BioTheRoS

Collaborative actions to bring novel **BIO**fuels **THE**rmochemical
ROutes into industrial **S**cale

Advancing Biofuel Production with Pyrolysis and Gasification – Integrating the benefits of Carbon Capture and Hydrogen Production

BioTheRoS Online Webinar, 12th May 2026

Moderation: Andrea Sonnleitner (BEST)

Speakers: Patrick Reumerman (BTG), Doris Matschegg (BEST), Philipp Graefe (BEST)

The BioTheRoS Project has received funding from the European Union’s Horizon Europe research and innovation programme under Grant Agreement No. 101122212.

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Webinar

Co-funded by the European Union

Advanced Biofuel Production with Pyrolysis and Gasification – Integrating the benefits of Carbon Capture and Hydrogen Production

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14:00 BioTheRoS General Presentation: Gasification and pyrolysis technical overview
Patrick Reumerman, BTG

14:10 Overview of technologies for CC(U)S
Doris Matschegg, BEST

14:20 Overview of technologies for renewable hydrogen production
Patrick Reumerman, BTG

14:30 Linking CC(U)S and hydrogen technologies with gasification
Philipp Graefe, BEST

14:40 Linking CC(U)S and hydrogen technologies with pyrolysis
Patrick Reumerman, BTG

14:50 Wrap-up and concluding remarks

12 MAY 2026

ONLINE

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BioTheRoS General Presentation: Gasification and pyrolysis technical overview

Patrick Reumerman, BTG

BioTheRoS Overview

Project Details

BioTheRoS is an EU Horizon Programme under Grant Agreement No 101122212 running from 2023

Consortium Members

CERTH CENTRE FOR RESEARCH & TECHNOLOGY HELLAS

circe

MOTOR OIL

btg biomass technology group

BEST Bioenergy and Sustainable Technologies

WIP RENEWABLE ENERGIES

Demonstration Cases

Application in pyrolysis and upgrading units in Netherlands & gasification unit in Austria

BioTheRoS Objectives

BioTheRoS develops **innovative** & cost-competitive **Fast Pyrolysis-to-biofuels** and **Gasification-FT-Synthesis value chains**, combining **Carbon Capture Utilization (CCU)** and **fuel upgrading** for accelerating the scale-up of sustainable biofuels.

BioTheRoS Goal: Transfer biomass into an opportunity

1. Development of cost-effective & sustainable technologies for thermochemical conversion of biomass to produce biofuels to TRL5
2. Selection and assessment of several biomass feedstocks suitable for scaled-up sustainable pyrolysis & gasification biofuel value chains employing predictive biomass demand AI models
3. Development of scale-up rules of biofuels production based on advanced modelling techniques and lab/pilot-scale trials.
4. Development of an LCSA framework, integrating technical, environmental, economic & social parameters via multi-criteria decision analysis techniques
5. Identification of concrete measures to improve the sustainability of thermochemical conversion of biomass to biofuels via pyrolysis and gasification
6. Provide clarity into the market dynamics of scaled-up pyrolysis and gasification biofuel value chains

Demo sites & related technologies

The Netherlands – Pyrolysis and Upgrading units

btg
biomass technology group

Pyrolysis Units:

- Bench-scale unit: 2–5 kg/h
- Pilot plant: 80–200 kg/h

Upgrading Unit (for pyrolysis oil to fuels):

- Continuous operation
- Capacity: 0.8–1.5 kg/day

Austria – Gasification Unit

BEST
Bioenergy and Sustainable Technologies

Gasification Units:

- 1 MW DFB reactor: ~200 kg/h feed rate
- 250 kW Fischer–Tropsch pilot unit: produces 15-20 L of FT raw product

Upgrading Unit (for FT waxes to fuels):

- Hydrocracking pilot plant located in Greece

Gasification – transport fuels value chain

Wood chips

Forestry residue

Gasifier

Fine gas cleaning

FT-synthesis

Full Gasification value chain operation

Gas production

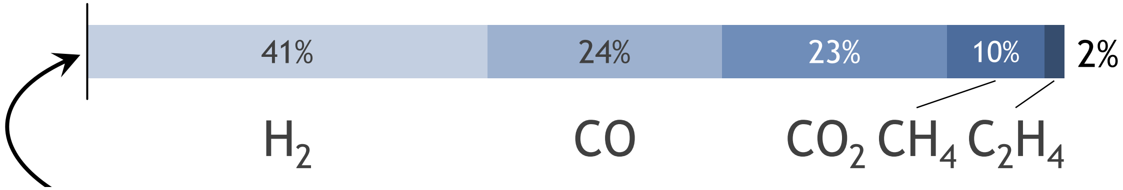
Gas cleaning

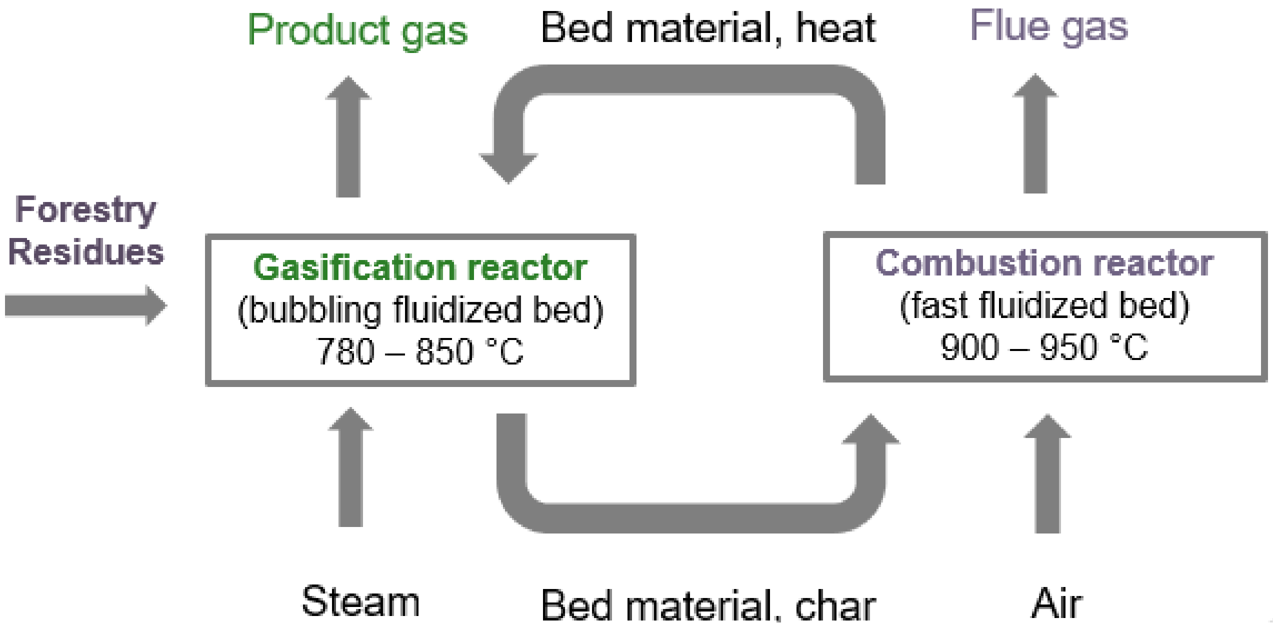
Synthesis

FT raw product

The full value chain was succesfully demonstrated.

Gasification – Dual fluidised Bed technology





Product gas

Bed material, heat

Flue gas

Forestry Residues

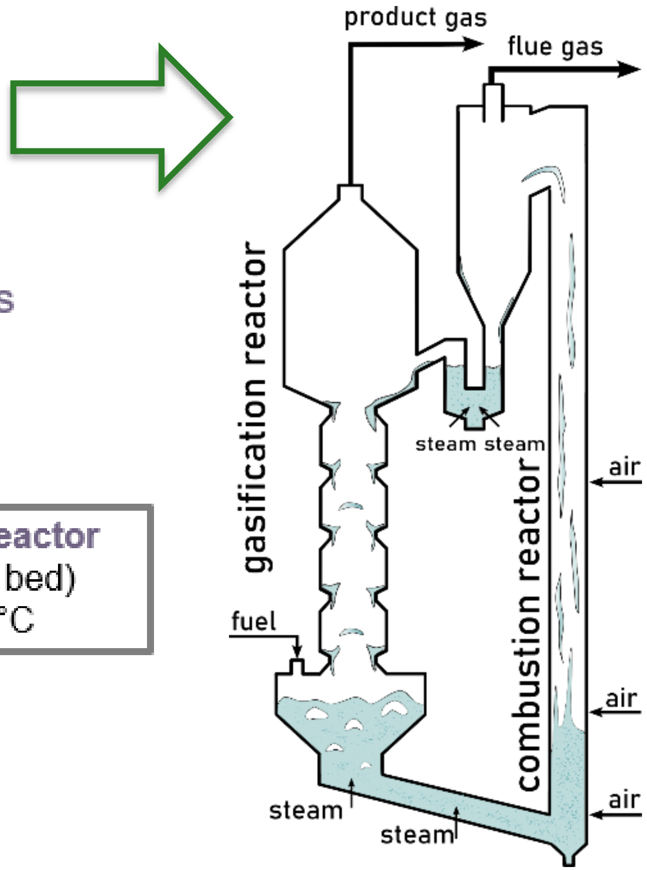
Gasification reactor
(bubbling fluidized bed)
780 – 850 °C

Combustion reactor
(fast fluidized bed)
900 – 950 °C

Steam

Bed material, char

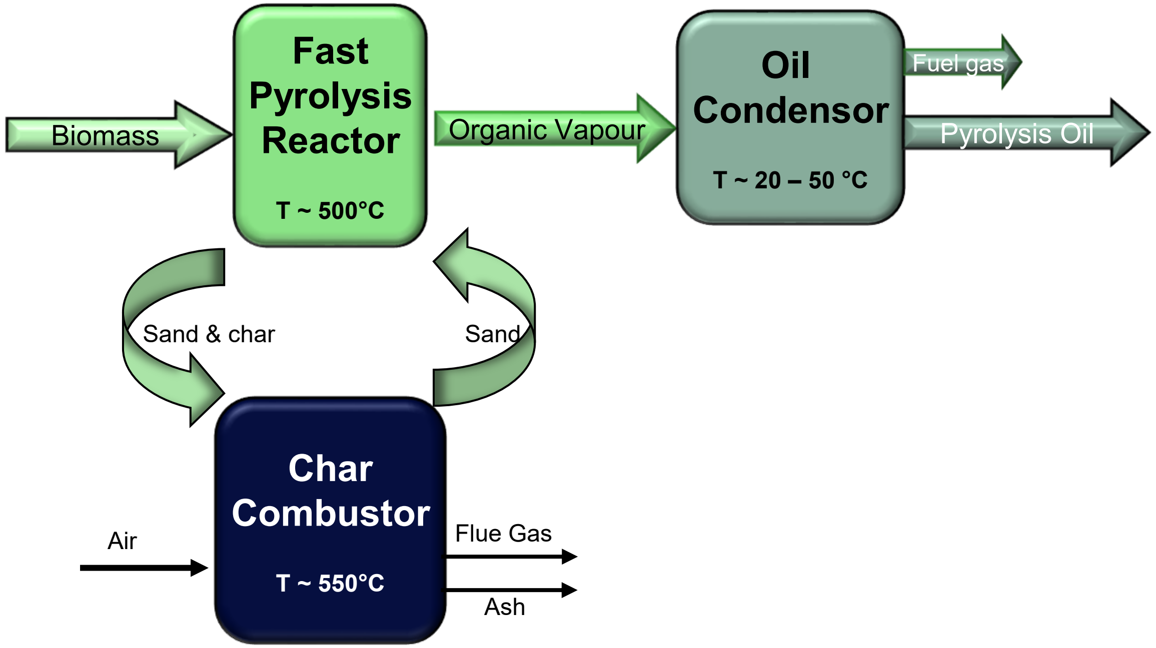
Air



Separation gasification and combustion means no nitrogen in syngas, and a very high quality (high H2 content)

