THE VALUE OF FLEXIBLE POWER AND BIOMASS-TO-X SYSTEMS BASED ON GASIFICATION OF SECOND GENERATION BIOMASS

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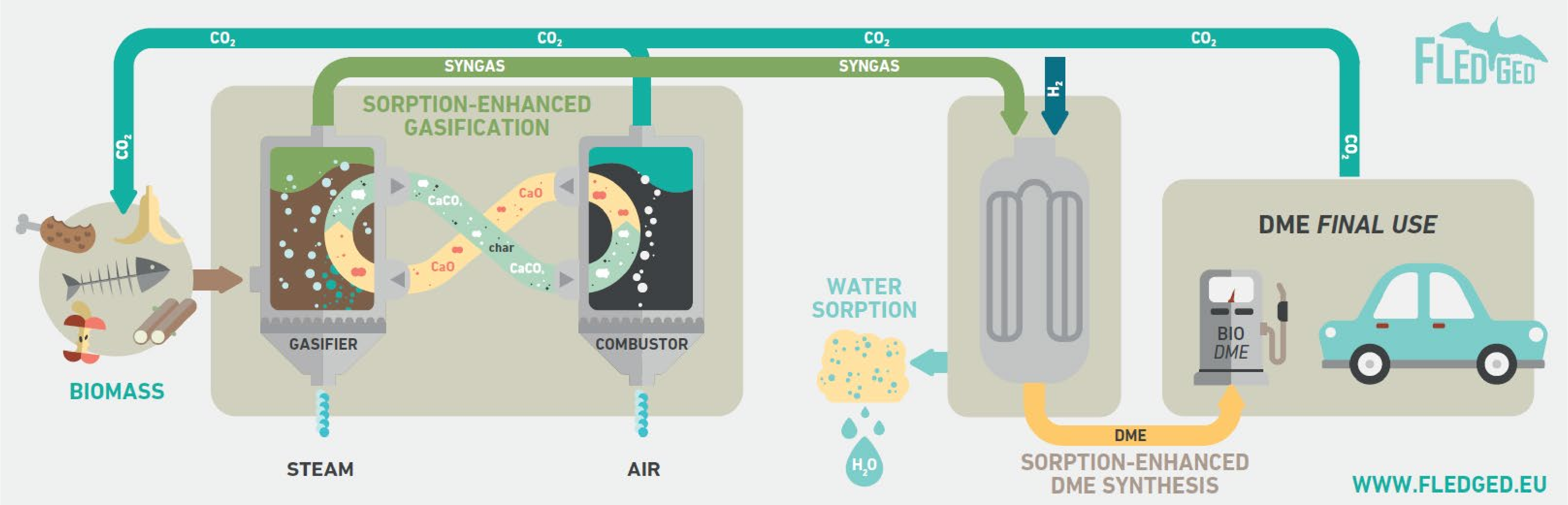
FLEDGED PROJECT (2016-2020)

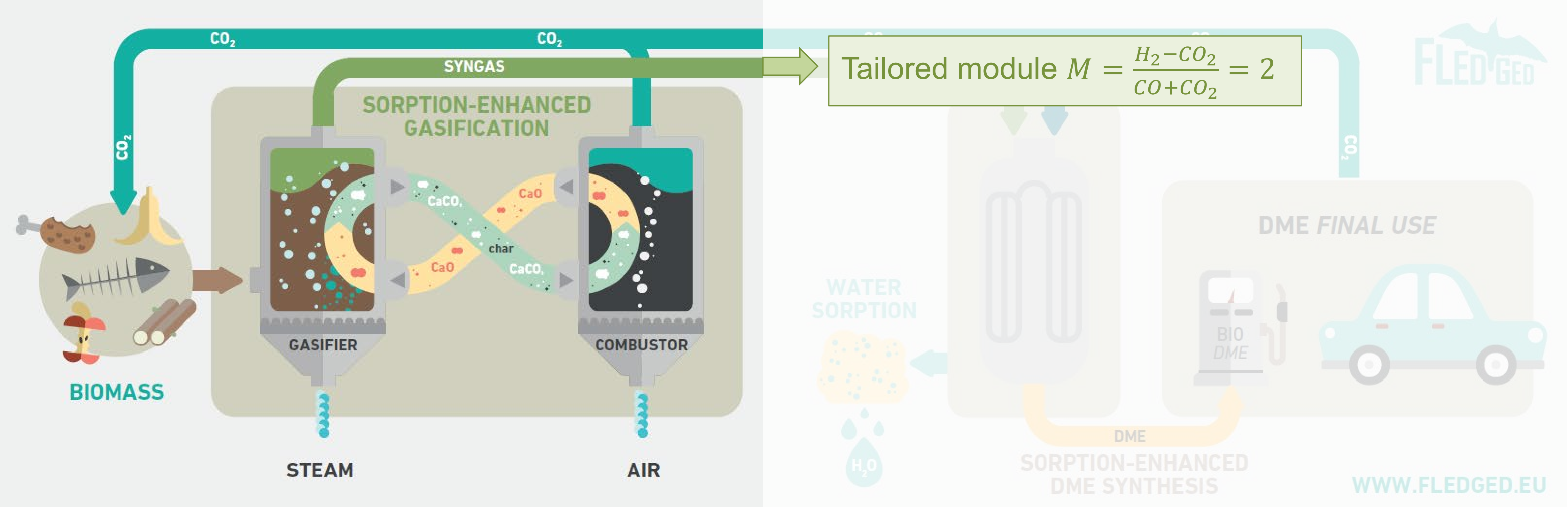
The ***FLEDGED*** project has delivered two technologies *validated in industrially relevant environment* (**TRL5**) for the production of ***Bio-Dimethyl Ether (DME) from biomass gasification***:

- **Process intensification**
- **Process flexibility**



In ***Sorption-Enhanced Gasifier***, CaO-rich sorbent circulates between a gasifier-carbonator and a combustor-calciner to produce:

- a **N_2-free syngas** with **no need of air separation unit (*indirect gasification*)**
- a syngas with **tailored module "M"** thanks to **in-situ CO_2 separation** by reaction: $CaO + CO_2 \rightarrow CaCO_3$



Tailored module $M = \frac{H_2 - CO_2}{CO + CO_2} = 2$

FLEDGED PROJECT: SORPTION-ENHANCED DME SYNTHESIS (SEDMES)

