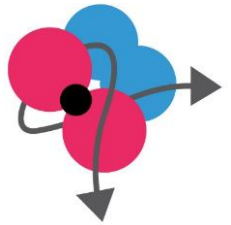
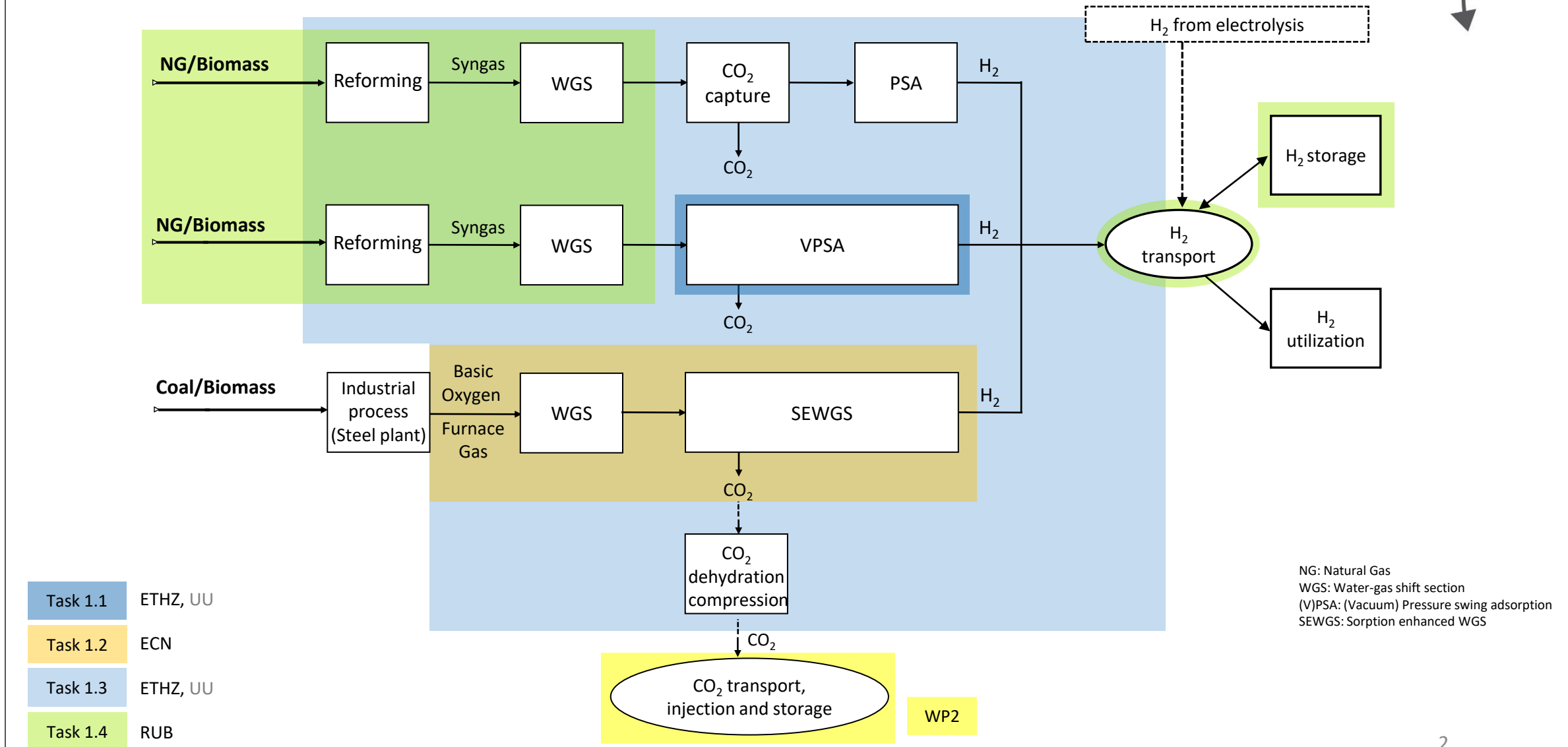


Biomass to hydrogen with CCS: can we go negative?

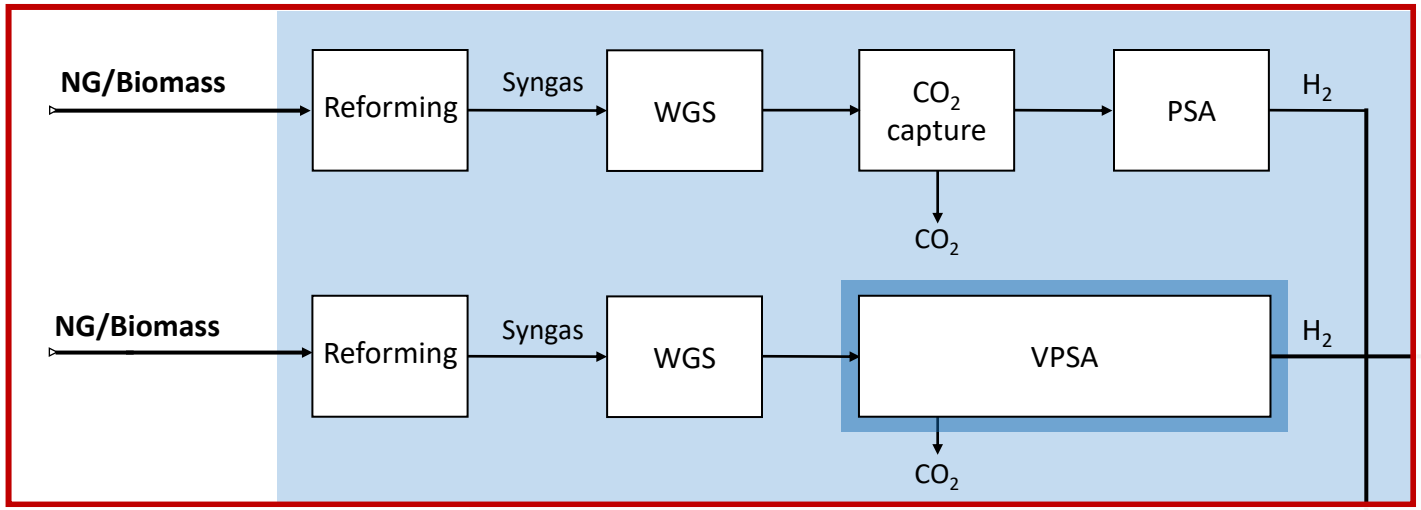
Cristina Antonini and Marco Mazzotti

2020-06-22

ELEGANCY - Overview



ELEGANCY - Low-C H_2 production



Goals:

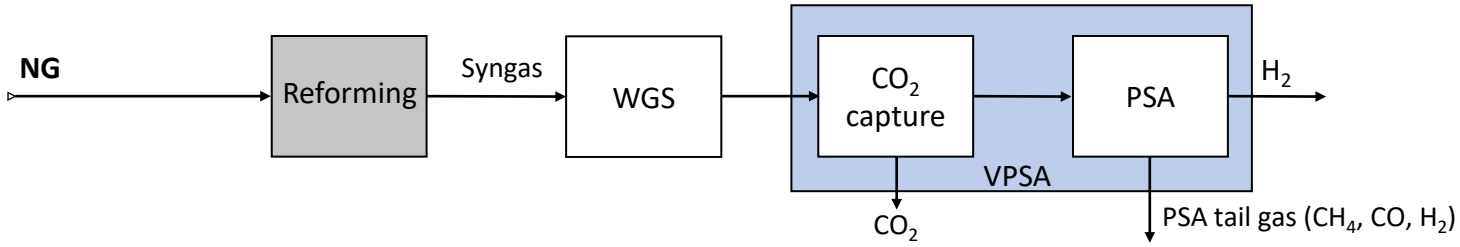
1) Study low-C hydrogen production with CO_2 capture and storage

   - starting from different feedstocks
   - using different production technologies
   - comparing benchmark with novel CO_2/H_2 separation processes

2) Investigate the possibility to deliver negative emissions

NG: Natural Gas
WGS: Water-gas shift section
(V)PSA: (Vacuum) Pressure swing adsorption
SEWGS: Sorption enhanced WGS

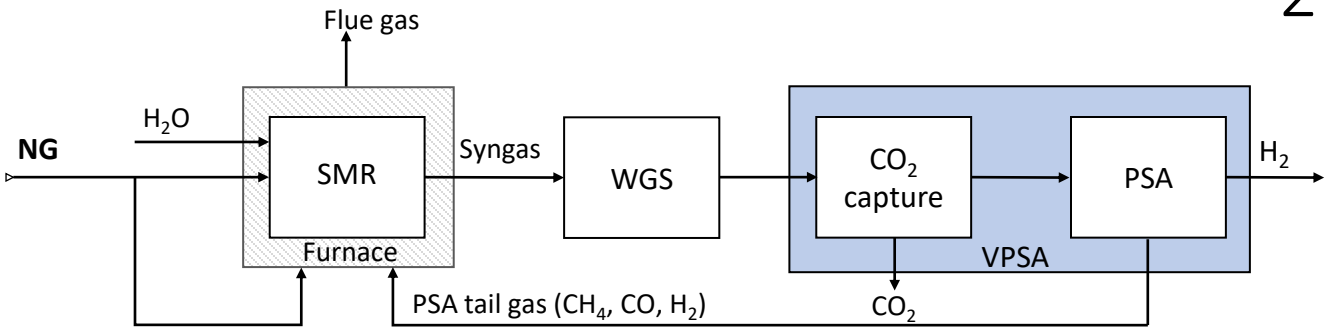
Low-C H_2 production



Feedstock	Feedstock conversion	Technology
– Natural gas (NG)	Reforming	

NG: Natural Gas
WGS: Water-gas shift section
(V)PSA: (Vacuum) Pressure swing adsorption

Low-C H_2 production



Feedstock	Feedstock conversion	Technology
– Natural gas (NG)	Reforming	• Steam methane reforming (SMR)

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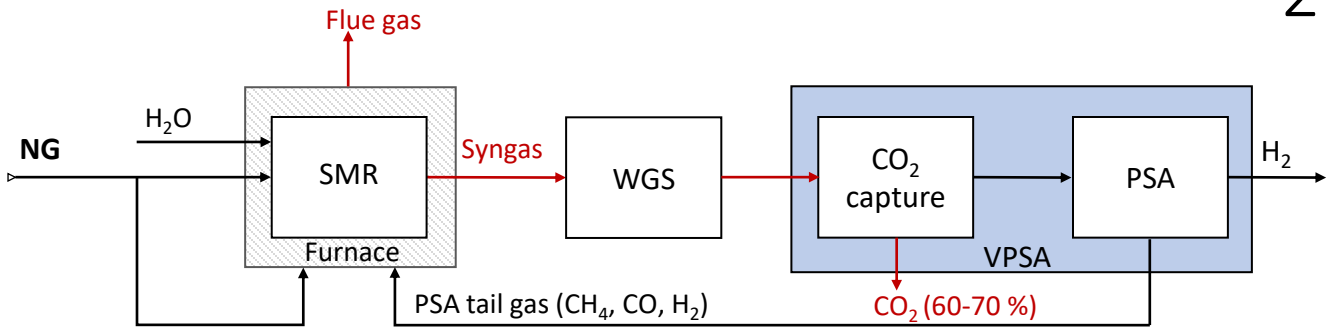
(V)PSA: (Vacuum) Pressure swing adsorption
SMR: Steam methane reforming