Fast Pyrolysis Value Chain

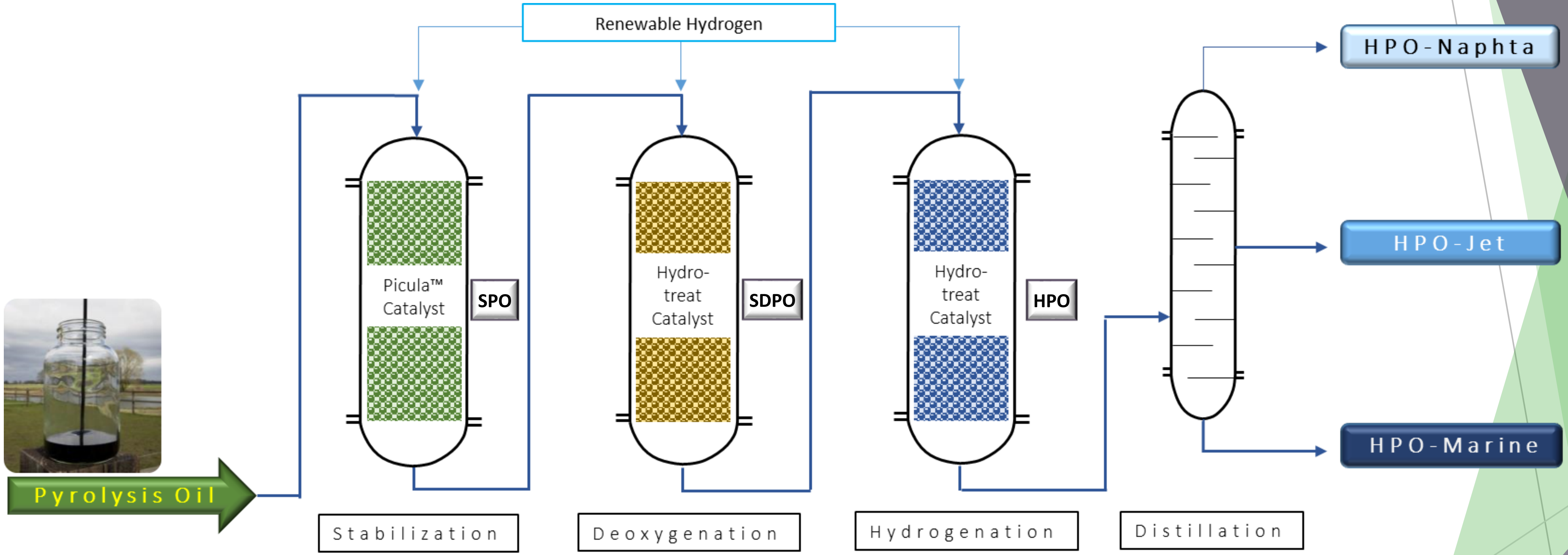
Biomass → Fast Pyrolysis → FPBO → Hydrotreatment → HPO → Distillation → Advanced biofuels



Simplified representation of BTG's pyrolysis process

Water content	25	wt%
Density	1,170	kg/m^3
LHV	16	MJ/kg
Acid Number	70	mg_{KOH}/g
Sulfur	< 0.05	wt%
FlashPoint	?	°C
Cetane Number	< 20	-
MCRT	> 15	wt%

FPBO to advanced biofuels



SPO = Stabilized Pyrolysis **SDPO** = Stabilized Deoxygenated Pyrolysis Oil **HPO** = Hydrotreated Pyrolysis Oil

Integration of CC and H2 technologies

Both value chains have been successfully demonstrated on pilot scale

Both value chains can in theory benefit from CC/H2 technologies:

- CO2 can be captured for boosting gasification yields
- Hydrogen is needed for the pyrolysis oil upgrading
- Etc..

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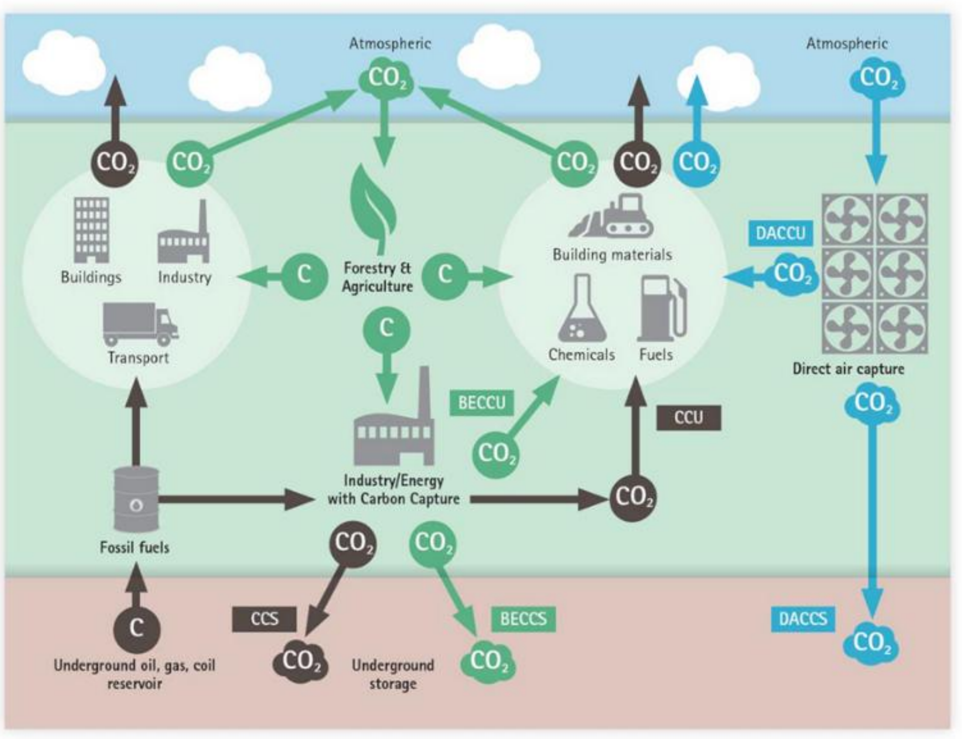
Overview of technologies for CC(U)S

Doris Matschegg, BEST

Carbon Capture Utilization and Storage CC(U)S

- Carbon capture (utilization) and storage involves the capture, transport, (utilization) or long-term storage of CO_2 from industrial processes.
  - Since plants absorb CO_2 as they grow, this is one way to remove CO_2 from the atmosphere when capturing from bioenergy technologies.
- The BioTheRoS project scope includes:
  - technologies to capture CO_2 from point sources,
  - relevant for the combination with biomass gasification or pyrolysis.

→ excludes DACC and pre-combustion technologies



Schematic illustration of BECCS, BECCU, CCS, CCUS, DACCU and DACCS.
Source: Austrian Biomass Association

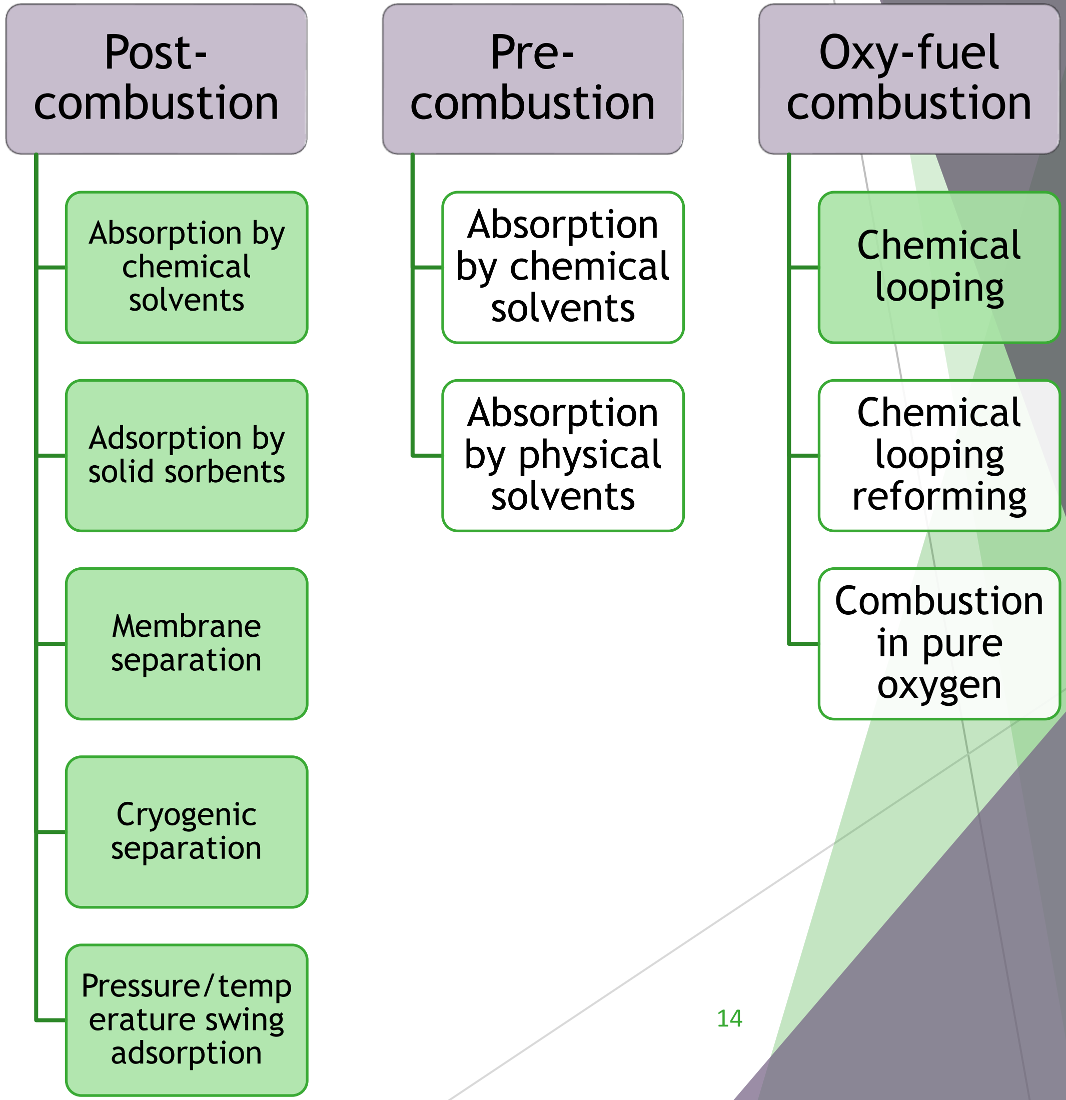
BioTheRoS - CC(US) technology overview

Post combustion technologies

- Membrane technologies
- Cryogenics
- Solid adsorption
- Solvent-based absorption

Oxy-fuel combustion technologies

- Chemical looping with in-situ conversion

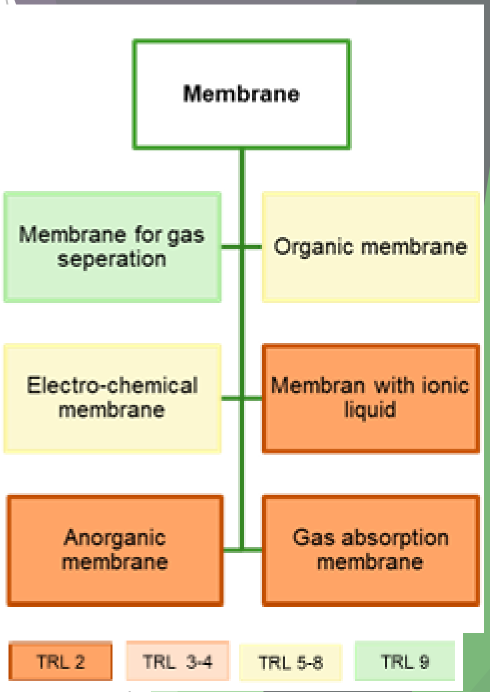


Post-combustion
- Absorption by chemical solvents
- Adsorption by solid sorbents
- Membrane separation
- Cryogenic separation
- Pressure/temperature swing adsorption

Pre-combustion
- Absorption by chemical solvents
- Absorption by physical solvents

Oxy-fuel combustion
- Chemical looping
- Chemical looping reforming
- Combustion in pure oxygen

Membrane separation



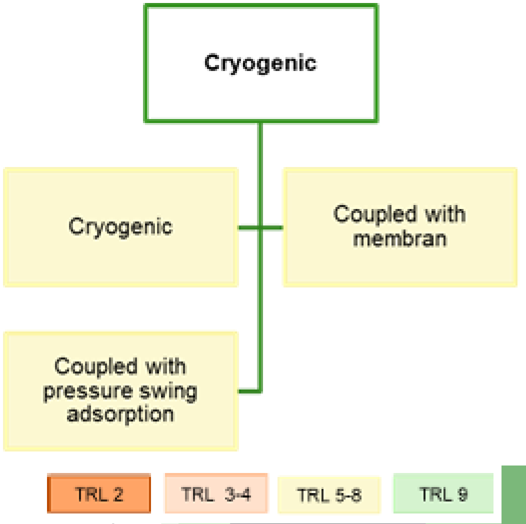
https://bioenergyeurope.org/wp-content/uploads/2025/06/BECCS-Report_final.pdf

- Membranes separate CO_2 from exhaust emissions by utilizing the partial pressure difference.
- These membranes are selected on two key properties:
  - high selectivity (for a pure product)
  - high permeability (to accommodate the high flow rate of industrial flue gas)
- Membranes can be made from organic material, inorganic material or a hybrid of both.