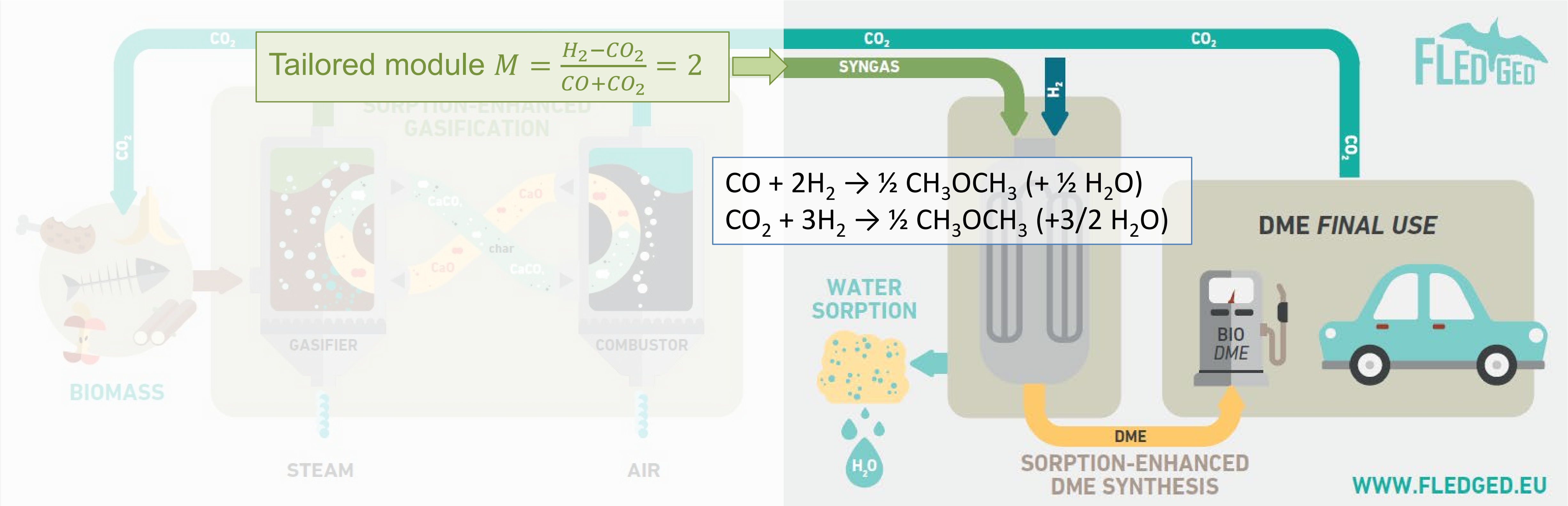
Sorption-Enhanced DME Synthesis is a direct DME synthesis process using sorbent for **in-situ water sorption**:

- **high per-pass DME yield**, thanks to the reduced thermodynamic limitation of methanol dehydration reaction
- **insensitivity on the CO/CO_2 ratio in the feed** (if module M ≈ 2)

Tailored module $M = \frac{H_2 - CO_2}{CO + CO_2} = 2$

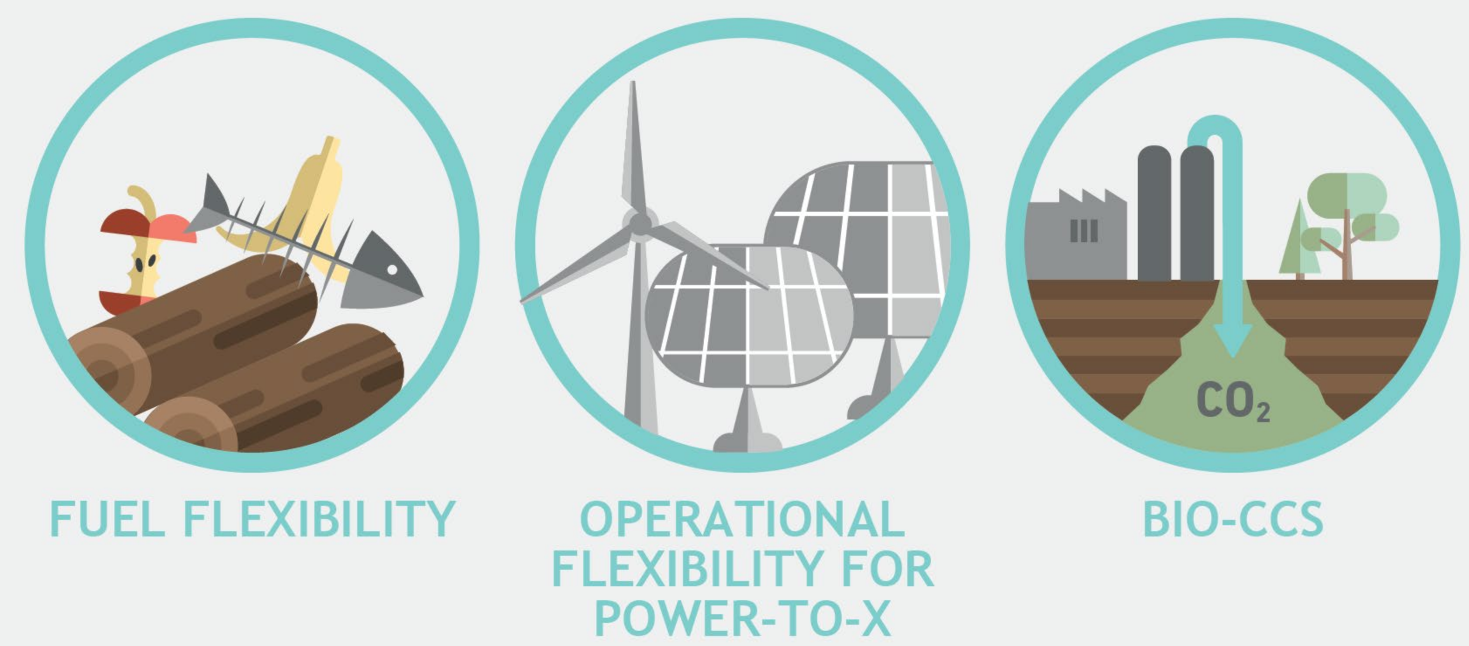
$CO + 2H_2 \rightarrow \frac{1}{2}\, CH_3OCH_3\ (+ \frac{1}{2}\, H_2O)$

$CO_2 + 3H_2 \rightarrow \frac{1}{2}\, CH_3OCH_3\ (+3/2\ H_2O)$



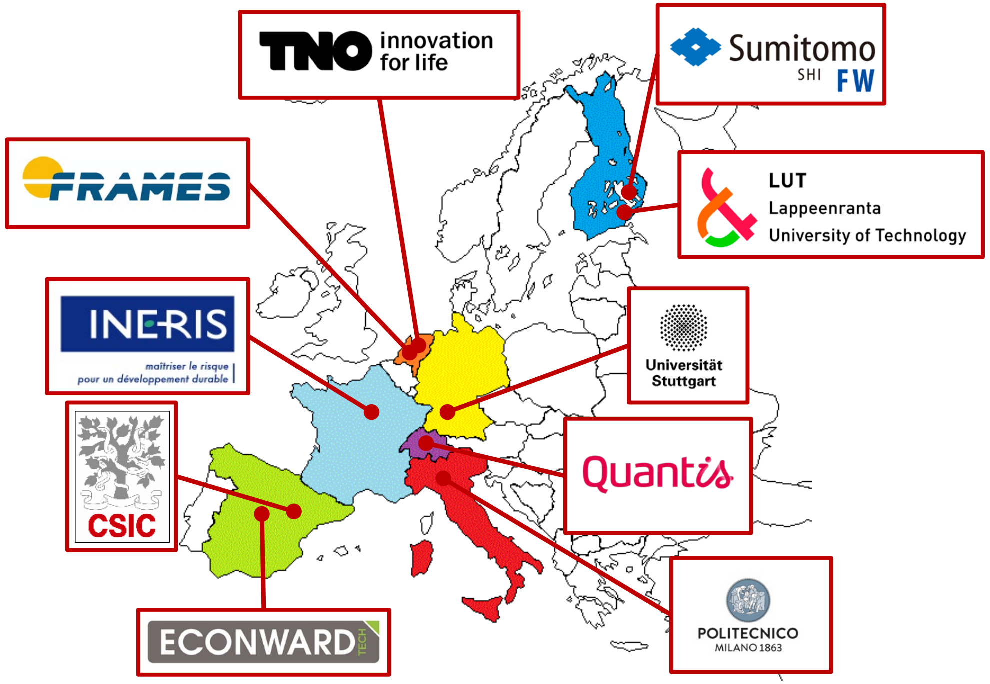
FLEDGED PROJECT: FLEXIBILITY

- **Fuel flexibility**: SEG exploits the fuel flexibility typical of fluidized beds and has been tested with woody biomass, agricultural waste, municipal solid waste as feedstocks.
- **Operational flexibility**: by changing the solids circulation in the SEG unit, CO_2 separation can be reduced, allowing the integration with intermittent H_2 from electrolysis for energy storage via power-to-DME
- **Bio-CCS**: with an O_2-blown SEG combustor, concentrated CO_2 stream is produced, suitable for geologic storage, delivering a negative emission system



