Small and High scale Biorefineries. Definition based on sensitivity analysis

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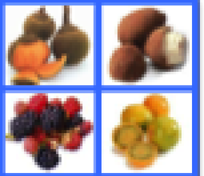
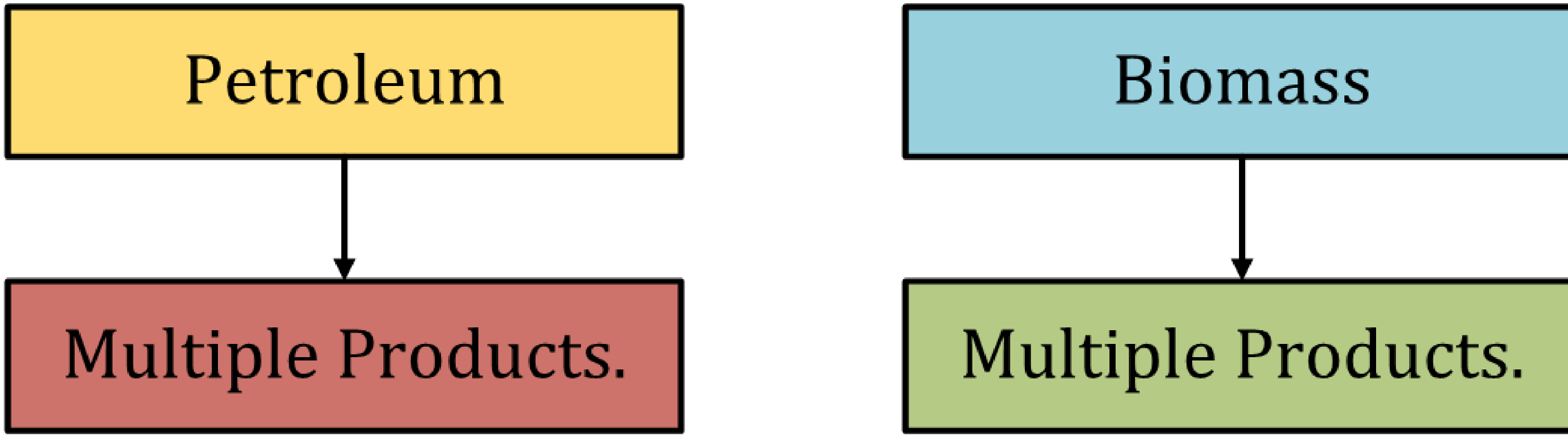


The Biorefinery Concept



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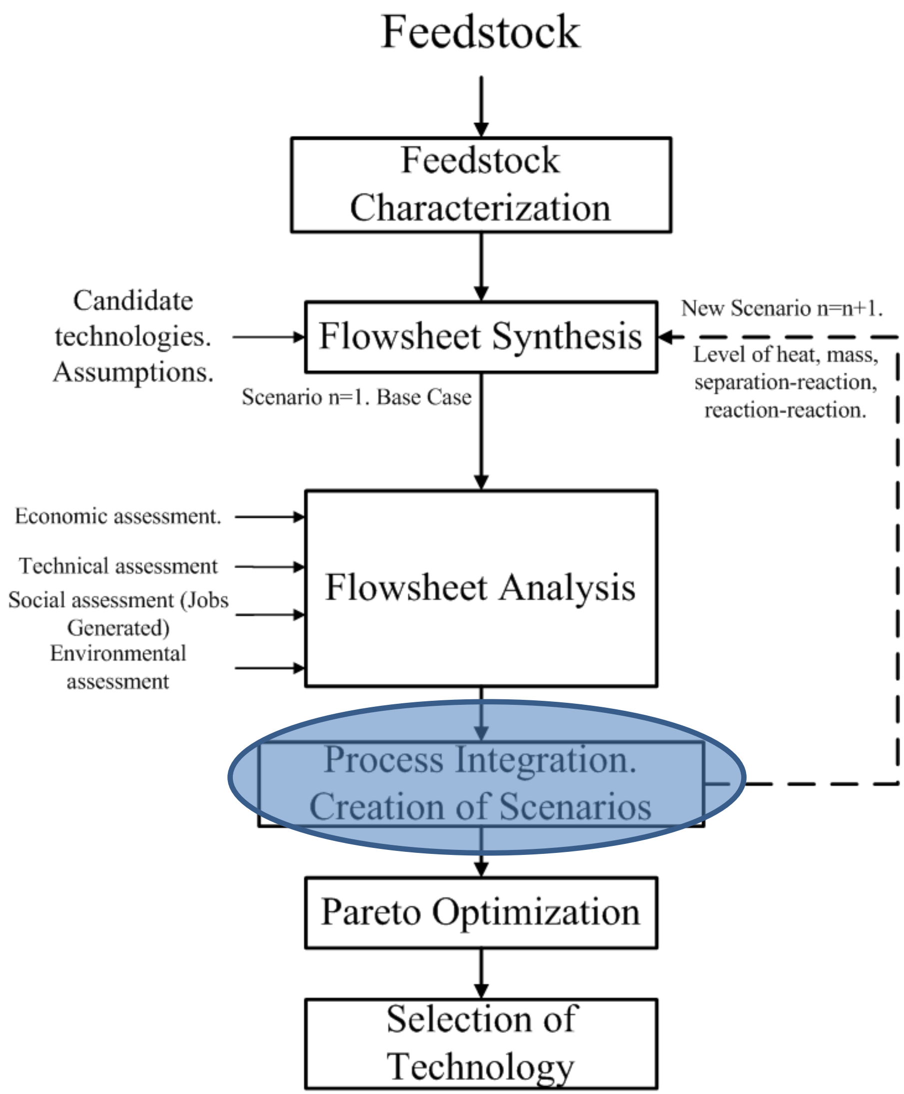
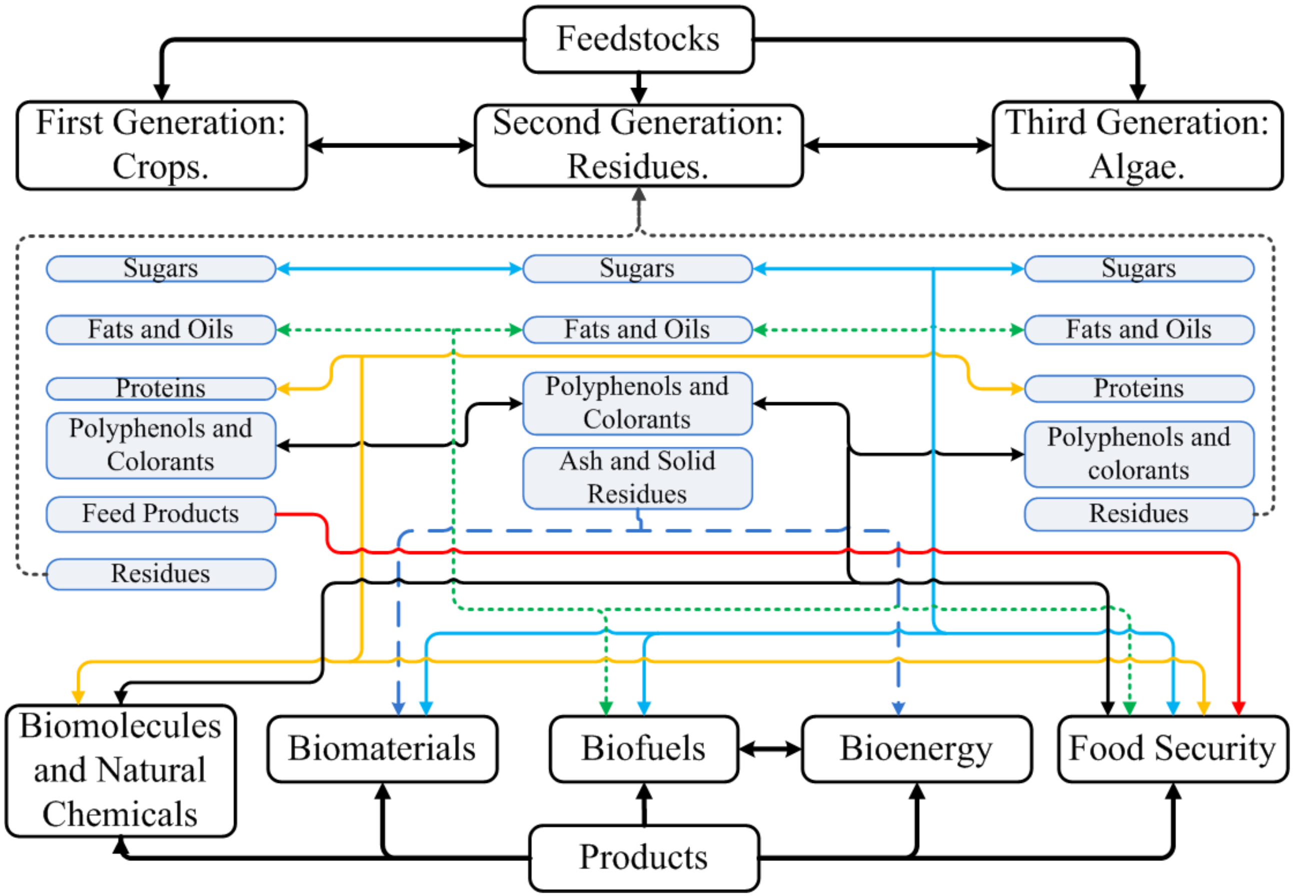
Biorefineries: Design strategy