Benefits	Drawbacks
Low energy consumption	Fouling effect
Simple installation	Performance affected by operating conditions

Cryogenics

- Cryogenics uses the differences in physical properties to separate CO_2.
  - Boiling point in cryogenic distillation
  - Desublimation properties in vapor-solid separation.



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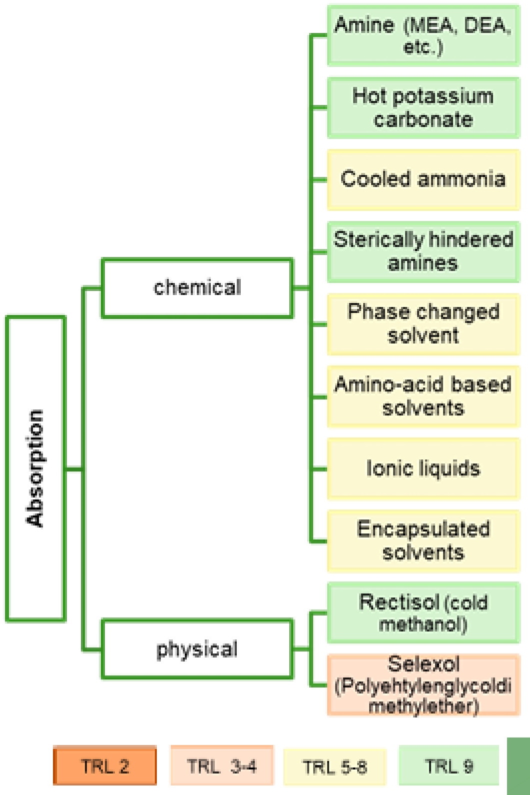
Benefits	Drawbacks
Used commercially (for high concentration and pressure gases)	High energy demand (cooling)
Results in liquid CO_2 for further use	Flow must be free of water (prevent ice formation)

Solvent-based absorption

- Solvent-based or chemical absorption uses a chemical solvent to absorb CO_2. The solvent is regenerated by changing the temperature, which separates CO_2 and solvent.
  - Different chemicals have been tried to achieve the best results, aiming for:
    - High absorption rate
    - Large absorption capacity
    - Low energy requirement for the regeneration of the solvent.

Benefits	Drawbacks
Applied worldwide in large scale (MEA – TRL 9)	High equipment corrosion rate
New solvents are being investigated	High energy consumption
	Environmental impacts due to solvent emissions



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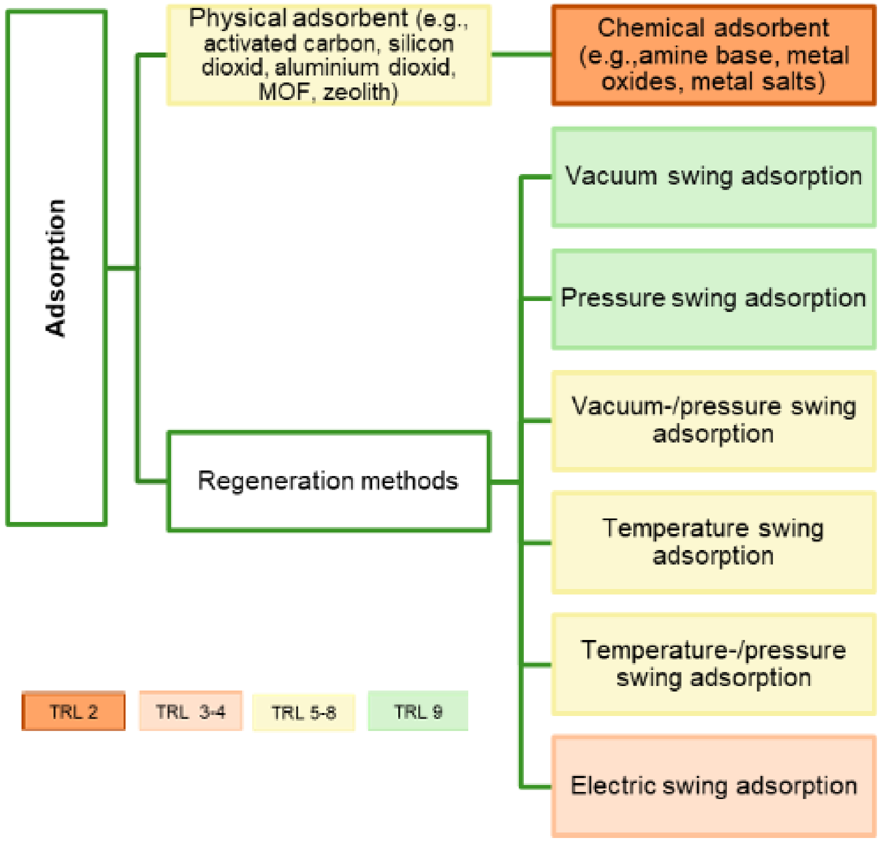
Solid adsorption (PSA/TSA)

- Solid adsorption works by adsorbing CO_2 as a thin film on a solid material (e.g., zeolites, activated carbon).
  - Adsorbent selection according to volume of CO_2, kinetics, pore size, structure, …
- By changing the pressure (PSA) or temperature (TSA) the adsorbed CO_2 is released/desorbed.



Adsorption

Physical adsorbent (e.g., activated carbon, silicon dioxid, aluminium dioxid, MOF, zeolith)

Chemical adsorbent (e.g.,amine base, metal oxides, metal salts)

Regeneration methods

Vacuum swing adsorption

Pressure swing adsorption

Vacuum-/pressure swing adsorption

Temperature swing adsorption

Temperature-/pressure swing adsorption

Electric swing adsorption

TRL 2

TRL 3-4

TRL 5-8

TRL 9

https://bioenergyeurope.org/wp-content/uploads/2025/06/BECCS-Report_final.pdf

Benefits	Drawbacks
High adsorption capacity	Low CO_2 selectivity
Reversible	Periodic regeneration required

Chemical looping with in-situ conversion (CL-ICCC)

Specific adsorption process

- Oxy-fuel combustion: An air separator unit separates nitrogen from oxygen prior to combustion – fuel is combusted in an oxygen environment, instead of air.
- CO_2 is adsorbed at an active site of a bifunctional material and is then spilled over to the catalytic site of the bifunctional material, where it reacts with a reduction agent into valuable products such as syngas.

Benefits	Drawbacks
Potential to be efficient and comparably low-cost	In development (low TRL)
Combines CO_2 capture and utilization	No retrofitting potential

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Overview of technologies for renewable hydrogen production

Patrick Reumerman, BTG

Significance

Both the Gasification and the Pyrolysis value chains can benefit from integration of H2 technologies

Gasification

- H2 can be necessary to obtain the right H2:CO ratio
- H2 is an important component in the syngas

Pyrolysis

- About 5% (wt basis) of hydrogen is needed for upgrading of pyrolysis oil to transport fuels

Boundary conditions:

- Hydrogen production should be sustainable (low CO2eq emissions) because of REDII/III requirements
- Technologies should be appropriate to the typical scales of gasification and pyrolysis

H2 production technologies

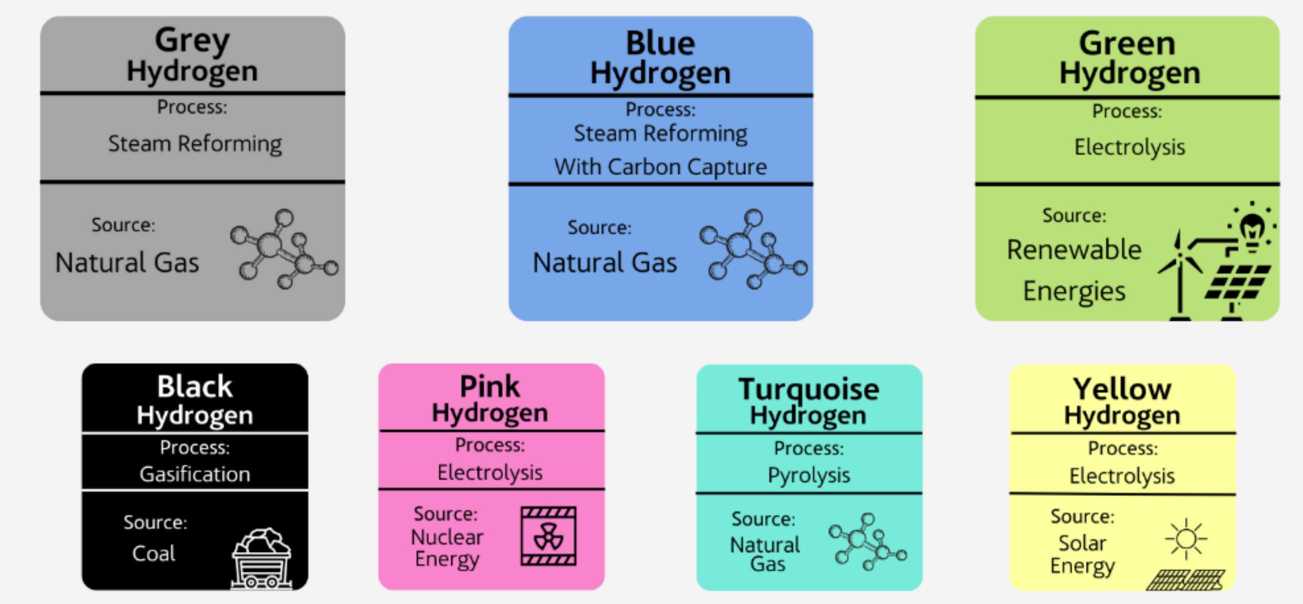
Rapid development expected from 0.05 Mtonne/year (2024) in Europe to 14 Mtonne/y (2030) and 55 Mtonne/y (2050)

Typical technologies:

- Most common (85%) of global sustainable production is SMR (Steam Methane Reforming) of Natural Gas in combination with Carbon Capture.

- “Green hydrogen” can also be produced from Biowaste – though scalabilty is an issue

- Electrolysis
  - Low temperature electrolysis
  - High temperature electrolysis



Grey Hydrogen
Process: Steam Reforming
Source: Natural Gas

Blue Hydrogen
Process: Steam Reforming With Carbon Capture
Source: Natural Gas

Green Hydrogen
Process: Electrolysis
Source: Renewable Energies

Black Hydrogen
Process: Gasification
Source: Coal

Pink Hydrogen
Process: Electrolysis
Source: Nuclear Energy

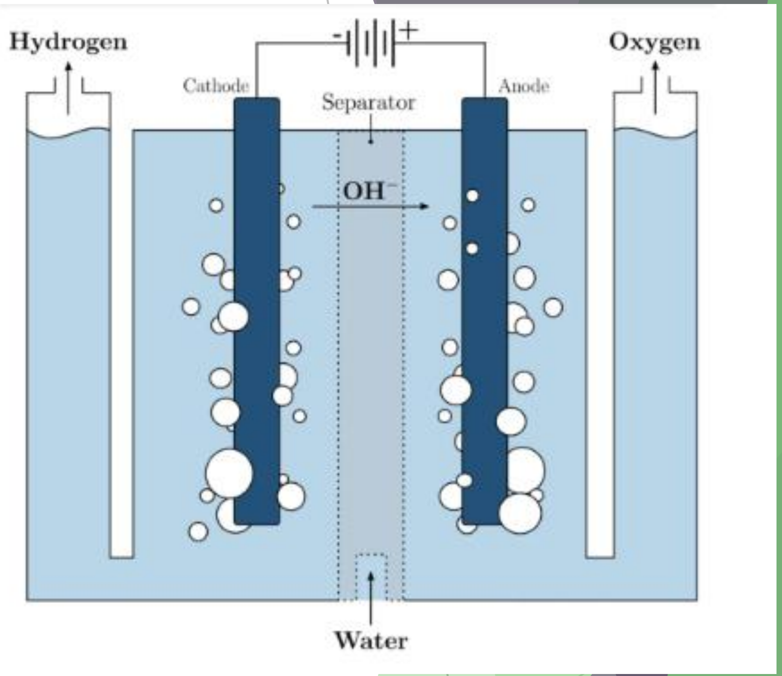
Turquoise Hydrogen
Process: Pyrolysis
Source: Natural Gas