Low-C H_2 production



→ CO_2

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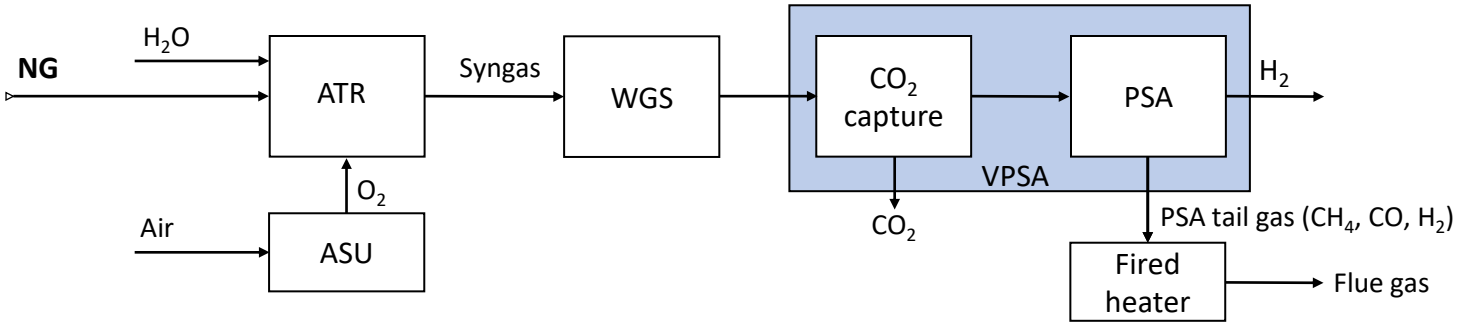
Low-C H_2 production



Feedstock	Feedstock conversion	Technology
– Natural gas (NG)	Reforming	• Steam methane reforming (SMR) • Autothermal reforming (ATR)

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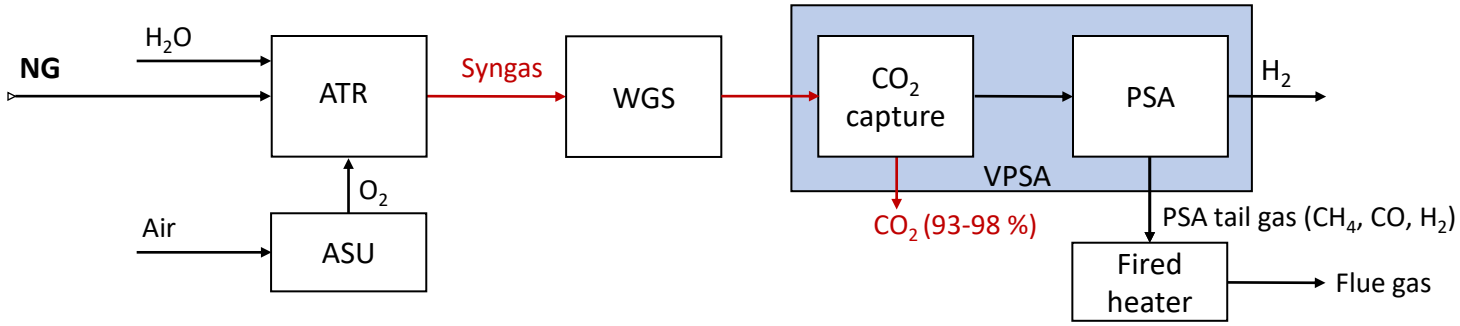
SMR: Steam methane reforming
ATR: Autothermal reforming
ASU: air separation unit

Low-C H_2 production



→ CO_2

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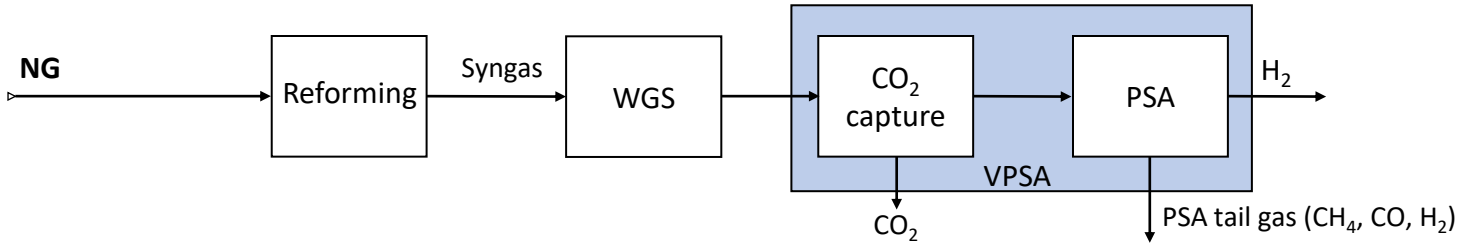

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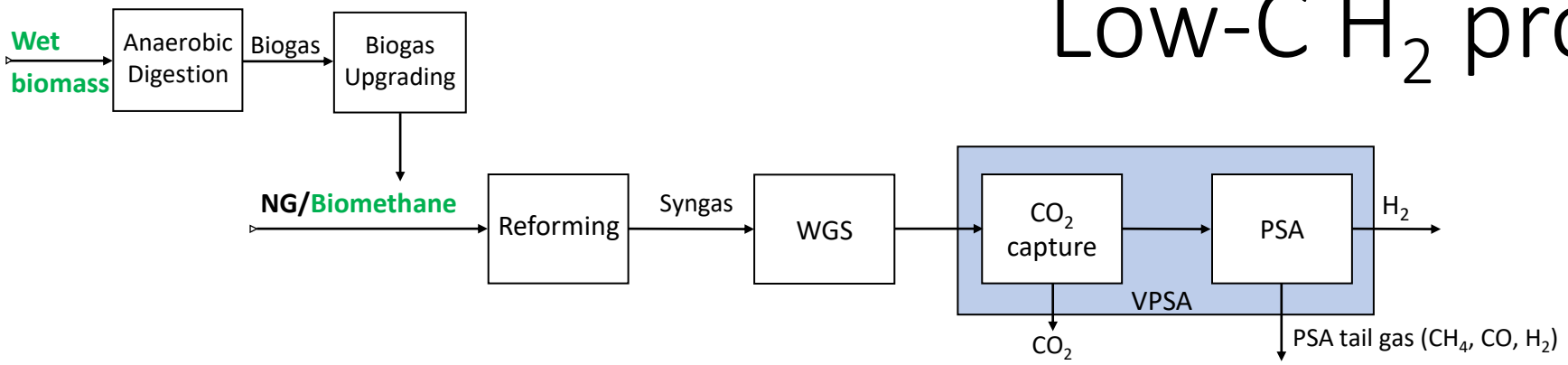

Feedstock	Feedstock conversion	Technology
– Natural gas (NG) – Biomethane from WB	Reforming	• Steam methane reforming (SMR) • Autothermal reforming (ATR)

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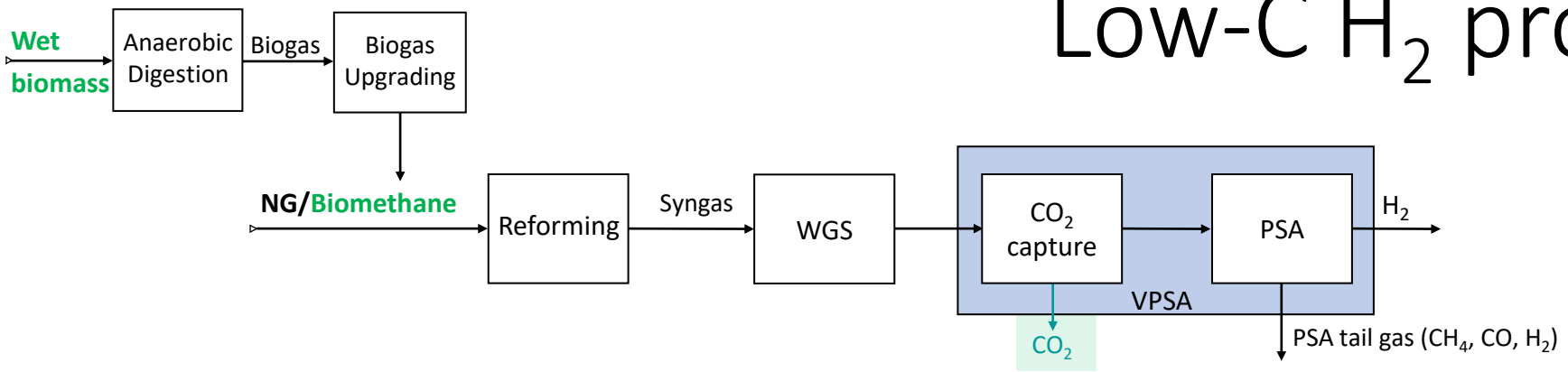
WB: Wet biomass

Low-C H_2 production



Negative emissions

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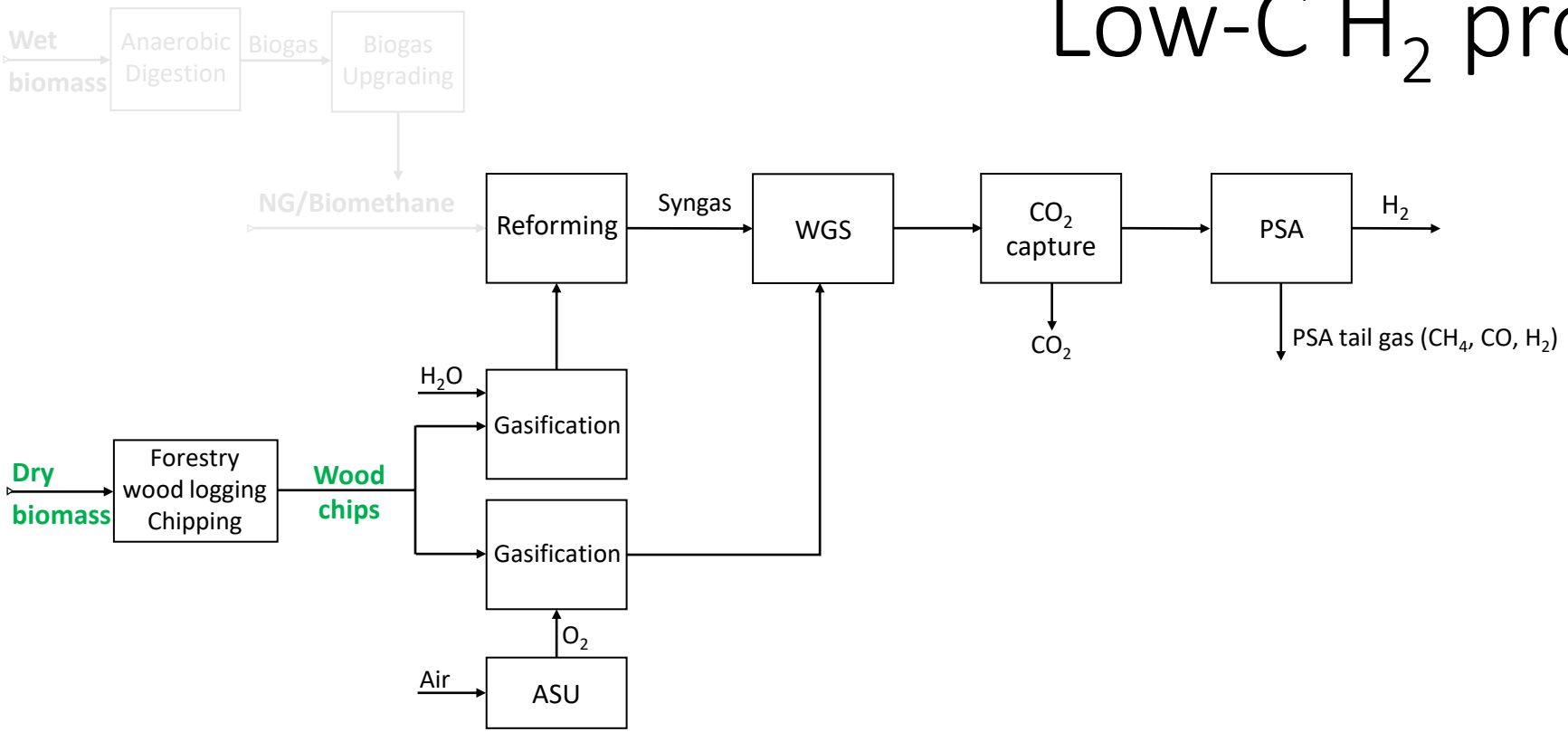

