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Exergy analysis of thermochemical and biochemical pathways for bioethanol production

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Future biomass conversion systems have to be developed using advanced conversion routes in order to compete with fossil fuels. An attractive biomass feedstock for bioethanol production is lignocellulosic biomass, particularly various agricultural and forest residues, such as sugarcane bagasse, which are available in large amounts. Lignocellulosic biomass can be converted into bioethanol using biochemical route, including pretreatment processes followed by hydrolysis of cellulose and hemicellulose into sugars and their subsequent fermentation. On the other hand, the thermochemical route can also be applied to bioethanol production, in which biomass gasification represents a pathway for the production of variety of biofuels, including ethanol, methanol, dimethyl ether, Fischer-Tropsch (F-T) fuels, hydrogen and Synthetic Natural Gas (SNG). However, although biochemical or thermochemical routes are promising technological options due to their large-scale production of lignocellulosic ethanol, they are still to be further developed to achieve commercial outcomes. In this work, a detailed exergy analysis of the biochemical and thermochemical conversion routes for bioethanol production from sugarcane bagasse is presented. In addition, a performance comparison in terms of exergy efficiency and destroyed exergy rate of each stage involved in these routes is determined. Hence, in an effort to compare these technological routes, the simulation processes were performed using Aspen Plus® software to a plant with 500 t/h milling capacity.

Biography

Pablo A. Silva Ortiz has a BS in Energy Engineering from the Universidad Autonóma de Bucaramanga-UNAB (2006) in Colombia. He also has an MS in Mechanical Engineering from the Universidade Federal de Itajubá-UNIFEI (2011) in Brazil. Currently, he is a pursuing PhD in Mechanical Engineering at the Universidade de São Paulo-USP in Brazil. He is working on the research project entitled *"Exergy and environmental ranking of bioethanol production routes"*.

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Notes:

Exergy analysis of the thermochemical and biochemical pathways for bioethanol production

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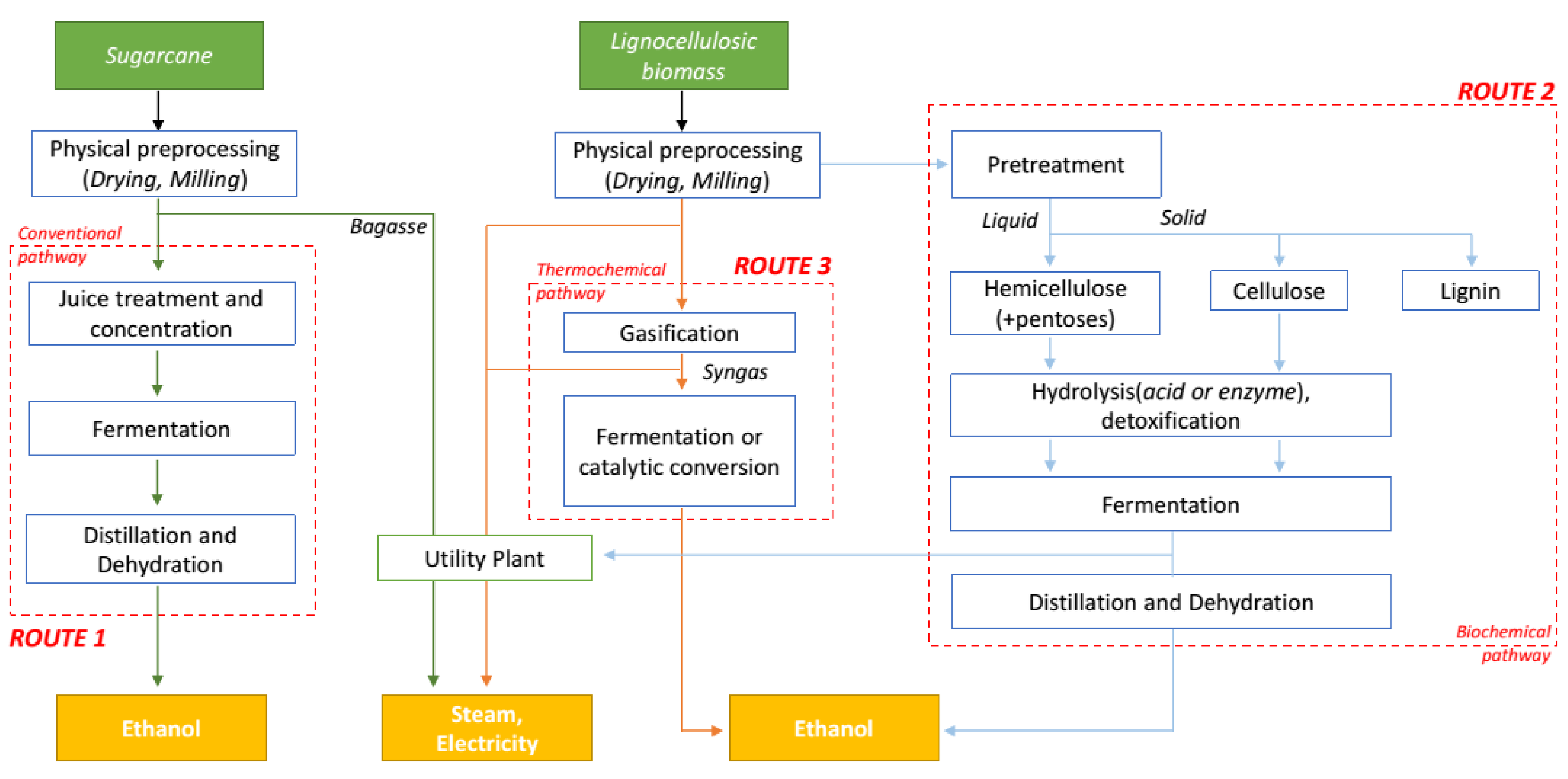
RESEARCH AIMS