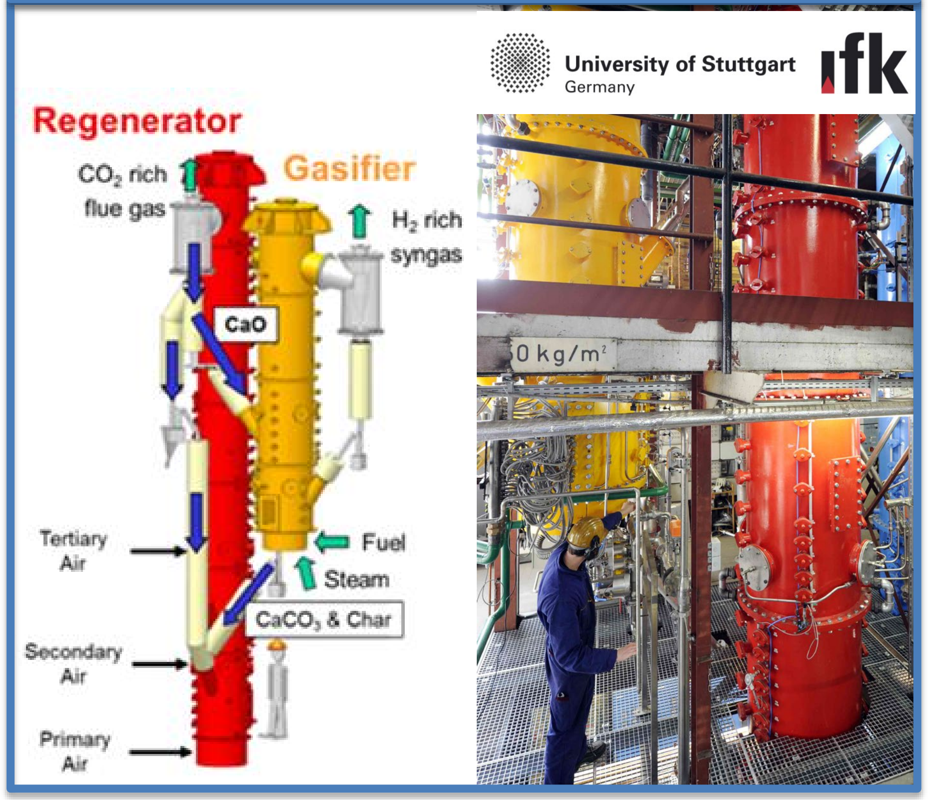
FLEDGED PROJECT

The consortium



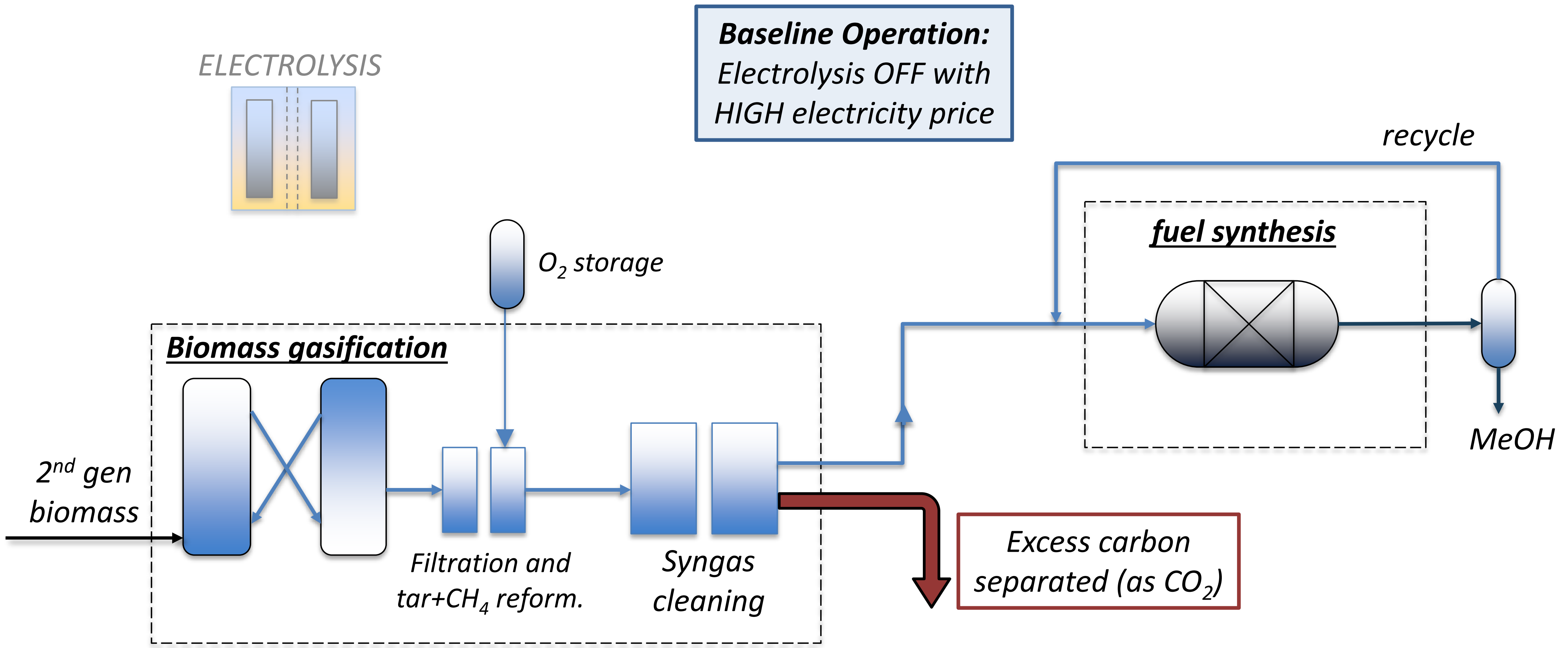
Facilities for demonstration at TRL5

Flexible SEG process demonstrated in the 200 kW dual fluidized bed facility at IFK, University of Stuttgart.