Feedstock	Feedstock conversion	Technology
– Natural gas (NG) – Biomethane from WB	Reforming	• Steam methane reforming (SMR) • Autothermal reforming (ATR)
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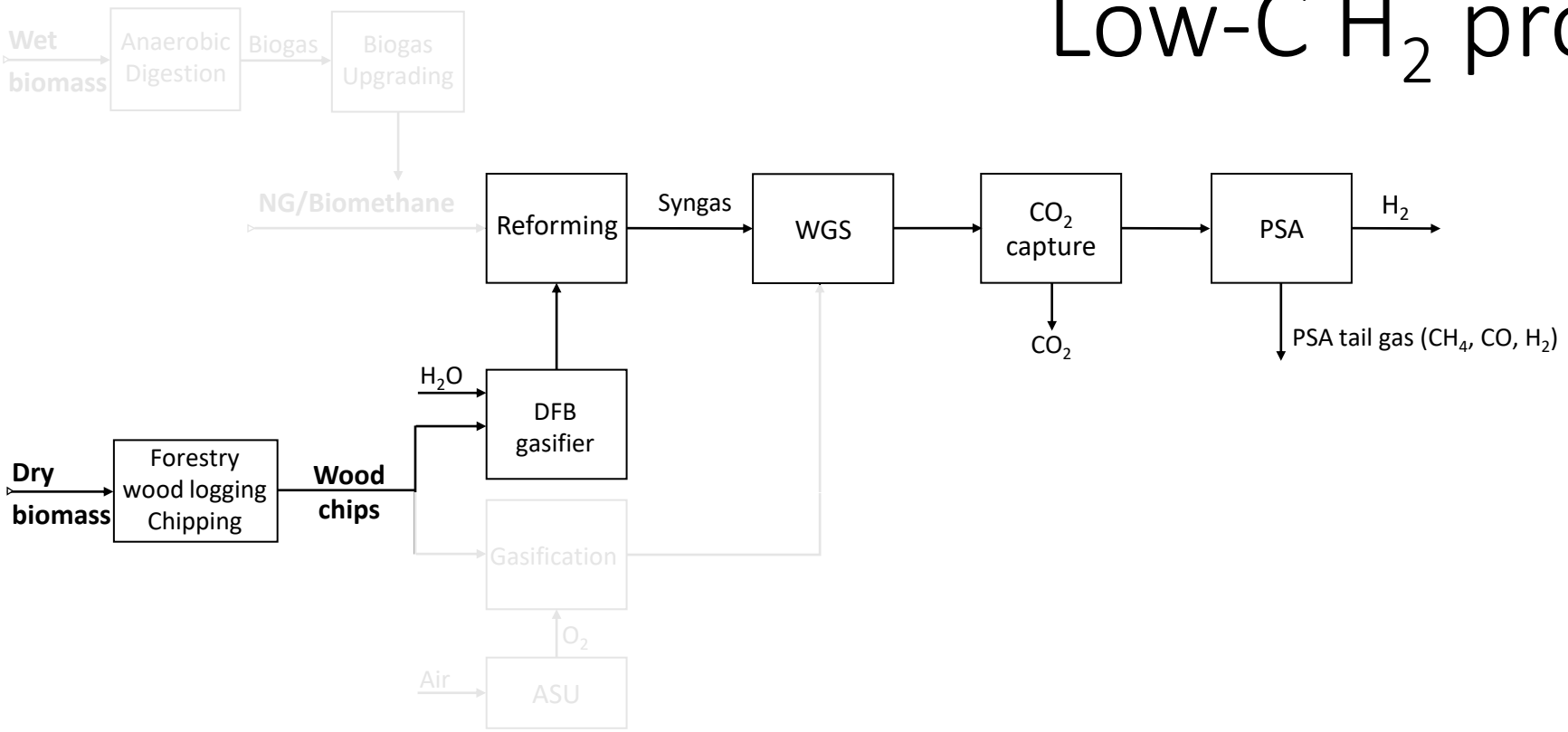

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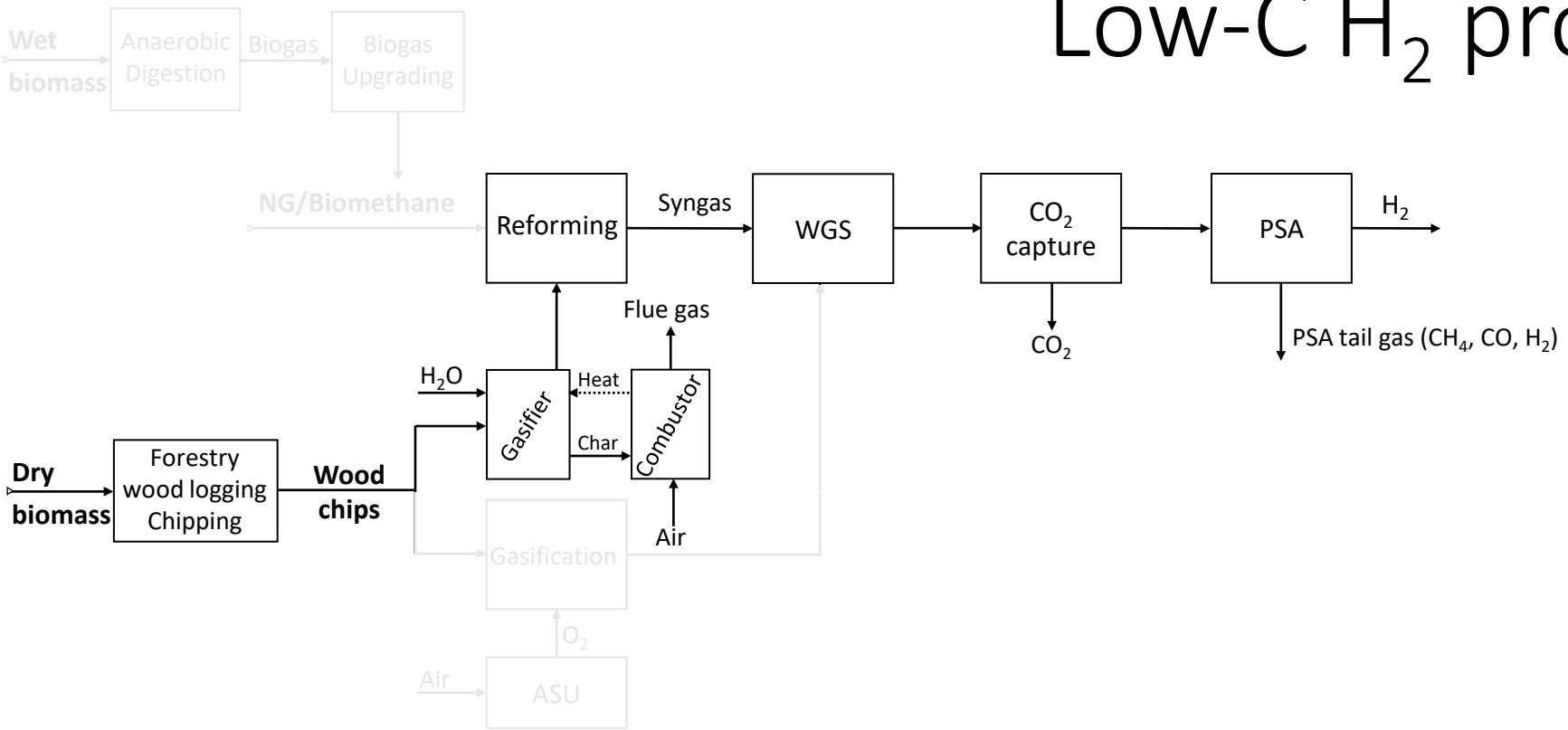
Low-C H_2 production



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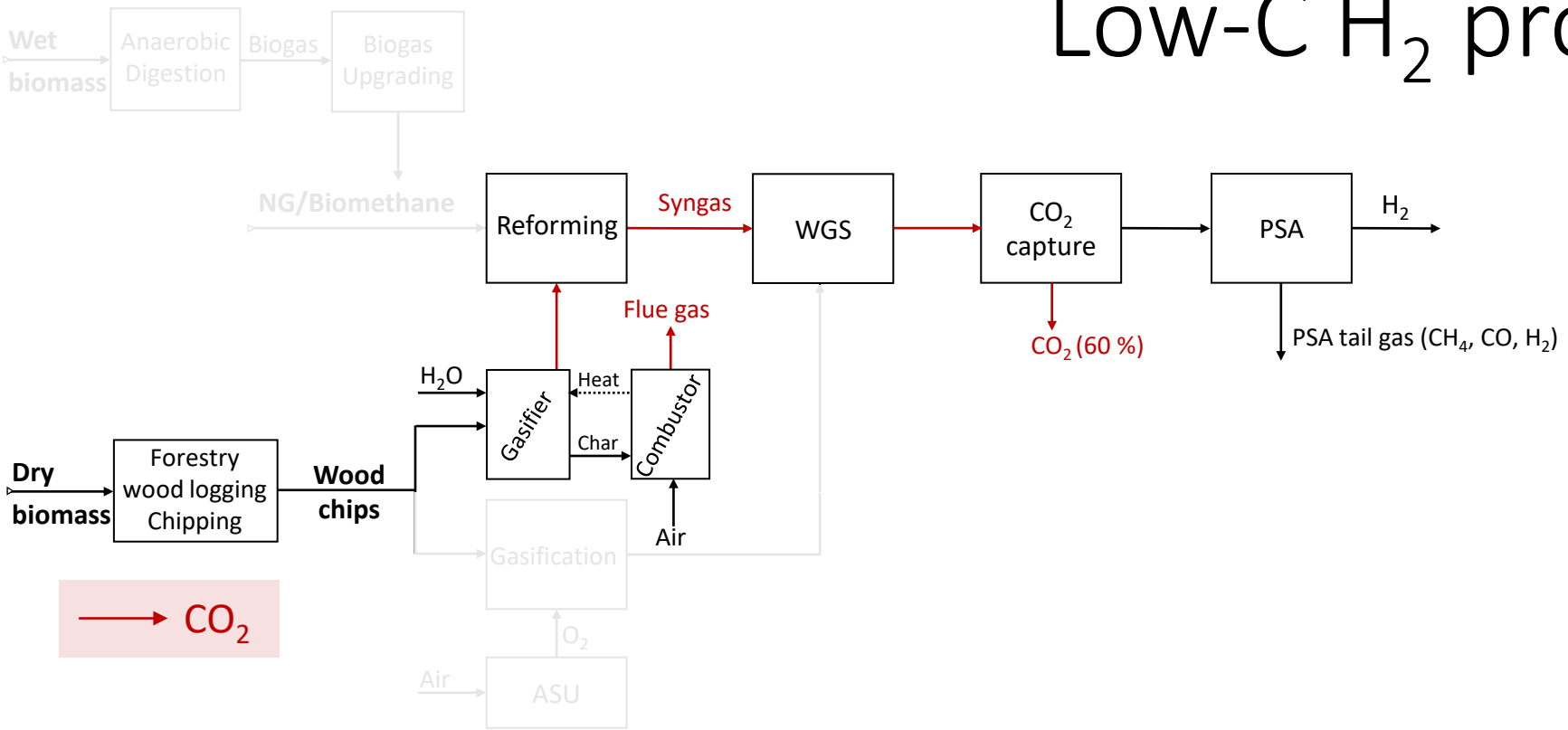

