UNIVERSIDAD NACIONAL DE COLOMBIA SEDE MANIZALES

CYPRUS 2016

ENVIRONMENTAL COMPARISON OF THERMOCHEMICAL AND BIOCHEMICAL WAYS FOR PRODUCING ENERGY FROM AGRICULTURAL SOLID RESIDUES: COFFEE CUT-STEMS CASE

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Outline

Agricultural Residues

Agricultural Crops

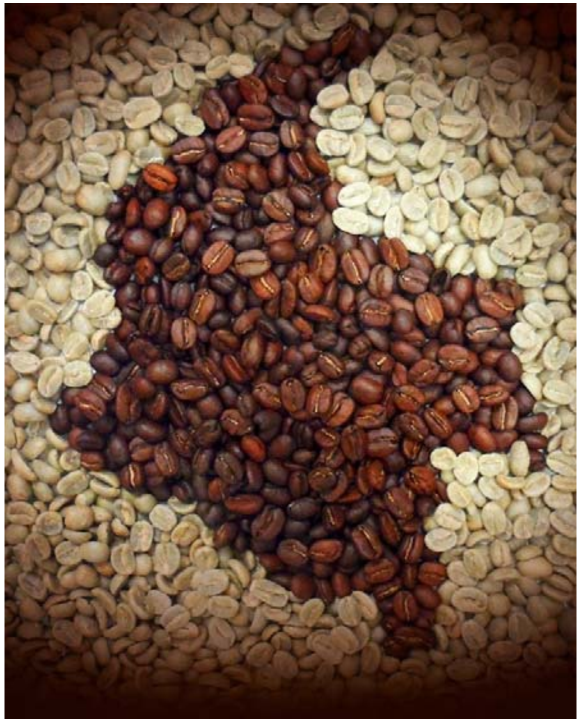
Harvesting

Crop Residues

Processing

Agroindustrial Residues

Coffee Cut-Stems



Colombia is the fourth largest producer of Coffee in the World.

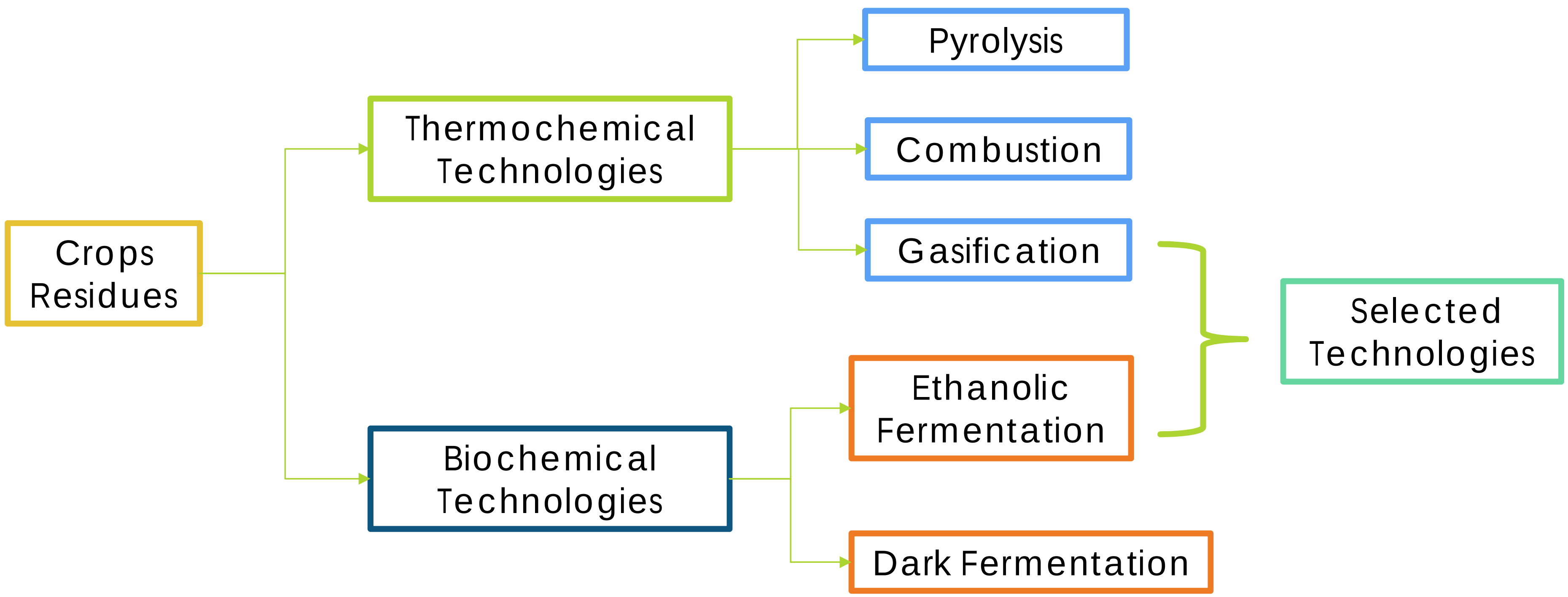
80,000 hectares of Coffee tree Wood are cutted to renew the plants