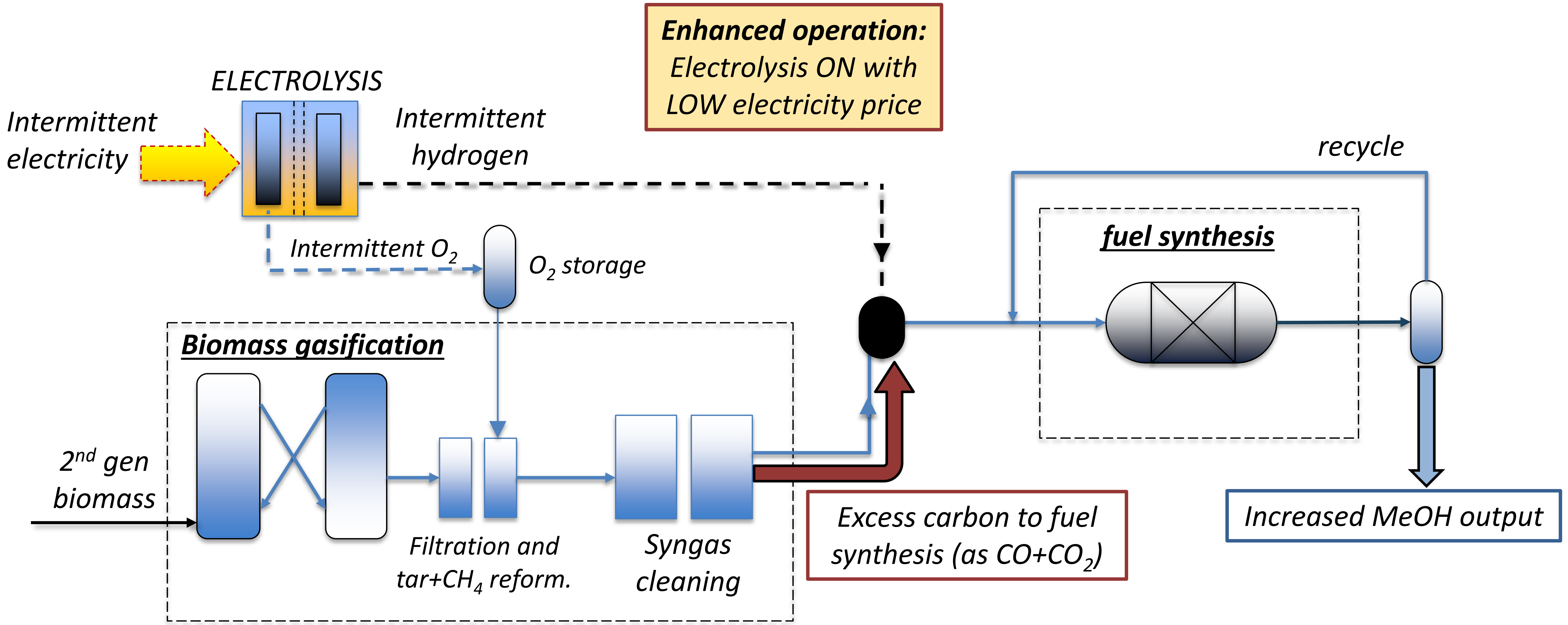


SEDMES process demonstrated in multi column PSA rig at TNO

FLEXIBLE POWER & BIOMASS TO MEOH PLANT



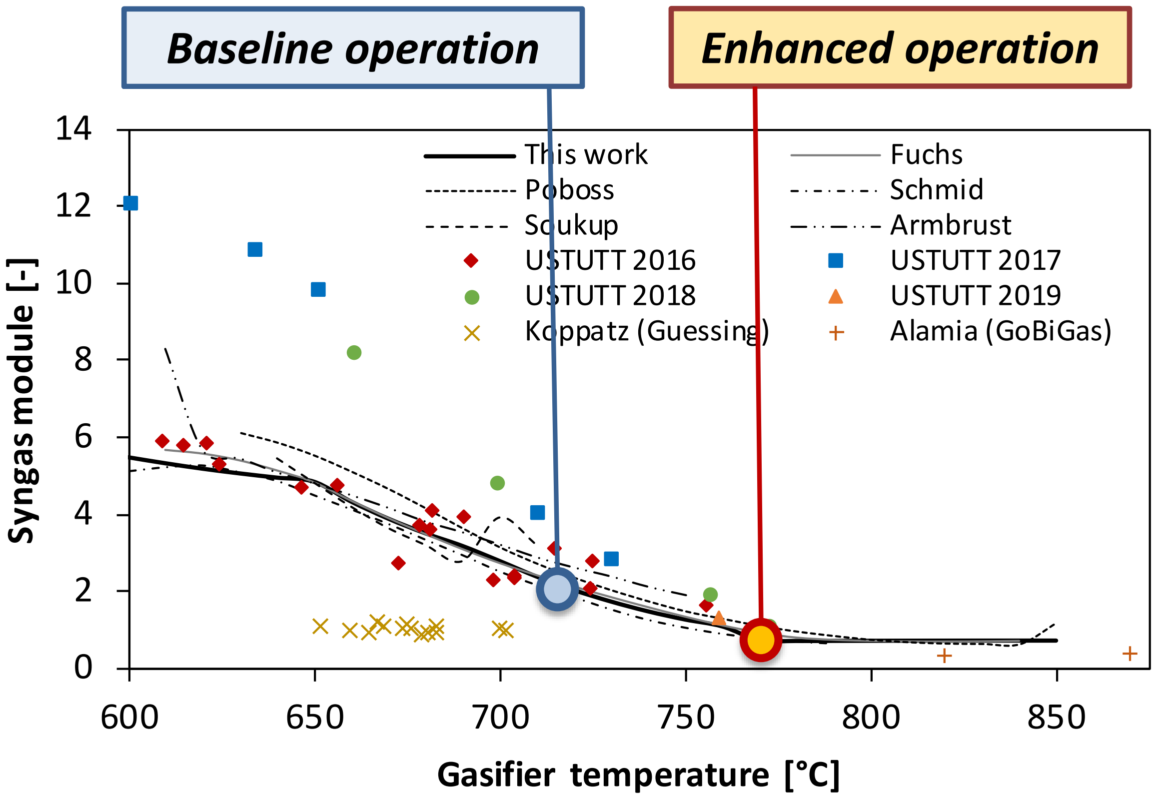
Flexible Power & Biomass to MeOH plant



FLEXIBLE POWER & BIOMASS TO MEOH PLANT

Flexibly operated <u>sorption-enhanced gasifier</u>:

increased solids circulation → increased gasification temperature → lower CO_2 uptake by CaO sorbent → lower M



Poluzzi et al., 2022. *Flexible Power & Biomass-to-Methanol plants: design optimization and economic viability of the electrolysis integration*. Fuel, 310, 122113.

PERFORMANCE

- Two reactor design assessed (i. Enhanced reactor design: 7580 tubes, ii. Baseline reactor design: 4700 tubes) in the two operating modes
- Biomass input: 100 MW_{LHV}

	Enhanced reactor design		Baseline reactor design	
	Baseline operation	Enhanced operation	Baseline operation	Enhanced operation
Carbon efficiency (CE), %	40.3	64.4	39.3	59.7
Methanol output, MW_{LHV}	62.0	99.0 (+60%)	60.4	91.8 (+52%)
Net electric power output, MW_{el}	-2.9	-67.2	2.0	-58.0
Power-to-MeOH efficiency (η_{P2F}),%	-	57.5	-	52.3%

- ➢ Much higher carbon efficiency in "enhanced operation" (+50-60%).
- ➢ Enhanced reactor design achieves significantly higher performance (especially in enhanced operation), with higher capital costs.