SCENARIOS PROPOSED

ROUTE 1: *Ethanol (1G) and electricity;*
ROUTE 2: *Ethanol (2G), hydrolysis and electricity;*
ROUTE 3: *Liquid fuels and electricity.*

SPECIFIC OBJECTIVES

- Characterizing energy conversion processes in each configuration analyzed in terms of waste/rejects and the most representative consumption-production data of these processes.
- Developing thermodynamic models for simulating the energy conversion processes of the proposed routes.
- Comparing the exergy performances of the routes evaluating alternatives to minimize entropy generation (irreversibility) in order to improve the quality of the products obtained.
- Defining appropriate exergo-environmental indicators for ranking the studied biorefineries configurations in certain scenarios for bioethanol and electricity production.
- Based on a thermo-economic analysis, assessing how the changes in the proposed biorefineries configurations alter the exergetic monetary costs of the products formation process.

METHODS

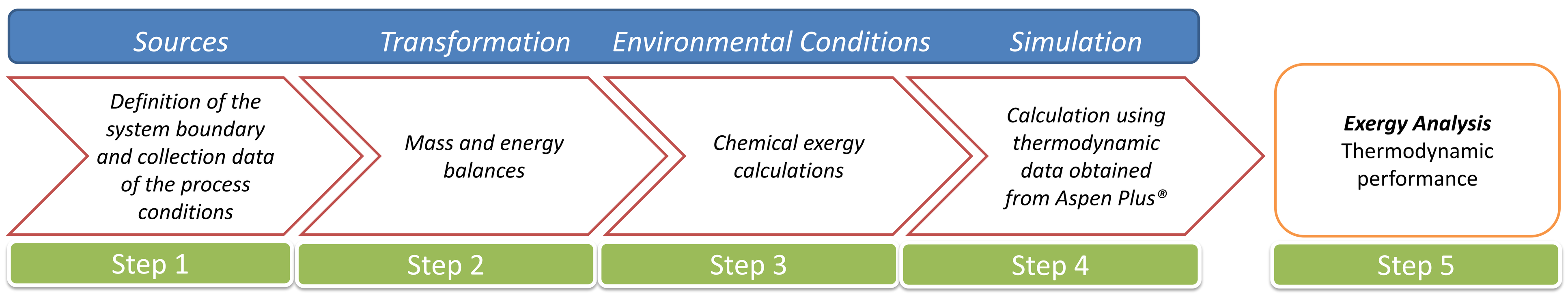
MAIN OPERATING CONDITIONS

Parameters	Values	Units
Bagasse	140	t/h
Milling (processed cane)	500	tc/h
Hours to harvest	5000	h/year
Moisture content of cane	50	(w/w)%
Exergy of sugar cane juice $_{\text{wet basis}}$	5614	kJ/kg
Exergy of bagasse $_{\text{wet basis}}$	9892	kJ/kg

