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Unlocking the lost carbono potential in existing sugarcane biorefinery: retrofitting residual biomass pyrolysis and syngas-fermentation

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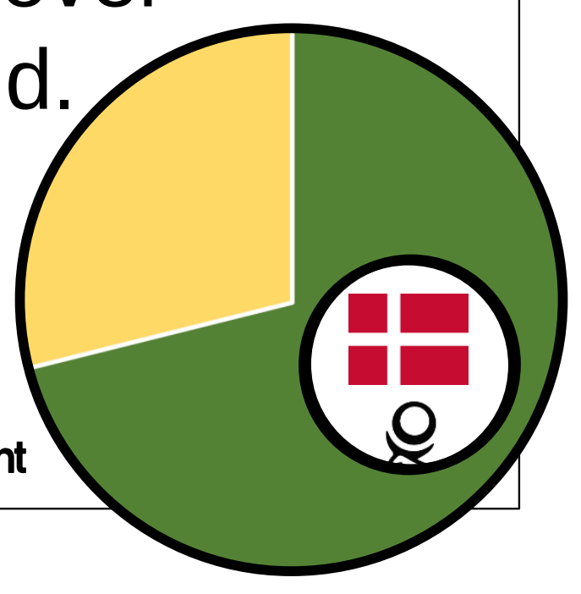
Background

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

The brasilian sugarcane (SC) industry alone annualy turns over 147,7 Mt carbon / 724,4 Mt SC/a, cultivated on 9,9 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.


Area proportional to CO_2-equivalent

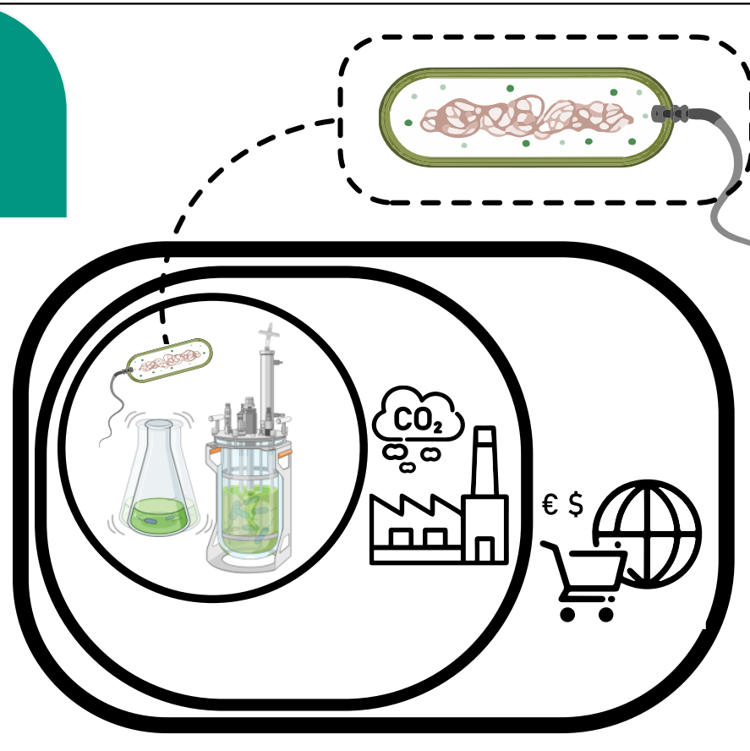
Objectives

- Accessing renewable carbon-based commodities, without requirement for repurposing or intensifying current land use
- Evaluating process routes to increase field-to-product carbon conversion in SC biorefineries (SCB) by potential low-tech retrofit:
  - **Gas fermentation** → Obtain commodity chemicals, e.g., Ethanol
  - **Fast pyrolysis** → Obtain Diesel-Substitute and CDR-Product

Conclusion – From bacteria to a process

Integration steps

1. Reactor: Up-/downstream **reactor embedding** determines operation
2. Process: **CO_2-Hubs** enable industrial application of gas-fermentation
3. Market: A viable process **value chain defines target product**



Open points on integration

1. Conti long-term operation at **varying feed properties**:
   How much plant capacity does process variance cost?
2. Mixed culture to allow **variable fermenter temprature**:
   Which advantage has a temperature adaptive culture?

