Nº 179257

Valorizing residues of sugarcane biorefinery operation to produce liquid fuels: assessment of energy balances and influence of energy balances and influence of major inorganic elements to produce fast pyrolysis bio-oil

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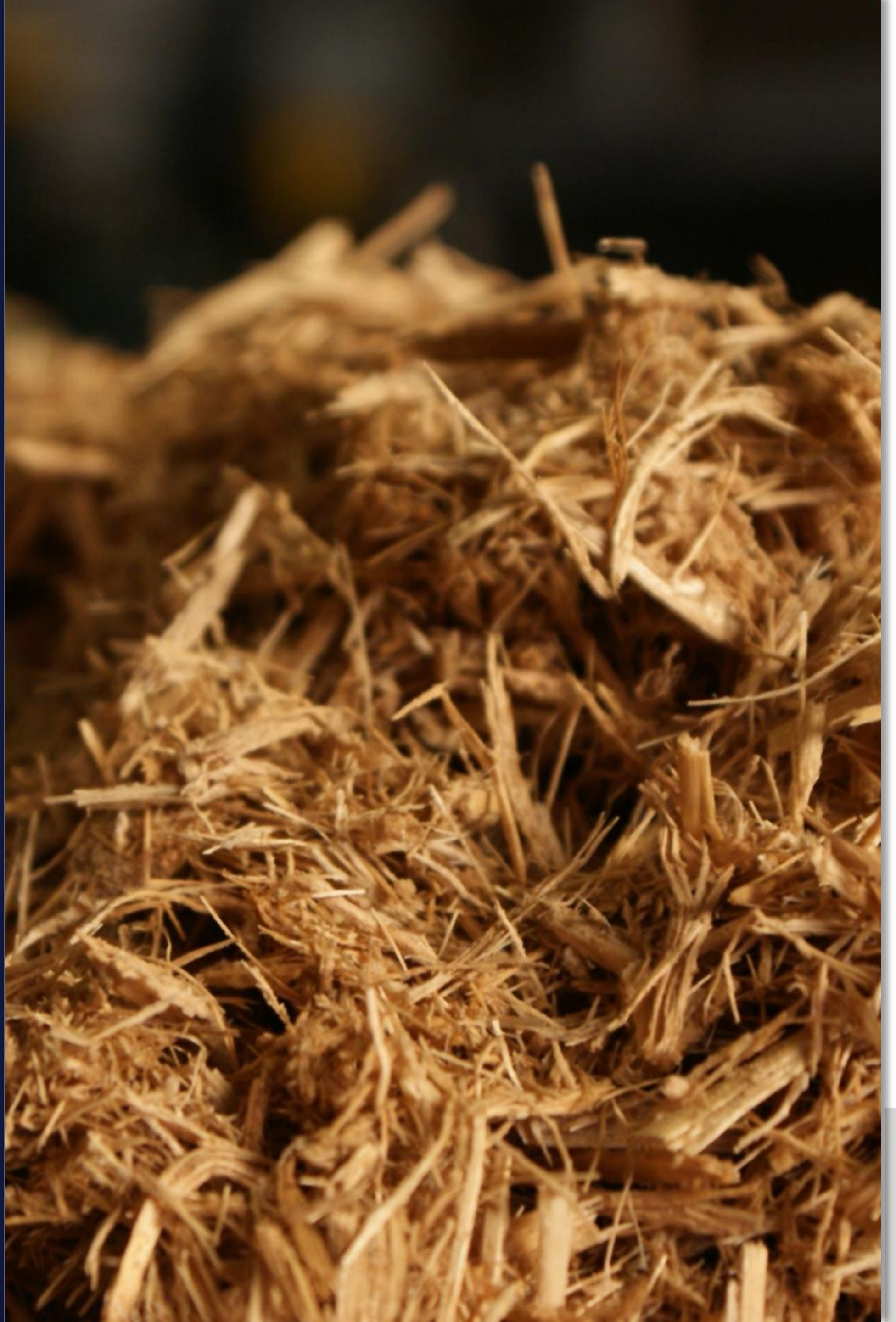
Lecture and abstract apresented
BRAZILIAN BIOENERGY SCIENCE AND TECHNOLOGY CONFERENCE, BBEST, 2024, São Paulo. 14 slides