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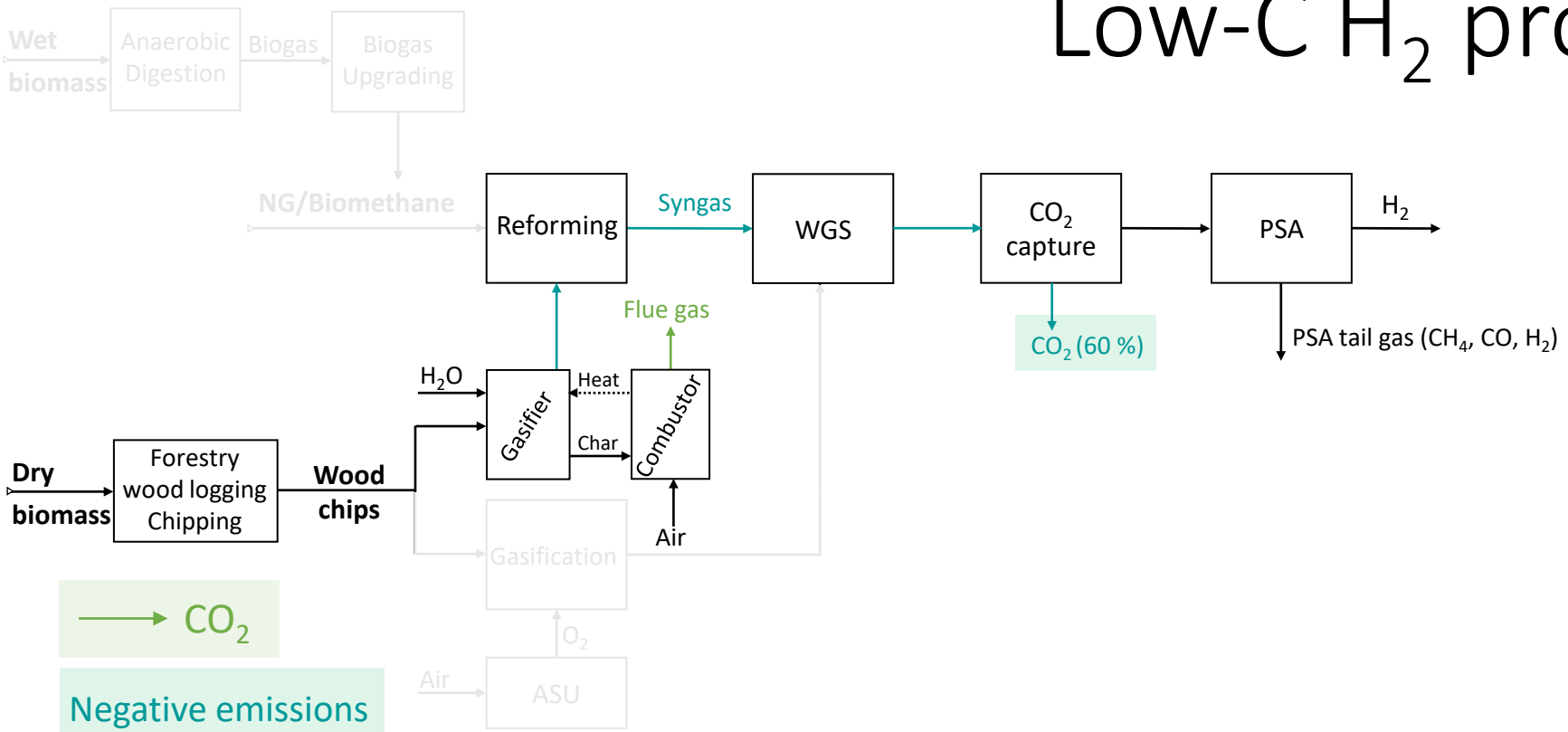

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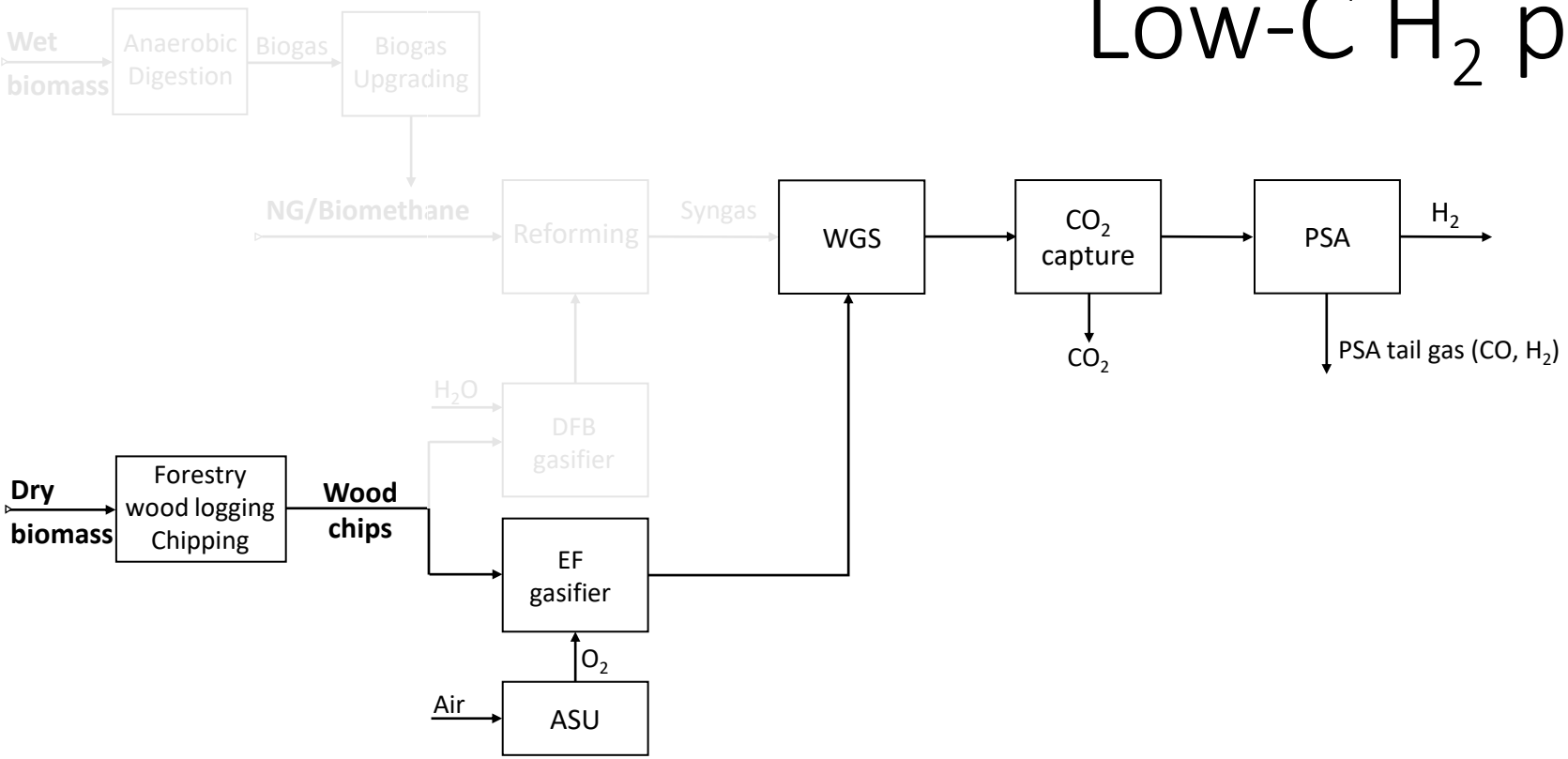

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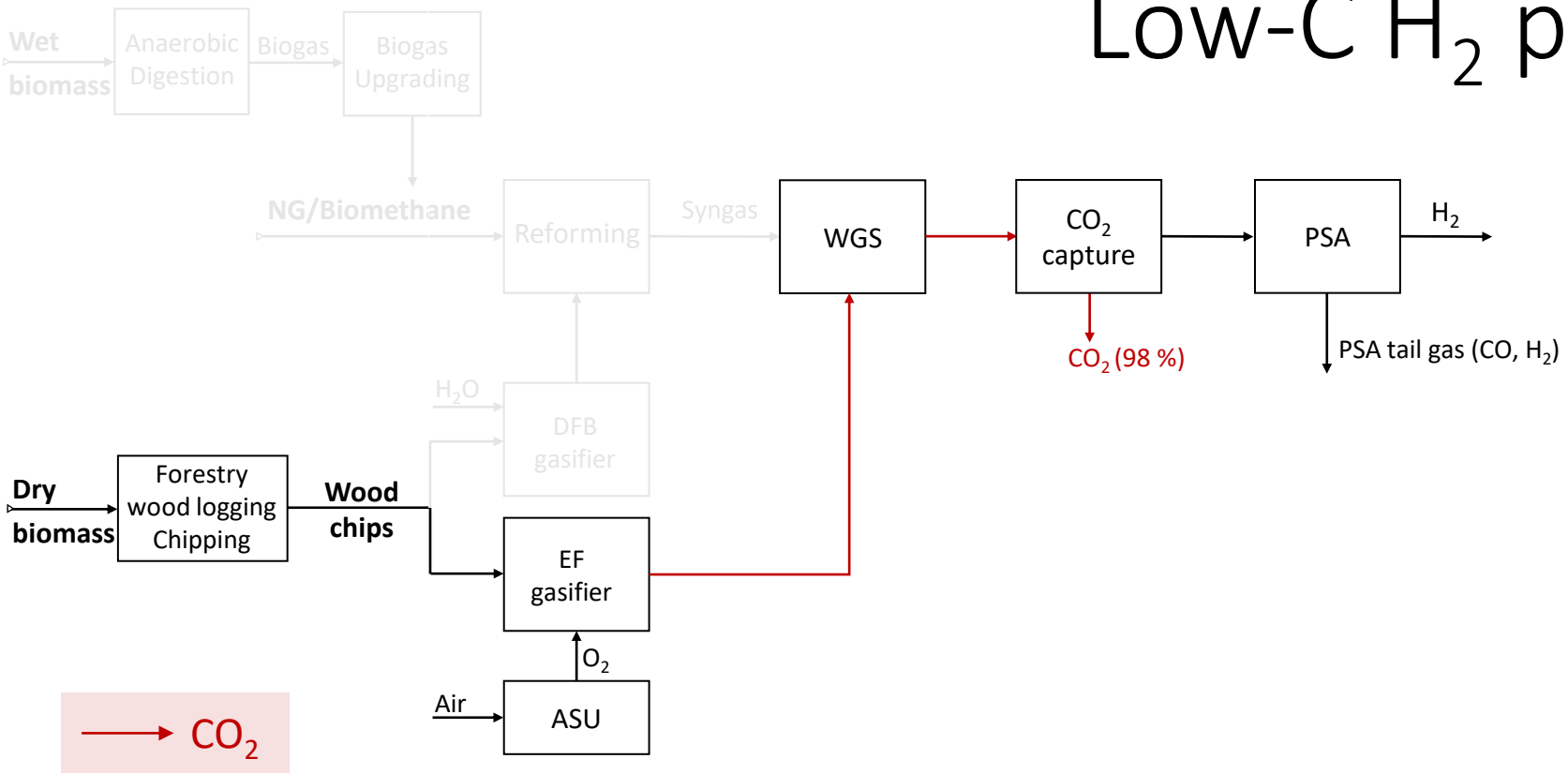