Process Concept

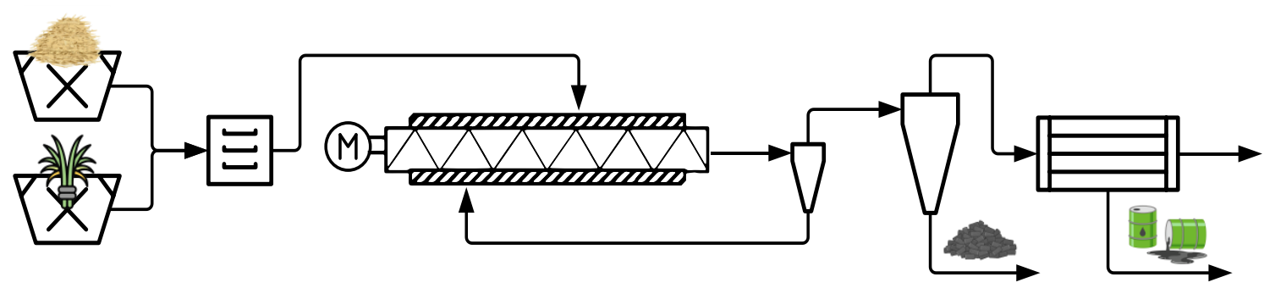
① Sugarcane field

- Average in São Paolo (state) assumed

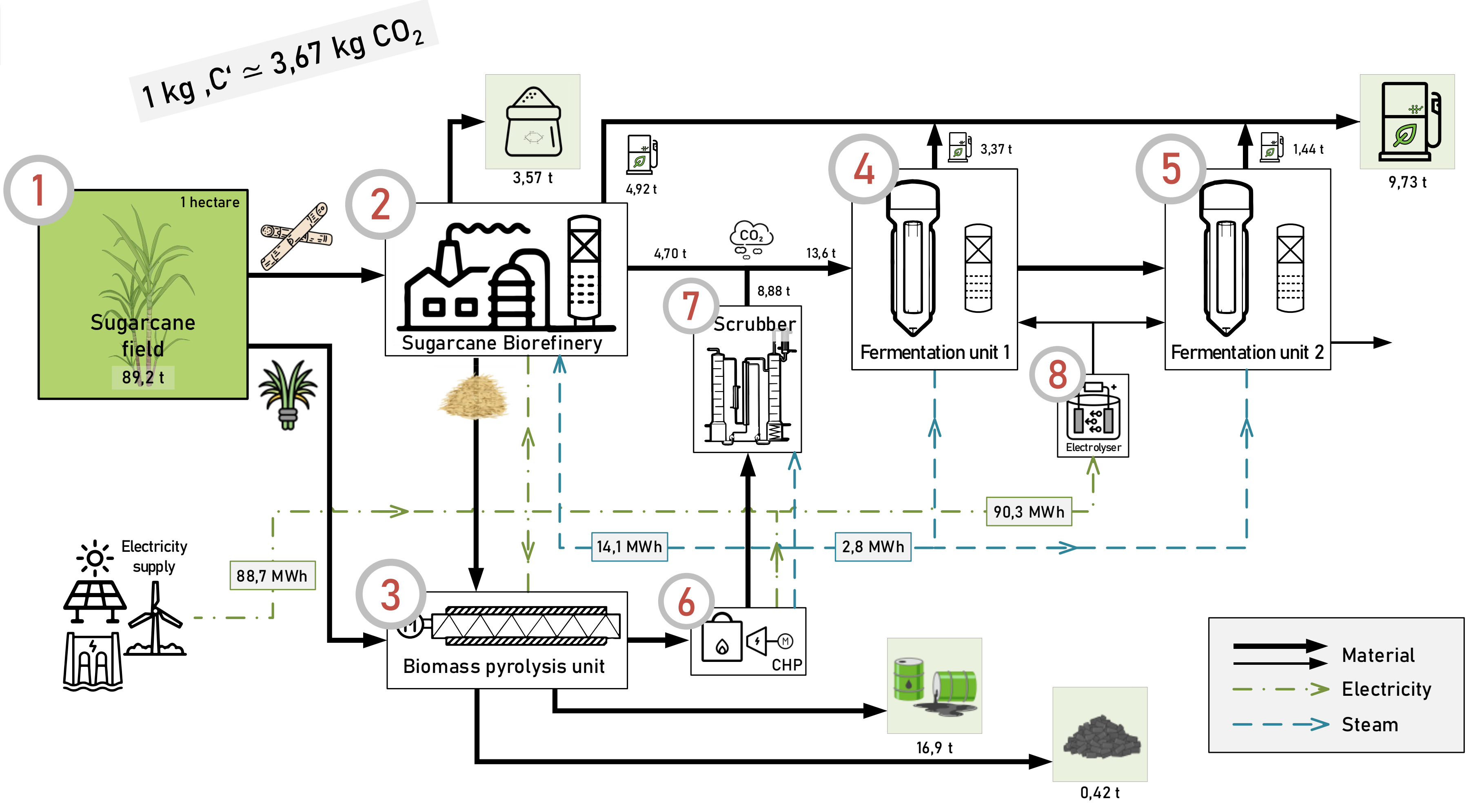
	Sugarcane Field properties
SC yield	73,4 [t ha^{-1} a^{-1}]
SC properties	20,4 w% C / 56,9 w% moisture
Straw yield	14,7 [t ha^{-1} a^{-1}], 70% collectible: 10,3 [t ha^{-1} a^{-1}] / 140 [kg t_{SC}^{-1}]
Straw properties	45,1 w% C
Carbon fixation	21,6 [$t_{“C“}$ ha^{-1} a^{-1}] ≃ 79,2 [$t_{CO2,eq}$ ha^{-1} a^{-1}]
Ashes removed	2,32 [t ha^{-1} a^{-1}]
Straw collection	No energy demand considered Ash-optimised collection Storage baled at field
Harvest season	April – September (9 months)