Karlsruher Institut für Technologie

INSTITUTO DE PESQUISAS TECNOLÓGICAS

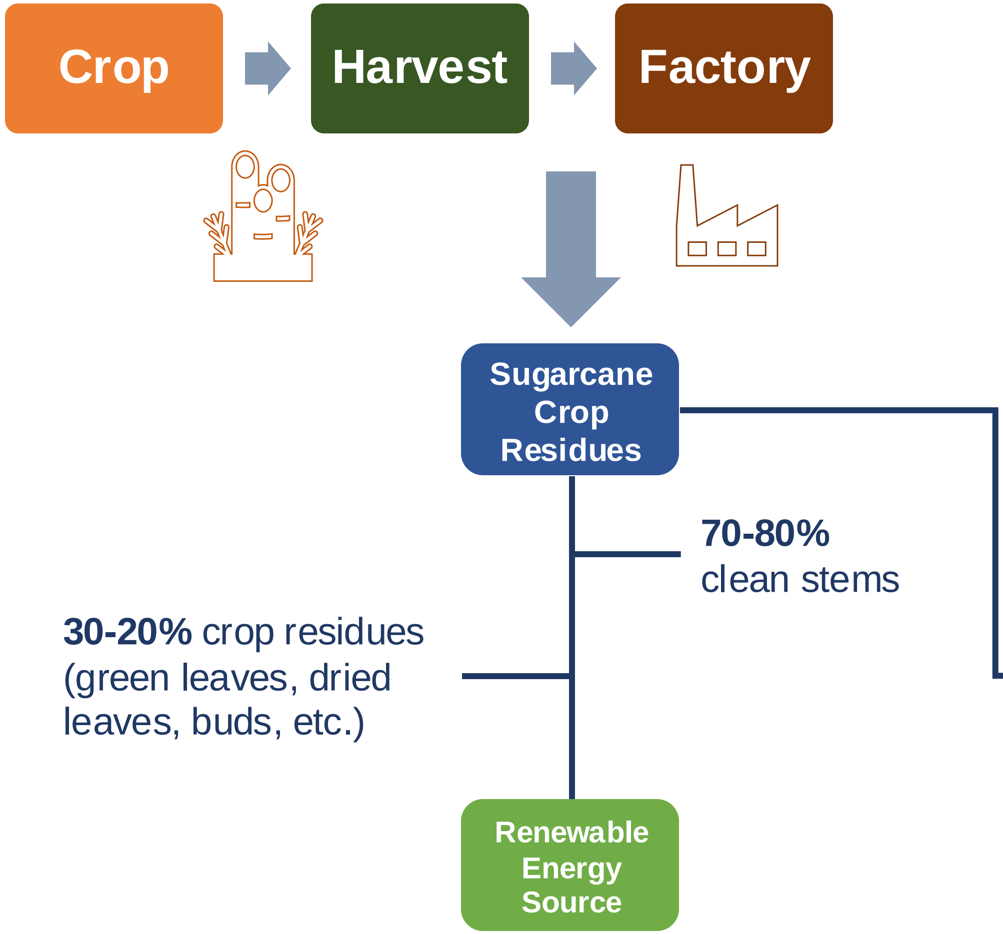
VALORIZING RESIDUES OF SUGARCANE BIOREFINERY OPERATION TO PRODUCE LIQUID FUELS - ASSESSMENT OF ENERGY BALANCES AND INFLUENCE OF MAJOR INORGANIC ELEMENTS TO PRODUCE FAST PYROLYSIS BIO-OIL

Danilo Eiji Hirayama, Renata Moreira, Lizet Rodríguez-Machín, Caroline Carriel Schmitt, Frederico Gomes Fonseca, Axel Funke

BBEST 2024 | Bioenergy and Bioproducts: Accelerating the transition towards sustainability | October 22nd to 24th, 2024 São Paulo - SP

INTRODUCTION

Sugarcane industry → Main activities



Crop → **Harvest** → **Factory**

Sugarcane Crop Residues

70-80% clean stems

30-20% crop residues (green leaves, dried leaves, buds, etc.)

Renewable Energy Source

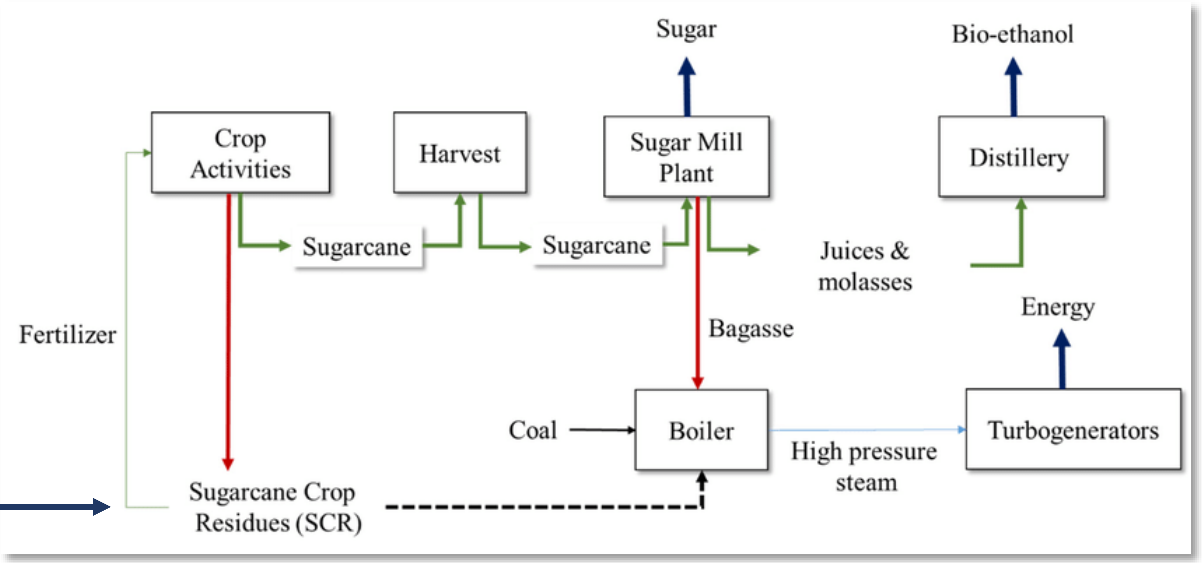


Figure 1. Cogeneration process and main activities in the sugar industry (Rivera-Cadavid, L., Manyoma-Velásquez, P.C., Manotas-Duque, D.F., 2019)