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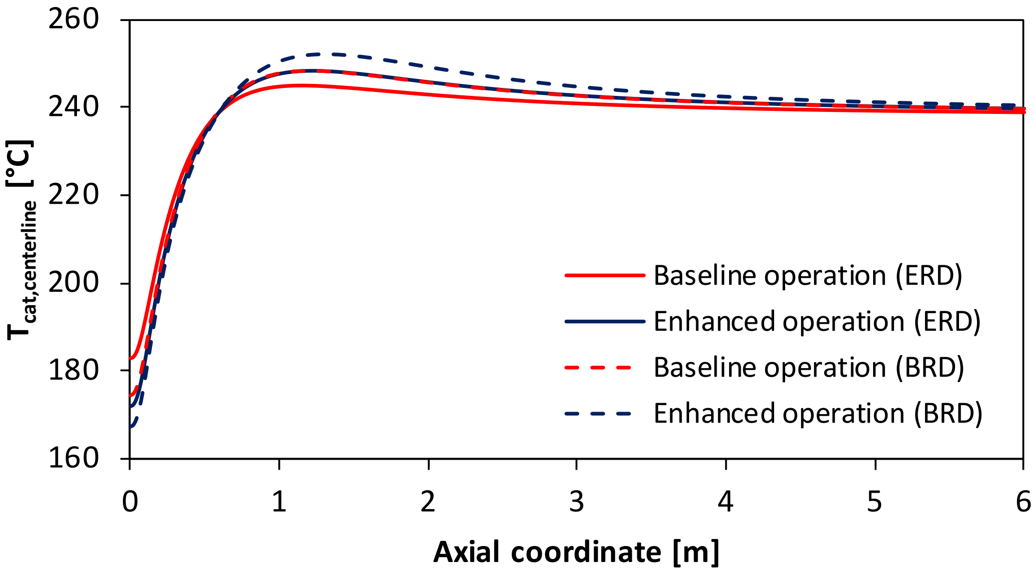
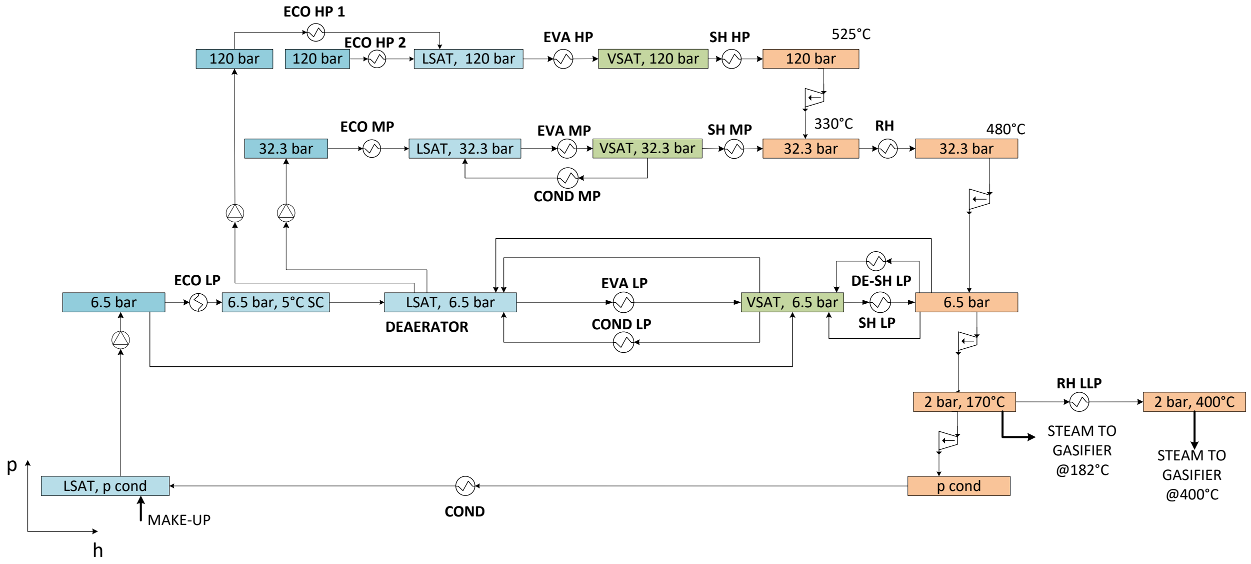
Technical feasibility and optimization

MeOH synthesis unit can be designed and operated avoiding hot spots in the reactor working with different feed flow rates.



Multi-period economic optimization of the heat recovery steam cycle parameters.



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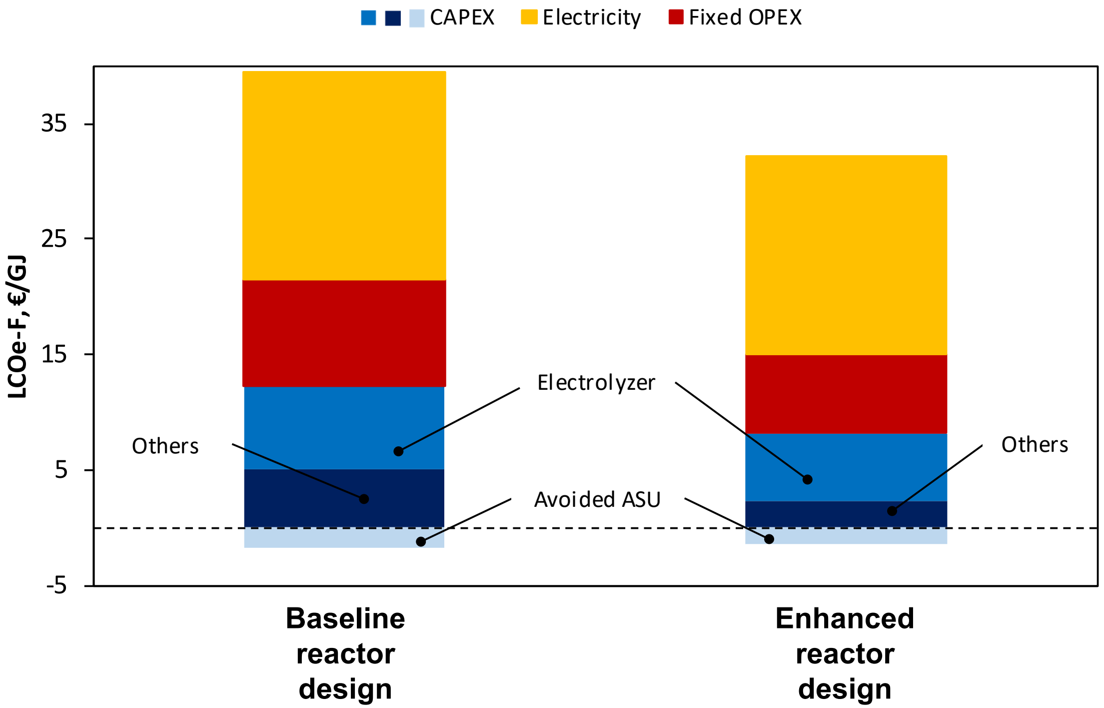
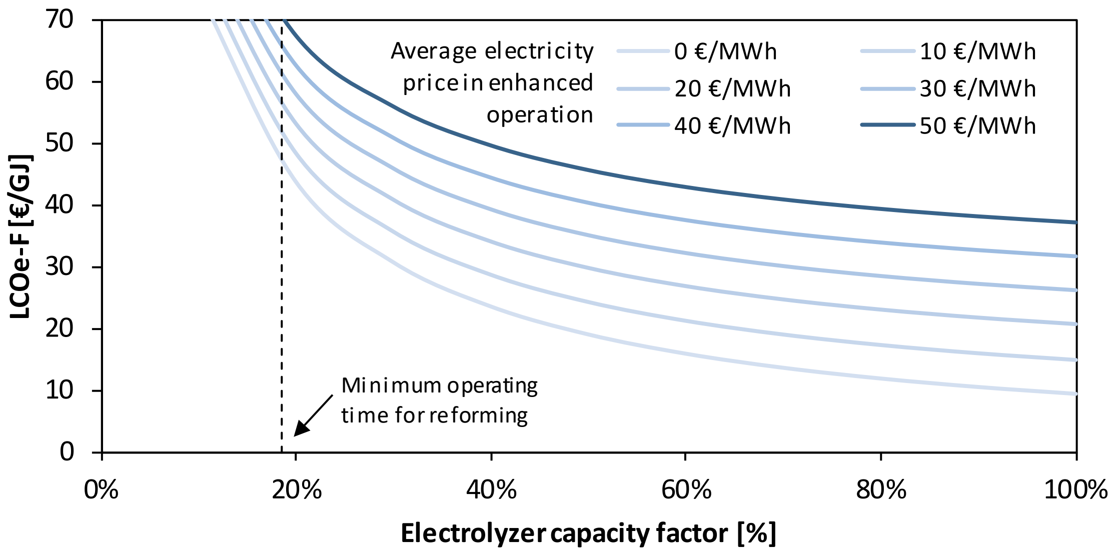
ECONOMIC ANALYSIS