17 tonne of dry Wood per day can be obtained

690 GWe can be generated

Heating and Cooking

Transformation Methods



Gasification

Raw Material

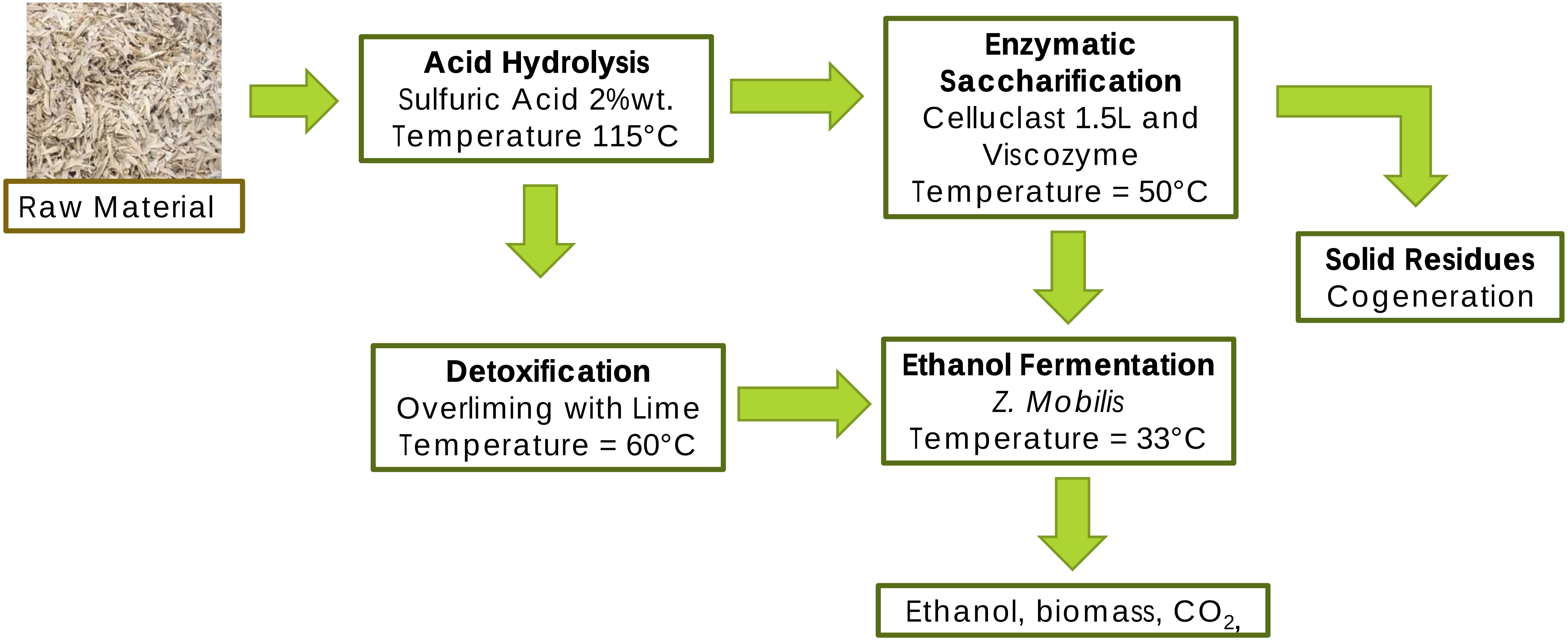
Gasifying Agent
Air

Synthesis Gas
Hydrogen, Carbon Monoxide, Methane, Carbon Dioxide and Nitrogen

Bioethanol

Power Generation

Ethanol Fermentation



Objective

- The aim of this study is to evaluate and compare the energy and environmental assessment of two processes for energy production (ethanol fermentation and gasification) from Coffee Cut-Stems.