INTRODUCTION

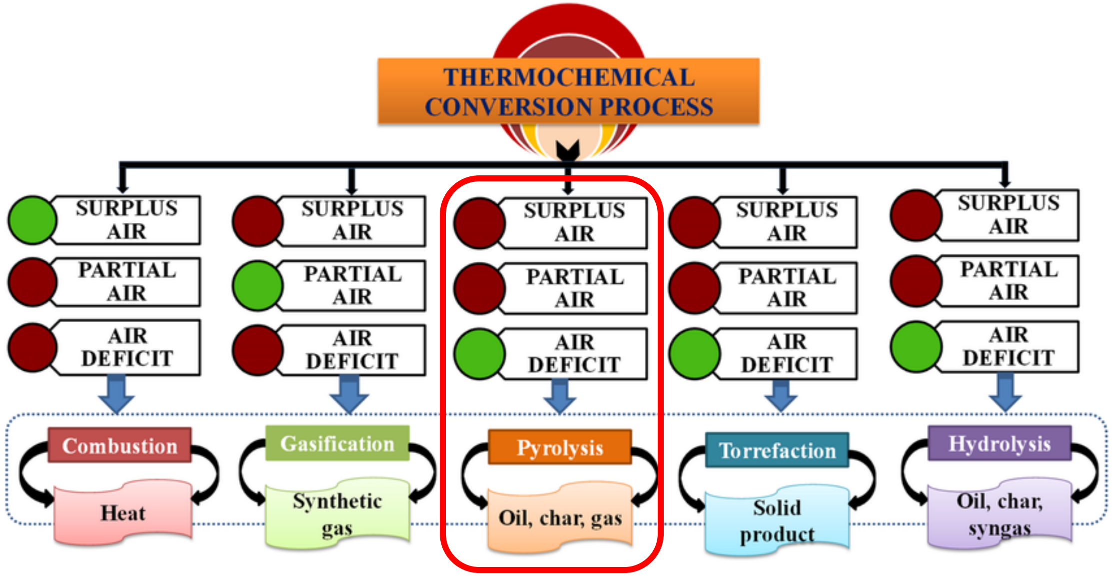


Figure 2. Concept of thermochemical conversion processes of biomass (BEGUM, *et al*., 2024)

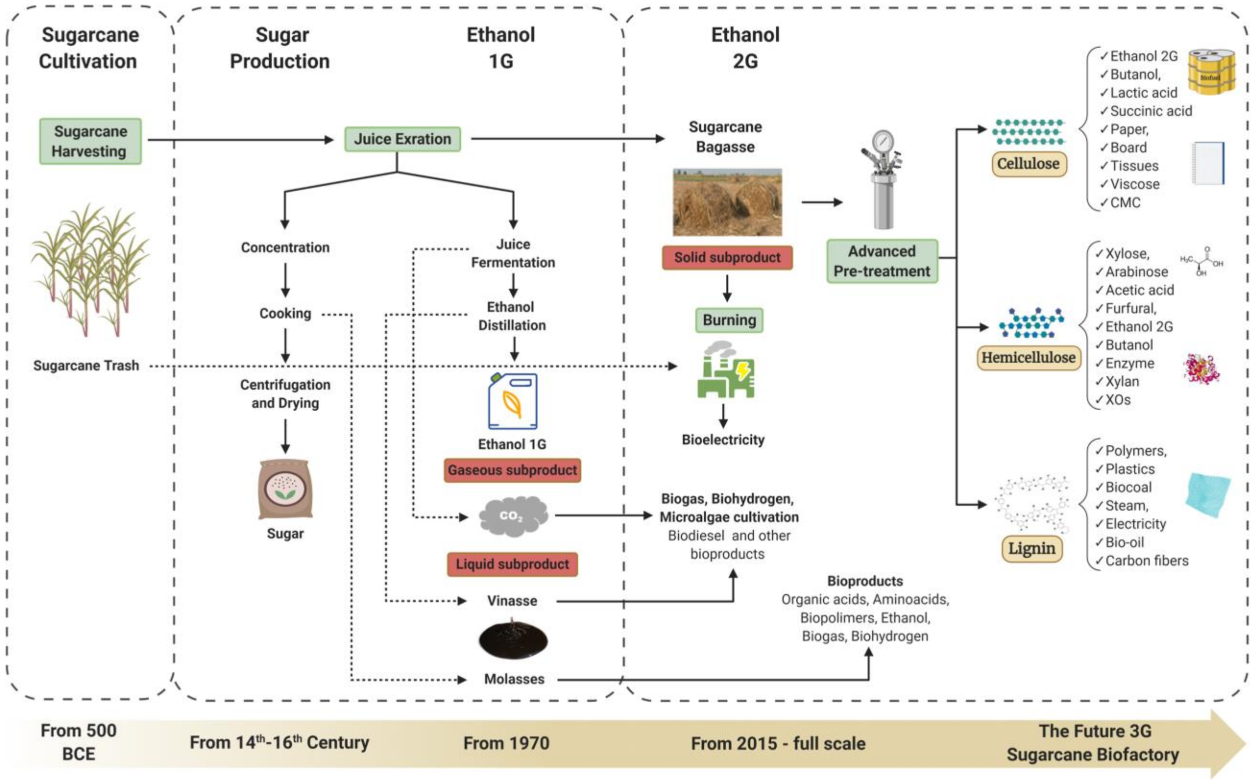


Figure 3. Timeline of sugarcane biofactory evolution (VANDERBERGHE *et al*., 2022)

