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Retrofitting residual biomass pyrolysis and syngas-fermentaaation to existing surgane

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Karlsruhe Institute of Technology

Institute of Catalysis Research and Technology

Retrofitting residual biomass pyrolysis and syngas-fermentation to existing sugarcane biorefinery: A conceptual study

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Background

In 2022, the global carbon CO_2 emission reached 36,8 Gt, the first time above 10 Gt carbon.

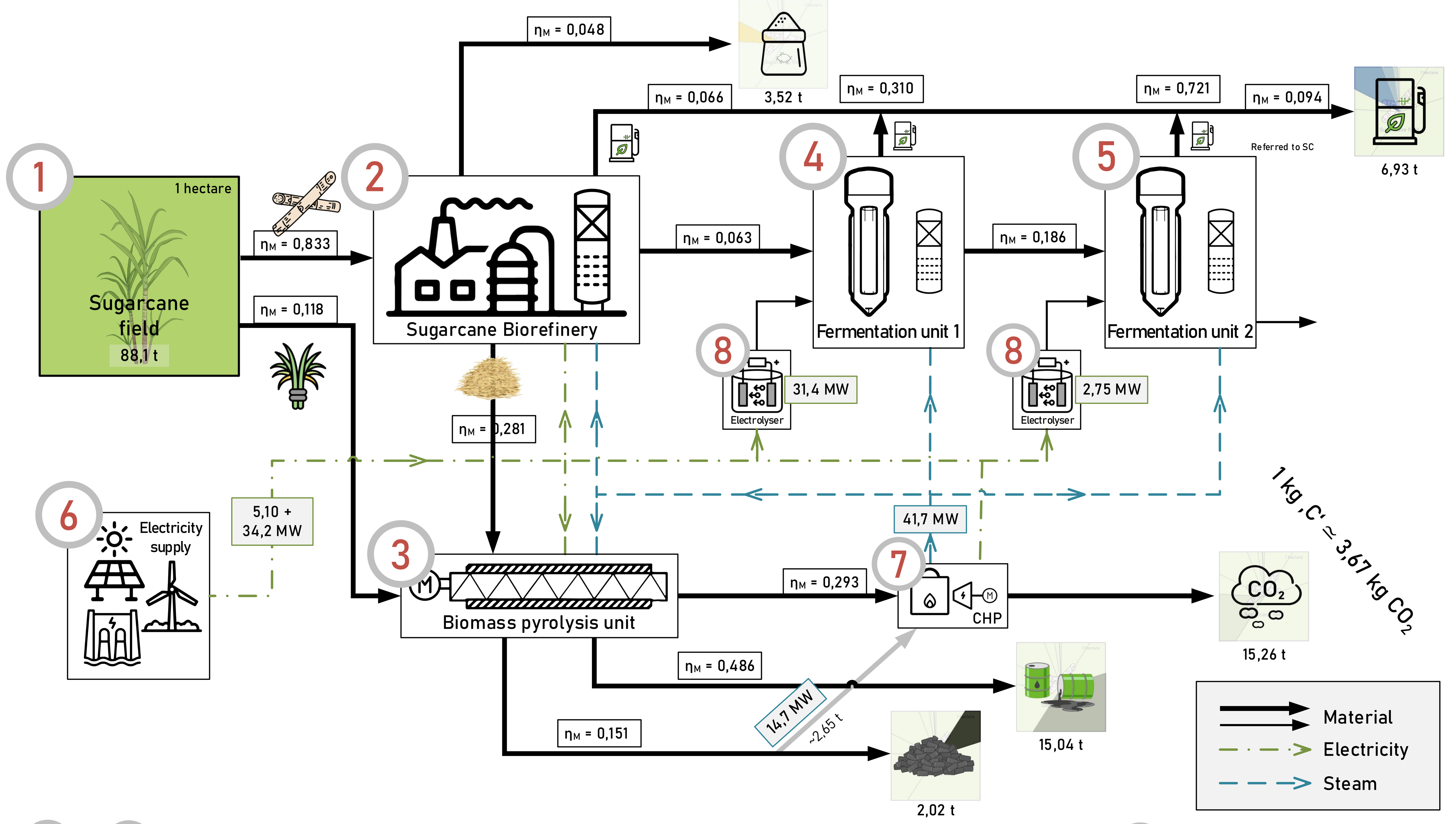
The brasilian sugarcane (SC) industry alone has an annual turnover of 147,7 Mt carbon (724,4 Mt SC/a), cultivated on 9,87 Mha land.