Green Biorefineries: Feedstocks



Relation between feedstocks and products in a green biorefinery

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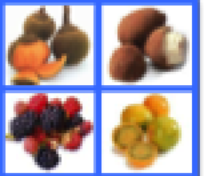

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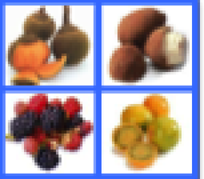
How to define the small or high scale biorefinery. Products

- High scale consumption of the products…high scale biorefineries…low added value…moderate profit (%). Good example: Corn and sugar cane biorefineries.
- Low scale consumption of products… small scale biorefineries…High added value…High profit (%). Practically not examples. Just under design as biorefineries based on exotic fruit. If using common raw materials production costs can be very high and finally the reached profit is very low.
- A combination of the last 2 cases… Most of the biorefinery cases



How to define the small or high scale biorefinery. Raw materials

- High availability and access to raw materials with no logistics restrictions - high scale biorefineries…low added value…moderate profit (%). Good example: Lignocellulosics, Palm oil, Corn and sugar cane biorefineries.

- High availability and access to raw materials with logistics restrictions - small scale biorefineries …lower added value… low profit (%). Good example: Energy producing biorefineries based on local residues as for example coffee cut stems in mountains, delocalized multiproduct biorefineries producing biogas, fertilizers and electriciity Lignocellulosics, Palm oil, Corn and sugar cane biorefineries.

- Low availability and access to raw materials… very small scale biorefineries…High added value…High profit (%). Practically not examples. Under design biorefienries based on exotic fruit.

- Combinations can also appear.

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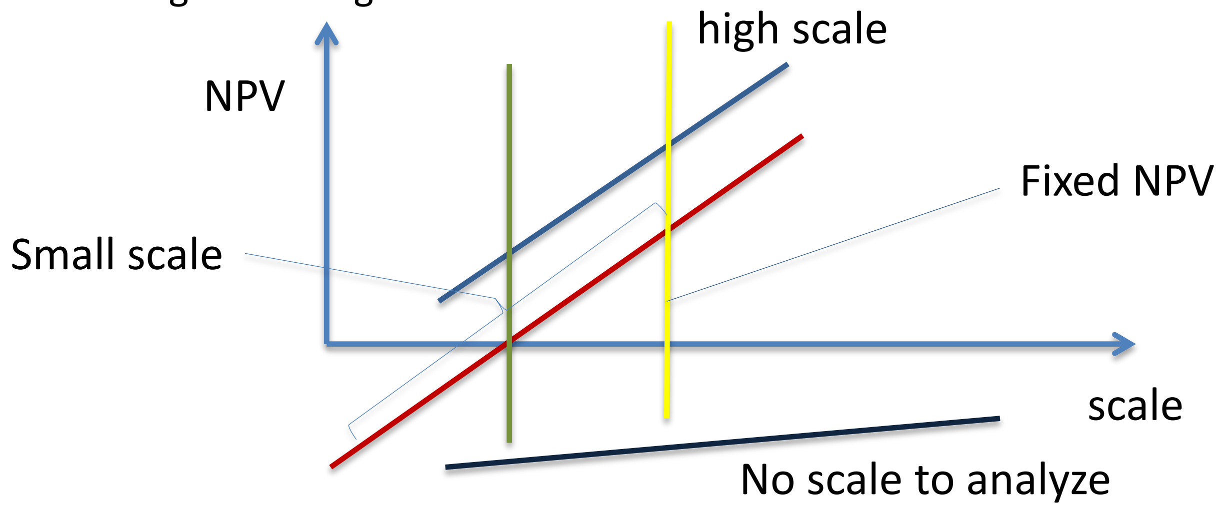
How to define the small or high scale biorefinery. Policy driven definition or justification.

- High scale biorefineries under government support to boost agriculture development in rural areas or to make more competitive any sector…low added value…moderate profit (%). Good example: Palm biorefineries.
- Small scale biorefineries to ensure the communities development and minimal surviving facilities….low or negative added value (always with subsides from the government)… very low profit (%). Practically not examples. Just under design as energy biorefineries (producing ethanol, biogas, biodiesel, fertilizers and electricity) based on just some ton/day of lignocellulosics to make feasible the existence of communities in not interconnected zones.

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".



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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 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.

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Case study 1: Biorefinery based on exotic fruits from Colombian Amazon Region

Fig 2. Colombian Amazon Region. Adapted from WWF

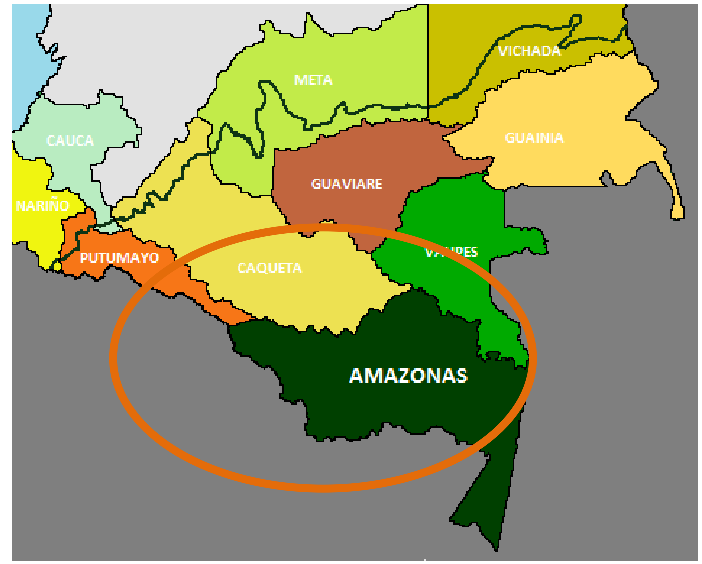

Fig 3. Political division of Colombian Amazon Region.