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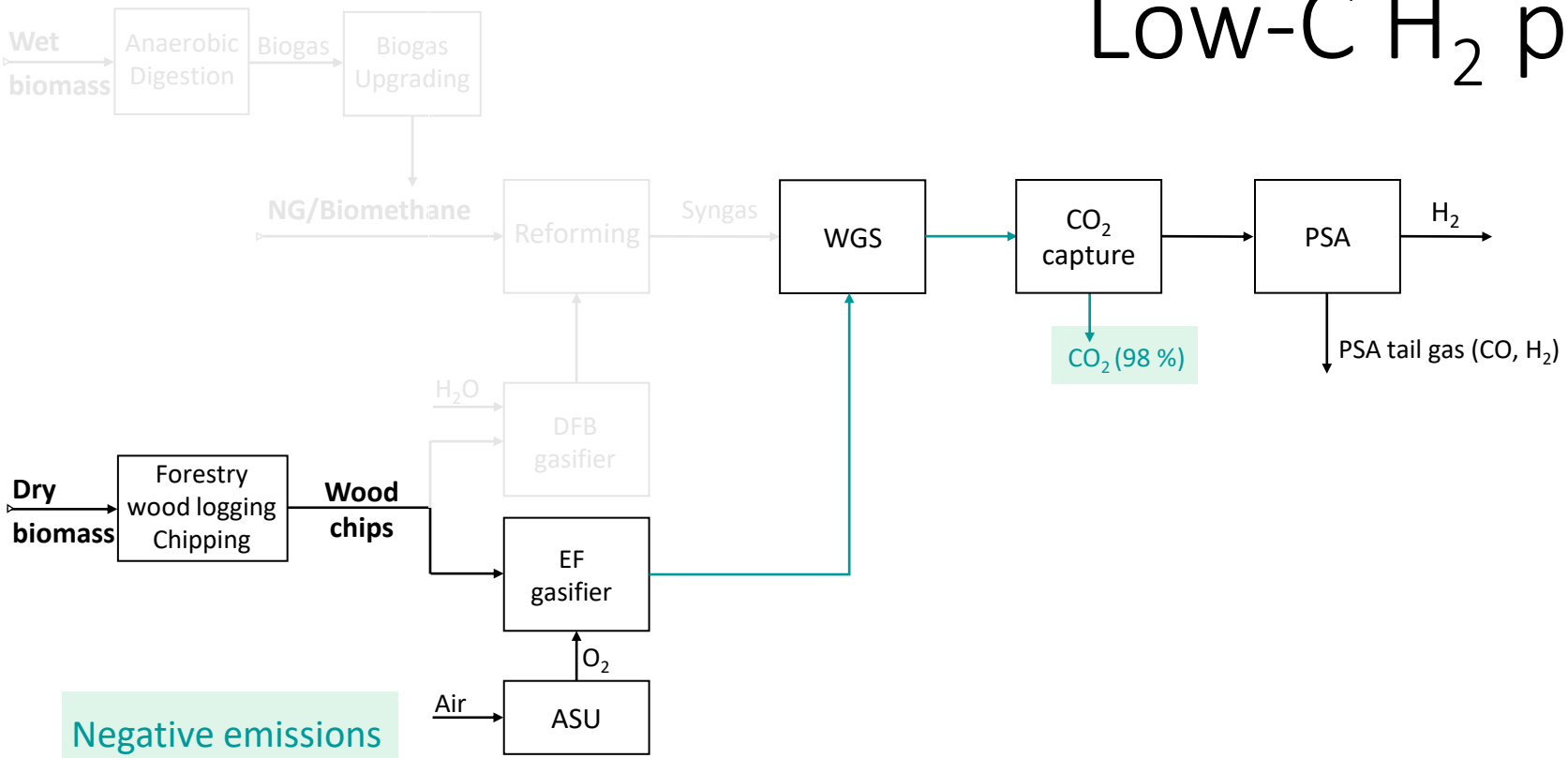

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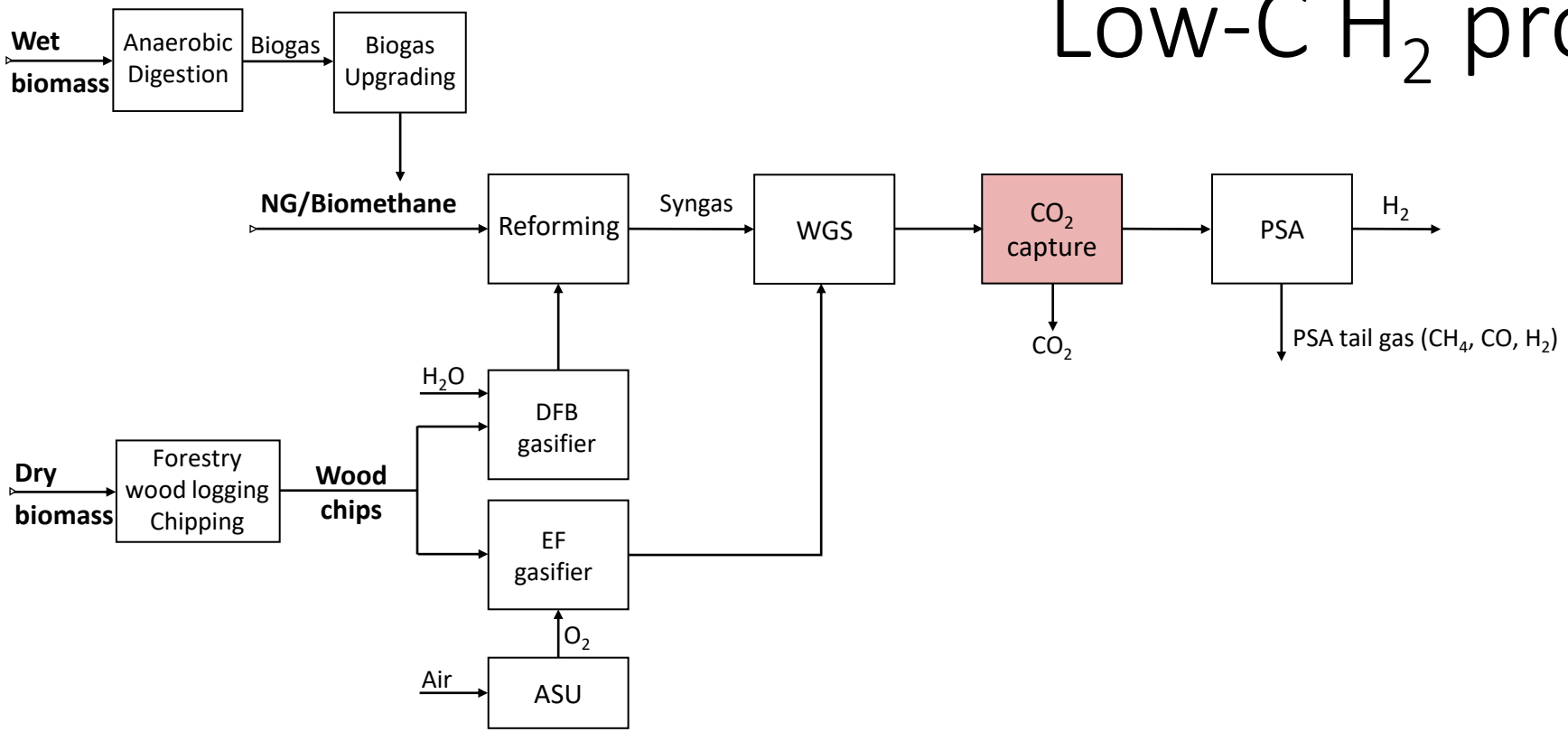

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➢ These production chains are modelled in Aspen Plus

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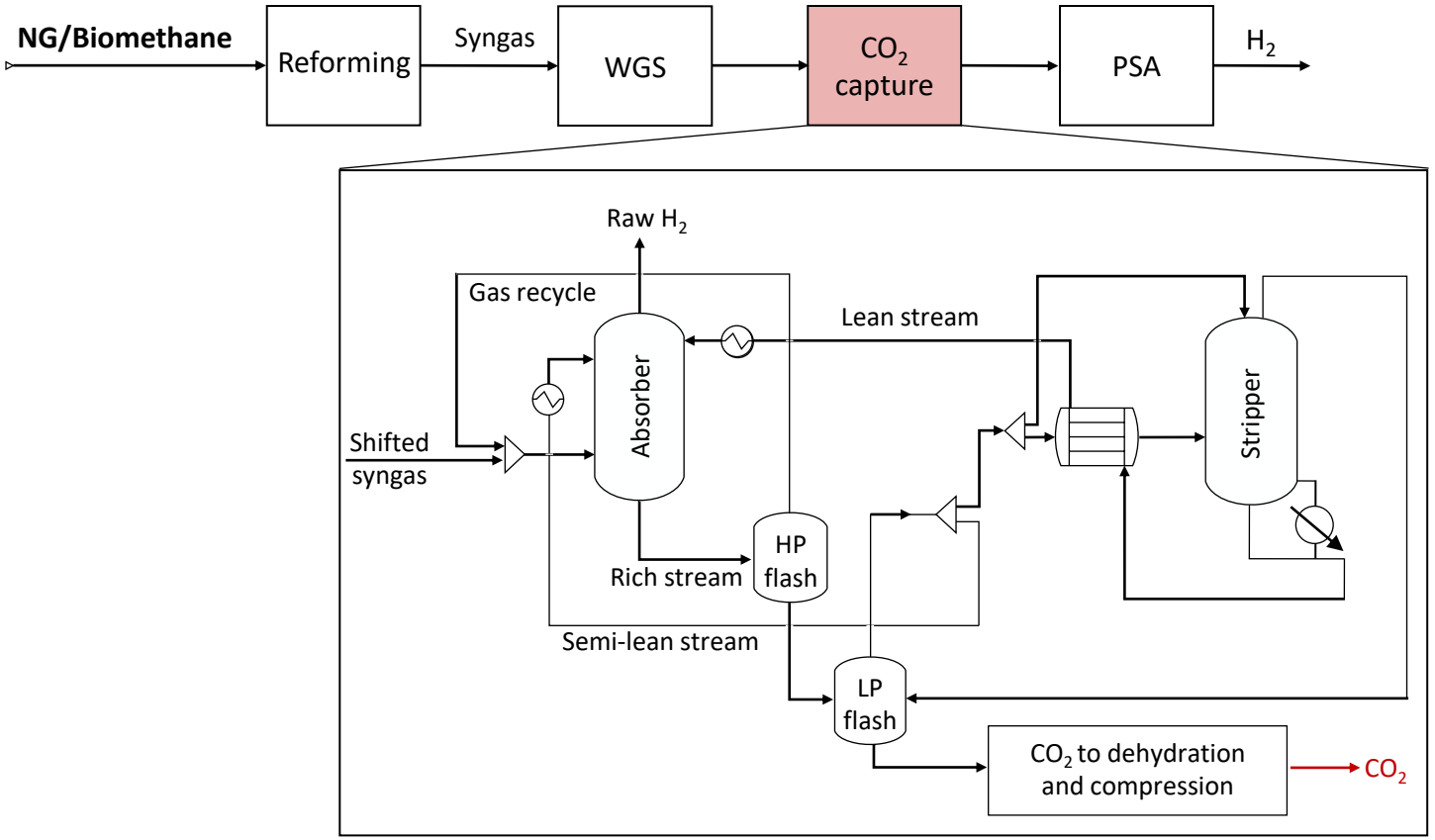
CO_2 capture - benchmark technology