General Description

Experimental

- CCS characterization
- Pilot-scale gasification
- Ethanol Fermentation

Simulation

- Aspen Plus V8.0
- Waste Reduction Algorithm (WAR)

Results

- Gas Composition
- Ethanol Yield
- Environmental Impact
- Energy Efficiency

Raw Material

Chemical Composition

Elemental Analysis

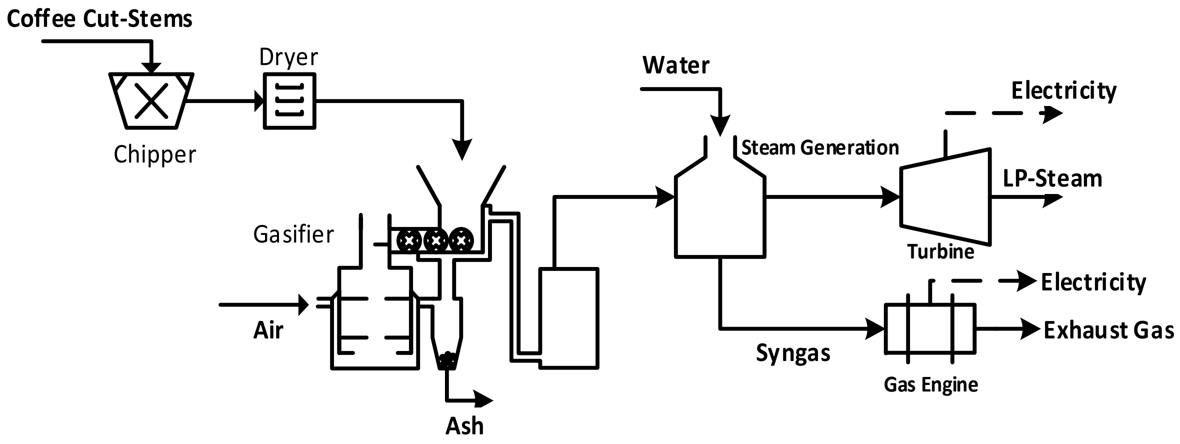
- $C = 0.635 * FC + 0.460 * VM + 0.095 * ASH$
- $H = 0.059 * FC + 0.060 * VM + 0.010 * ASH$
- $O = 0.34 * FC + 0.469 * VM + 0.023 * ASH$