MAIN OBJECTIVE

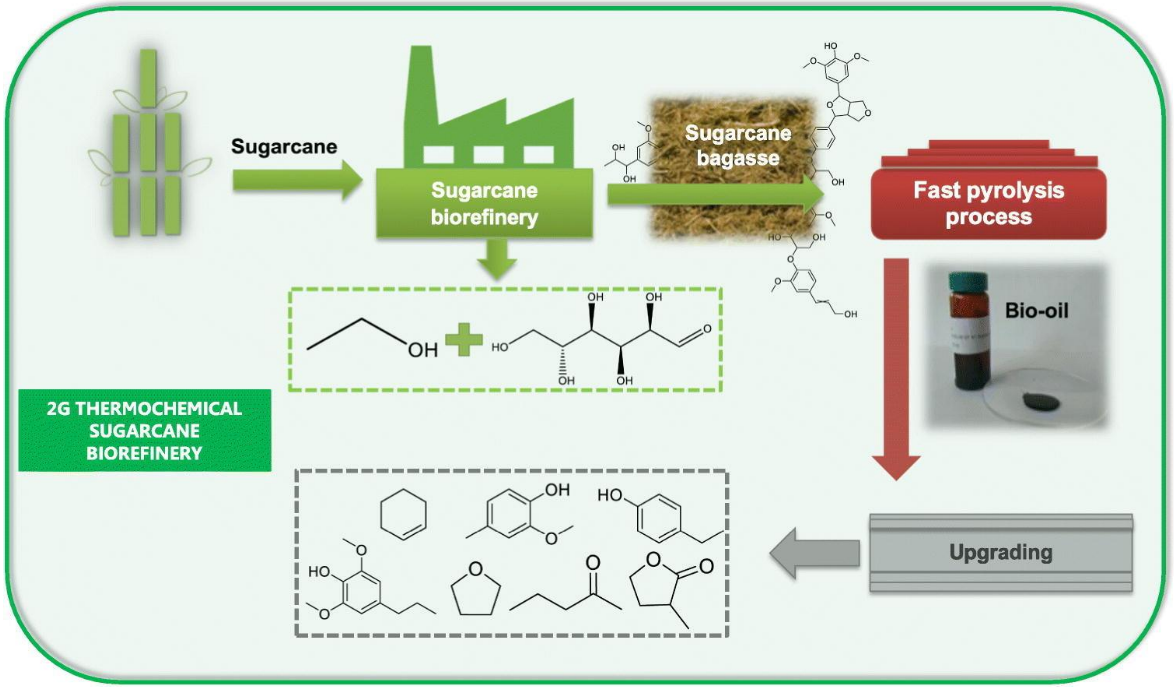


Figure 4. Scheme about valorization of sugarcane bagasse(SCHMITT *et al*., 2020)

- **Pretreatment**
- **Fast pyrolysis**
- **Bio-oil**
- **Process modeling**

MATERIAL

Figure 5. Sugarcane bagasse (SCB)

Figure 6. Sugarcane straw (SCS)

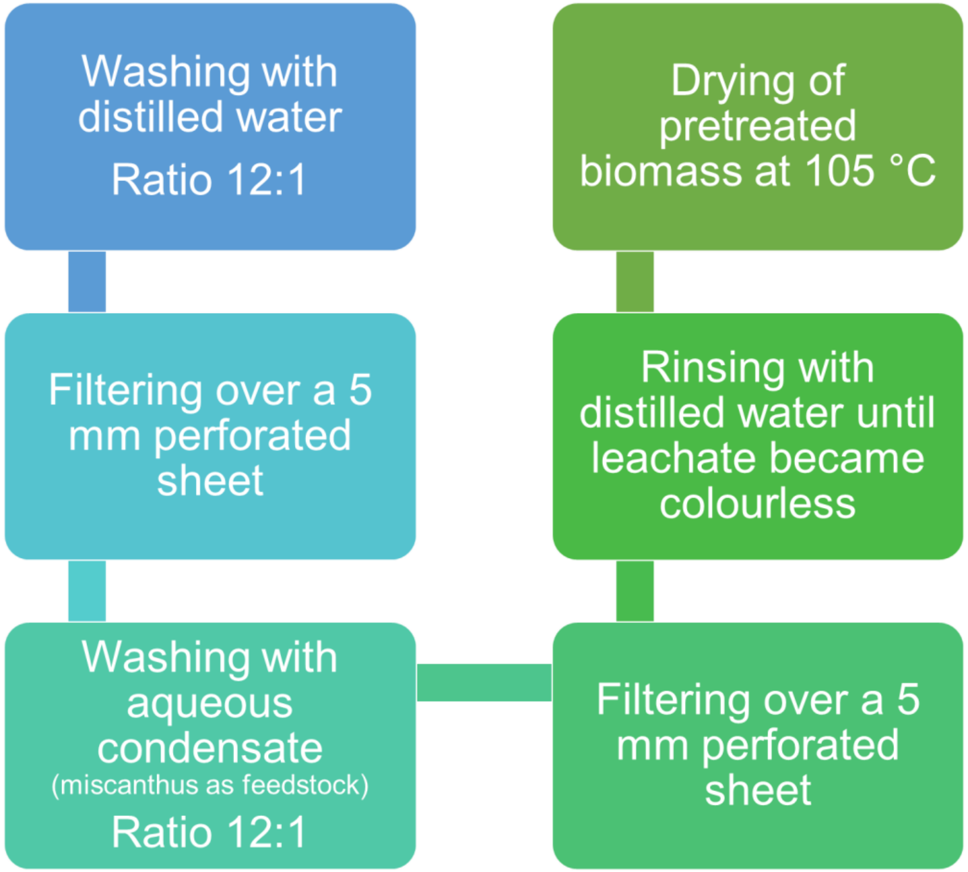
Biomass mixture (SCB/S-Mix)