Economy: Natural resources exploitation.

Colombian Amazon Region: 483.164 km² (41% of the Country area)

By 2011 the region recorded poverty rates of 35,6%

Source from: https://www.dane.gov.co/files/investigaciones/condiciones_vida/pobreza/cp_pobreza_2011.pdf

Process design according to the raw material potential

Products selection:

Chemical characterization and published data.

Technology selection:

Logistical context of the region.

Scenarios definition:

Two process configurations (scenarios).

Scenario 1: base case.

Scenario 2: Extension of Sc 1 with wastes reduction. – Biorefinery concept.

Scenario 1 - rural areas.

Scenario 2 - Leticia.
Process extraction associated with the solvent use had to be limited due to the constraints attached with illicit traffic.

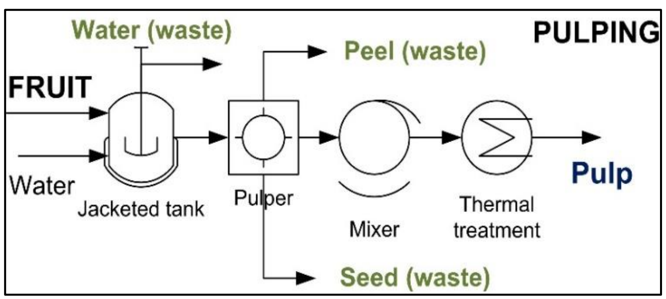

Figure 15. Simplified process-flow Scenario 1

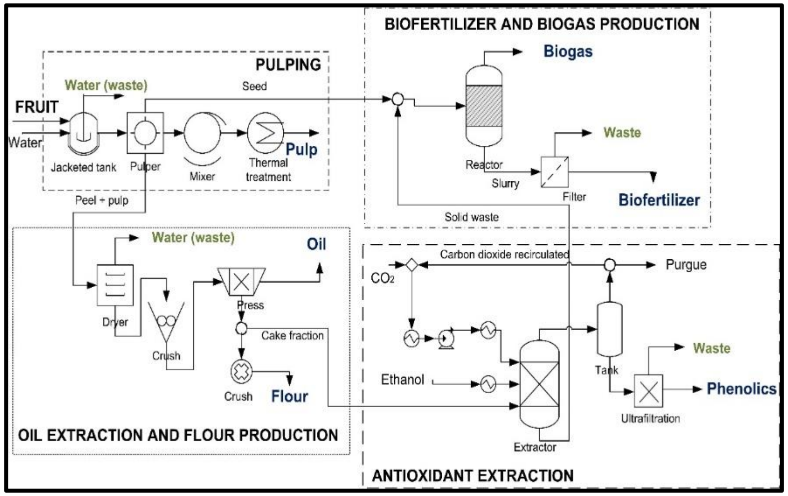

Figure 16. Simplified process-flow Scenario 2

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Chemical characterization Makambo

Features	**Pulp (%)**	**Seed (%)**	**Peel (%)**
Fruit proportion	**25,7 ± 3,7**	36,0 ± 3,1	38,3 ± 4,3
Moisture	84,90 ± 0,37	55,52 ± 0,64	52,88 ± 0,58
Extractives	5,71 ± 0,03	0,24 ± 0,02	4,01 ± 0,01
Lipids	-	15,65 ± 0,02	-
Palmitic acid (%)		7,56	
Stearic acid (%)		34,16	
Oleic acid (%)		**44,51**	
Linoleic acid (%)		6,11	
Arachidic acid (%)		4,23	
Behenic acid (%)		3,43	
Hemicellulose	-	8,66 ± 1,84	10,58 ± 1,81
Cellulose	-	14,89 ± 0,02	11,98 ± 1,81
Lignin	-	2,29 ± 0,52	16,67 ± 0,02
Fiber	3,29 ± 0,03	-	-
Ash	6,10 ± 0,02	2,70 ± 0,11	3,88 ± 0,80
Phenolic compounds (mgGAE/100 g dw)	857,64 ± 0,02	1520,94 ± 0,01	**2153,03 ± 0,01**
Phenolic comp. (mg Catechin/ 100 g dw)	n.d.	n.d.	222,70 ± 0,30
Antioxidant activity (meq Trolox/g dw)	0,073 ± 0,000	0,699 ± 0,002	**0,797 ± 0,008**

Table 4. Chemical composition of Makambo fruit

Theobroma bicolor

Products:

Pasteurized pulp.

Seed butter.

Residual cake (it is paste, that should be used as an ingredient in a food industry) as a substitute for cacao.

Phenolic compounds.

Biogas.

Biofertilizer.

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Experimental yields

SFE

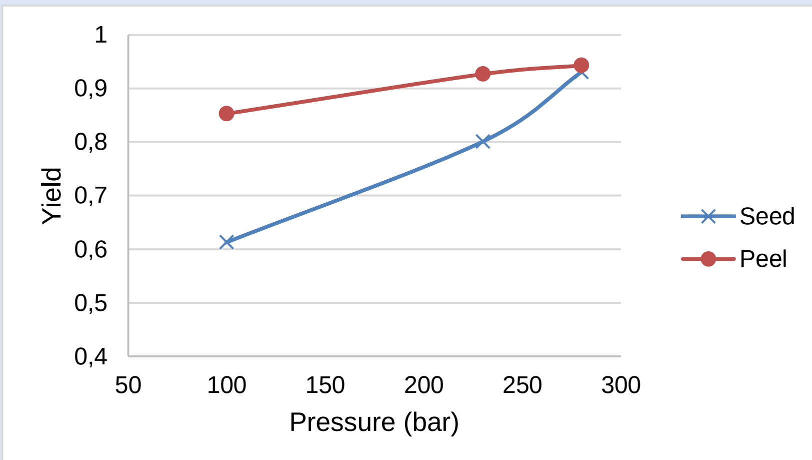


Fig 19. Yield of phenolic compounds extraction by EFS from Makambo seeds and peel

BUTTER EXTRACTION

Temperature (°C)	Yield (g Butter extracted/g Lipids in RM)
40	0,55 ± 0,02
70	0,82 ± 0,03