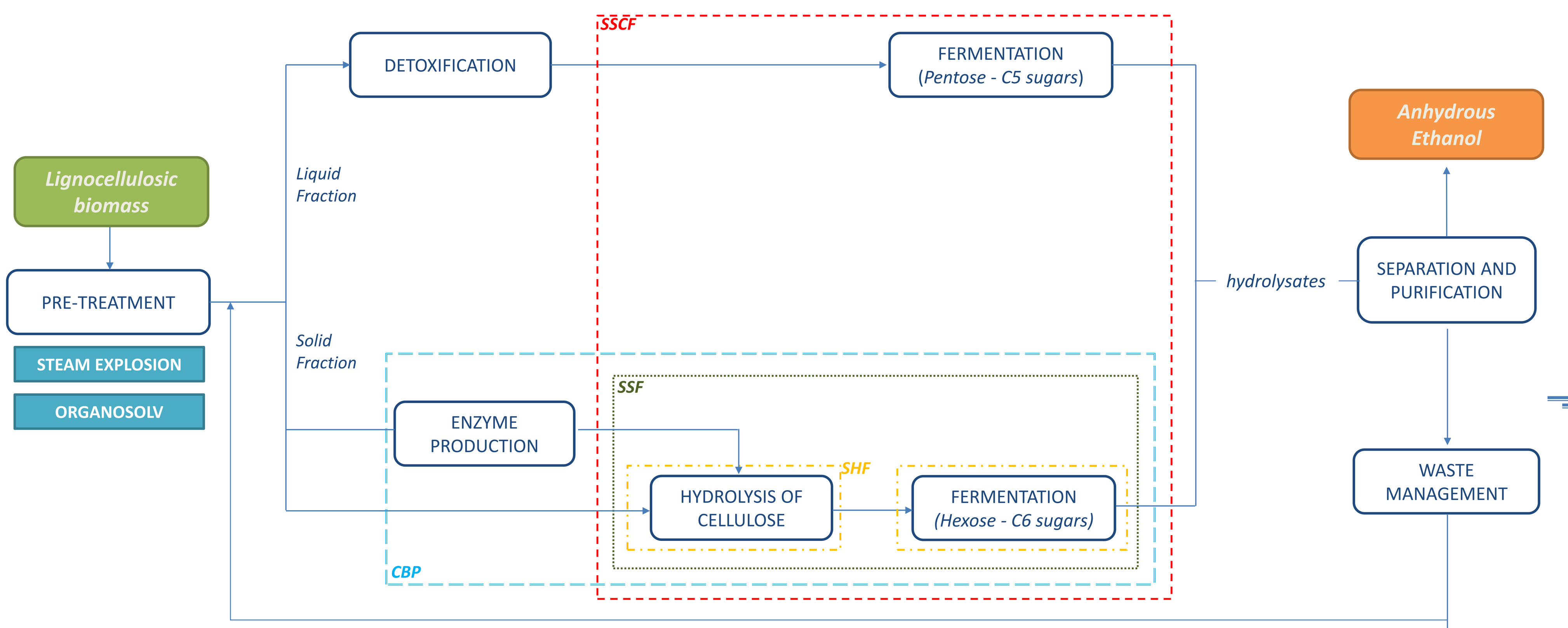
(w/w)%: mass percent

Raw material 1 (w/w)
cellulose 47.5%
hemicellulose 20%
lignin 30%
ash 2.5%

Raw material 2 (w/w)
cellulose 43.38%
hemicellulose 25.63%
lignin 23.24%
ash 2.94%
extractives 4.81%



