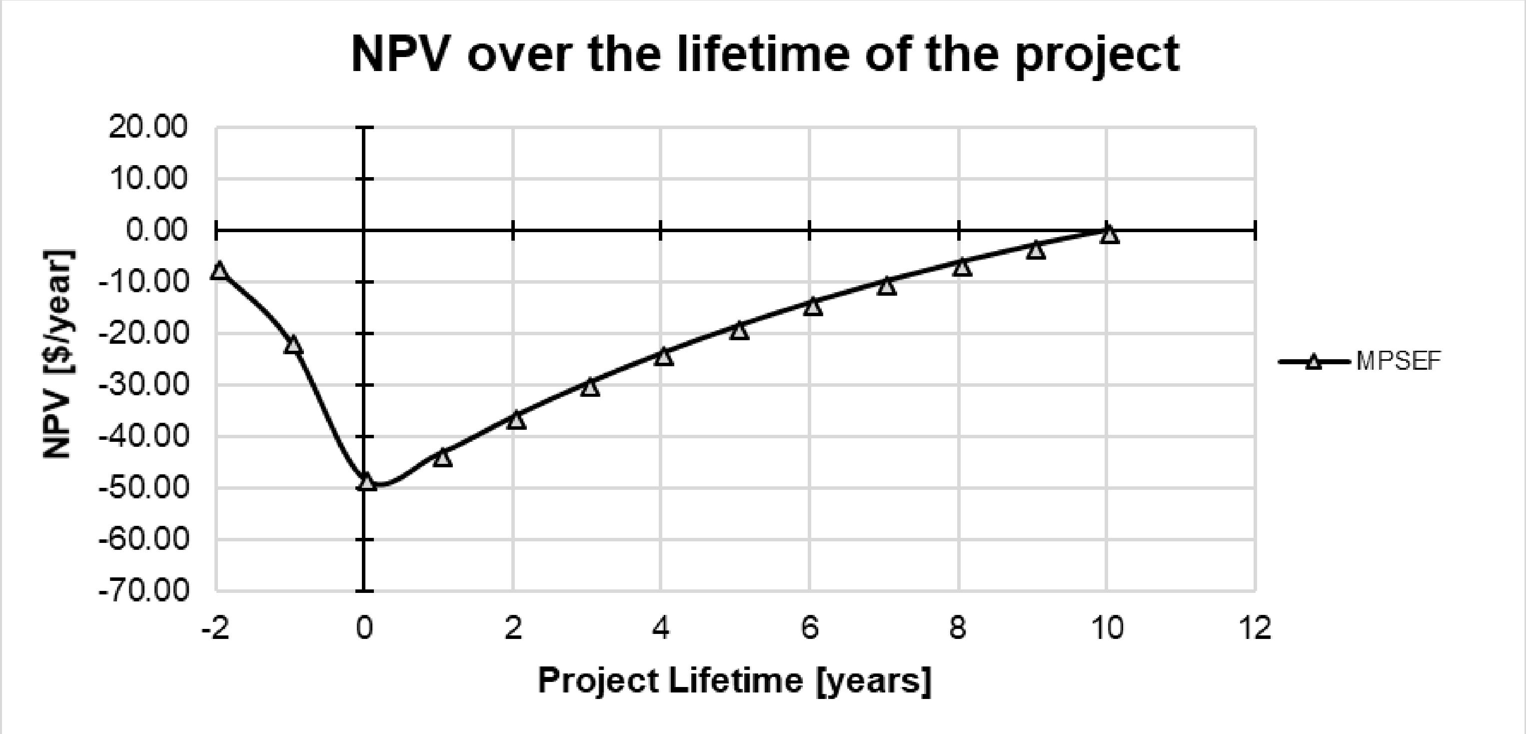
Minimum processing scale for economic feasibility (MPSEF):

Processing scale at which the process will achieve an accumulated NPV of zero after the total lifetime of the project. This implies that the process will use the entire planned lifetime to recover the investment and no profits will be generated. Every processing scale below the MPSEF will not have a positive economic performance and all those superior to the MPSEF will at least reach positive economic performance and generate profits.