Calorific Value

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

Simulation Procedure

Air Gasification



Pyrolysis

$$Biomass + heat \rightarrow C_s + tar\ gases$$

Combustion

$$\boldsymbol{C_s, tar\ gases + O_2 \rightarrow CO_2 + H_2O + heat}$$

$$\boldsymbol{tar\ gases + heat \rightarrow CO + H_2}$$

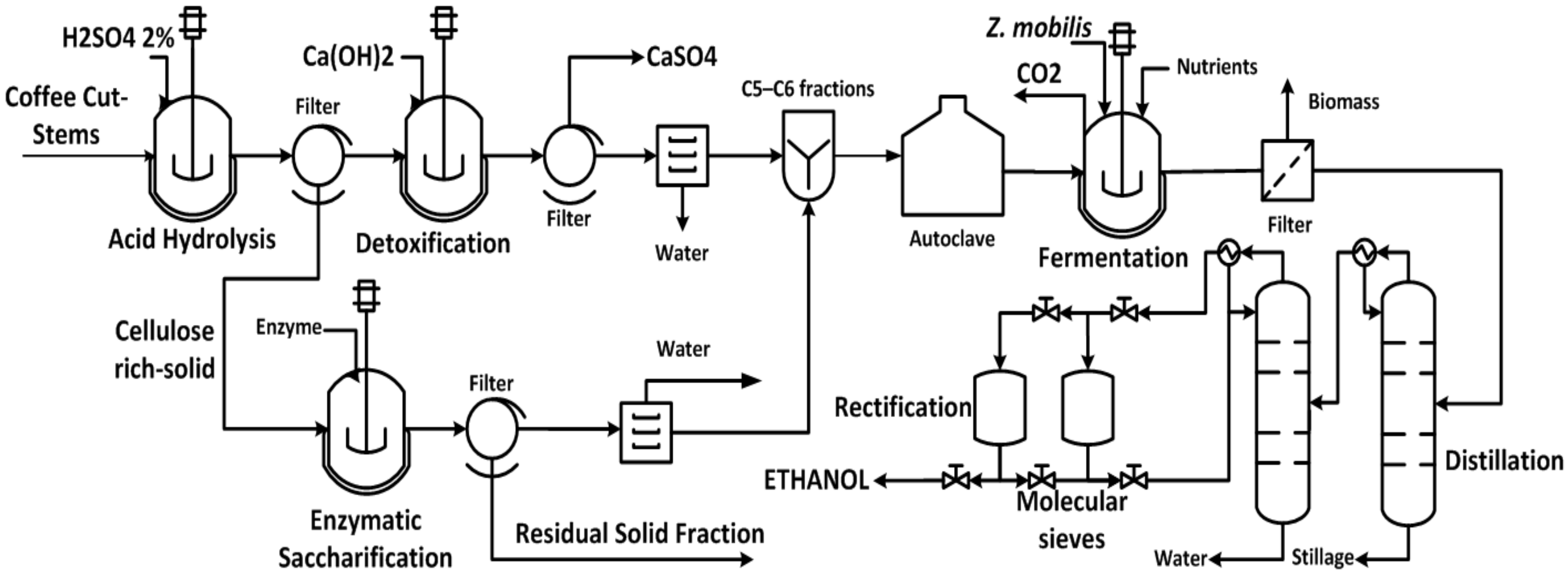
Reduction

$$C_s + CO_2 \leftrightarrow 2CO$$
$$C_s + H_2O \leftrightarrow CO + H_2$$
$$C_s + 2H_2 \leftrightarrow CH_4$$
$$CH_4 + H_2O \leftrightarrow CO + 3H_2$$
$$CO + H_2O \leftrightarrow CO_2 + H_2$$

Reaction Mechanism

Simulation Procedure

Ethanol Fermentation



Waste Reduction Algorithm (WAR)

EPA
United States
Environmental Protection
Agency

WAR Algorithm

- A one-dimensional sustainability metric – only considers environmental aspects.
- Considers Potential Environmental Impacts (PEI) generated by the process.
- Based on input/output-style balance equations
- Eight impact categories defined in WAR

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

What topics are evaluated?

- Human toxicity potential by ingestion (HTPI)
- Human toxicity potential by dermal and inhalation exposure (HTPE)
- Terrestrial toxicity potential (TTP)
- Aquatic toxicity potential (ATP)
- Global warming potential (GWP)
- Ozone depletion potential (ODP)
- Photochemical oxidation potential (PCOP)
- Acidification potential (AP)

Physicochemical Characterization

Raw Material	HHV (Mj/kg)
Sugarcane Bagasse	17.70
Rice Husk	16.47

	Coffee Cut-Stems
Moisture Content (%wt)	8.7
Chemical Composition (%wt dry)	
Cellulose	40.39
Hemicellulose	34.01
Lignin	10.13
Extractives	14.18
Ash	1.27
Proximate Analysis (%wt dry)	
Volatile Matter	82.15
Fixed Carbon	16.78
Ash	1.07
Elemental Analysis (%wt dry)	
Carbon	48.35
Hydrogen	5.93
Oxygen	44.21
HHV (MJ/Kg) calculated	19.32
HHV (MJ/Kg) experimental	**18.26**

Pilot-scale gasification

Composition (%Vol)	Coffee Cut-Stems	Zainal et al., *Pinus Radiata*
Hydrogen	17.41	15.23
Methane	3.13	1.58
Carbon Monoxide	12.88	16.42
Carbon Dioxide	15.8	23.04
Nitrogen	49.6	42.31
Calorific Value (Mj/kg)	4.74	3.92

Zainal, Z. a., Ali, R., Lean, C.H., Seetharamu, K.N., 2001. Prediction of performance of a downdraft gasifier using equilibrium modeling for different biomass materials. Energy Convers. Manag. 42, 1499–1515.

Ethanol Fermentation

Pretreatment Results

Process	Concentration (g/L)	Conversion Yield (%)
Acid Hydrolysis	33.4	74
Detoxification	19.5	43
Enzymatic Saccharification	18.3	45

High detoxification temperature reduces the content of toxic compounds but increases the decomposition of sugars and thus reduces the acid hydrolysis yield.

Lower ethanol production due to the low acid hydrolysis yield after the detoxification process

	Ethanol Yield (g/g substrate)
This study	0.41
Aristizabal et al.,	0.495

Aristizábal M, V., Gómez P, Á., Cardona A, C.A., 2015. Biorefineries based on coffee cut-stems and sugarcane bagasse: Furan-based compounds and alkanes as interesting products. Bioresour. Technol. 196, 480–9.