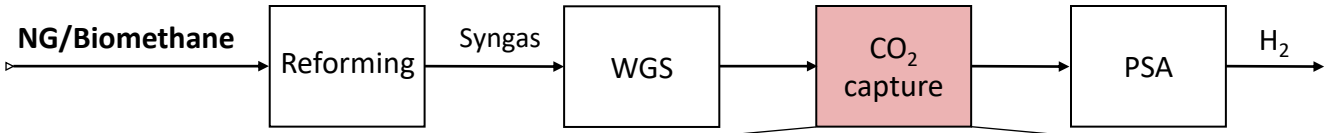


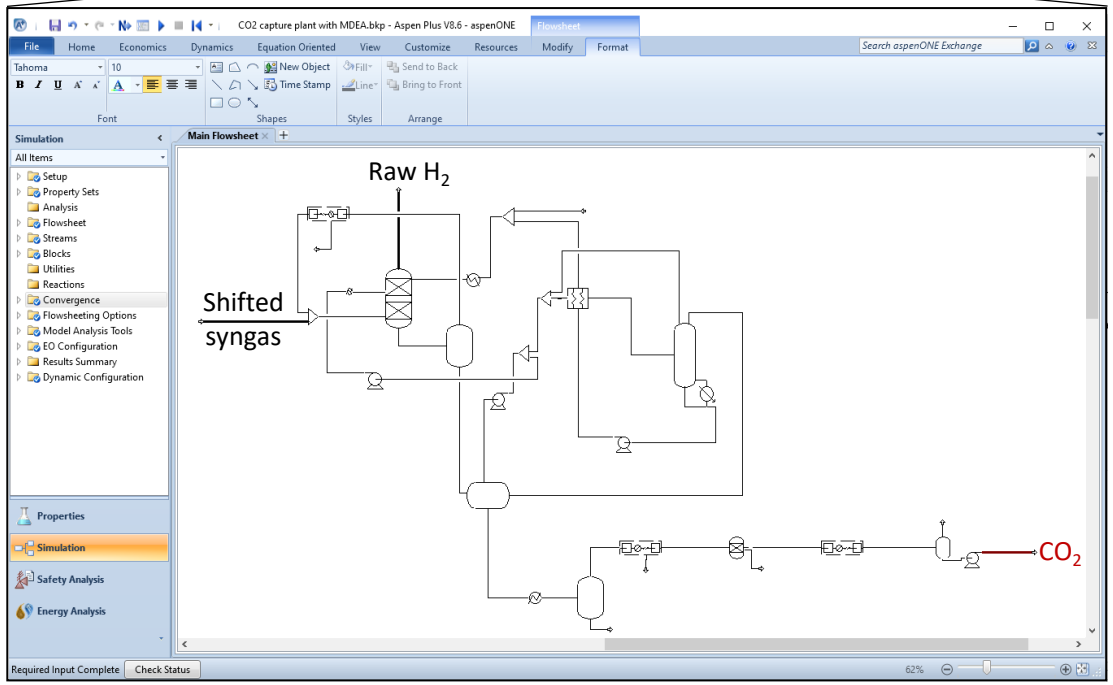
Benchmark: amine absorption

Standard solvent: Methyl diethanolamine (MDEA)

NG: Natural Gas
WGS: Water-gas shift section
(V)PSA: (Vacuum) Pressure swing adsorption
LP: Low pressure
HP: High pressure

CO_2 capture - benchmark technology





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- Detailed model in Aspen Plus

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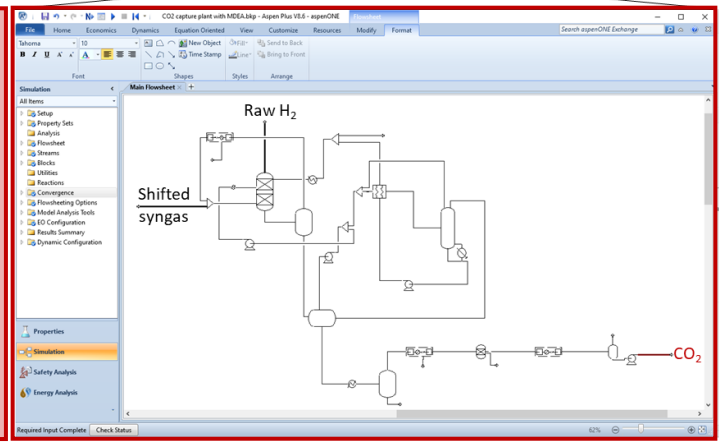
CO_2 capture technology – optimization

Process model in Aspen Plus



Goal: optimize the CO_2 capture plant for different H_2 production chains

CO_2 capture rate:

$$\psi = \frac{m_{CO_2}^{captured}}{m_{CO_2}^{in}}$$

Total specific equivalent work:

$$\omega = \frac{W_{tot}}{m_{CO_2}^{captured}} \quad [MJ/kgCO_2]$$

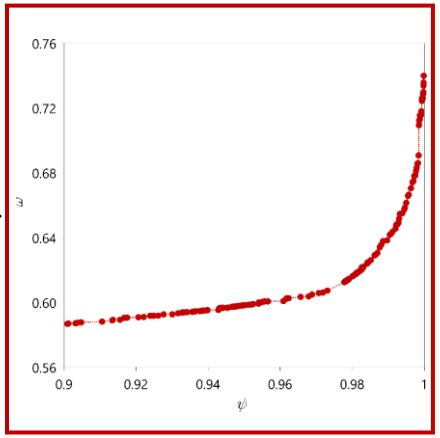
Multi-objective optimization

$$\min_{x,y} \left[\omega, \frac{1}{\psi}\right]$$

subject to

$$\boldsymbol{x}_{min} \leq \boldsymbol{x} \leq \boldsymbol{x}_{max}$$

$$\boldsymbol{y} \in \{\boldsymbol{y_1}, \boldsymbol{y_2}, \dots \boldsymbol{y_N}\}$$

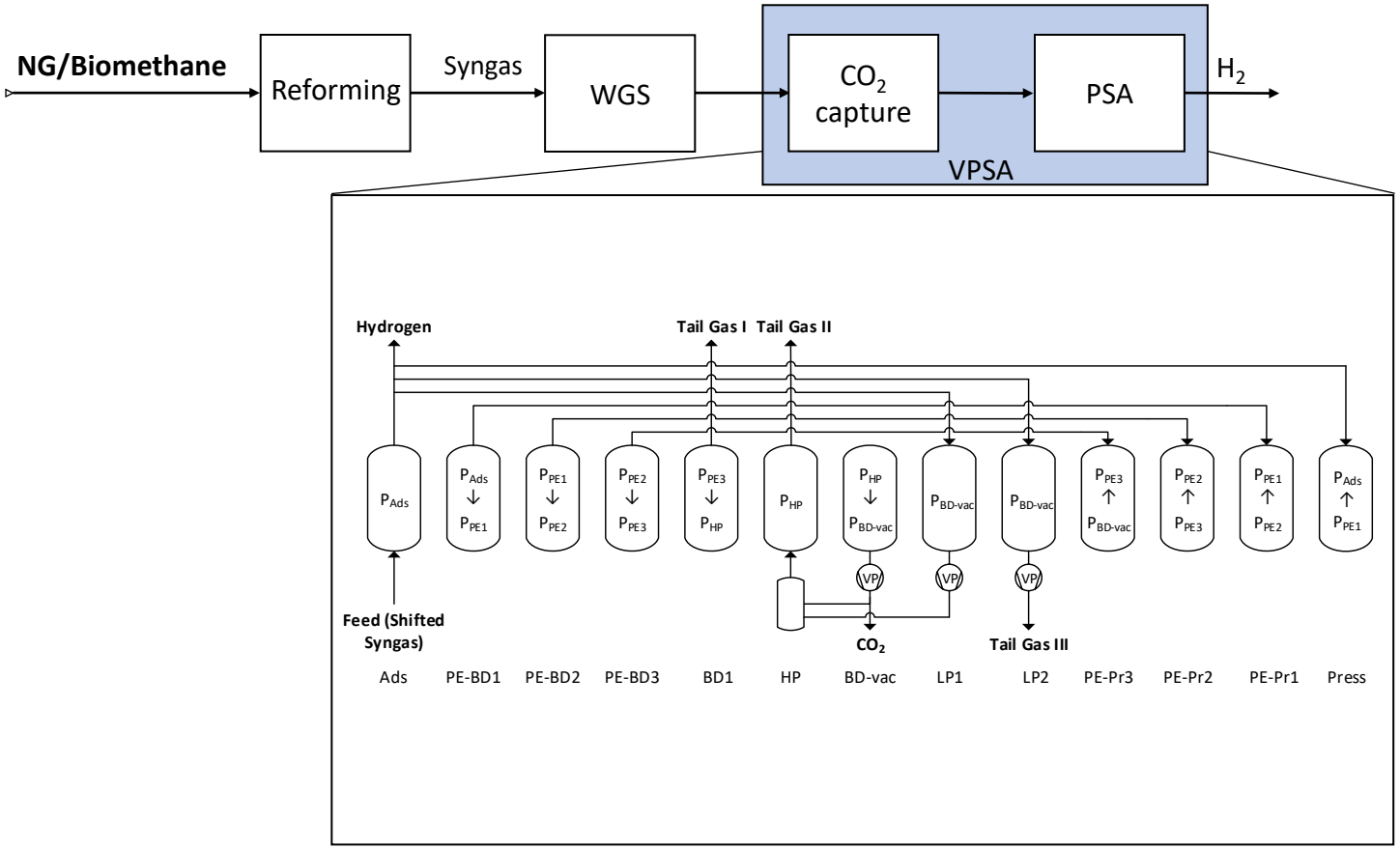


- Detailed model in Aspen Plus

1) Sensitivity analysis on the process variables
2) Select the decision variables, continuous ($\boldsymbol{x}$) and discrete ($\boldsymbol{y}$)
3) Two objective functions to optimize
   - CO_2 capture rate ψ
   - Total specific equivalent work ω
4) The optimization problem is solved using a genetic algorithm