Yellow Hydrogen
Process: Electrolysis
Source: Solar Energy

Low temperature electrolysis

Based on the principle of splitting water into hydrogen and oxygen via electricity

- Fully commercial (TRL 9), and being scaled up
- Several types, based on the way the ions are separated:
  - PEM (Membrane- separated H+)
  - AME (Membrane- separated OH-)
  - AWE (Electrolyte and porous diafragm)
- Energetic efficiency is ca 60% - 65%
- Key aspects:
  - Water use and purity is an issue
  - Can be switched on and off easily → direct coupling with renewable electricity production



Alkaline cell (AWE)

High temperature electrolysis

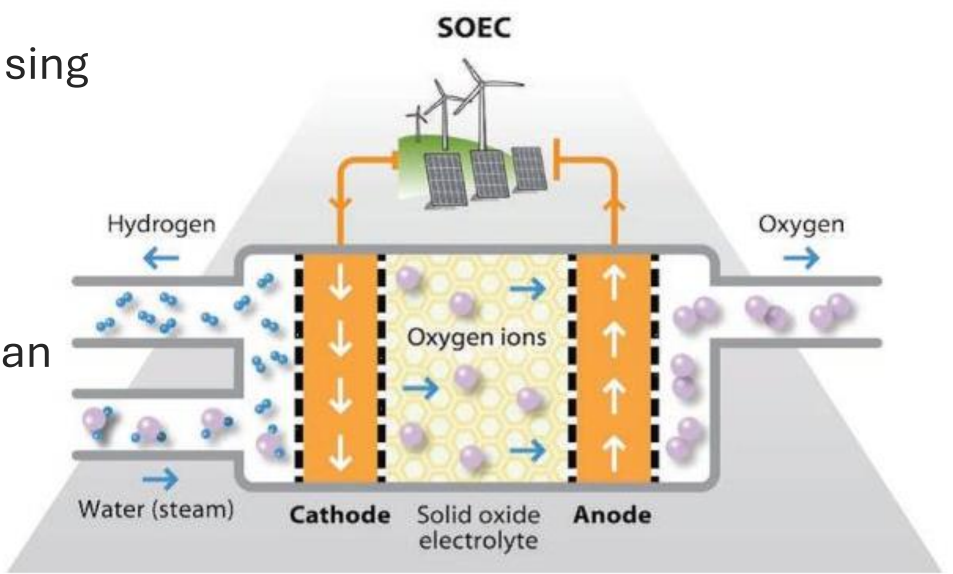
Based on the principle of splitting water into hydrogen and oxygen using electricity and heat

- Not yet fully commercial (TRL 8)

- Carried out in Solid Oxide Electrolysis Cells. Ions migrate throug an electrolyte between 500 °C and 1000°C.

- Electrical efficiency is ca 75% - 85% - rest is heat.

- Key aspects:
  - Water use and purity is an issue
  - Promising if a ‘free’ source of high temperature heat is available
  - Dynamic behaviour is more limited (‘thermal inertia’)



Anaerobic Digestion and SMR

Based on the principle of reacting CH4 with water to to CO and hydrogen, using steam and a catalyst at elevated temperatures (700 – 1000°C)


Air Liquide SMR plant in Anwerpen (B)

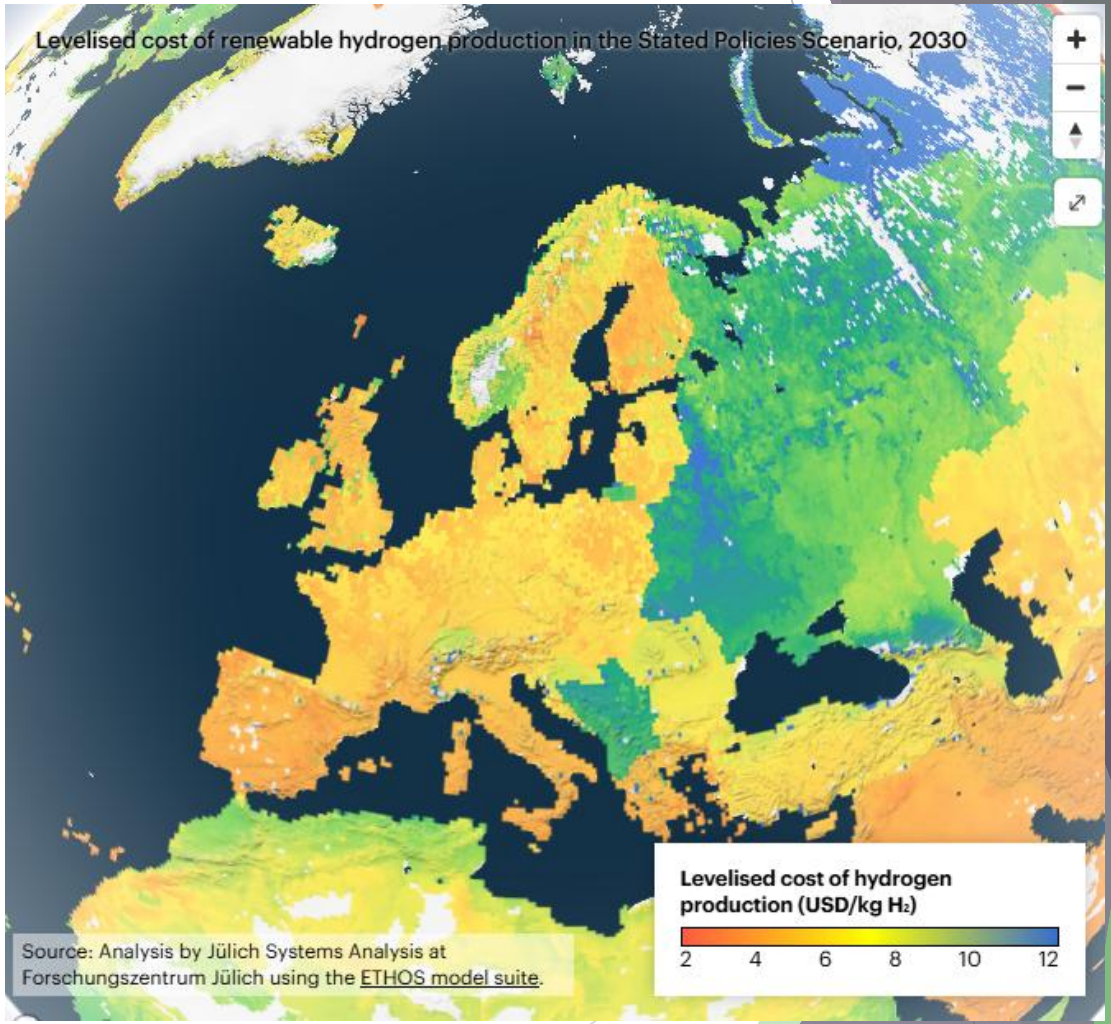
- Fully mature, as it is used also for hydrogen production from natural gas
- The AD part – including the CO2 separation from the biogas is also fully mature.
- Reasons why it is not implemented more is probably:
  - Scale (max low-medium scale because of AD limits)
  - High value of ‘green’ methane
- Key aspects:
  - Well-suited for pyrolysis upgrading because of the existence of a wastewater stream.

Costs

- Costs for hydrogen production from renewable electricity is highly dependent on geographical location – see the IEA Hydrogen production cost tracker map.

- Because – in Europe – CAPEX is still a significant factor, overall H2 costs are dependent on operating hours

- H2 production using SMR lower, with 3.3 Euro/kg H2, of which the natural gas component is 2.5 Euro/kg H2. This explains the attractiveness of the AD/SMR combination



Source: Analysis by Jülich Systems Analysis at Forschungszentrum Jülich using the ETHOS model suite.

Summary

- Hydrogen production from sustainable sources is limited – but significant scale-up is projected
- Low temperature electrolysis remains a dominant technology – but with issues and specific draw-backs
- Costs are highly regional, scale- and technology dependent

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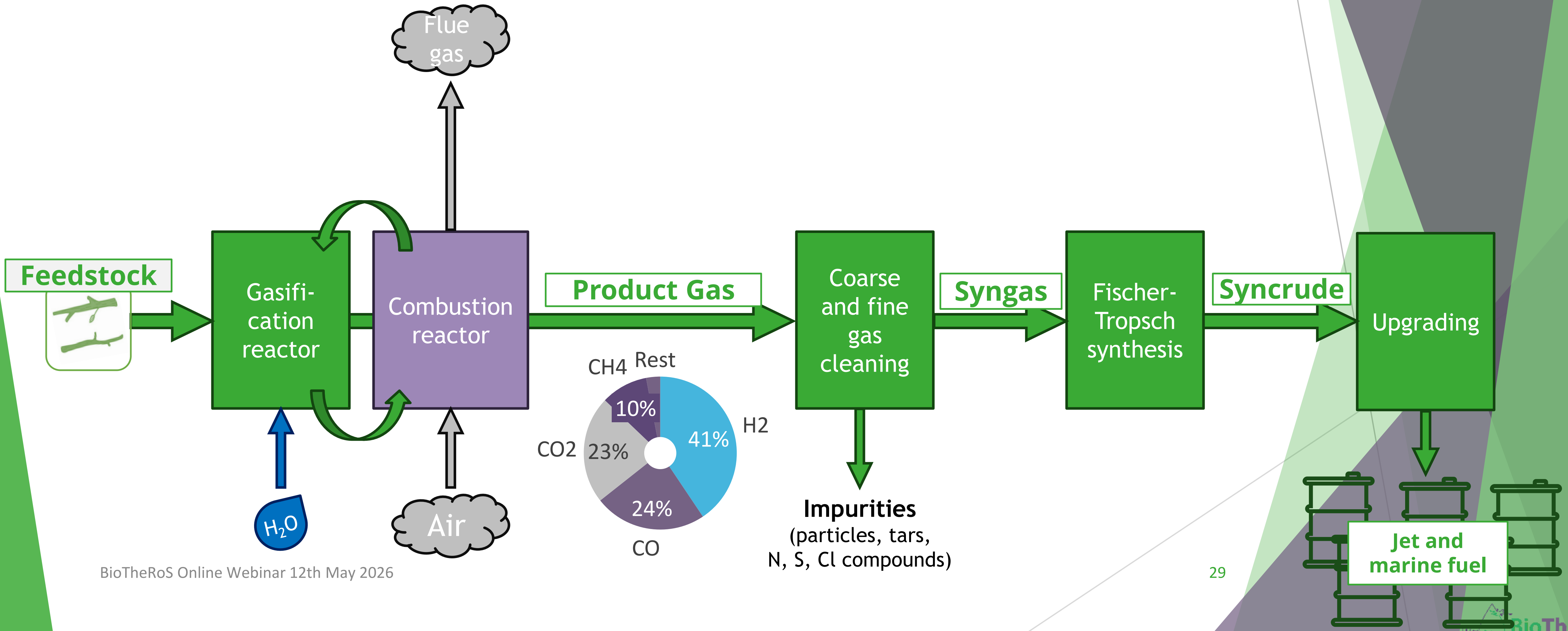
Linking CC(U)S and hydrogen technologies with gasification