Currently, only ~18,3 w% of assimilated SC carbon is converted into products like sugar and ethanol, the rest is re-emitted locally.

Objectives

- Accessing renewable carbon-based commodities, without requirement for repurposing or intensification of land use
- Evaluating process routes to increase field-to-product carbon conversion through potential low-tech retrofit:
  - **Gas fermentation** → Increase Ethanol production
  - **Fast pyrolysis** → Obtain Diesel-Substitute and CDR-Product

Process Concept



1 Sugarcane field

- No seasonality addressed

	Sugarcane Field properties
Straw yield	14,7 [t ha^{-1} a^{-1}], 70% collectible: 10,3 [t ha^{-1} a^{-1}] / 140 [kg t_{SC}^{-1}]
Straw properties	45,1 w% C, ash-optimised collection
SC yield	73,4 [t ha^{-1} a^{-1}]
SC properties	20,4 w% C / 56,9 w% moisture
Carbon fixation	21,6 [$t_{„C"}$ ha^{-1} a^{-1}] ≃ 79,2 [$t_{CO2,eq}$ ha^{-1} a^{-1}]
Ashes removed	2,318 [t ha^{-1} a^{-1}]
Straw collection	No E-demand cons., low moisture (7%)

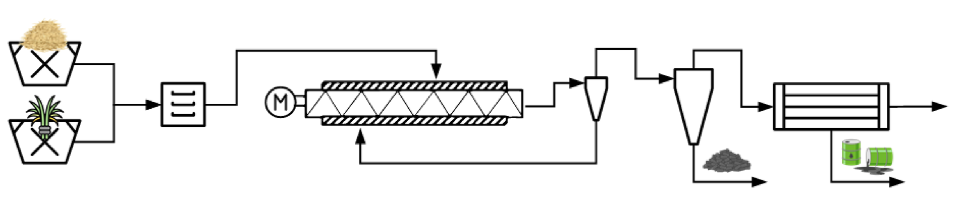
2 Sugarcane Biorefinery

- Black-Box model of brasilian case, av. sugar and ethanol co-production

	Sugarcane Biorefinery properties
Sugar production	48 [kg t_{SC}^{-1}] , as market product
Ferment. products	66,2 [kg_{EtOH} t_{SC}^{-1}] / 63,3 [kg_{CO2} t_{SC}^{-1}]
SC bagasse	280 [kg t_{SC}^{-1}] ; 20,6 [t ha^{-1} a^{-1}]
SC bagasse prop.	47,4 w% C / 9,3 w% moisture
Steam demand	190 [kW t_{SC}^{-1}] at 140 °C
Electricity demand	25 [kW t_{SC}^{-1}]