- Calculation of the cost of the e-fuel (i.e. marginal cost of the additional MeOH produced)
- Key assumptions:
  - Electrolysis capacity factor: 80%
  - Average electricity price (from DK 2019): 34.3 €/MWh in enhanced operation, 55.3 €/MWh in baseline operation
  - Electrolysis system cost: 700 €/kWe





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Flexible Power & Biomass to MeOH plant

Coupling with the electricity price curve:

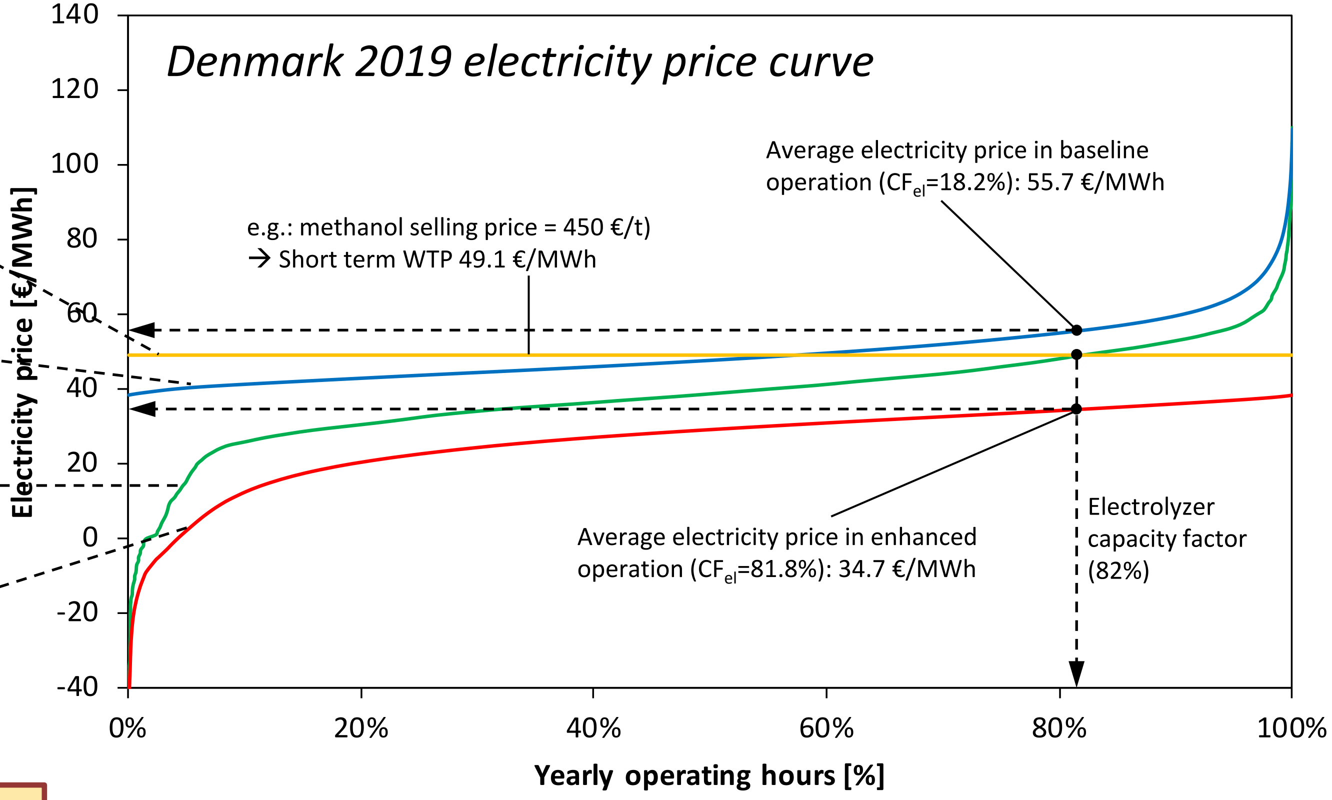
Short- and long-term "willingness to pay" approach (van Leeuwen & Mulder, 2018)

Short term willingness to pay: Breakeven OPEX

Descending average electricity price

Cumulative electricity price

Ascending average electricity price



The number of electrolysis operating hours depends on the "willingness to pay": electricity price vs. product selling price.