Table 5. Yield of Makambo butter extraction

Scenarios

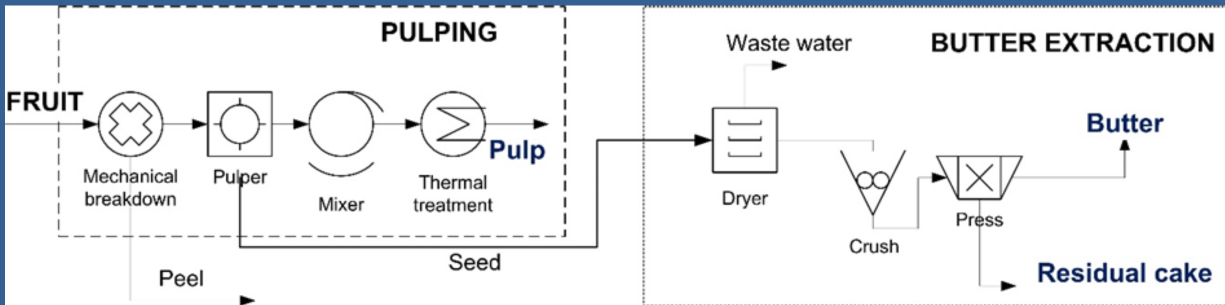


Fig. 20 Simplified process-flow Sc 1

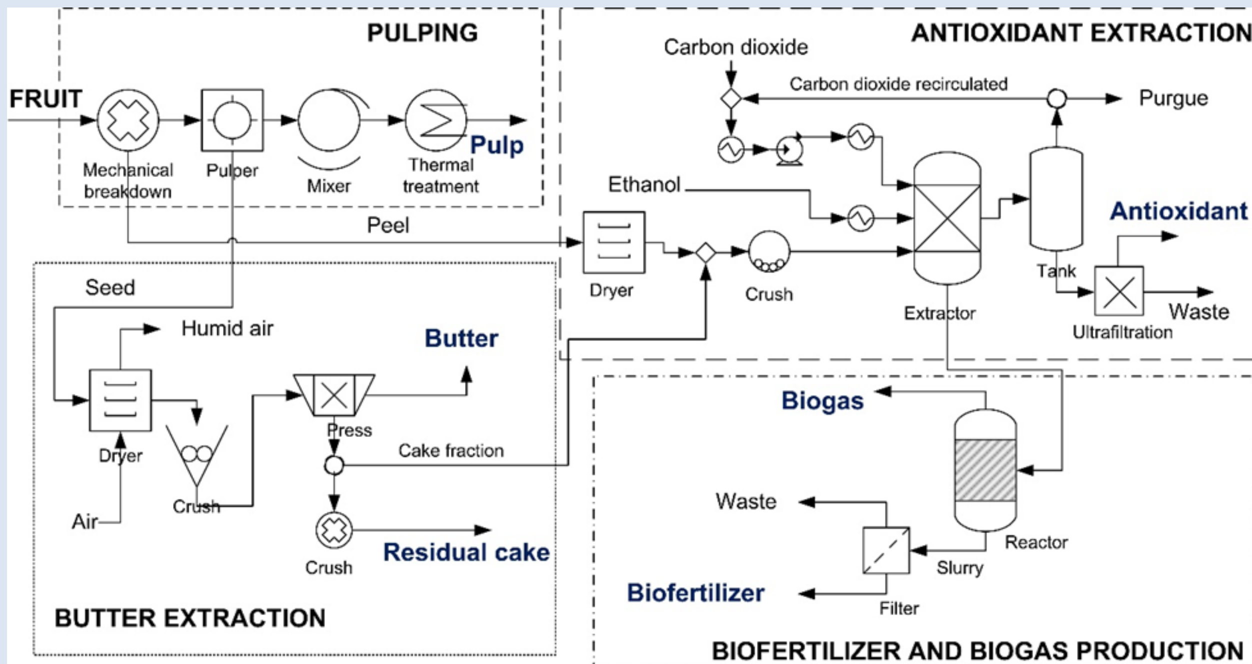
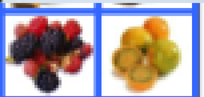


Fig. 21 Simplified process-flow Sc 2



Mass balance

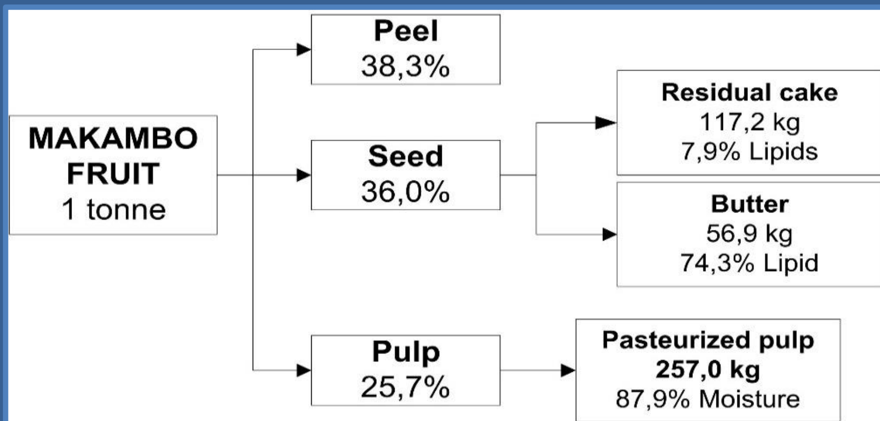
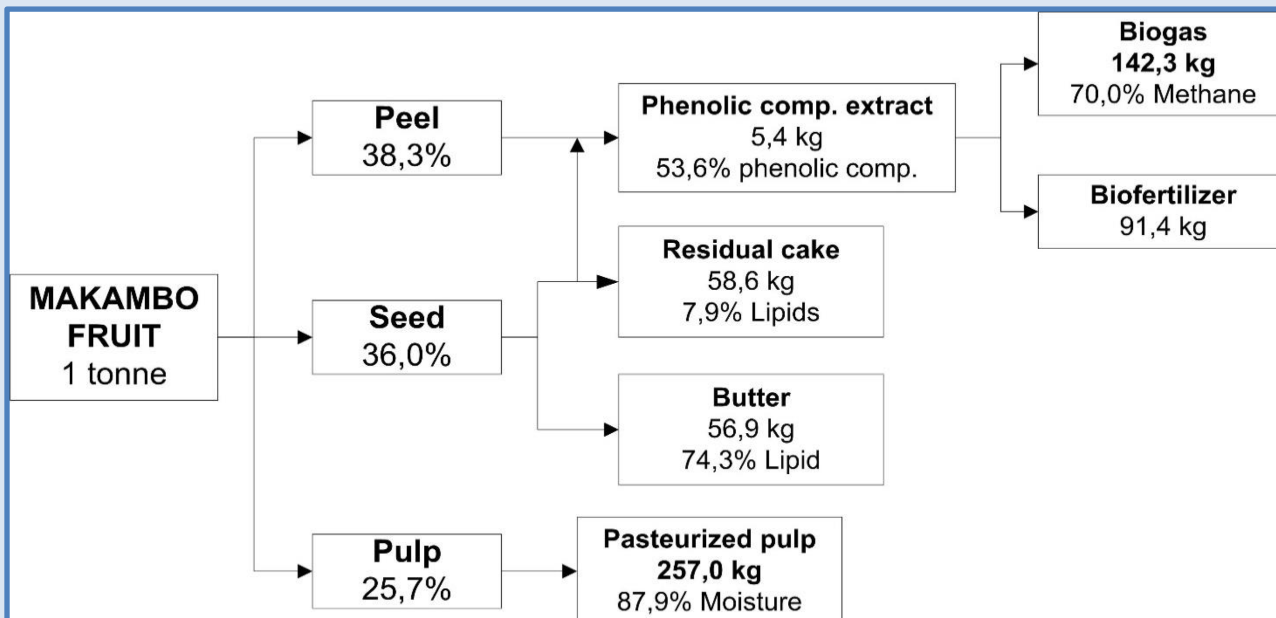