3 Biomass pyrolysis unit

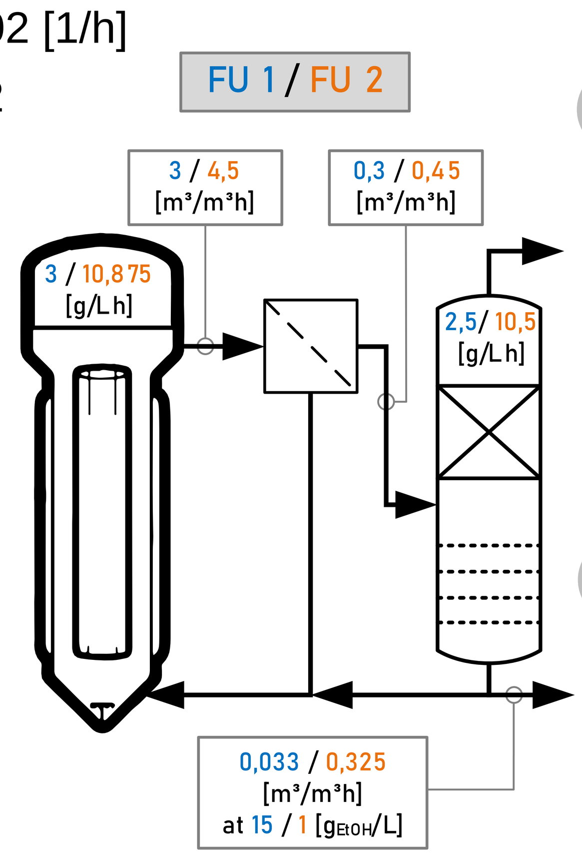
- Auger Reactor -> low ashes (0,86 – 1,93 w%) in fast pyrolysis bio oil (FPBO)
- Linear miscibility of bagasse and straw



	Biomass pyrolysis unit properties
Pretreatment	Separate bagasse and straw chopper, shared dryer
Reactor	Fast pyrolysis, $\tau_{biomass}$ < 2 s at > 500 °C
Condenser	Single-stage quench at 120 °C
Char separation	90 % separable
Energy recovery	No internal energy recovery
Ashes distribution	10% of Ashes in Pyrolysis vapor

4 & 5 Fermentation unit 1 (FU 1) & Fermentation unit 2 (FU 2)

- Reductive Acetyl-CoA pathway
- Adapted / engineered strains
- Overall dil. rate D = 0,02 [1/h]
- pH uncontrolled in FU2



	FU 1 and FU 2 properties
Reactor condition	6 bar_a, high $k_La_{(H2)}$ (microbubble sparged)
Cell retention	Cross-flow-filtration, 10/1 Feed / Permeate
Tolerances	25 [g_{EtOH} L^{-1}] / 30 [$g_{Acetate}$ L^{-1}] at pH_{FU1} 5,2

	Fermentation unit 1	Fermentation unit 2
Reaction equation (simplified)	$2\ CO_2 + 6\ H_2 \rightarrow 0{,}8\ C_2H_5OH + 0{,}2\ CH_3COOH$	$CH_3COOH + 2\ H_2 \rightarrow C_2H_5OH$
Cell concentration	5 [g_{cDW} / L]	5 [g_{cDW} / L]
Cell-specific consumption	1,45 (CO_2) [$g_{Feed(C)}$ / g_{cDW} h]	1,75 (Acet.) [$g_{Feed(C)}$ / g_{cDW} h]
Selectivity S_P	0,8 [mol_{Poduct} / $mol_{cons.}$]	0,9 [mol_{Poduct} / $mol_{cons.}$]
Conversion X_P	0,9 [$mol_{cons.}$ / mol_{Feed}]	0,9 [$mol_{cons.}$ / mol_{Feed}]
Volumetric productivity	3 [g_{EtOH}/Lh], 1 [$g_{Acetate}$/Lh]	6 [g_{EtOH}/Lh]
Volumetric consumption	7,25 [g_{CO_2}/Lh], 1 [g_{H_2}/Lh]	8,75 [$g_{Acet.}$/Lh] , 0,85 [g_{H_2}/Lh]

6 Electricity supply

- Sufficiently available

7 Cogeneration

- Cogeneration plant (CHP) with burner and load-flexible turbine

	Cogeneration properties
Eff. thermal	η = 0,9
Eff. electric	η = 0,8, total η = 0,72