③ Biomass pyrolysis unit

- Autothermal fluidised bed reactor with char separation, experimental input
- 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	10 % separable
Energy recovery	Heat pump quenche -> dryer / heating
Ashes distribution	10 % of Ashes in Pyrolysis vapor
Carbon recovery	80 % of inlet carbon in overall outlet
Seasonal straw co-feeding	0,253 [t_{straw} $t_{bagasse}^{-1}$]
Off-seasonal operation	1167 [h a^{-1}]

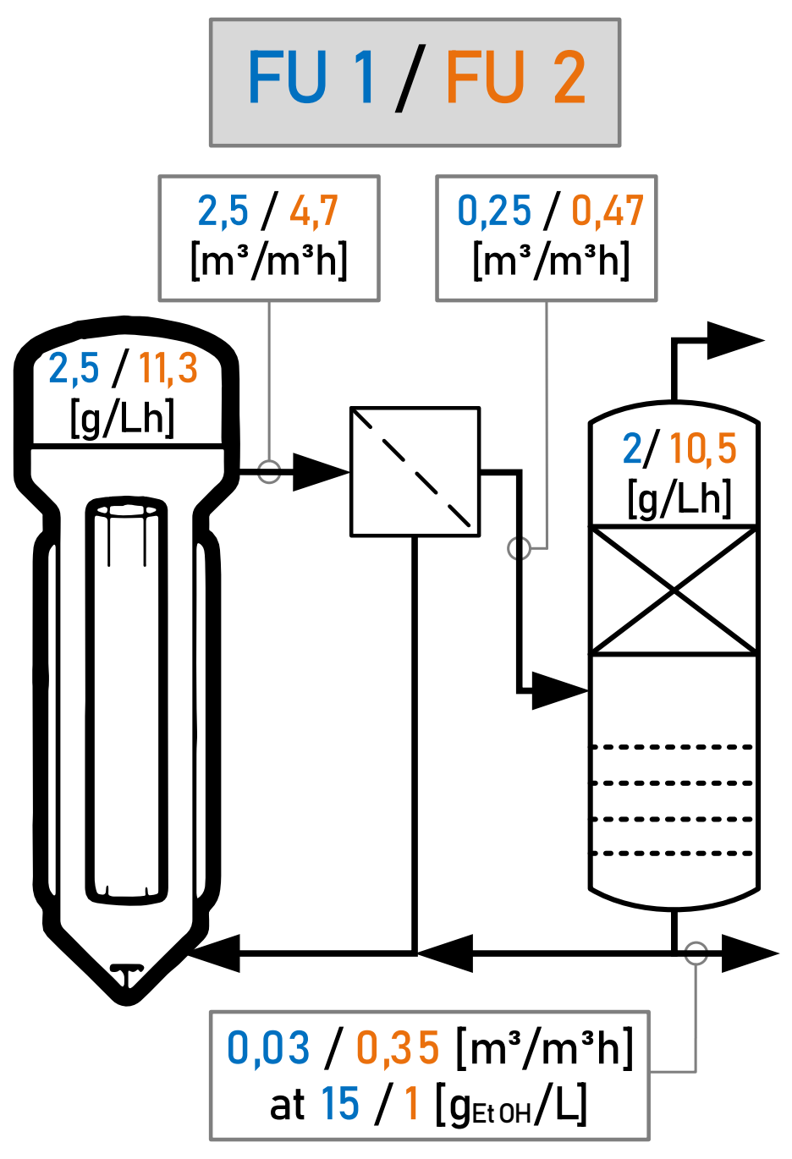


④ & ⑤ Fermentation unit 1 (FU 1) & Fermentation unit 2 (FU 2)