Fig. 22 Material balance for Sc. 1

Fig. 23 Material balance for Sc. 2



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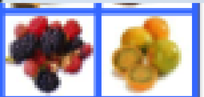
Economic assessment

	Scenario 1	Scenario 2
Product	USD/year	USD/year
Pasteurized pulp	5,43	3,50
Cocoa mass	1,09	0,70
Butter	2,72	1,75
Phenolic compounds	-	280,15
Biogas	-	0,04
Biofertilizer	-	0,18

Table 6. Production cost per product

Economic metric	Scenario 1	Scenario 2
NPV	805.655,00	4.009.910,00
Payout period (years)	7,33	5,11
Profitability index	1,12	1,35

Table 7. Economic metric per scenario



Sensitivity analysis

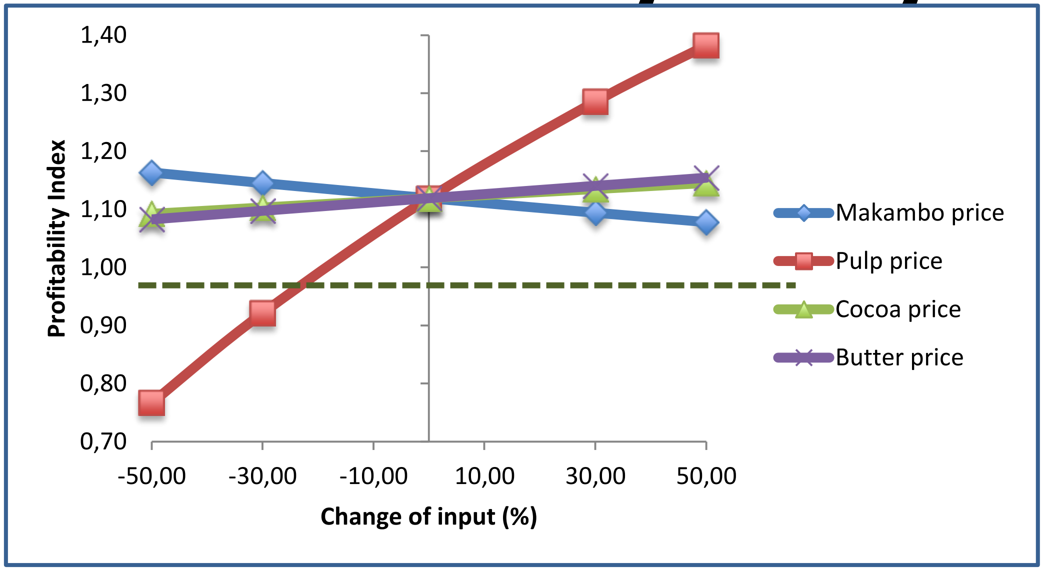


Figure 24. Scenario 1

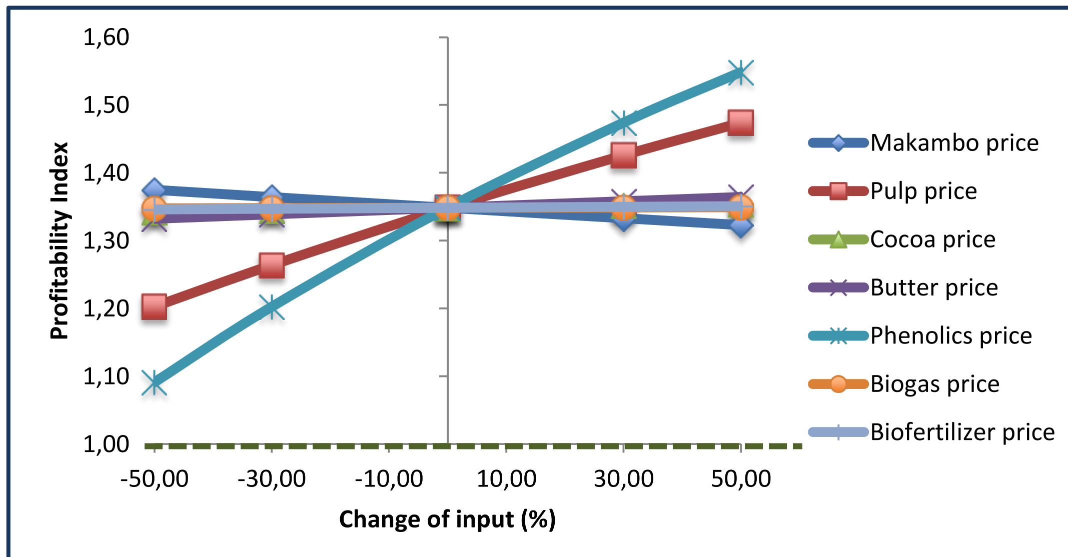
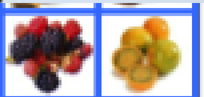