Biochemical route - Configurations of processes of bioethanol production from sugarcane



SHF >> Separate (or sequential) hydrolysis and fermentation
SSF >> Simultaneous saccharification and fermentation
SSCF >> Simultaneous saccharification and co-fermentation
CBP >> Consolidated bioprocessing

Bioethanol 1G-2G biorefineries – SHF Process

Configuration I
(using 50 % of bagasse in the 2G process and steam explosion pretreatment)

Products (kw)	
Power	320
Bioethanol	285
Efficiencies (%)	
Energy efficiency	49
Exergy efficiency	39

Streams Parameters

stream	m (kg/s)	T (°C)	P (bar)	b (kJ/kg)
Sugarcane	138.9	25	1	5750
Bagasse for cogeneration	22.4	30	1	9979
Bagasse for hydrolysis	15.3	30	1	9979
Must	110	30	1	3520
Lignin cake	6.5	50	1	10.80
Wine	147	32	1	2102
Enzyme	0.6	29	1	23,73
Vinhasse	135	75	1.4	440
Anhydrous ethanol	9.6	78	1	29.15

Configuration II
(using 50 % of bagasse in the 2G process and Organosolv pretreatment)

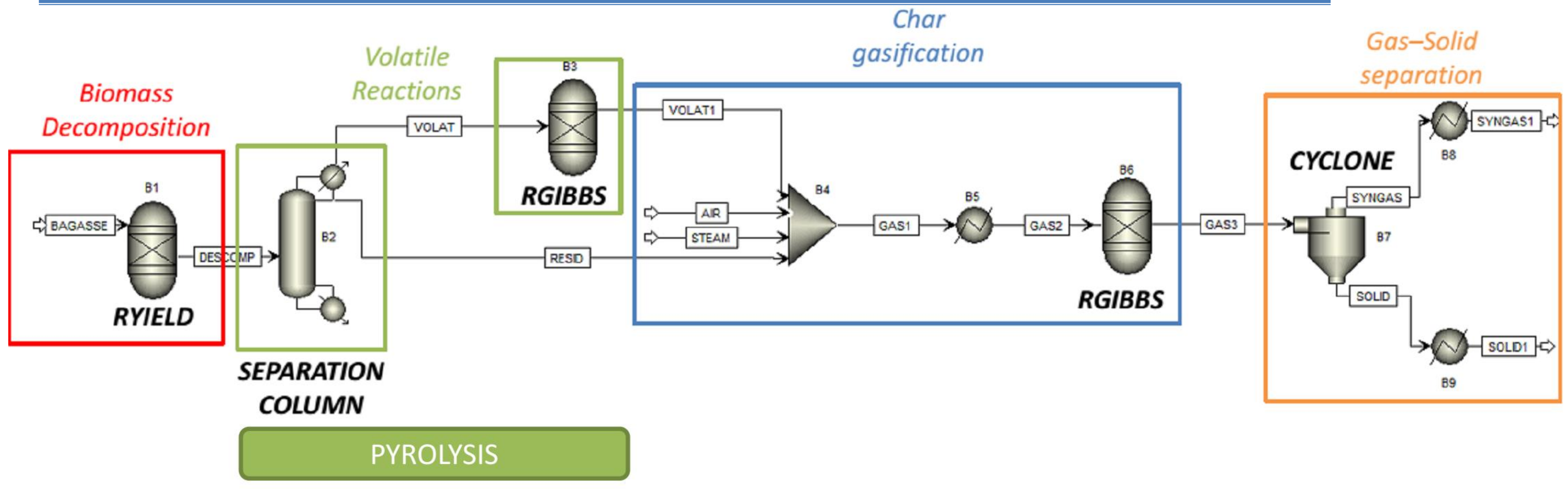
Products (kw)	
Power	300
Bioethanol	280
Efficiencies (%)	
Energy efficiency	41
Exergy efficiency	31