70% SCB
30% SCS

Table 1. Characterization of *in natura* sugarcane biomass

z	SCB	SCS
HHV (MJ kg^{-1})	18,49 ± 0,05	8,76 ± 0,39
Proximate analysis (wt.%)		
Ash	5,08 ± 0,11	54,73 ± 1,33
Volatile matter	79,78 ± 0,43	36,91 ± 0,38
Fixed Carbon	15,15 ± 0,36	8,36 ± 1,51
Elemental analysis (wt.%)		
C	47,23 ± 0,49	22,20 ± 2,01
H	6,15 ± 0,04	3,09 ± 0,24
N	0,3	0,4
O	41,17 ± 0,56	19,28 ± 3,31
S	0,07 ± 0,01	0,10 ± 0,01
Cl^-	0,02	0,07
Major elements (g kg^{-1})		
Al	2,49	36,40
Ca	0,99	2,41
Fe	2,49	27,80
K	2,07	4,56
Mg	0,59	1,43
Si	17,06	210,42
Ti	0,63	6,39

PRETREATMENT



Washing with distilled water

Ratio 12:1

Filtering over a 5 mm perforated sheet

Washing with aqueous condensate (miscanthus as feedstock)

Ratio 12:1

Filtering over a 5 mm perforated sheet

Rinsing with distilled water until leachate became colourless

Drying of pretreated biomass at 105 °C

Figure 7. Steps of the SCB/S-Mix pretreatment process

Figure 8. Steps of the SCB/S-Mix pretreatment process

(a) IKFT reactor under stirring.

(b) Collection of the mixture after washing steps in the reactor.

(c) SCB/S-Mix-PT

Alkali metals

AC as acid leaching

Fast pyrolysis

*AC – aqueous condensate

IKFT/KIT PYROLYSIS DEVELOPMENT UNIT (PDU)

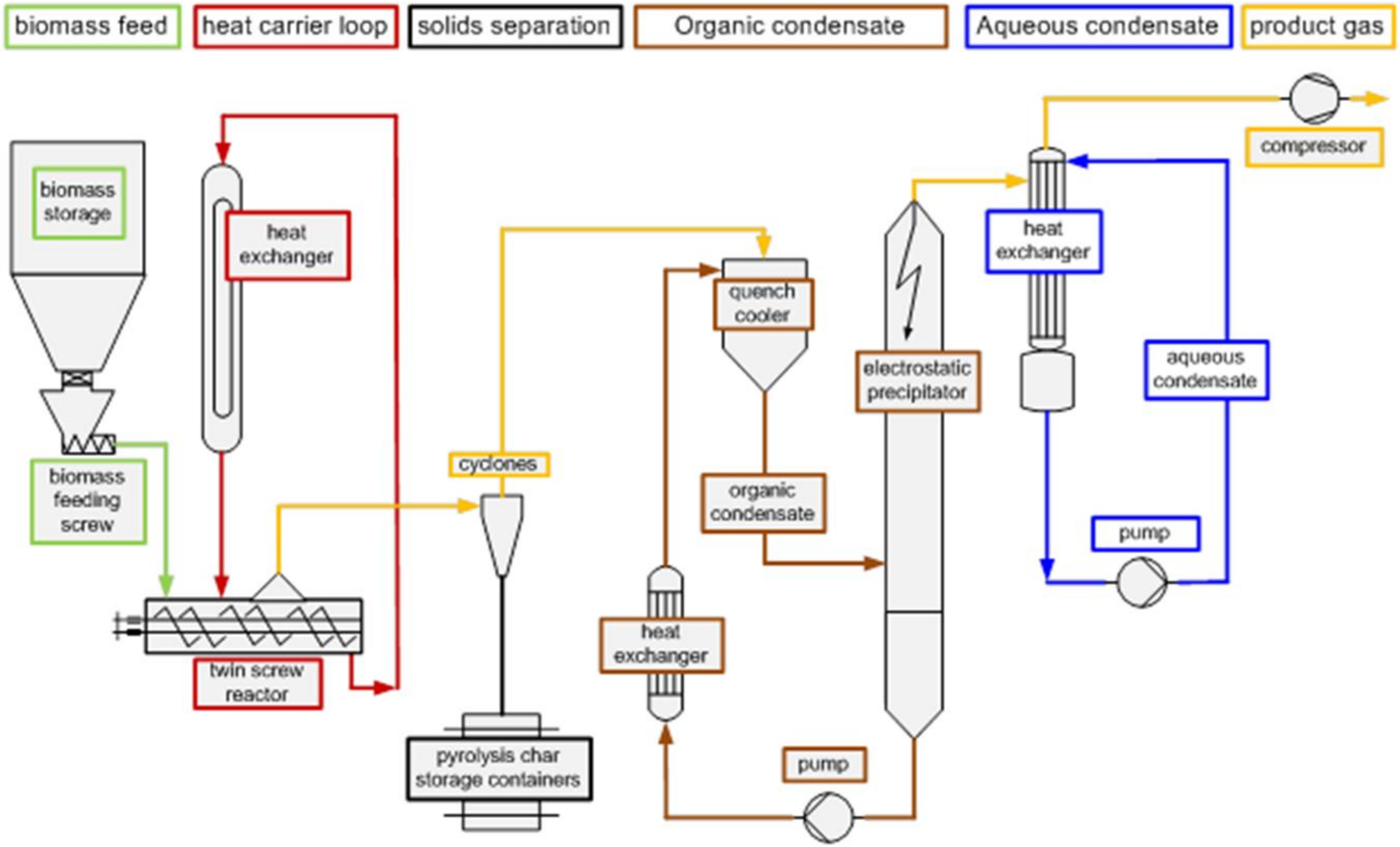


Figure 9. Flowchart of the Process Development Unit of IKFT/KIT (Copyright 2021 by KIT)