Analysis of Scale

Important scales to determine:

MPSEF:



Minimum processing scale for economic feasibility

Examples of application:

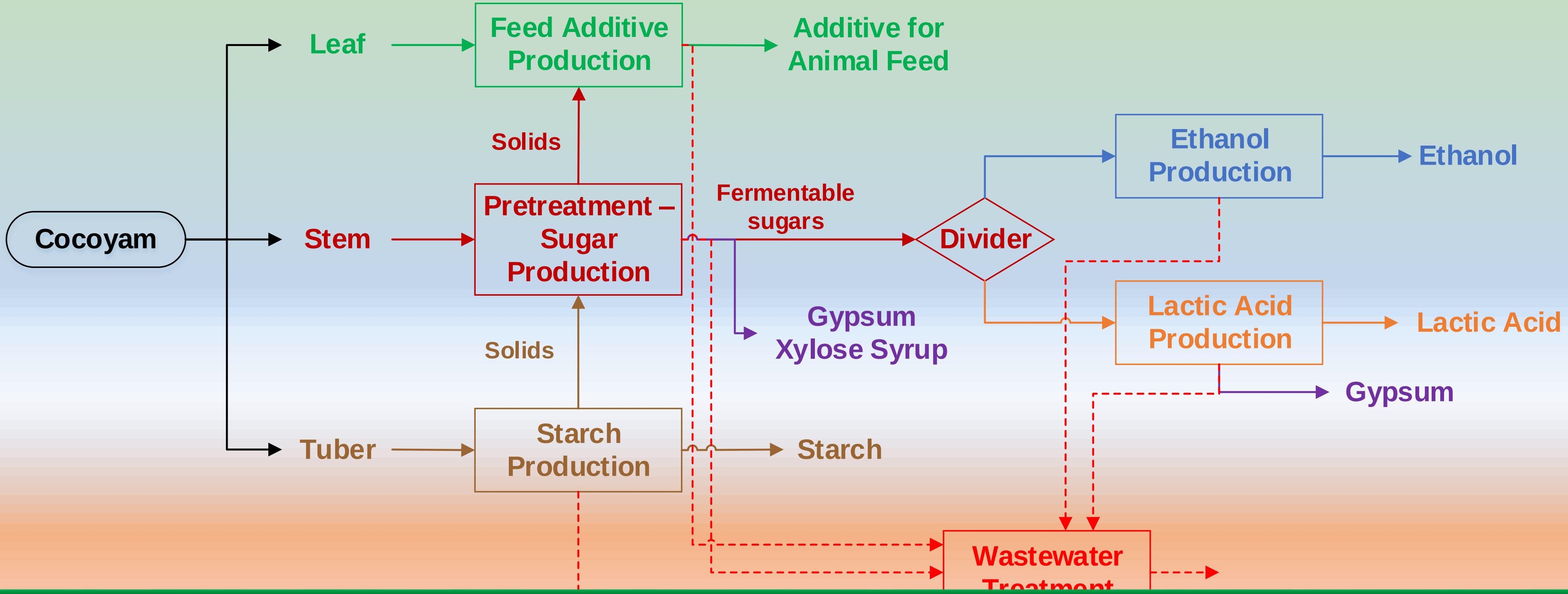
Cocoyam-based biorefinery:

Cocoyam (Xanthosoma sagittifolium) is a tropical plant grown in countries of West Africa, Asia and Oceania. This plant belongs to the family of Araceas and grows between 500-2,000 meters above sea level (Giacometti and León, 1992; Gómez and Acero Duarte, 2002). It has been studied due to the different components and platforms that it has on its matrix (protein, lignocellulosics, and starch, among others) and different researches have been done for the production of animal feed, starch, starch-based compounds, beverages, and for biotechnological uses as the production of lactic acid and ethanol (Ndukwu et al., 2017; Owusu-Darko et al., 2014; Régnier et al., 2013; Serna-Loaiza, 2018; Shiraishi et al., 1995).