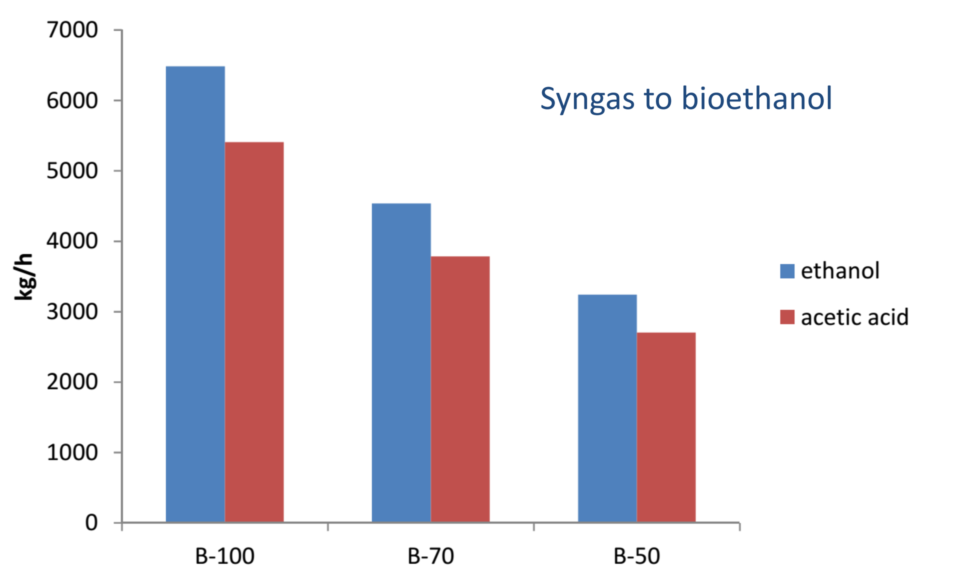
Streams Parameters

stream	m (kg/s)	T (°C)	P (bar)	b (kJ/kg)
Sugarcane	138.9	25	1	5750
Bagasse for cogeneration	25.8	30	1	9979
Bagasse for hydrolysis	16.4	30	1	9979
Must	112	30	1	3470
Lignin cake	10.2	50	1	12.30
Wine	158.3	32	1	2150
Enzyme	0.6	29	1	23,73
Vinhasse	135	75	1.4	440
Anhydrous ethanol	9.1	78	1	29.32

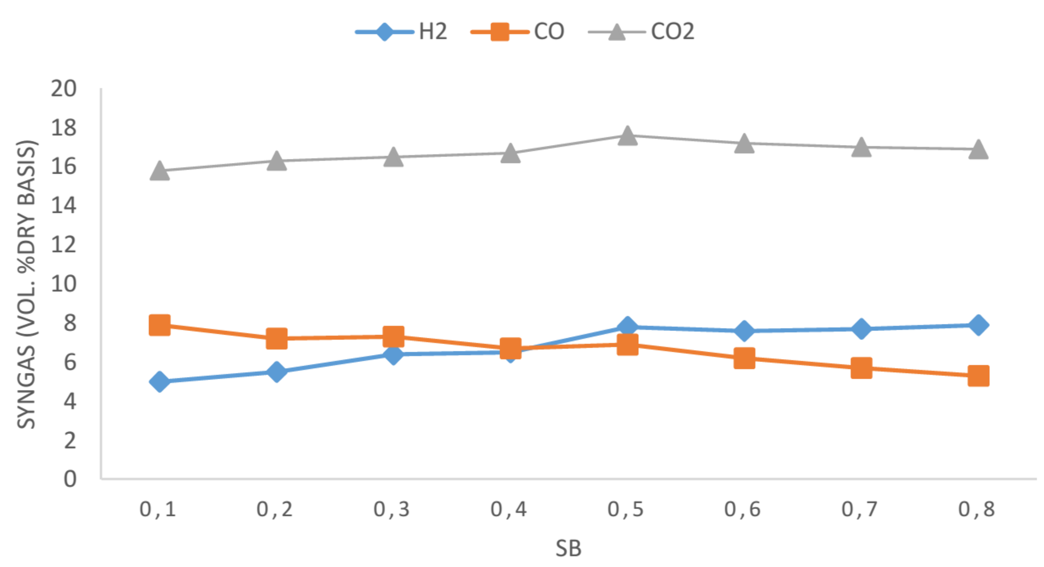
Thermochemical route of bioethanol production via sugarcane bagasse gasification