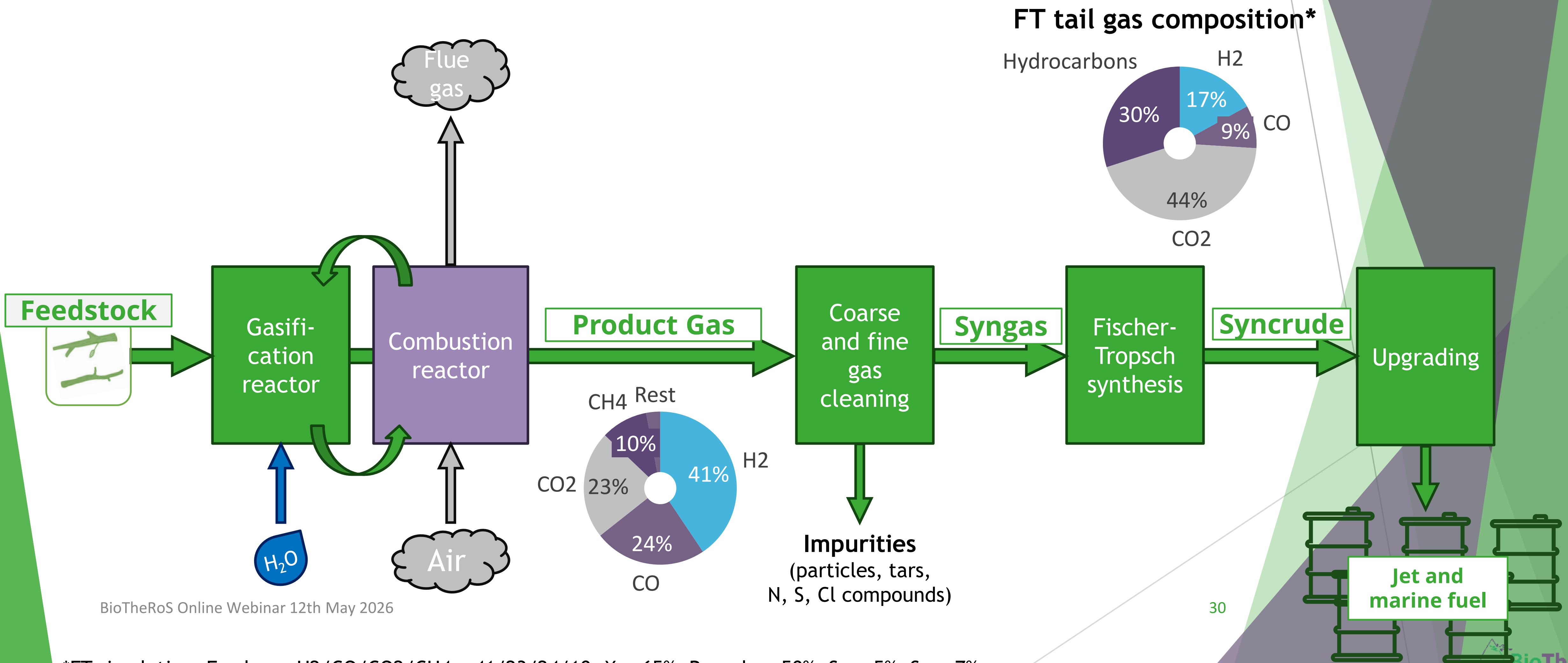
Philipp Graefe, BEST

Basic DFB biomass-to-liquid process chain



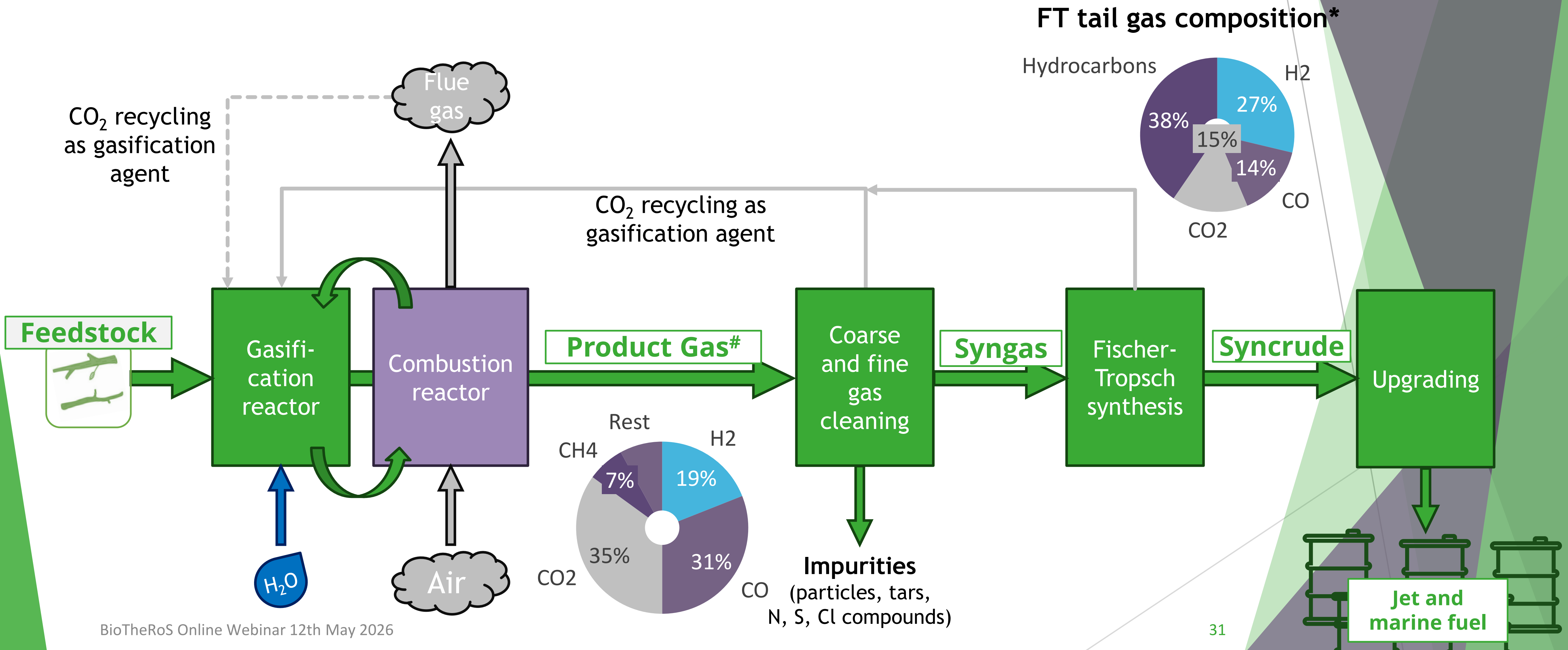
Impurities
(particles, tars,
N, S, Cl compounds)

Basic DFB biomass-to-liquid process chain



*FT simulation: Fresh gas H2/CO/CO2/CH4 = 41/23/24/10; X_{pp}=65%, Recycle = 50%, S_{CO2}=5%, S_{CH4}=7%

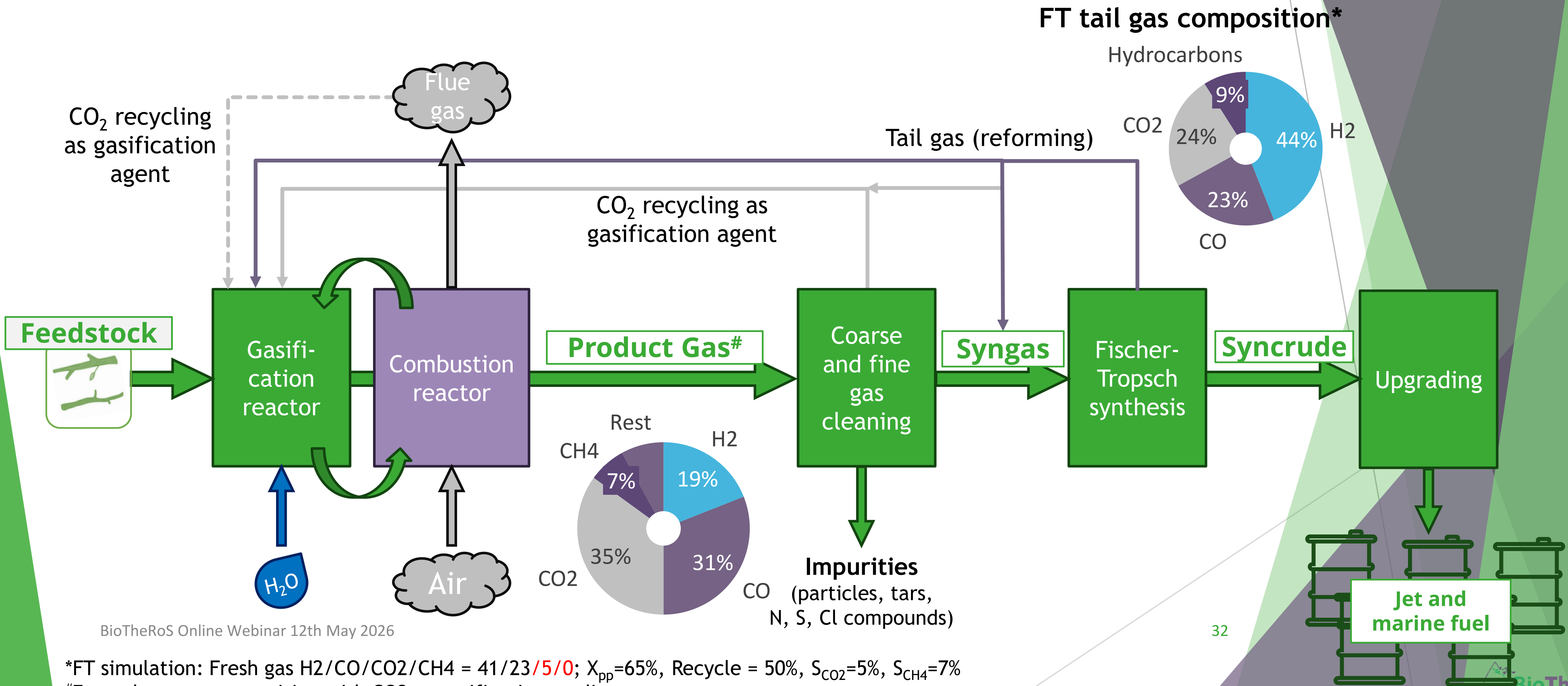
Integration of CO_2 separation and utilization



*FT simulation: Fresh gas H2/CO/CO2/CH4 = 41/23/5/10; X_{pp}=65%, Recycle = 50%, S_{CO2}=5%, S_{CH4}=7%

#Examplary gas composition with CO2 as gasification medium

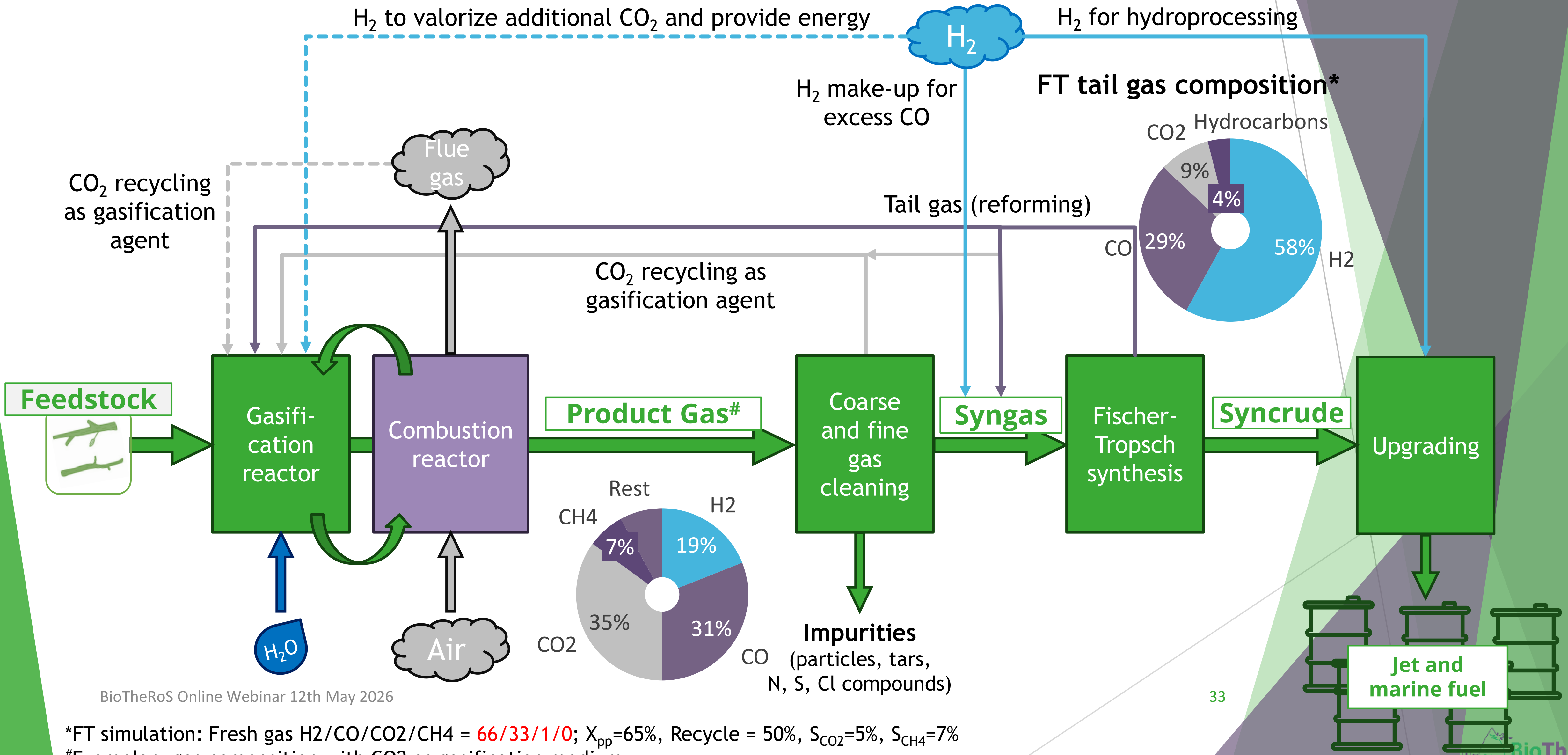
Integration of Tail gas valorization



*FT simulation: Fresh gas H2/CO/CO2/CH4 = 41/23/5/0; X_{pp}=65%, Recycle = 50%, S_{CO2}=5%, S_{CH4}=7%