Biomass feed rate: 5 kg h^{-1}

Reactor temperature: 500 °C

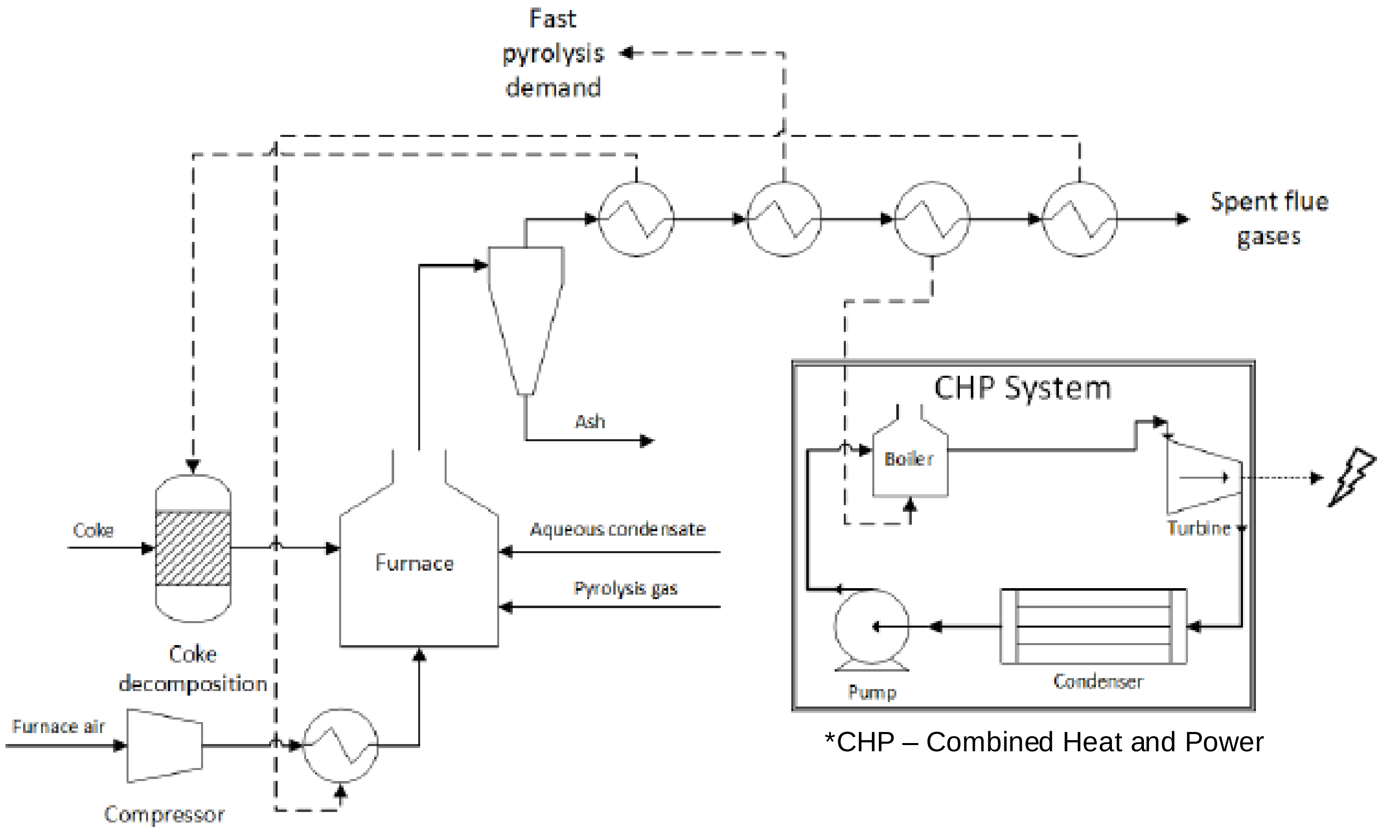
Residence time: 2 s

ORC temperature: 90 °C

AC temperature: 20 °C

ORC – Organic rich condensate; AC – aqueous condensate

PROCESS MODELLING TO SIMULATE COMBUSTION OF BY-PRODUCTS



*CHP – Combined Heat and Power

Figure 10. Scheme of the model conversion of pyrolysis side-products into electrical power using CHP (SEN *et al.*, 2024)

25 MW

Combustion of by-products

ORC not modeled

AC (water and acetic acid)

Excess of oxygen (10%)

REMOVAL RATE (η) OF THE SCB/S-MIX PRETREATMENT

Table 2. Physico chemical characterization of SCB/S-Mix before and after the pretreatment

	SCB/S-Mix	SCB/S Mix-PT
Proximate analysis (wt.%)		
Ash	14,5 ± 2,3	7,8 ± 2,7
Volatile matter	69,1 ± 0,9	77,0 ± 0,5
Fixed Carbon	16,4 ± 0,7	15,2 ± 2,8
Elemental analysis (wt.%)		
C	41,2 ± 0,5	47,5 ± 0,6
H	5,1 ± 0,1	5,4 ± 0,1
N	0,4	0,5 ± 0,1
O	38,8 ± 0,9	38,8 ± 3,0
S	n/a	n/a
Cl$^-$	n/a	n/a
Major elements (g kg^{-1})		
Al	6,4	3,7
Ca	1,5	0,4
Fe	7,8	4,8
K	2,2	0,1
Mg	0,7	0,1
Si	96,4	30,7
Ti	0,8	0,6