Minimum processing scale for economic feasibility

Examples of application:

Cocoyam-based biorefinery (Serna-Loaiza, 2017):

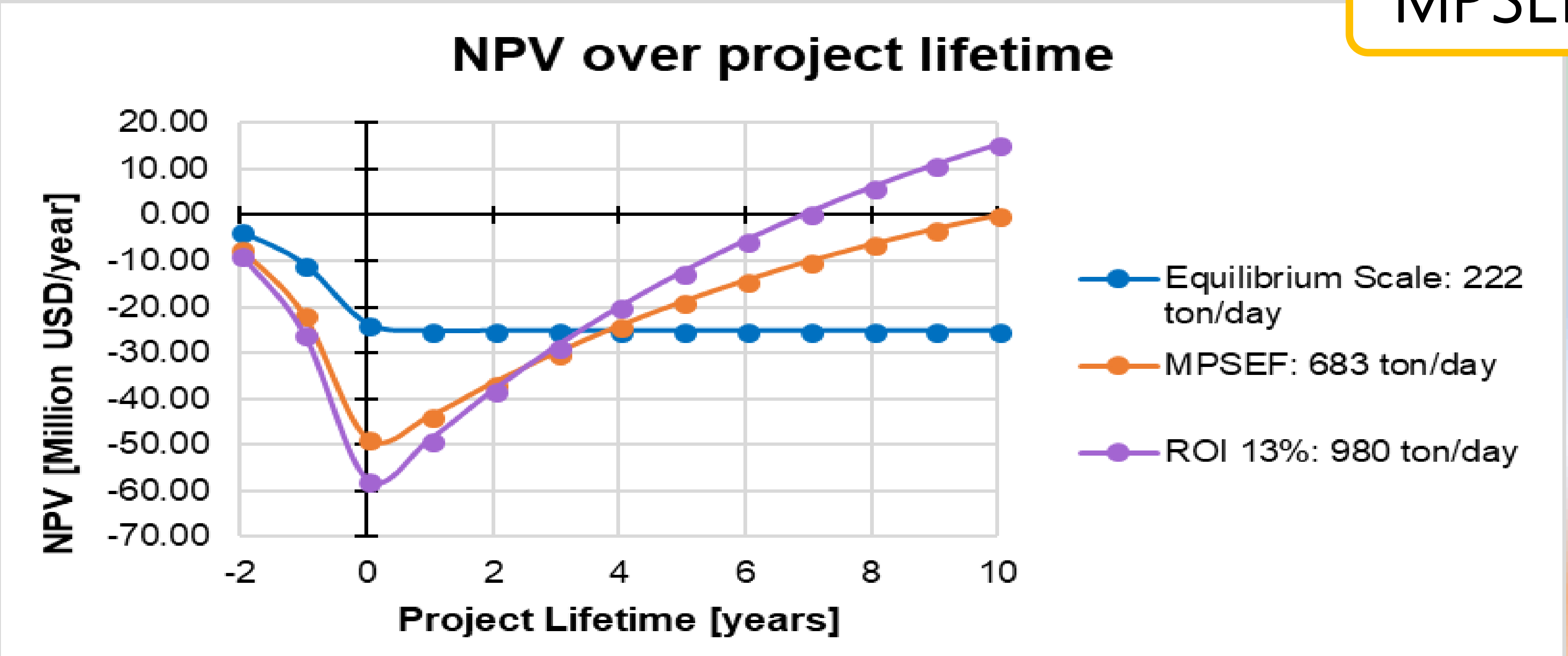


Minimum processing scale for economic feasibility

Examples of application:

Cocoyam-based biorefinery:

MPSEF = 683 ton/day



Minimum processing scale for economic feasibility

Examples of application:

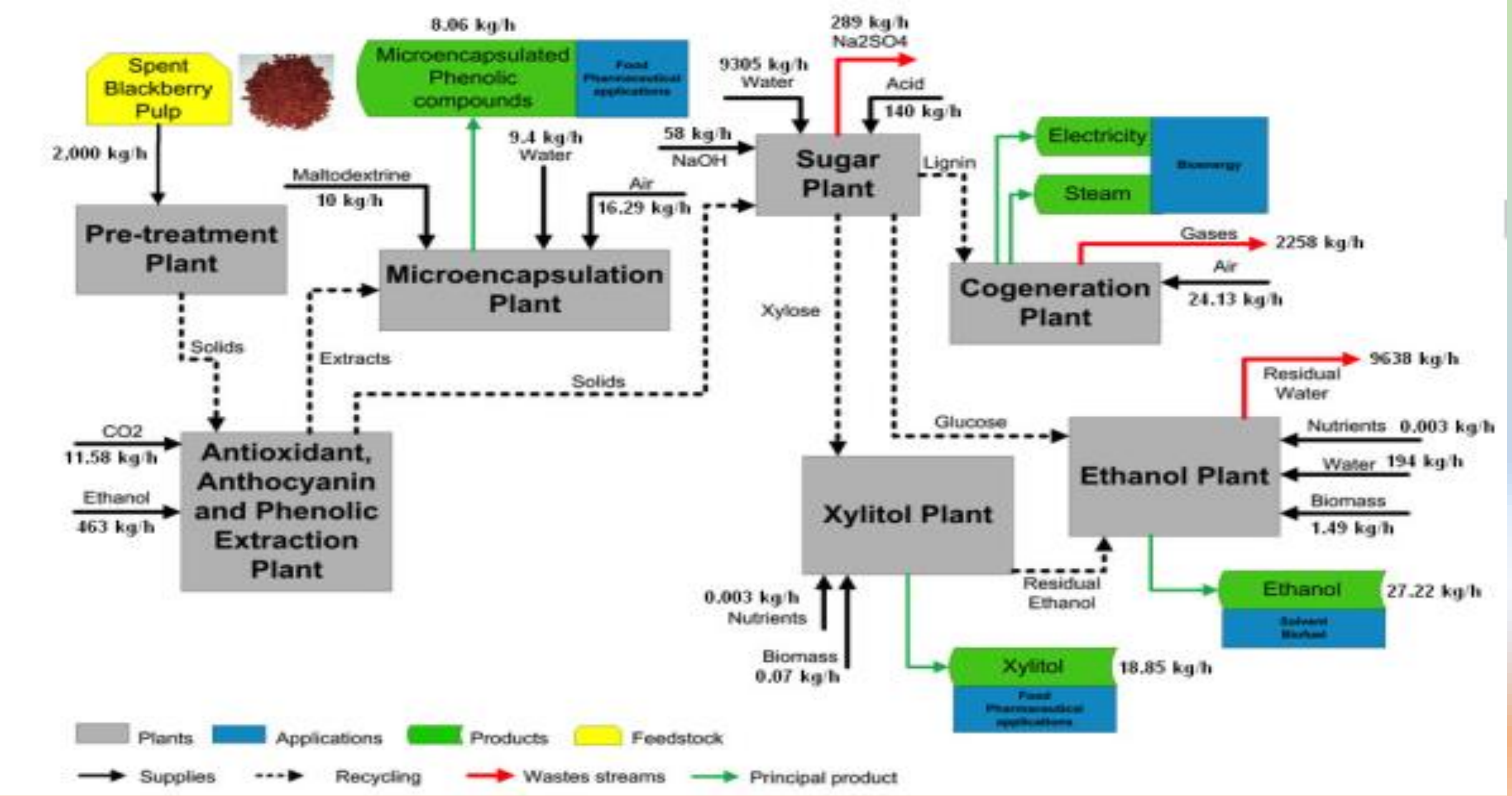
Andes berry-based biorefinery (Dávila et al, 2016):

The utilization and processing chain of Andes Berry (Rubus glaucus benth) in Colombia is well established. The annual production of this fruit amounted to 105,285 tons that were produced on more than 10,743 ha, throughout the national territory (Ceron et al. 2012). Blackberry is commonly processed into concentrates, jams and juices (Ceron et al. 2012) and significant amounts of spent blackberry pulp (SBP) are generated as the principal residue. The blackberry fruit contains different biologically-active compounds that are desired in pharmaceutical, food and chemical applications.