- Engineered strains
- Overall dilution rate D = 0,02 [1/h]
- FU1 pH controlled

	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	2,45 [g_{EtOH}/Lh], 0,8 [$g_{Acetate}$/Lh]	6 [g_{EtOH}/Lh]
Volumetric consumption	7,25 [g_{CO_2}/Lh], 1 [g_{H_2}/Lh]	8,75 [$g_{Acet.}$/Lh] , 0,6 [g_{H_2}/Lh]



② Sugarcane Biorefinery

- Black-Box model of brasilian case
- Sufficient el. Energy (grid or island)

	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}]

⑥ 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
Turbine load	0,33 [kg $kg_{prouced}^{-1}$]

⑦ Gas scrubbing

- CO_2 separation with Amine scrubbing
- Removal of H_2S, COS, HCN

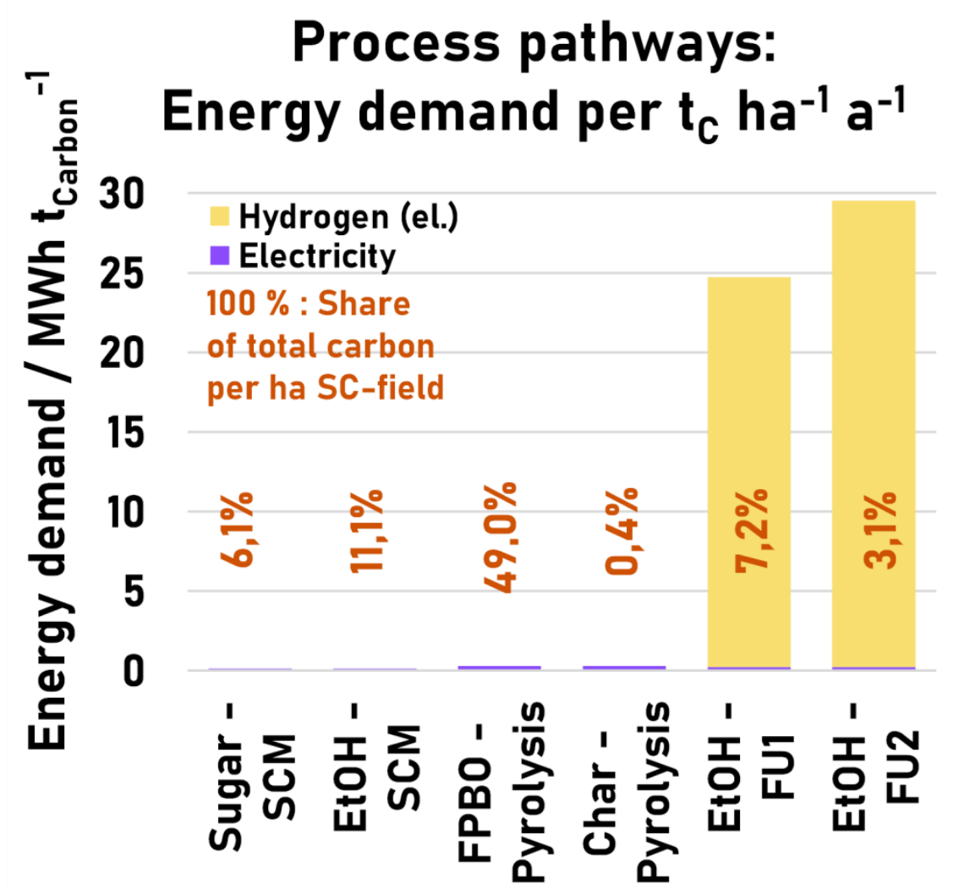
	Gas scrubber properties
Separation eff.	η_{CO2} = 0,9, η_{O2} = 0,99
Energy cons.	210 [kWh t_{CO2}^{-1}]