Figure 25. Scenario 2

Scale production assessment



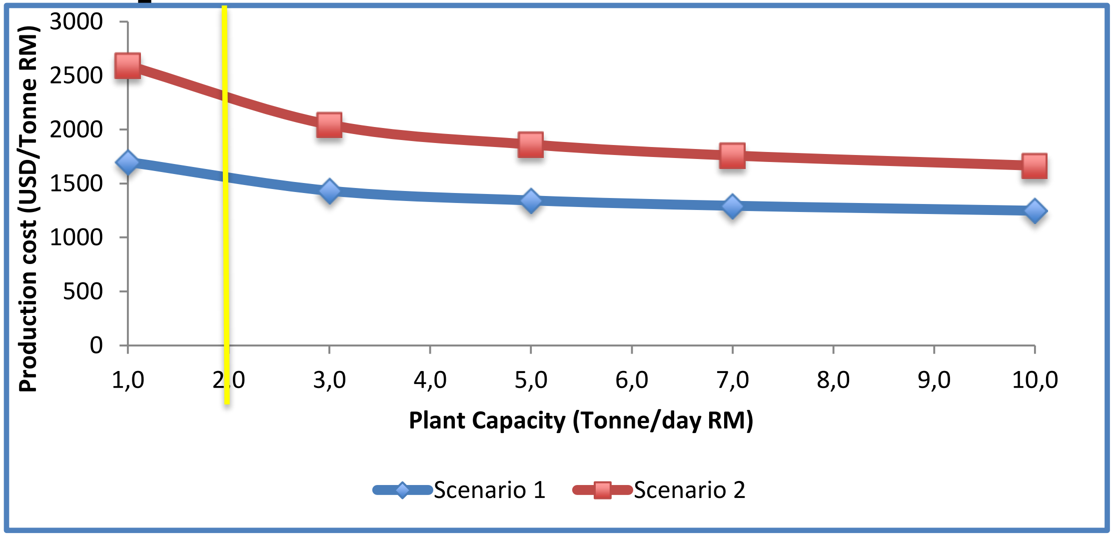


Figure 26. Annualized cost for different production scales

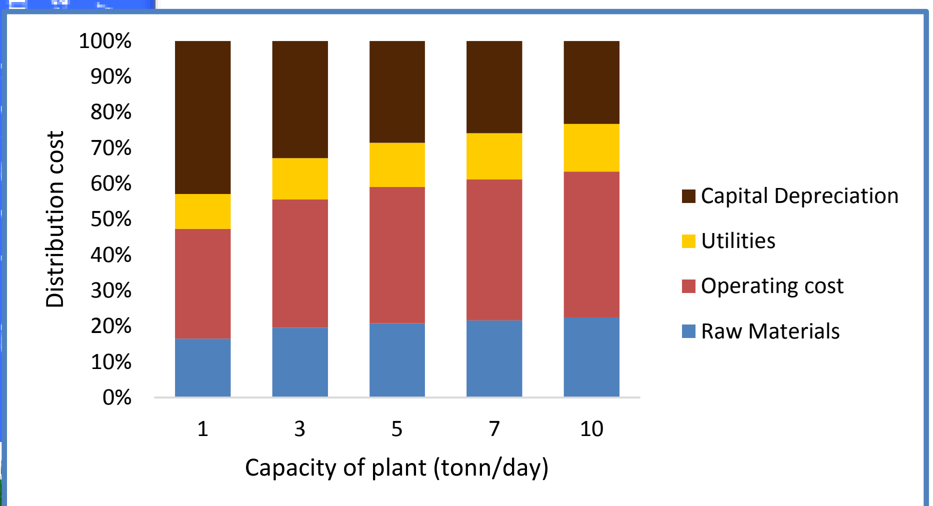


Figure 27. Annual cost distribution for different production scales for Sc 1

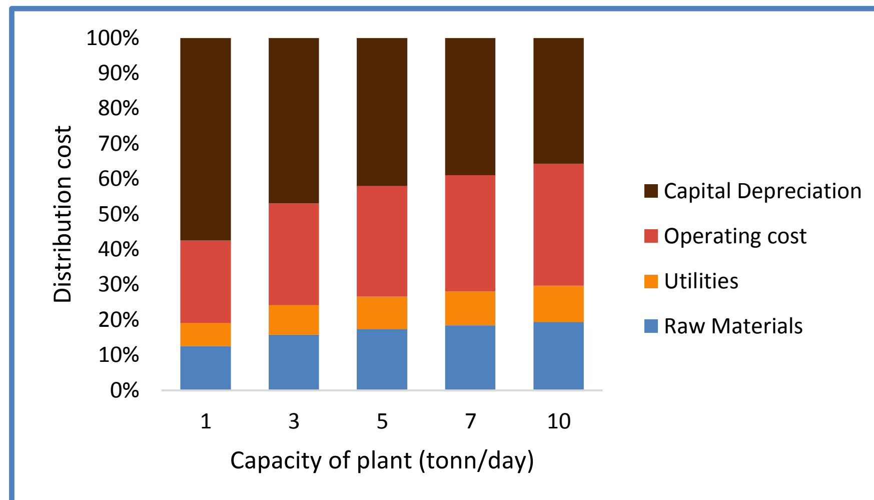


Figure 28. Annual cost distribution for different production scale for Sc 2

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Case study 2: Energy producing biorefineries. A.Pinus Patula (PP)

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High availability

High access

Moderate logistic problems

Figura 3. Chips

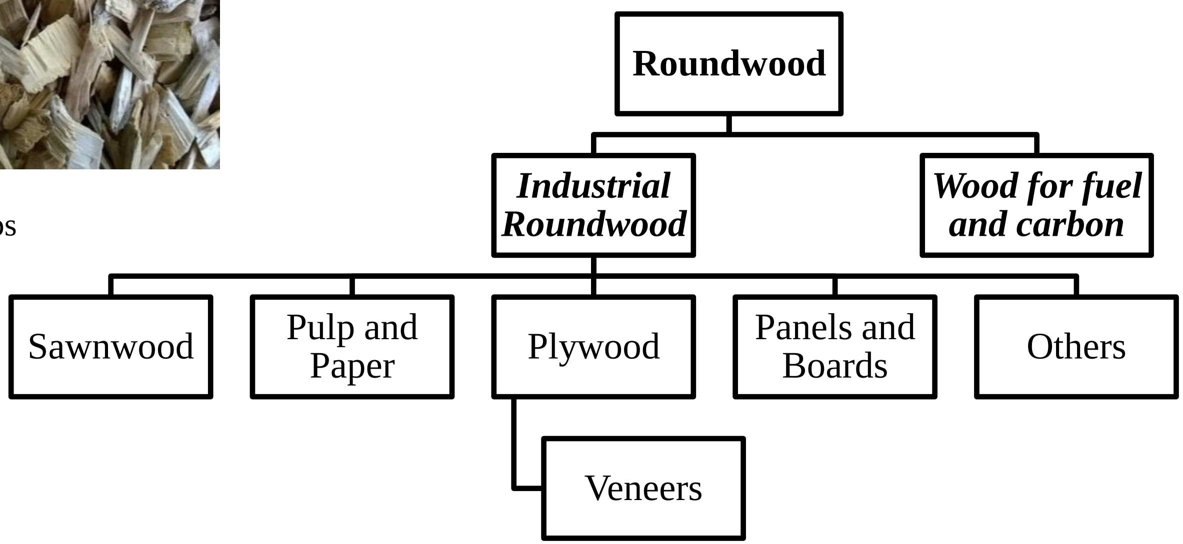

Figura 4. Applications of PP

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b.Coffee cut stems

Figura 4. Chips

Colombia 4th producer

↓

90,000 Hectares are renovated every year

↓

17 tons of residues per hectare

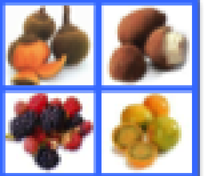
↓

Up to 690 GWe

→ Logistics restrictions

↓

Only 20% used for dryingg coffee



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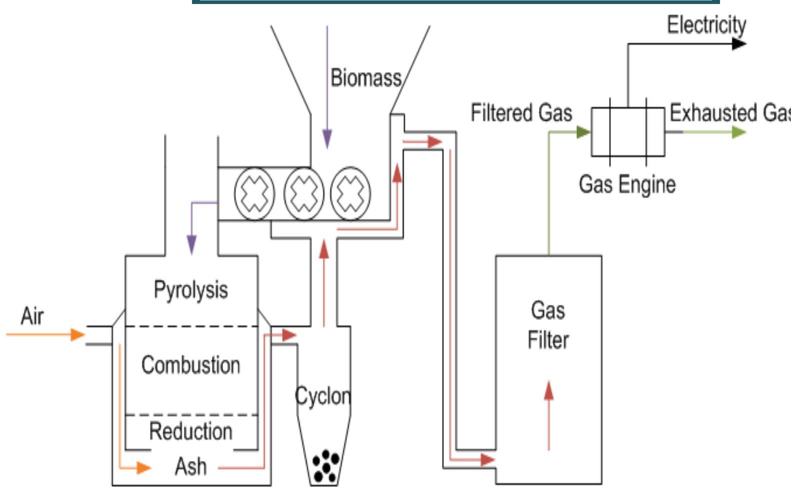
Experimental work

Gasification

syngas

Composition

Caracterization



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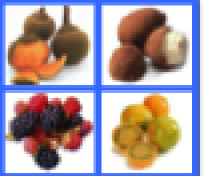
Elemental Analysis