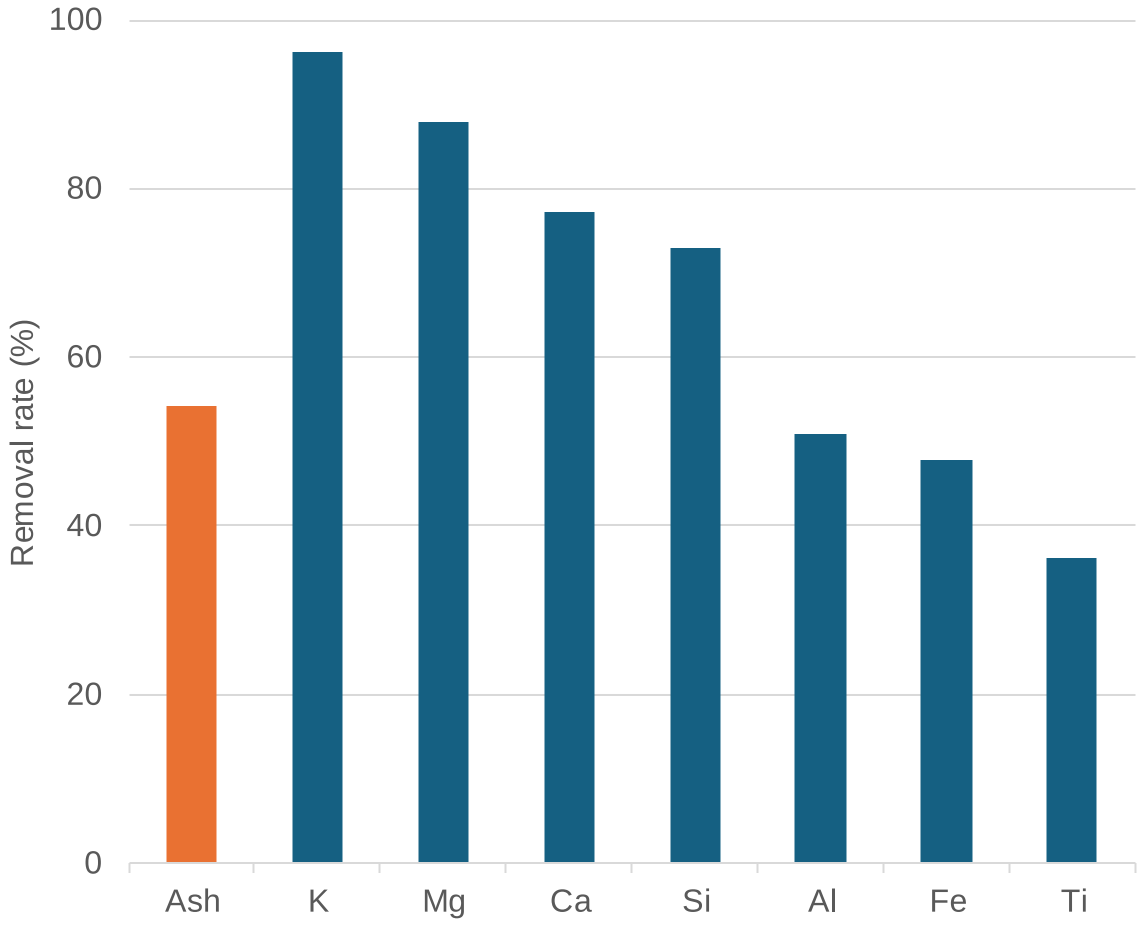


Figure 11. Removed ash and major inorganic elements fraction in the pretreated

FAST PYROLYSIS MASS BALANCE

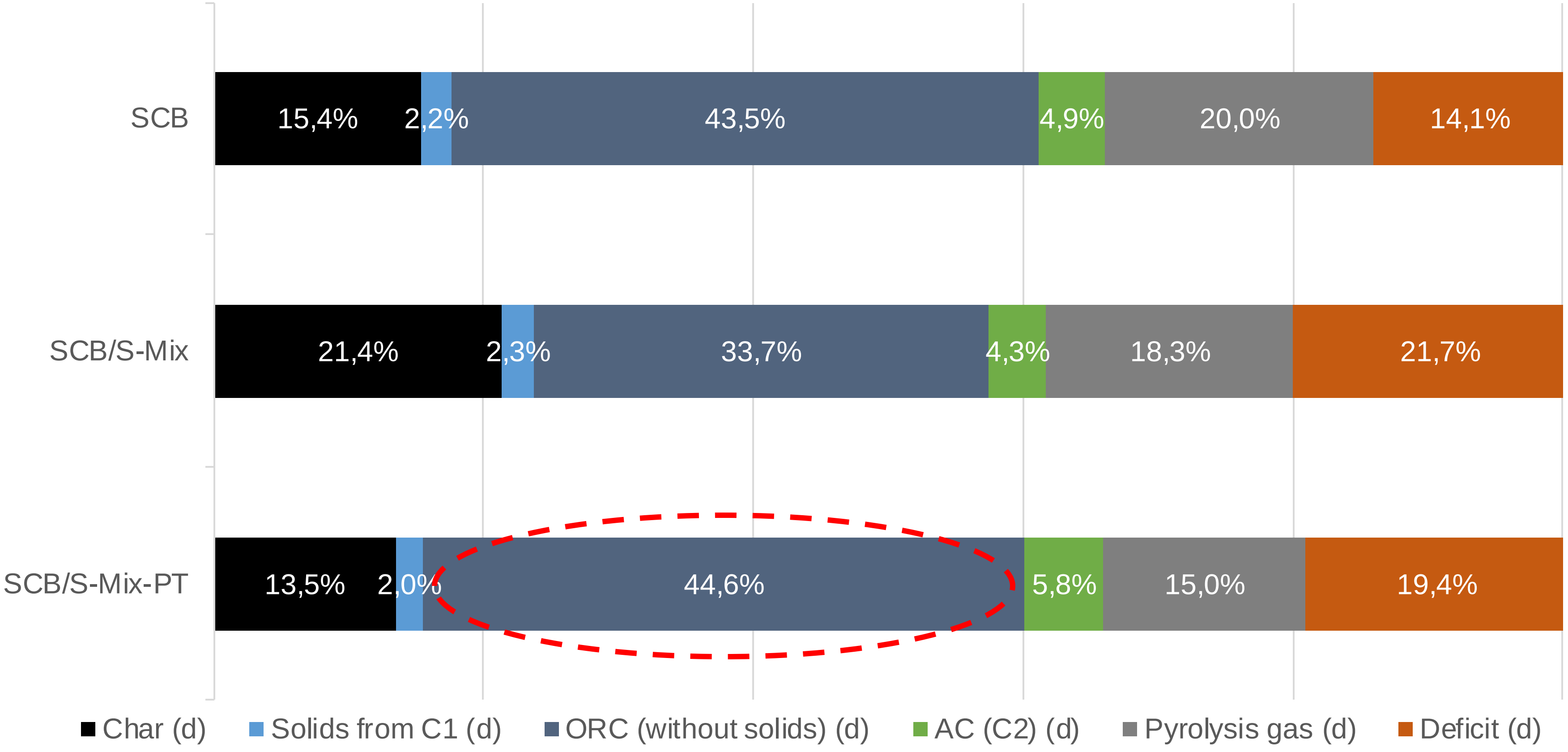


Figure 12. Mass balance, on a dry basis, of the PDU/IKFT for the fast pyrolysis experiments of *in natura* SCB and untreated and pre-treated SCB/S-Mix.

PROCESS MODELING TO SIMULATE COMBUSTION OF BY-PRODUCTS

Table 3. Excess power and heat provided by CHP integrated in fast pyrolysis unit

	SCB	SCB/S-Mix
Power (MW)	4%	7%
Heat (MW)	20%	30%

- Available excess process heat of the fast pyrolysis unit can be integrate into biomass processing unit
- Use surplus waste heat for combined heat and power production

CONCLUSIONS

- Pretreatment demonstrated to be efficient in removing alkali metals, decreasing K in 96% and Si in 73%

- The ORC yield obtained of SCB/S-Mix-PT was higher than other conditions evaluated

- Process modeling to simulate combustion of fast pyrolysis by-products has shown that could provide power and heat to external utilities, e.g. sugarcane biorefinery

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THANK YOU

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Valorizing residues of sugar cane biorefinery operation to produce liquid fuels - Assessment of energy balances and influence of major inorganic elements to produce fast pyrolysis bio-oil

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Keywords: sugarcane biorefinery; residues; fast pyrolysis; leaching;

Sugarcane bagasse (SCB) and straw (SCS) are promising residues from a sugarcane biorefinery to produce fast pyrolysis bio-oil (FPBO), an industrial boiler fuel and a precursor for value-added chemical compounds and/ or transportation fuels. However, there are two major challenges that require attention to assess the feasibility of using these residues for conversion