#Examplary gas composition with CO2 as gasification medium

Integration of H_2 addition



H_2 to valorize additional CO_2 and provide energy

H_2

H_2 for hydroprocessing

H_2 make-up for excess CO

FT tail gas composition*

CO_2 recycling as gasification agent

Flue gas

Tail gas (reforming)

CO_2 recycling as gasification agent

Feedstock

Gasification reactor

Combustion reactor

Product Gas#

Coarse and fine gas cleaning

Syngas

Fischer-Tropsch synthesis

Syncrude

Upgrading

H_2O

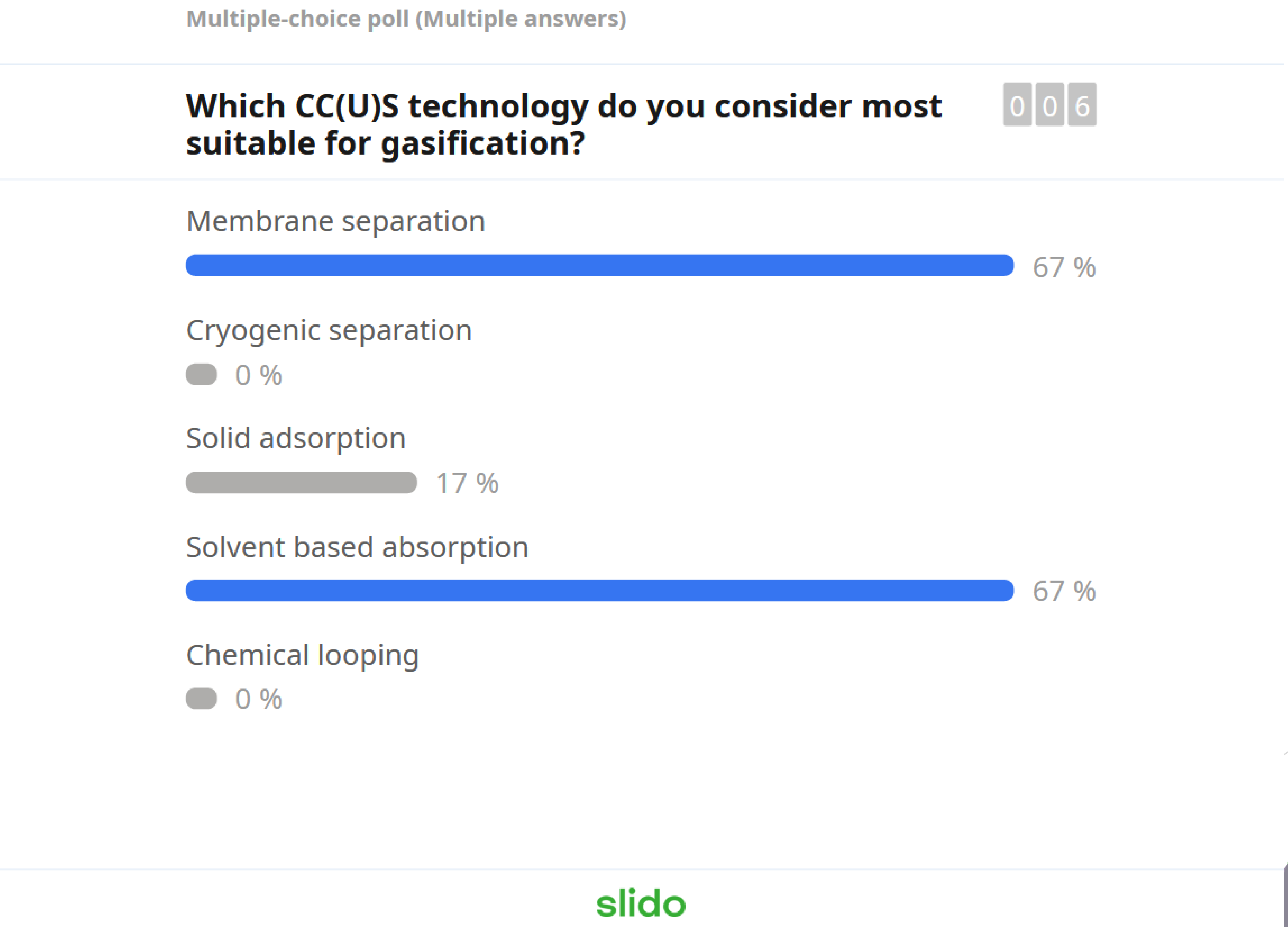
Air

Impurities
(particles, tars, N, S, Cl compounds)

Jet and marine fuel

*FT simulation: Fresh gas H2/CO/CO2/CH4 = 66/33/1/0; X_{pp}=65%, Recycle = 50%, S_{CO2}=5%, S_{CH4}=7%

#Examplary gas composition with CO2 as gasification medium



Multiple-choice poll (Multiple answers)

Which CC(U)S technology do you consider most suitable for gasification?

006

Membrane separation

67 %

Cryogenic separation

0 %

Solid adsorption

17 %

Solvent based absorption

67 %

Chemical looping

0 %

slido

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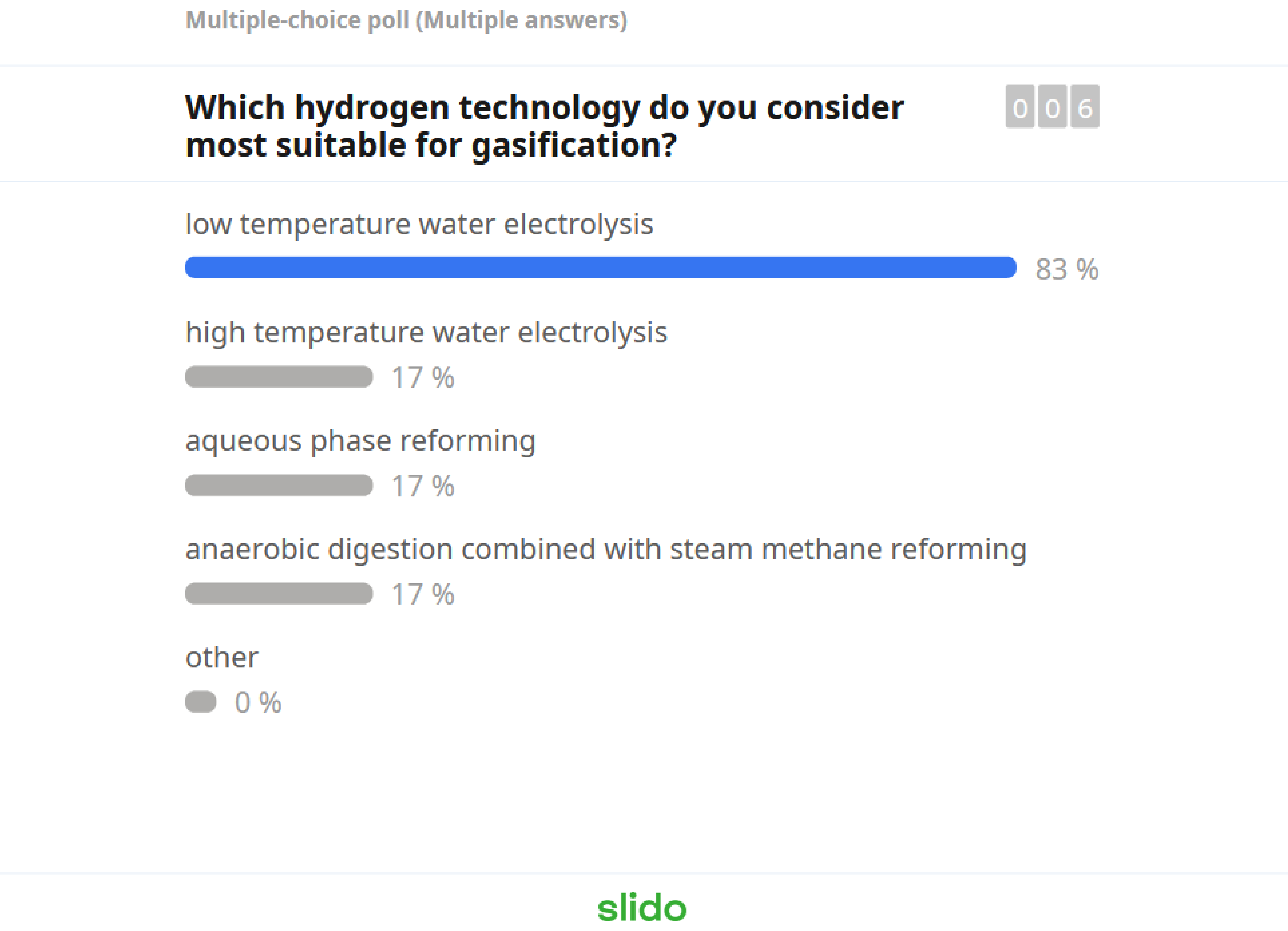

Multiple-choice poll (Multiple answers)

Which hydrogen technology do you consider most suitable for gasification?