Minimum processing scale for economic feasibility

Examples of application:

Andes berry-based biorefinery:

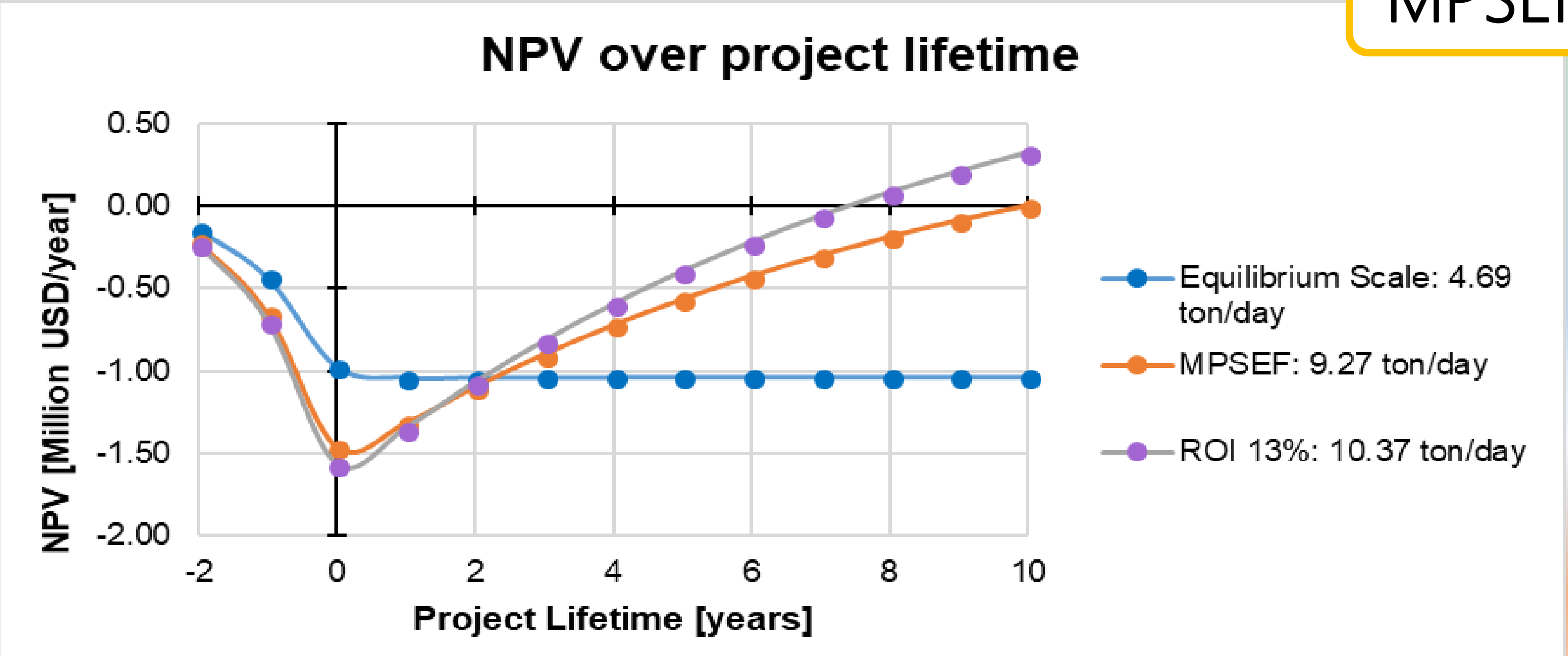


Minimum processing scale for economic feasibility

Examples of application:

Andes berry-based biorefinery:

MPSEF = 9.27 ton/day



CONCLUSIONS

To avoid surprises or risks in biorefinery projects a comprehensive analysis of the scale is needed. The knowledge based strategy is the only way to provide a real (practical) information to be used in terms of decisions or needed changes. The theory and calculations here described could be a very cheap approximation to define the real potential of new projects especially for tropical countries. However low scale biorefineries will have always the lower value.

It is expected an increased growth in biorefinery projects at different scales during the next years depending also on oil prices. However it can be concluded that the maturity of biorefineries is still very low, even when very high developed and mature technologies are applied for ethanol or electricity production as the starting point for these biorefineries operation (not being a very sustainable biorefinery).

Thanks for your attention

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Referencias

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