→ Pareto Optimum

CO_2 capture - novel technology



Novel CO_2/H_2 separation technology: Vacuum pressure Swing Adsorption

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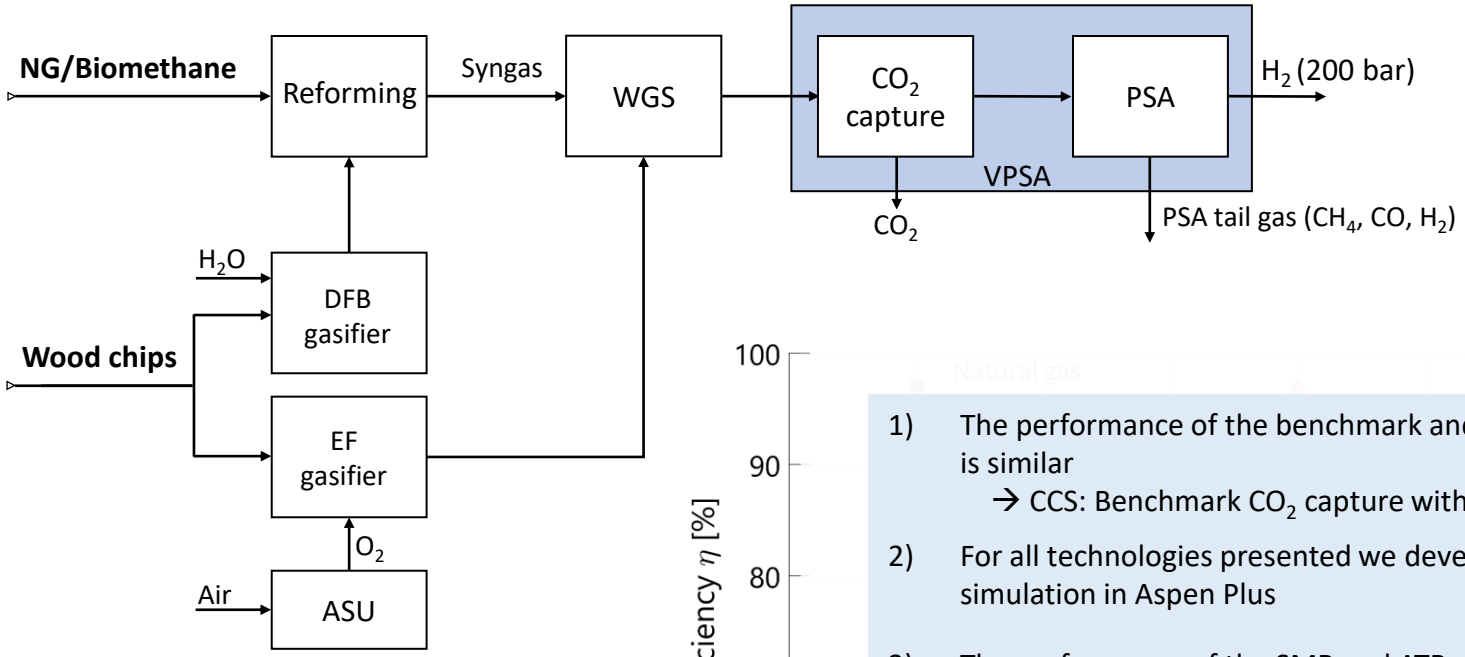
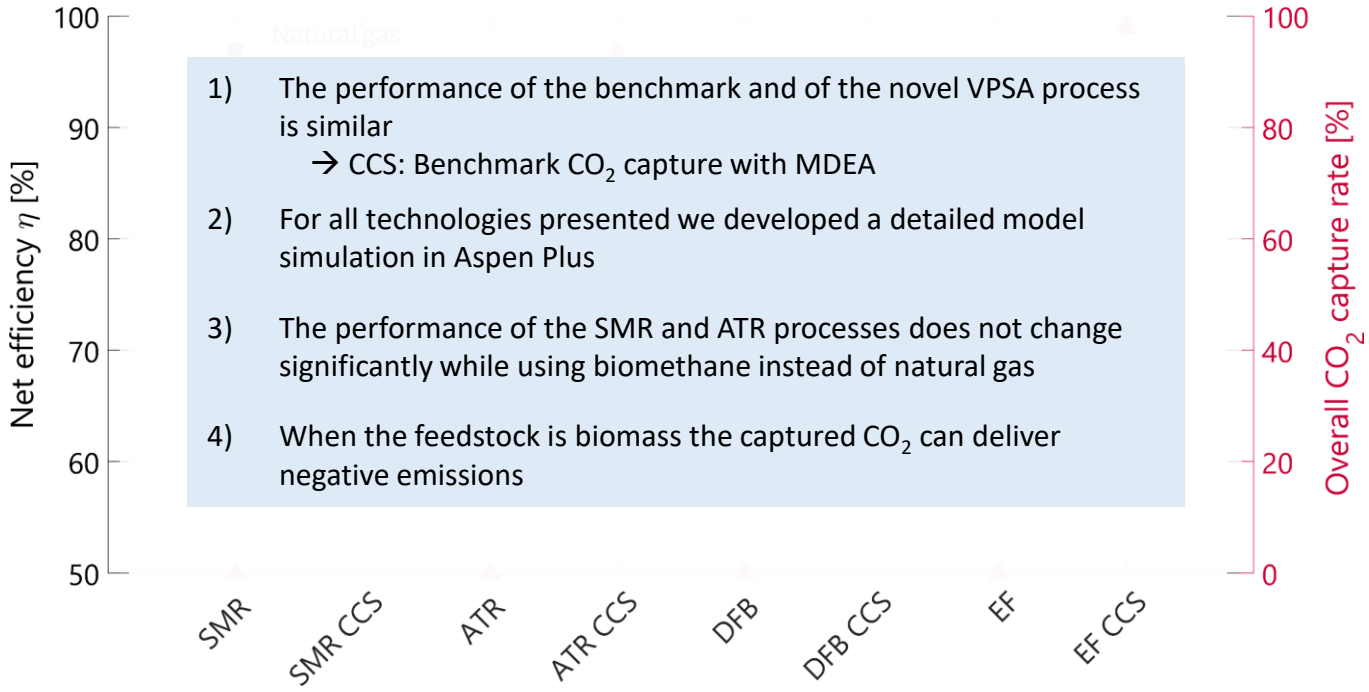
Low-C H_2 production - performance



$$\eta = \frac{E_{H_2}\,[\mathrm{MW}]}{E_{\mathrm{feedstock}}\,[\mathrm{MW}]}$$



1) The performance of the benchmark and of the novel VPSA process is similar
   → CCS: Benchmark CO_2 capture with MDEA
2) For all technologies presented we developed a detailed model simulation in Aspen Plus
3) The performance of the SMR and ATR processes does not change significantly while using biomethane instead of natural gas
4) When the feedstock is biomass the captured CO_2 can deliver negative emissions

Antonini, C., Treyer, K., Streb, A., van der Spek, M., Bauer, C., & Mazzotti, M. (2020). Hydrogen production from natural gas and biomethane with carbon capture and storage–A techno-environmental analysis. *Sustainable Energy & Fuels*.

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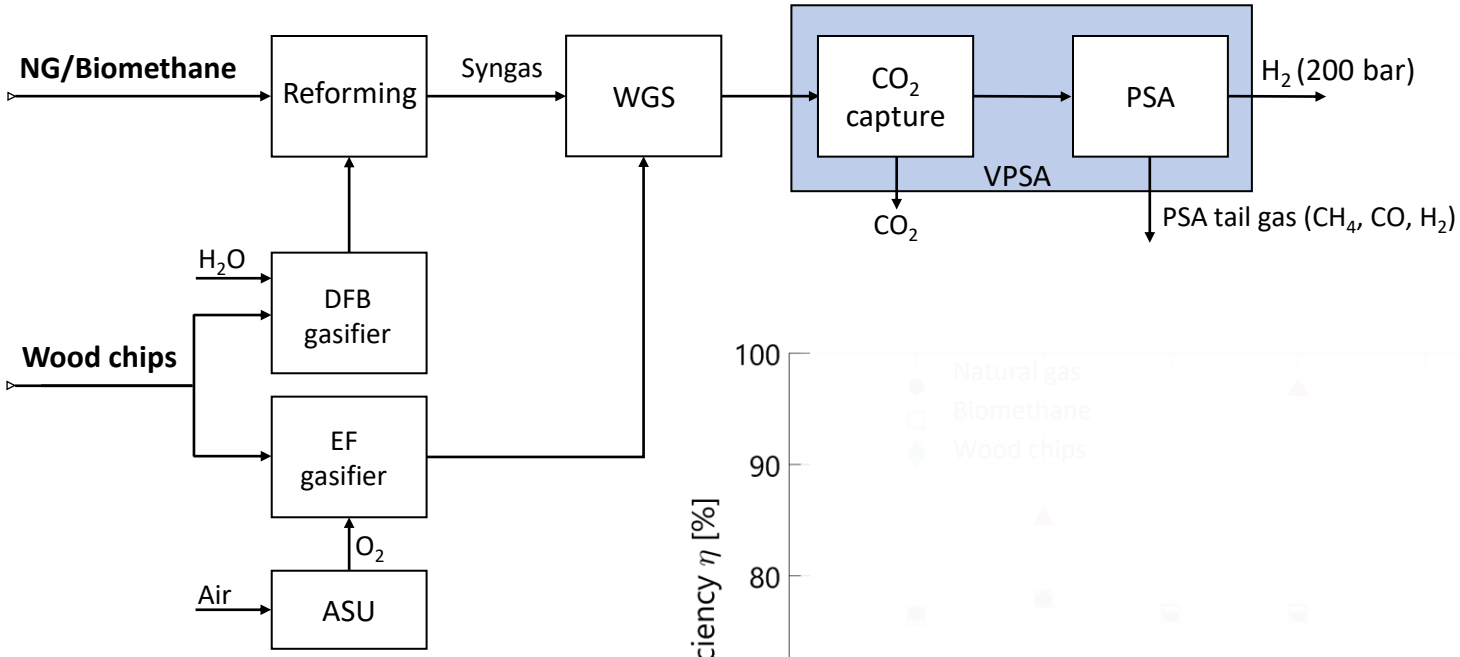
CCS: benchmark CO_2 capture with MDEA