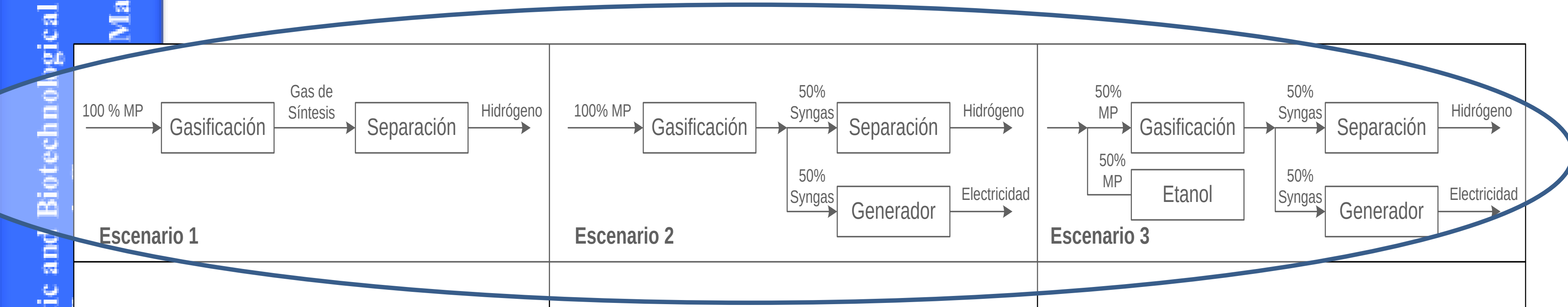
- $C = 0.635 * FC + 0.460 * VM + 0.095 * ASH$
- $H = 0.059 * FC + 0.060 * VM + 0.010 * ASH$
- $O = 0.34 * FC + 0.469 * VM + 0.023 * ASH$

- $HHV = 19.2880 - 0.2135\left(\frac{VM}{FC}\right) - 1.9584\left(\frac{ASH}{VM}\right) + 0.0234\left(\frac{FC}{ASH}\right)$

Heating value



Scenario


100 % MP
Gasificación
Gas de Síntesis
Separación
Hidrógeno
Escenario 1
100% MP
Gasificación
50% Syngas
Separación
Hidrógeno
50% Syngas
Generador
Electricidad
Escenario 2
50% MP
Gasificación
50% MP
Etanol
50% Syngas
Separación
Hidrógeno
50% Syngas
Generador
Electricidad
Escenario 3
100% MP
Fermentación Oscura
Hidrógeno
Escenario 4
100% MP
Fermentación Oscura
Mosto
Separación
Etanol
Hidrógeno
Escenario 4
100% MP
Fermentación Oscura
Mosto
Separación
Etanol
Acido Acético
Acido Butírico
Hidrógeno
Escenario 6

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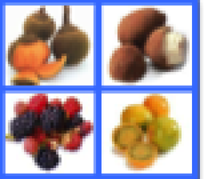
Caracterization

	Pinus	CCS
Moisture Content (%wt)	9.21	8.7
Chemical Composition (%wt dry)		
Cellulose	44.78	40.39
Hemicellulose	23.75	34.01
Lignin	20.22	10.13
Extractives	11.0	14.18
Ash	0.25	1.27
Proximate Analysis (%wt dry)		
Volatile Matter	82.14	82.15
Fixed Carbon	17.64	16.78
Ash	0.23	1.07
Elemental Analysis (%wt dry)		
Carbon	48.96	48.35
Hydrogen	5.97	5.93
Oxygen	44.51	44.21
HHV (MJ/kg)	19.97	19.32

feedstock	HHV (MJ/kg)
Sugarcane bagasse	17.70
Rice straw	16.47



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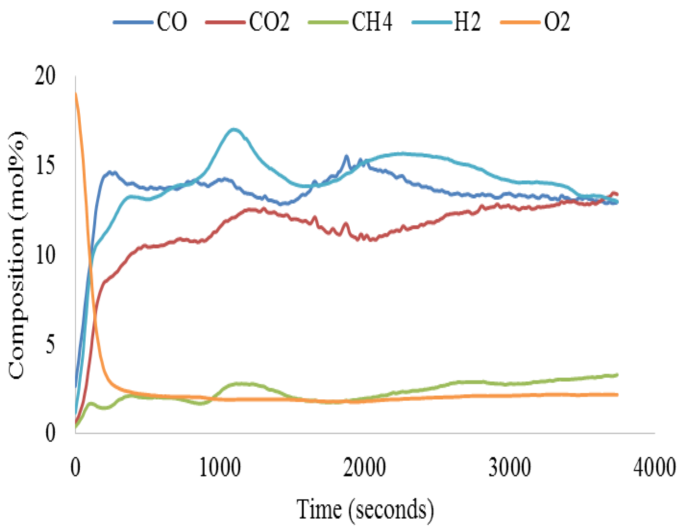
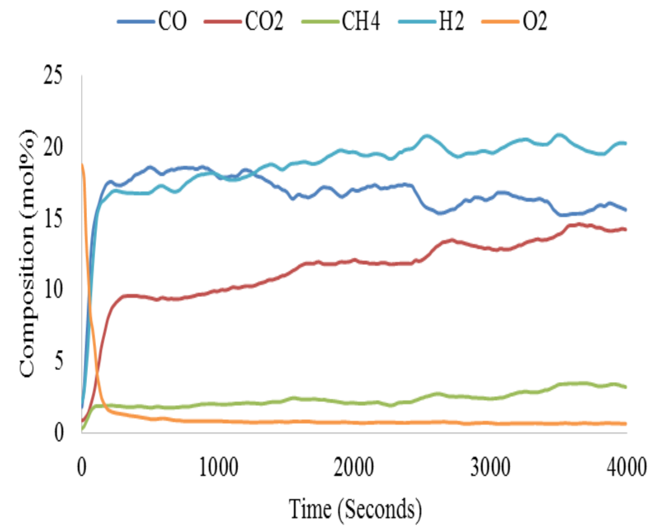
Gasification

PP

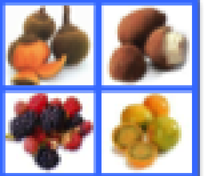


Componentes Gas de Síntesis	Composition (%mol)
H2	13 – 17%
CO2	13 – 16%
CH4	2 – 4%
Gas flow (Nm^3/h)	10.94 – 14.31

stems



Componentes Gas de Síntesis	Composition (%mol)
H2	15 -20 %
CO2	11 – 18%
CH4	2 – 4%
Gas flow (Nm^3/h)	6.77 – 10.37