Simulation Results

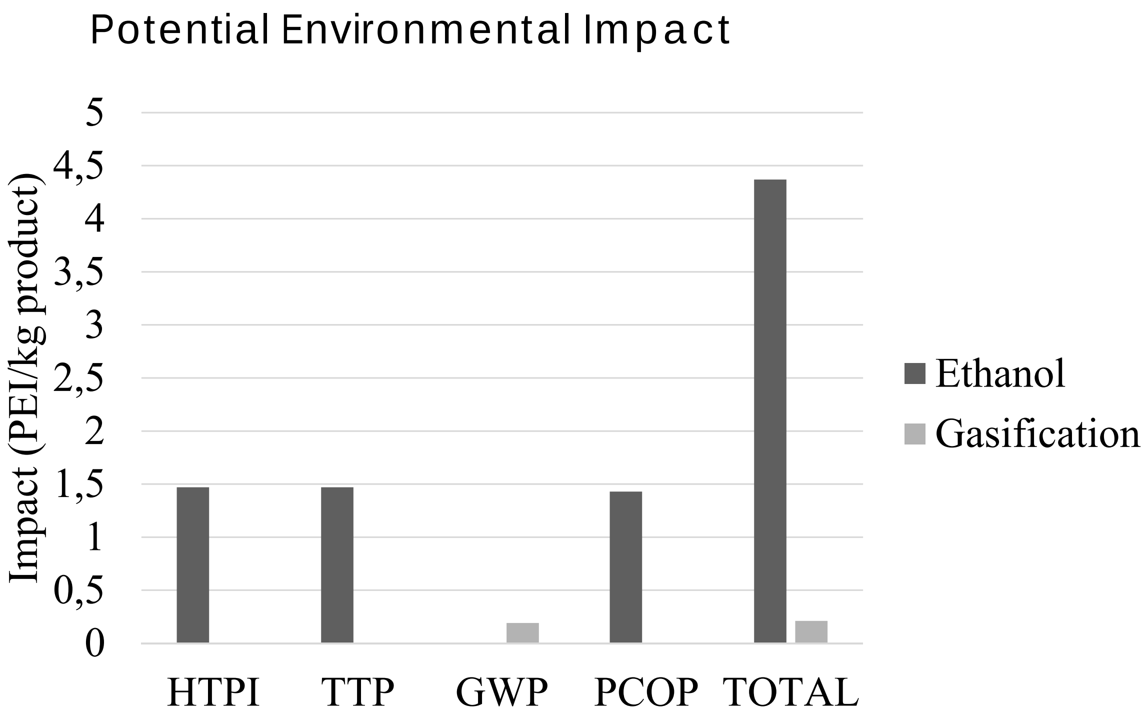
High syngas production but low fermentable sugars which is hindered mainly by the raw material and the pretreatment methods

Platform	Yield	Units
Synthesis gas	2.84	kg syngas/kg CCS
Fermentable sugars	0.38	kg sugars/kg CCS

Product	Productivity		Yield	
	Value	Units	Value	Units
Power	21.5	MW	7.09	Mj/kg CCS
Ethanol	2,056.52	kg/h	5.44	Mj/kg CCS

Despite the higher energy content of the ethanol, the production yield of electricity is higher due to the high productivity of synthesis gas from CCS.

Environmental Assessment



Ethanol – HTPI and TTP
Final disposition of the stillage from the downstream processing.

Gasification – GWP
CO_2 emissions as a consequence of the synthesis gas combustion

Conclusions

- This work evaluated a thermochemical and biochemical route to obtain bioenergy (ethanol and electricity) from the environmental point of view. The most promising technology to produce bioenergy seems to be the gasification due to the high syngas/biomass ratio in comparison to the platform to obtain sugars to be used in a fermentation.
- Besides, the amount of energy that can be obtained from the direct use of CCS to generate electricity through the synthesis gas platform presents a novel scenario for its implementation in zones where the power supplied is not carried out.

Conclusions

- The generation of electricity through gasification can be considered as a very low emission process since part of the energy is used in the same process and the remainder can be sold to the grid.

Acknowledgement

- The authors of this work acknowledge to the National University of Colombia at Manizales, the announcement 703 “Joven Investigador” of COLCIENCIAS and the Dirección de Investigación de Manizales (DIMA) for the financial support to develop this work.

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