Circulating Fluidized bed gasifier – Model Aspen Plus software





Effect of steam to biomass ratio (SB) on syngas composition



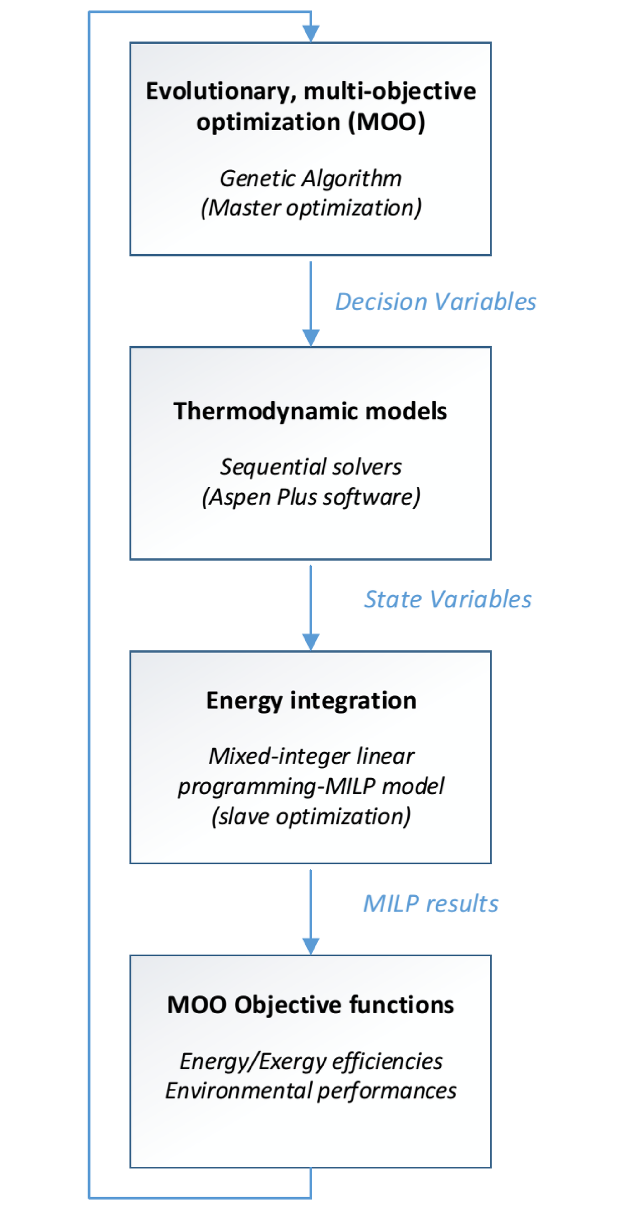
Assumptions

LHV (lower heating value)	7.10 MJ/kg
Gasifying medium (ER = 0:20)	AIR
Temperature	850 °C
Pressure	1 bar
Efficiencies (%)	
Exergy efficiency	56
Cold efficiency	76

Synthesis gas Composition	*(molar fraction % wet basis)*
H_2	15.7
CO	17.3
CO_2	13.9
N_2	49.6
H_2O	1.2
CH_4	2.3

Lignocellulosic biomass residues (%)	Mass Flow (kg/h)
B-50	29000
B-70	40600
B-100	58000

DESIGN OPTIMIZATION METHODOLOGY



SCIENTIFIC PAPERS

SILVA ORTIZ P., OLIVEIRA JR. S., *Exergy analysis of pretreatment processes of bioethanol production based on sugarcane bagasse.* **Energy, 2014, Vol. 76, p.130-138**
http://dx.doi.org/10.1016/j.energy.2014.04.090

SILVA ORTIZ P., OLIVEIRA JR. S., *Compared exergy analysis of sugarcane bagasse sequential hydrolysis and fermentation and simultaneous saccharification and fermentation.* **Int. J. Exergy, Vol. 20, No. 1, 2016**

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Best Poster Award

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The award has been attributed in recognition of research paper quality, novelty and significance.

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