to FPBO: 1) SCB is often used to cover internal energy requirements via combustion and 2) SCS exhibits high ash content that negatively impacts FPBO yield. The goal of this study was to further advance the valorization of SCB and SCS via fast pyrolysis by contributing to these two important aspects.

SCB and a 70:30 mixture of SCB and SCS (SCB/S-Mix) were pyrolysed in a pilot scale (5 kg h^{-1}) fast pyrolysis unit to provide relevant experimental data. In a first part of the study, energy balances were evaluated in AspenPlus with a process integrated combined heat and power unit. Surplus power and heat from the fast pyrolysis process were 4% and 20% of the supplied SCB chemical energy, respectively. These figures increased to 7% and 30%, respectively, for the case of a SCB/S-Mix. This is primarily due to an increased production of byproducts char and gas which are then combusted.

In a second part of the study, a mild pretreatment of the SCB/S-Mix using water and fast pyrolysis aqueous condensate as leaching agents was investigated. Potassium as one of the most catalytically active ash constituent during pyrolysis was almost entirely removed (>95%) with little loss of total feedstock mass (15%). The pretreated SCB/S-Mix was also converted in the same pilot fast pyrolysis unit. It was observed that the resulting FPBO yield was even higher than for the case of SCB.

This study highlights the available energy even when sugarcane biorefinery residues are further converted to FPBO and the flexibility in adjusting the process design to meet on-site energy requirements while producing value added products. **(1987 characters)**

Funding agency: The authors acknowledge gratefully the financial support of EU Horizon 2020 research and innovation programme under grant agreement number 731101 (Brisk 2) and Government of the State of São Paulo (GESP).