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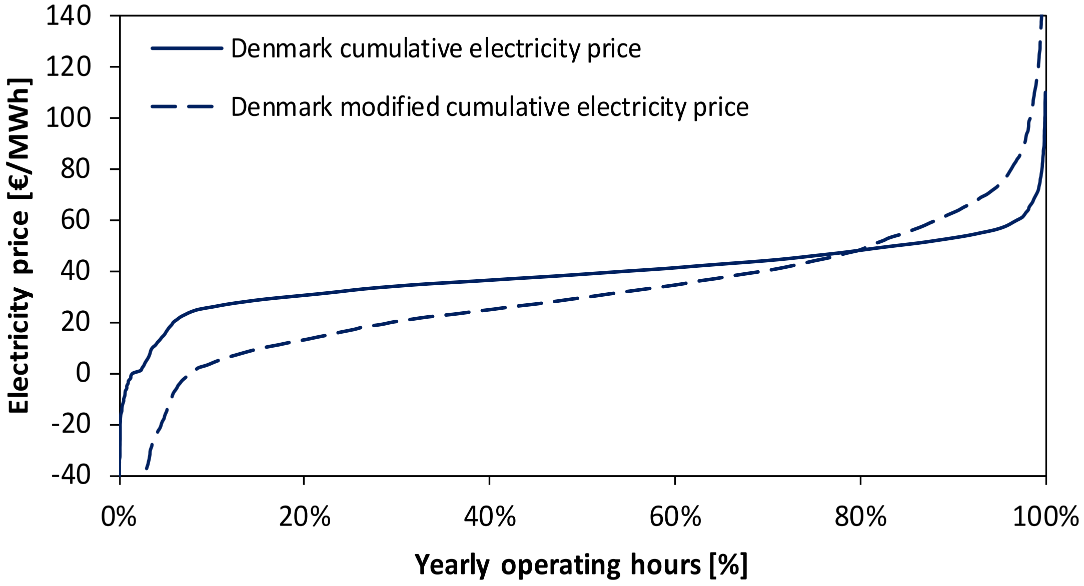
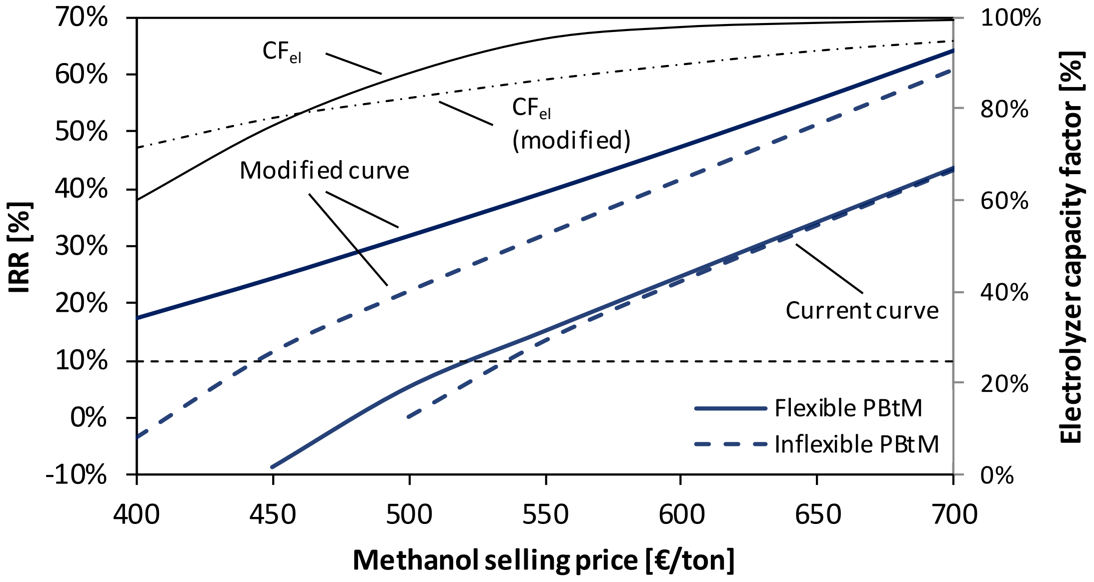
FLEXIBLE POWER & BIOMASS TO MEOH PLANT

Coupling with the electricity price curve





- With the "current" (DK, 2019) electricity price curve, the economic benefits deriving from a flexible plant are relatively small.
- Flexible plants become competitive in energy systems with low average electricity prices, but non-negligible periods of high electricity price.

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Key takeaways

- Due to the high cost of hydrogen from electrolysis in comparison with the cost of oversizing the MeOH synthesis unit, enhanced reactor design is to be preferred.

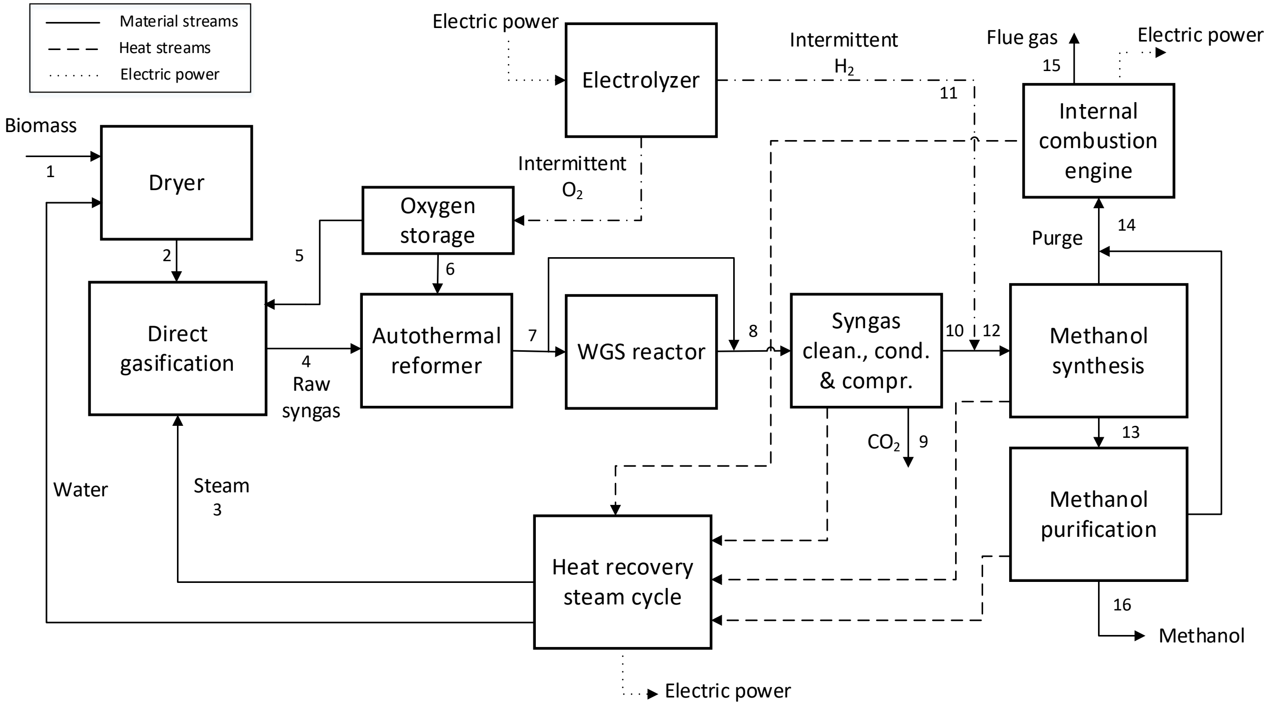
- Competitive cost of the produced e-MeOH can only be achieved with high electrolyzer capacity factors → change of common paradigm:
  - ~~*e-fuel plants should use low-cost surplus electricity*~~
  - *e-fuel plants should not operate during high electricity price periods*

- A prerequisite to make PBtM plants economically competitive is that the bio-MeOH/e-MeOH selling price must be sufficiently high to determine high "willingness to pay" price for the electric energy.

Other key messages (1/2)

- Different gasification technologies need different design and different operating strategies to manage operational flexibility.