⑧ Electrolyser

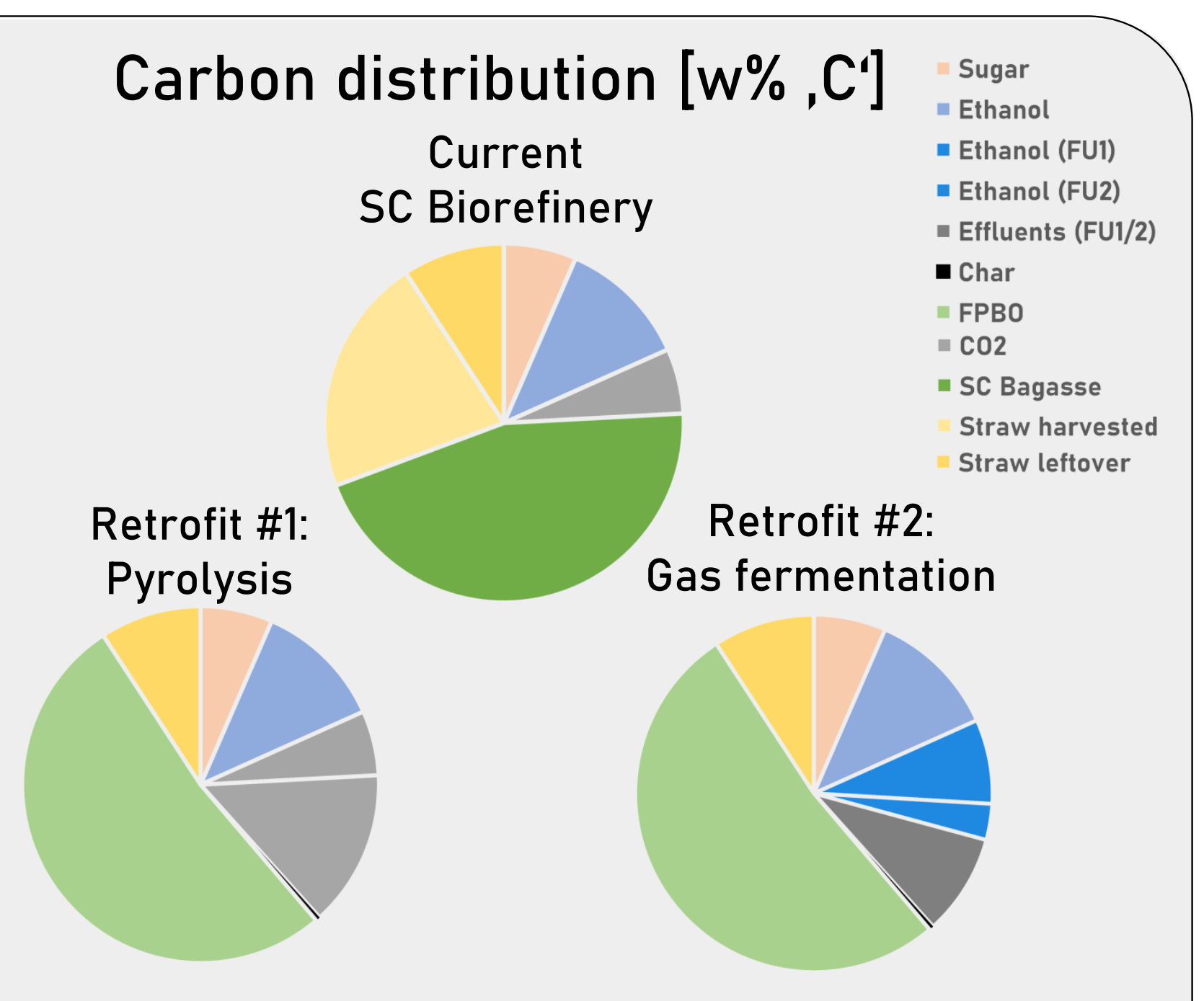
- Assumed as commodity

	Electrolyser properties
Conversion efficiency	49 [$kWh_{el.}$ kg_{H2}^{-1}] 10 [L_{H2O} kg_{H2}^{-1}]

Results



- Fast pyrolysis could **convert 50% carbon** from field to products and allows self-sufficient heat supply
- In combination, gas-fermentation could convert additional **10% of carbon** to products (≃ 67% danish $CO_{2,eq}$) at competitive energy costs
- An equivalent of **325 $Mt_{CO2,eq}$/a** are potentially accessible **without change in current land use**



Outlook

- Developing dynamic process and techno-economic model for plant sizing
- Product selection through cost abatement curves (cost per C)

Acknowledgement

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