006

low temperature water electrolysis

83 %

high temperature water electrolysis

17 %

aqueous phase reforming

17 %

anaerobic digestion combined with steam methane reforming

17 %

other

0 %

slido

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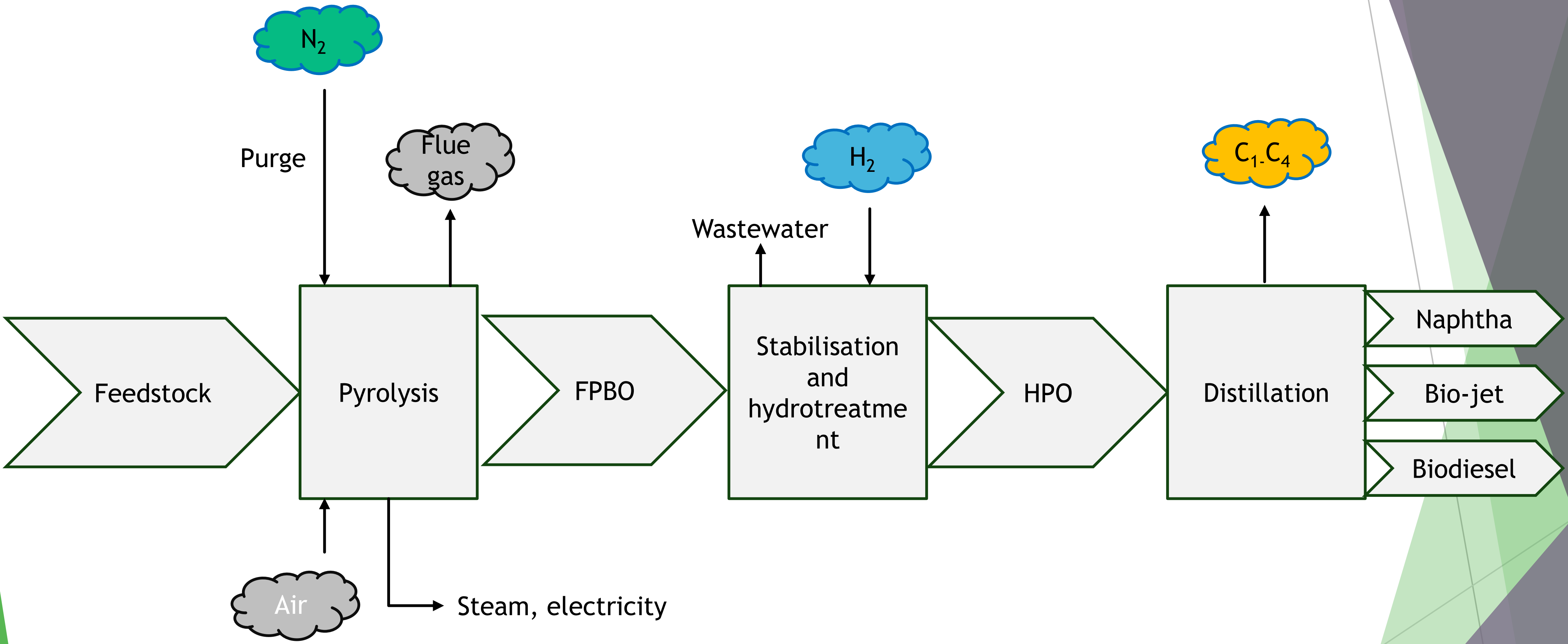
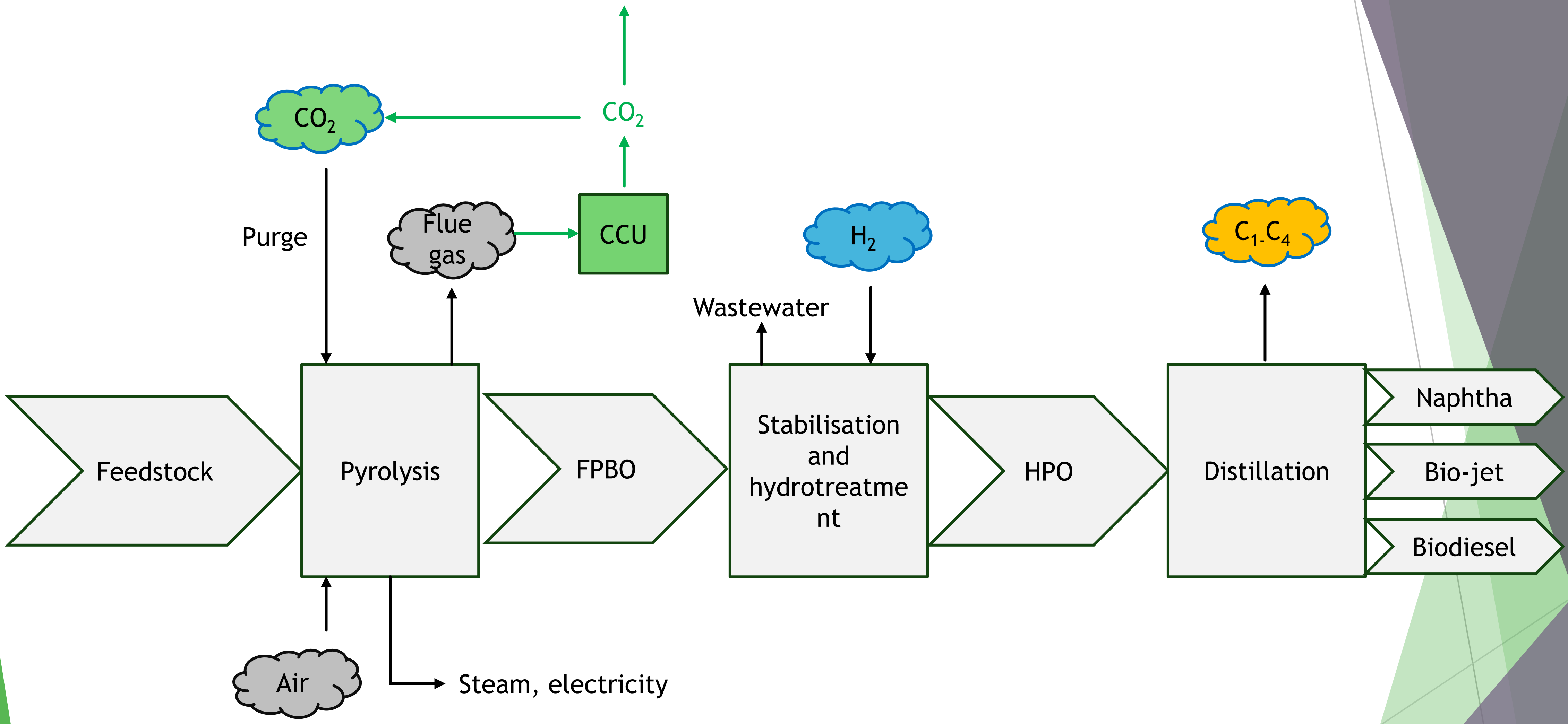
Linking CC(U)S and hydrogen technologies with pyrolysis

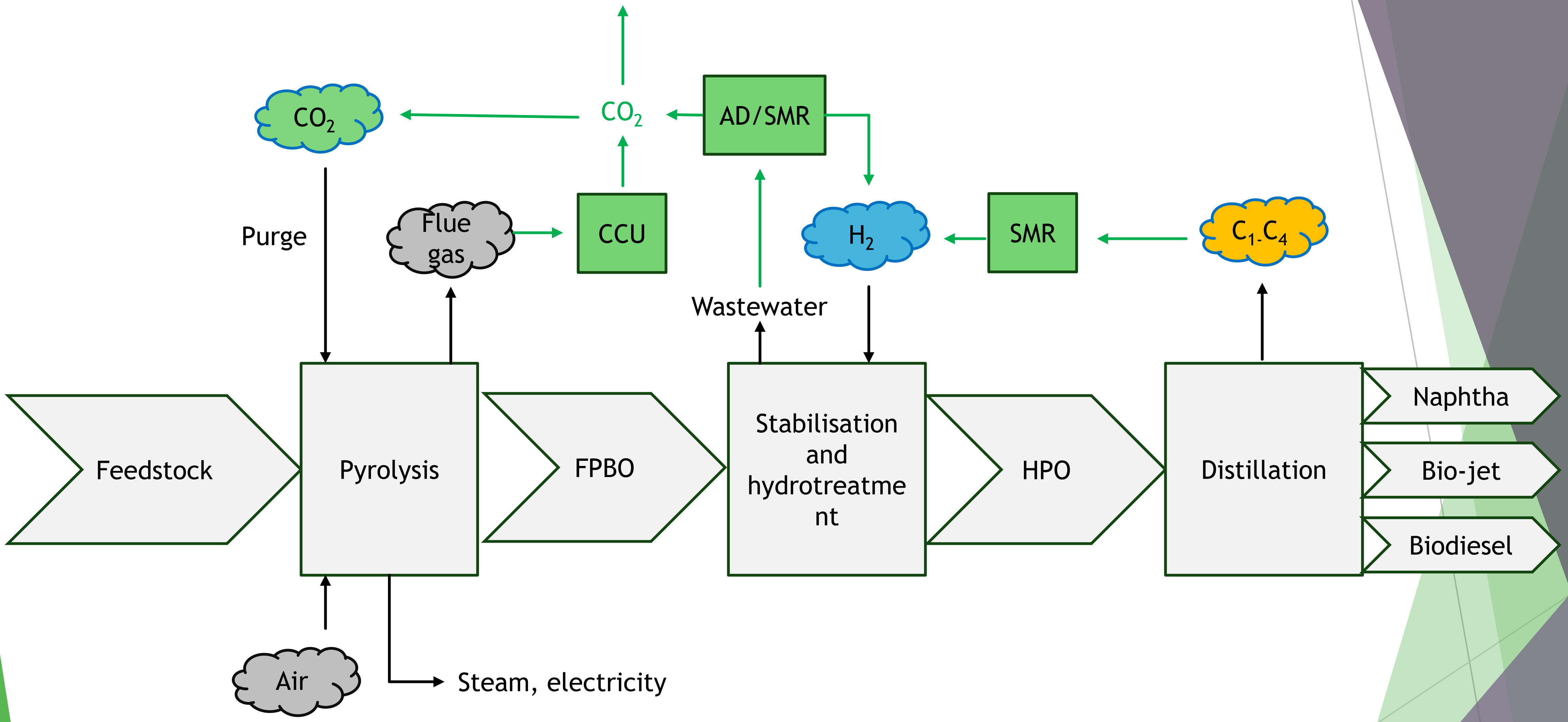
Patrick Reumerman, BTG

Pyrolysis value chain





Flue gas CO2 can be captured for external use – and as purge gas

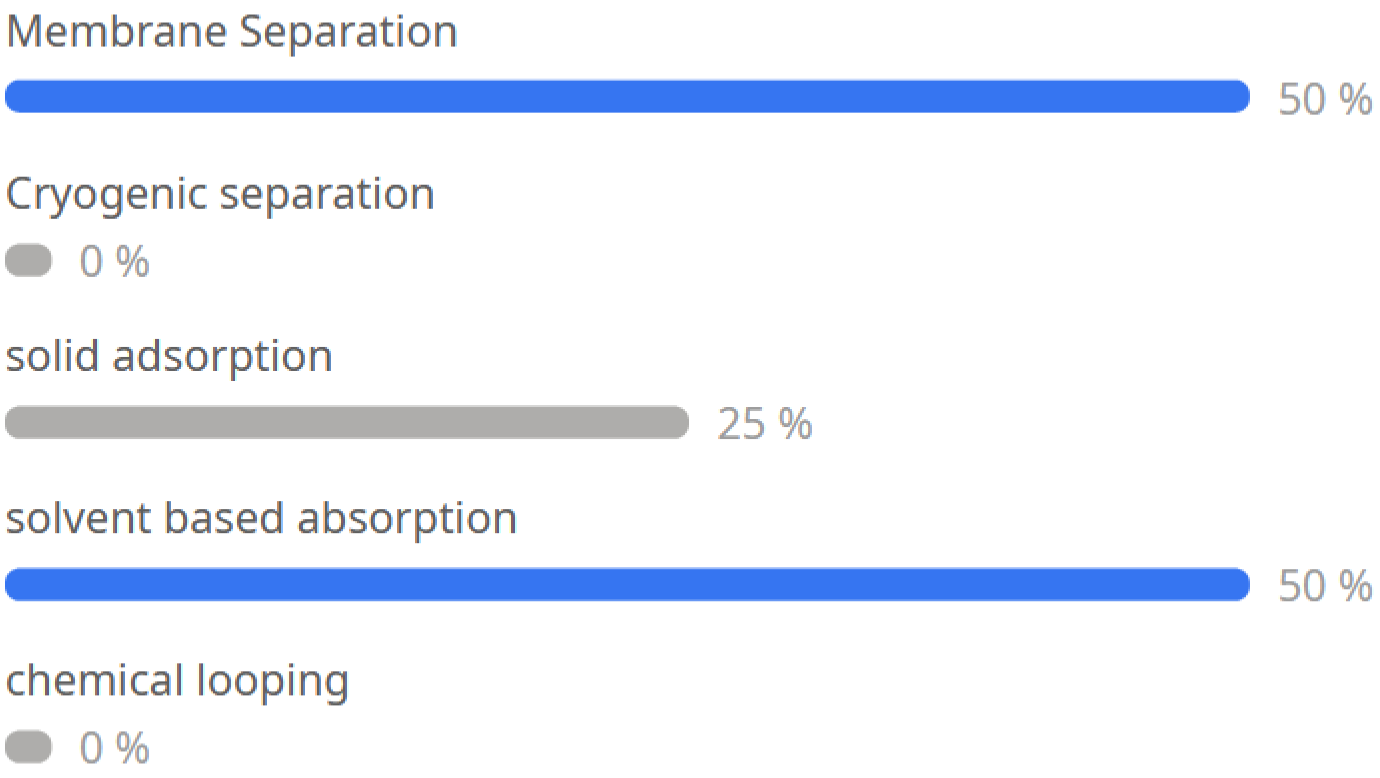


Hydrogen can be generated from the C1-C4 gases from distillation, and via the organics in the wastewater

Multiple-choice poll (Multiple answers)

Which CC(U)S technology do you consider most suitable for pyrolysis?

004



Multiple-choice poll (Multiple answers)

Which hydrogen technology do you consider most suitable for pyrolysis?