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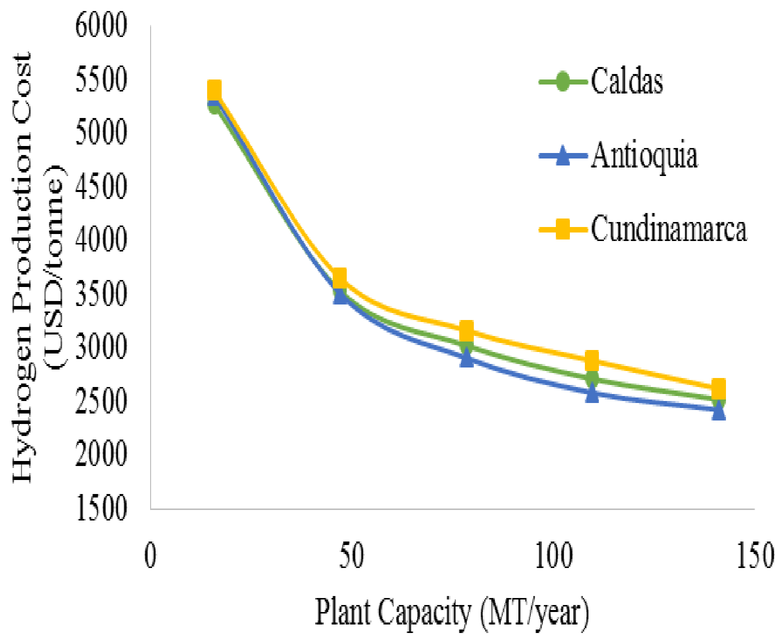
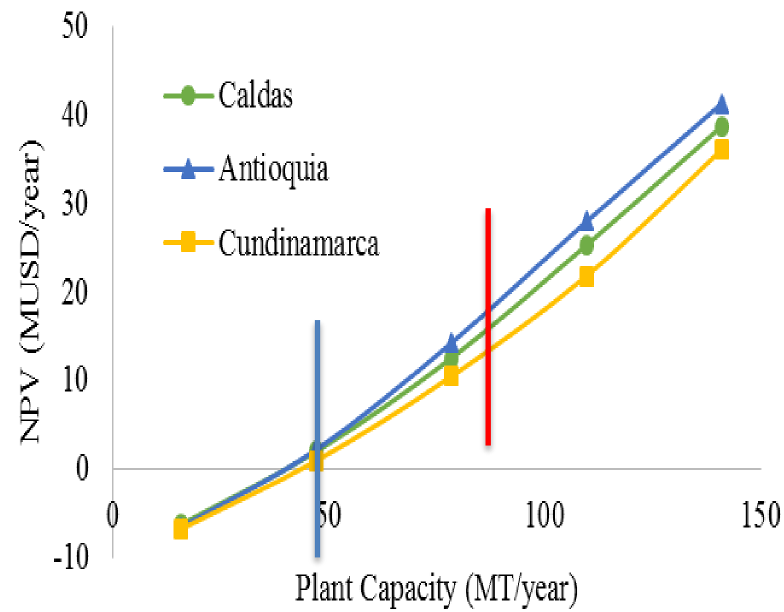
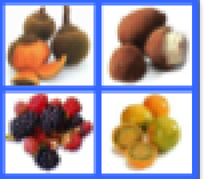
Plant location

Base case: hydrogen through gasification







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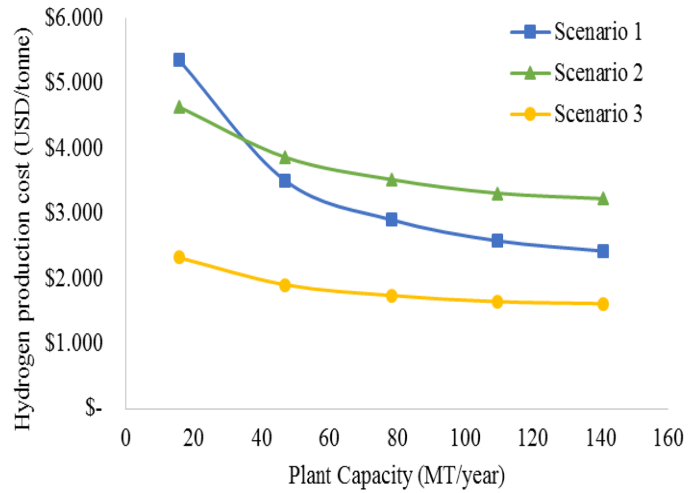
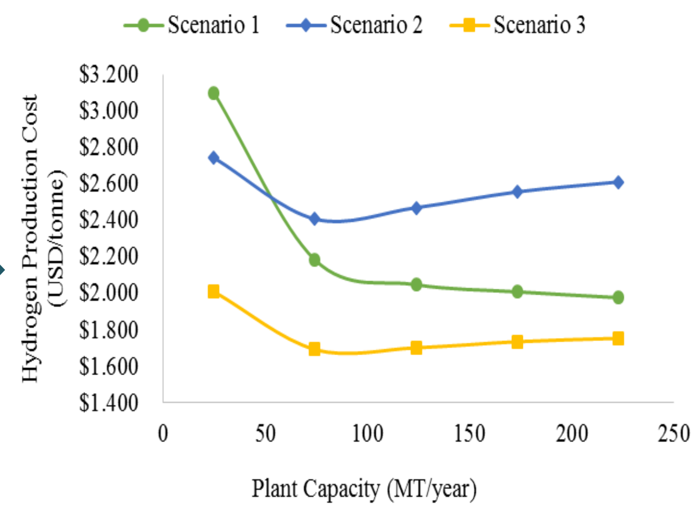
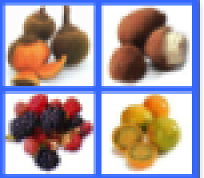
production costs for hydrogen

Pinus Patula



Coffee cut stems





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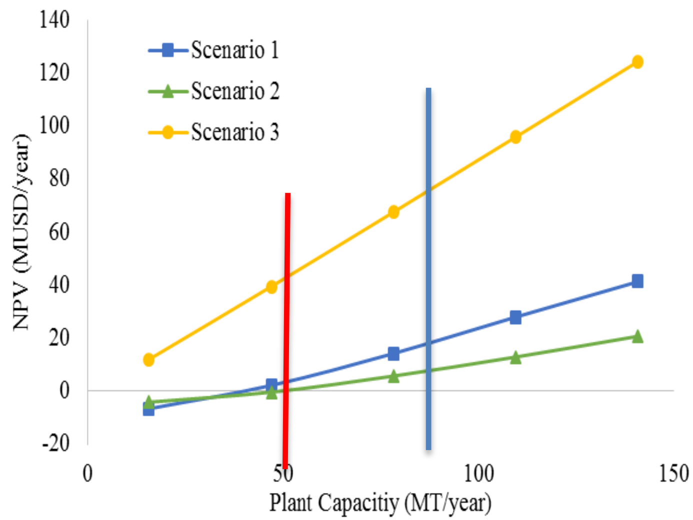
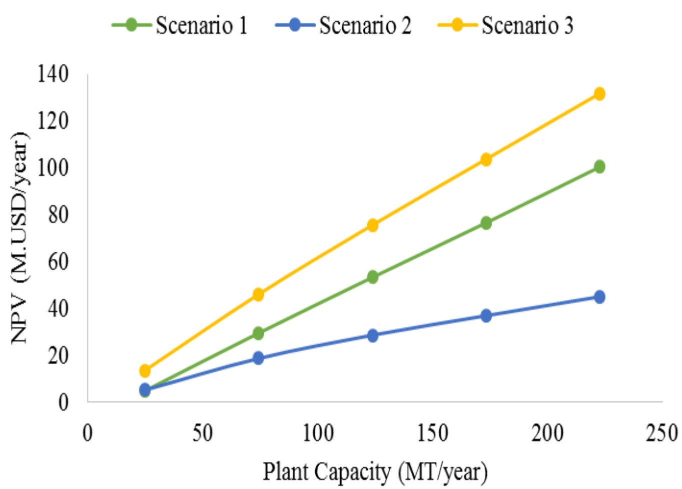
Net present value(NPV)



Pinus Patula



stems

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Conclusions

- The scale is the basis for understanding the type of products to obtain in the biorefinery. The biofuels for example cannot be produced at low scale and the high added value products cannot be produced at high scale.

- The small scale is a relative concept and it should be difined in any case. There is not a technical recommendation for this purpose but the sensitivity analysis for NPV or profit is really a good beginning to objectively define what are the limits you can have for the scale.

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Thank you for your attention