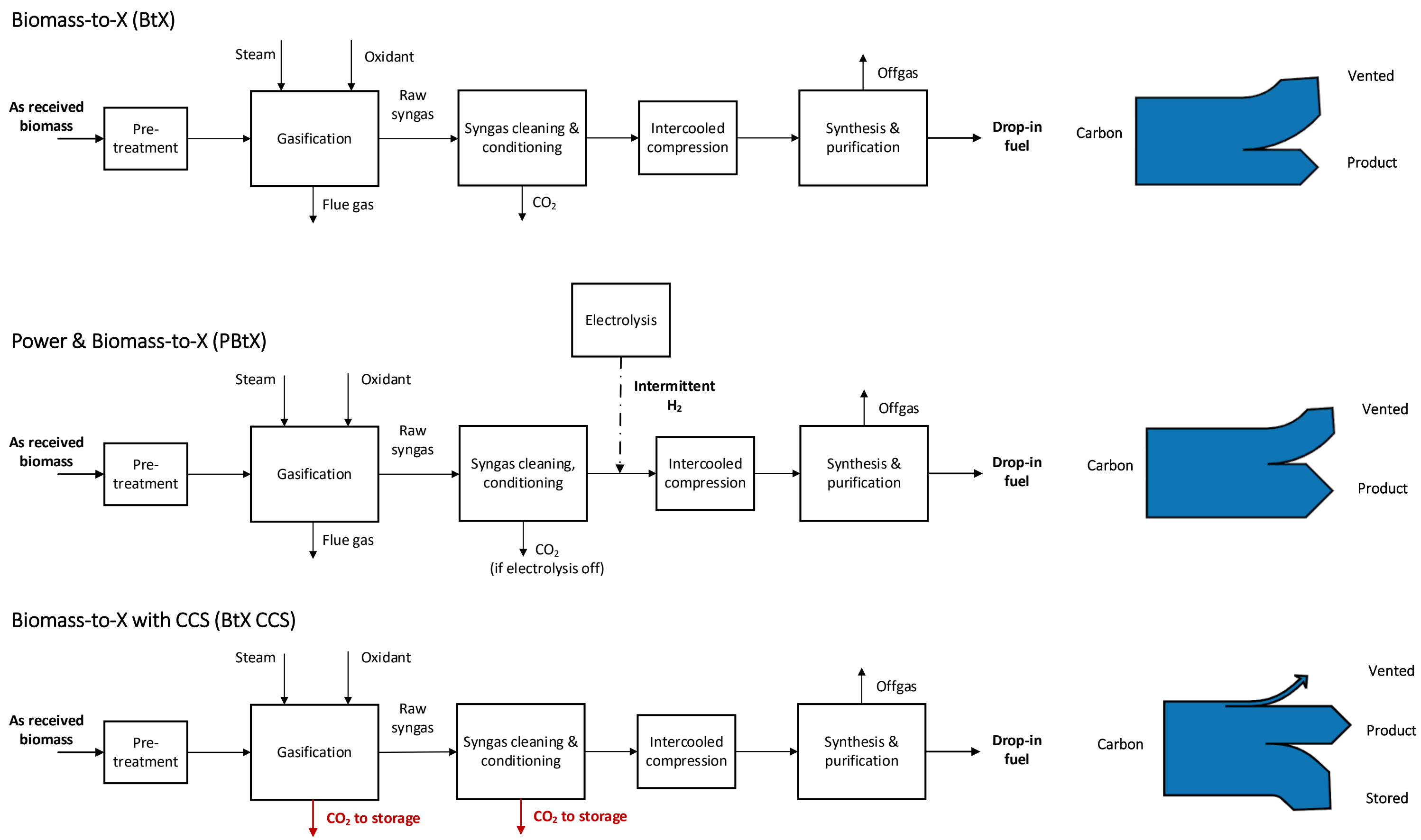
e.g.: <u>O_2-blown direct gasifier</u>: WGS and CO_2 separation (to be bypassed in enhanced operation) + MeOH purification (with MeOH recycle in baseline operation)

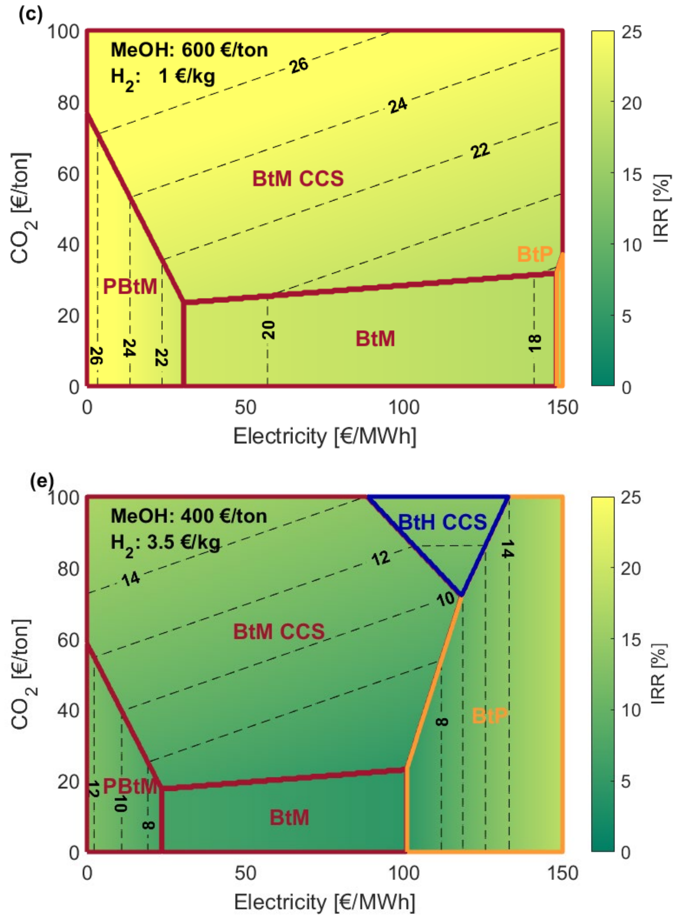


Poluzzi et al.. *Flexible Power & Biomass-to-Methanol plants with different gasification technologies*. Front. Energy Res. - Bioenergy and Biofuels. Under review.

Other key messages (2/2)

In future carbon-constrained world, the best bioenergy conversion pathway (electricity, H_2, MeOH, etc…) with/without CCS will depend on the relative value/price of the products and of CO_2, that vary over time with different time scales.





Poluzzi et al., 2021. *The Potential of Power and Biomass-to-X Systems in the Decarbonization Challenge: a Critical Review*. Current Sustainable / Renewable Energy Reports (2021).

Relevant publications

- Poluzzi A., Guandalini G., Guffanti S., Elsido C., Moioli S., Huttenhuis P., Rexwinkel G., Martelli E., Groppi G., Romano M.C., 2022. *Flexible Power & Biomass-to-Methanol plants: design optimization and economic viability of the electrolysis integration*. Fuel, 310, 122113.
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- Poluzzi A., Guandalini G., d'Amore F., Romano M.C., 2021. *The Potential of Power and Biomass-to-X Systems in the Decarbonization Challenge: a Critical Review*. Current Sustainable / Renewable Energy Reports (2021).
- Poluzzi A., Guandalini G., Romano M.C.., 2020. *Potential carbon efficiency" as a new index to track the performance of biofuels production processes*. Biomass and Bioenergy, 142, 105618.

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Thank you

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