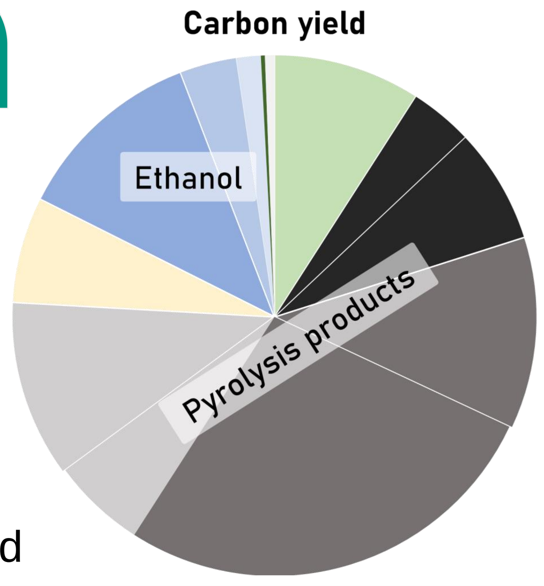
8 Electrolyser

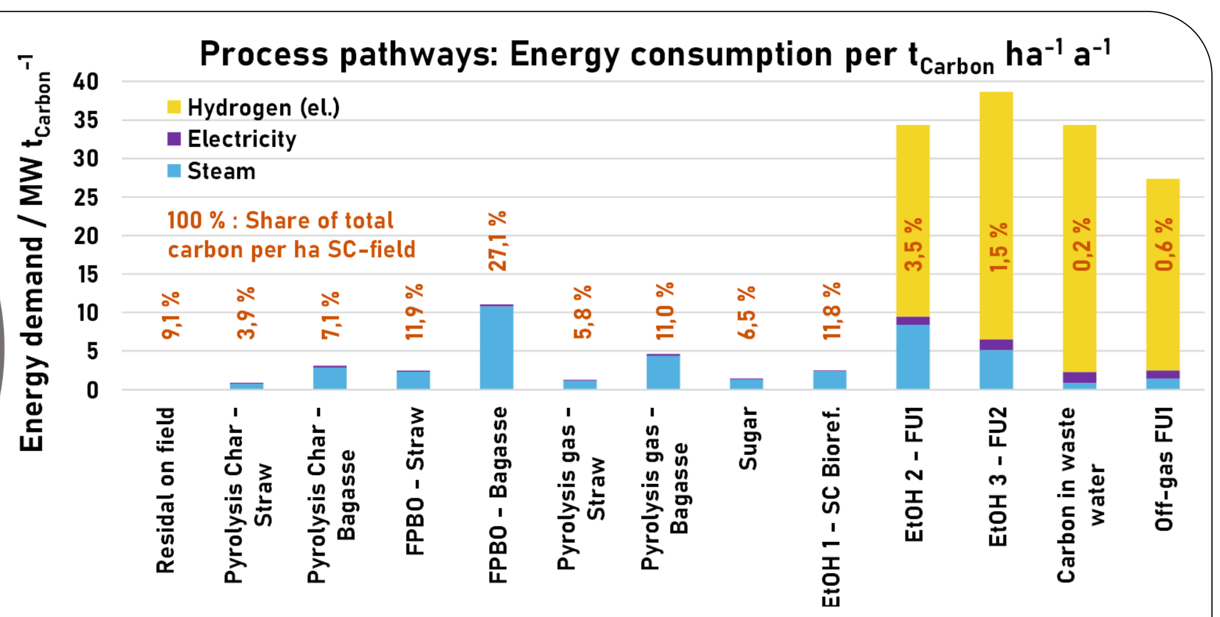
- Assumed as commodity

	Electrolyser properties
Conversion efficiency	49 [$kWh_{el.}$ kg^{-1}] 10 [L_{H2O} kg^{-1}]

Conclusion

- Pyrolysis products are less energy intense at a large Carbon-share
- Fermentative route should target higher value products
- Co-firing of Pyrolysis char should be avoided





Outlook

- Developing dynamic process and techno-economic model to assess individual cases
- Obtaining cost abatement curves (cost per C)

Acknowledgement

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