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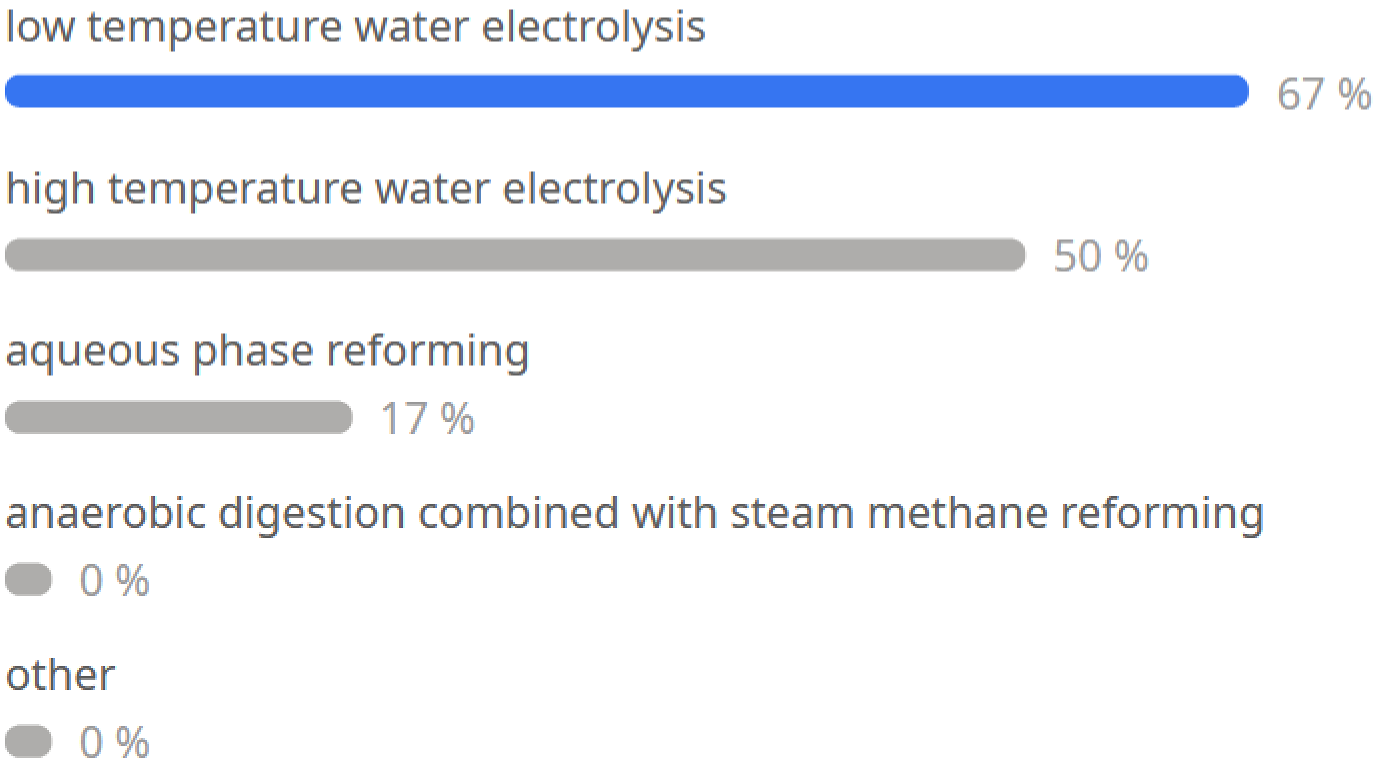

low temperature water electrolysis
67 %

high temperature water electrolysis
50 %

aqueous phase reforming
17 %

anaerobic digestion combined with steam methane reforming
0 %

other
0 %

slido

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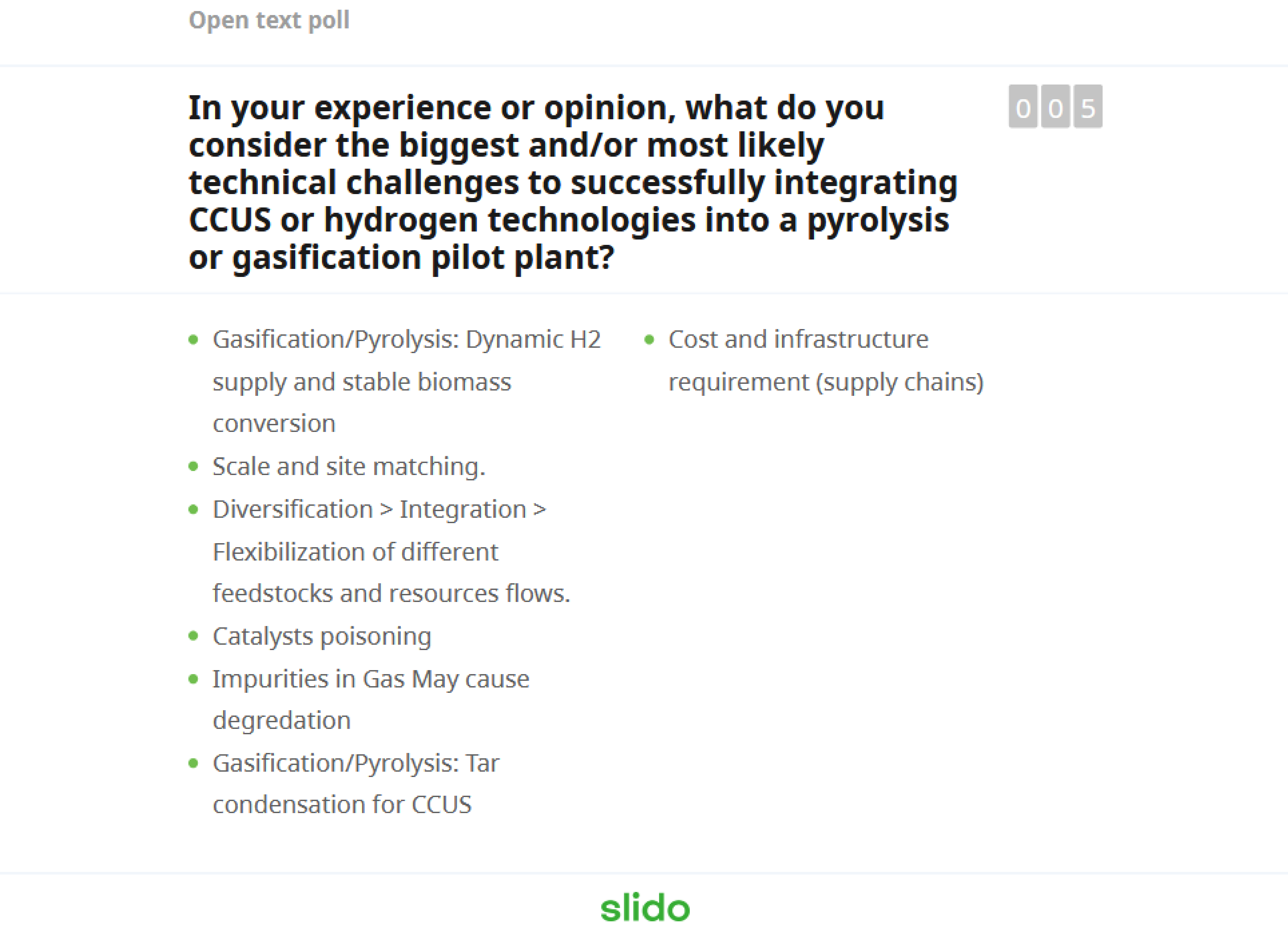


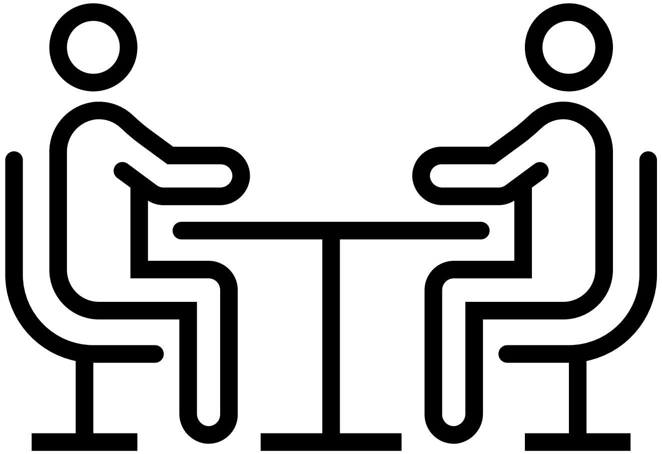
Open text poll

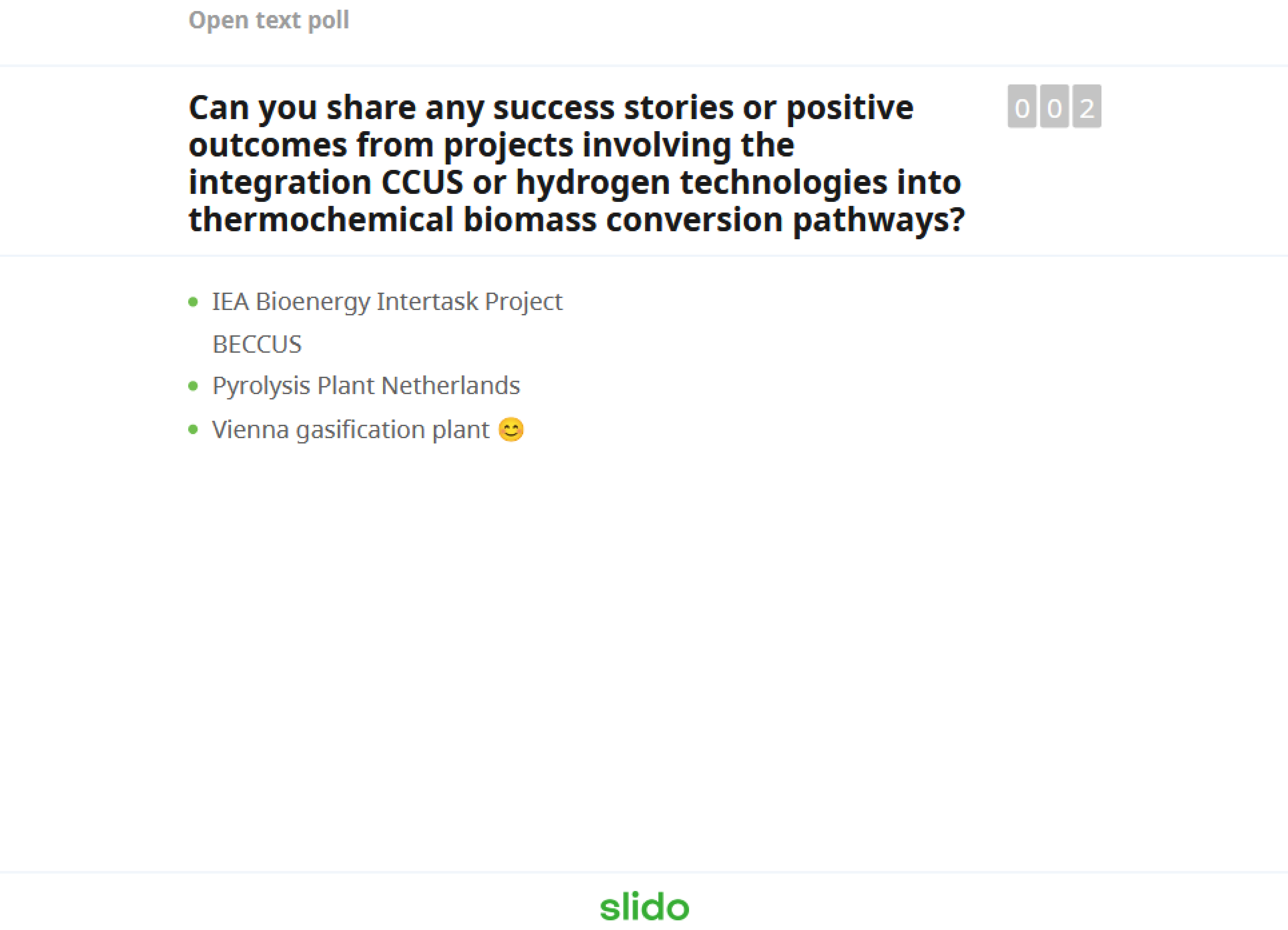
In your experience or opinion, what do you consider the biggest and/or most likely technical challenges to successfully integrating CCUS or hydrogen technologies into a pyrolysis or gasification pilot plant?

005

- Gasification/Pyrolysis: Dynamic H2 supply and stable biomass conversion
- Scale and site matching.
- Diversification > Integration > Flexibilization of different feedstocks and resources flows.
- Catalysts poisoning
- Impurities in Gas May cause degredation
- Gasification/Pyrolysis: Tar condensation for CCUS
- Cost and infrastructure requirement (supply chains)

Open discussion





Can you share any success stories or positive outcomes from projects involving the integration CCUS or hydrogen technologies into thermochemical biomass conversion pathways?

- IEA Bioenergy Intertask Project
  BECCUS
- Pyrolysis Plant Netherlands
- Vienna gasification plant 😊

BioTheRoS

Wrap-up and concluding remarks

- Integration of CC(U)S and/or hydrogen technologies in the BioTheRoS value chains:
  - Gasification
  - pyrolysis

- Next steps: techno-economic evaluation of integration in BioTheRoS value chains

- More information, events and publications: https://www.biotheros.eu/en/home/

Thanks for contributing! If you have any more comments or feedback please get in contact:

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