Low-C H_2 production - performance



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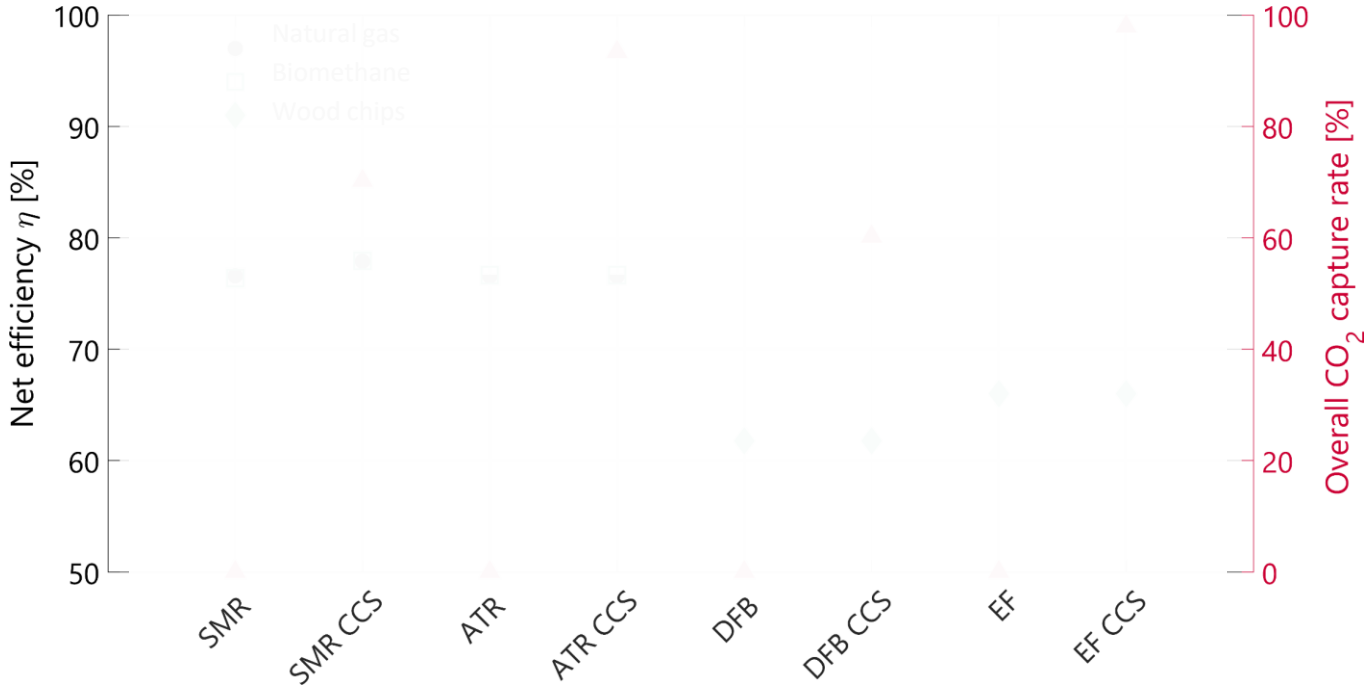

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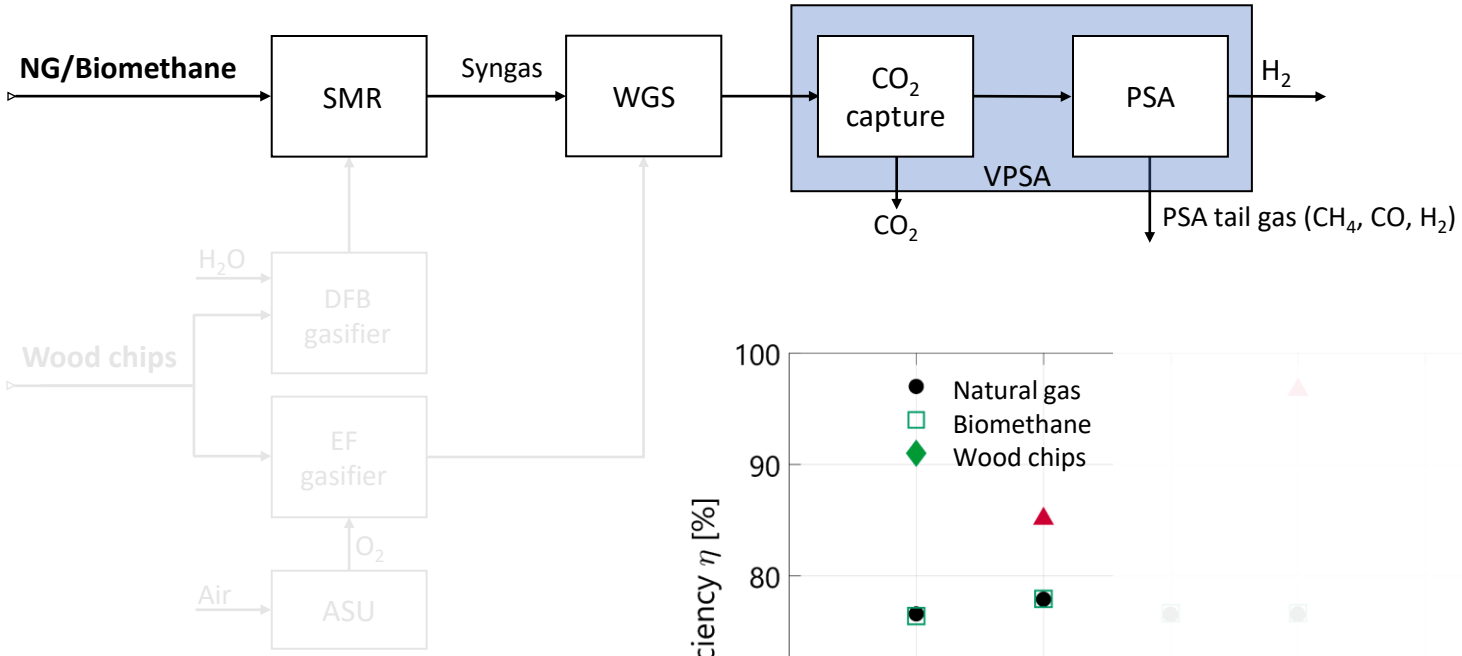

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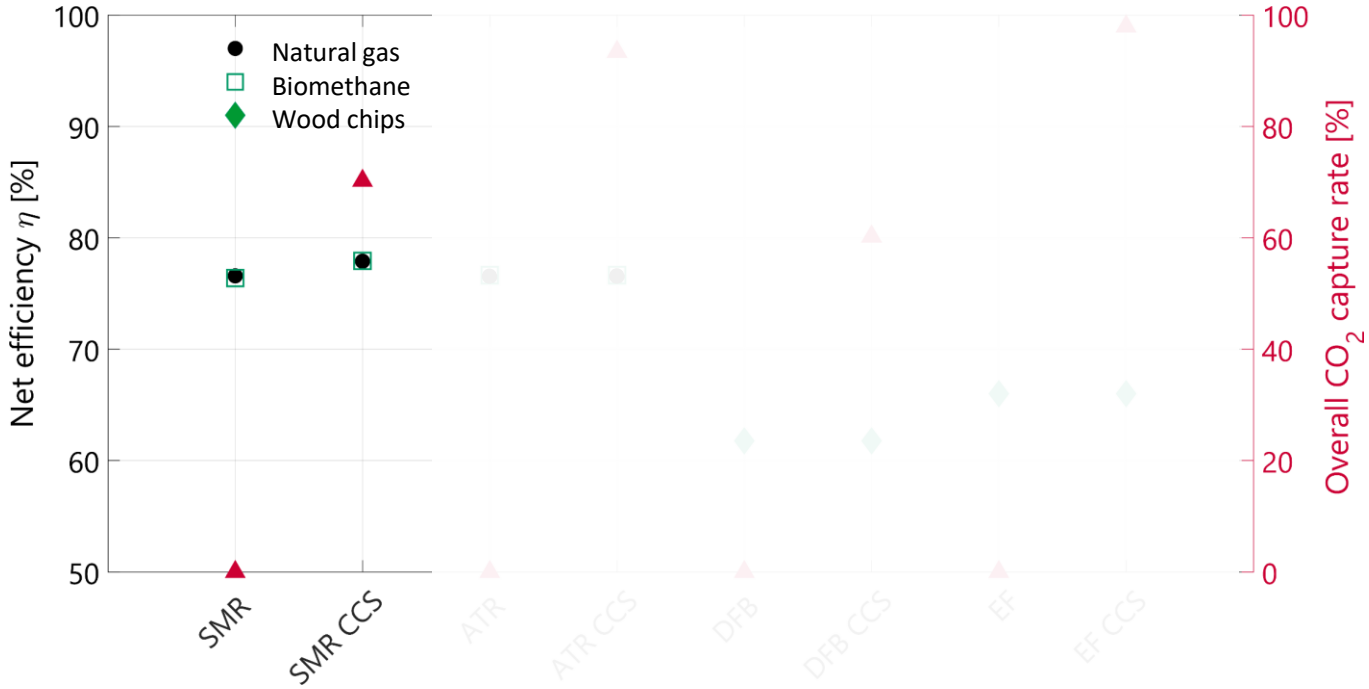

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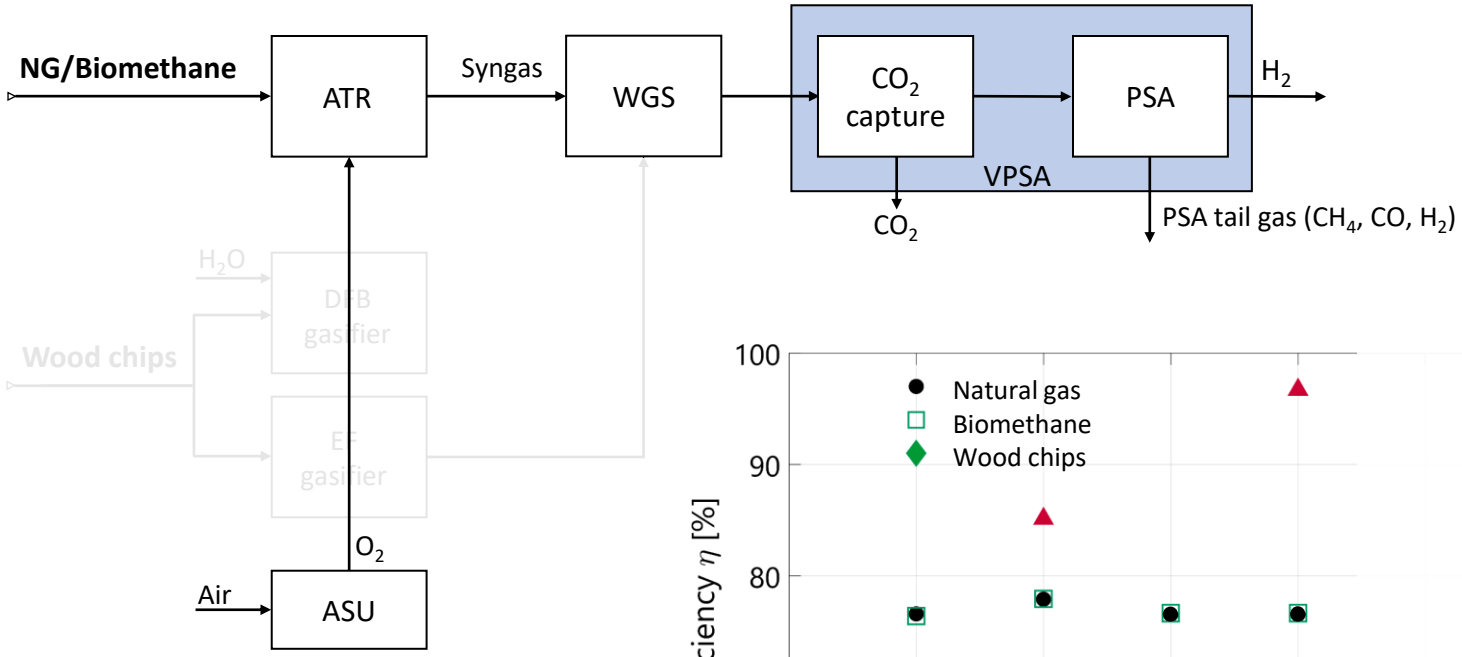

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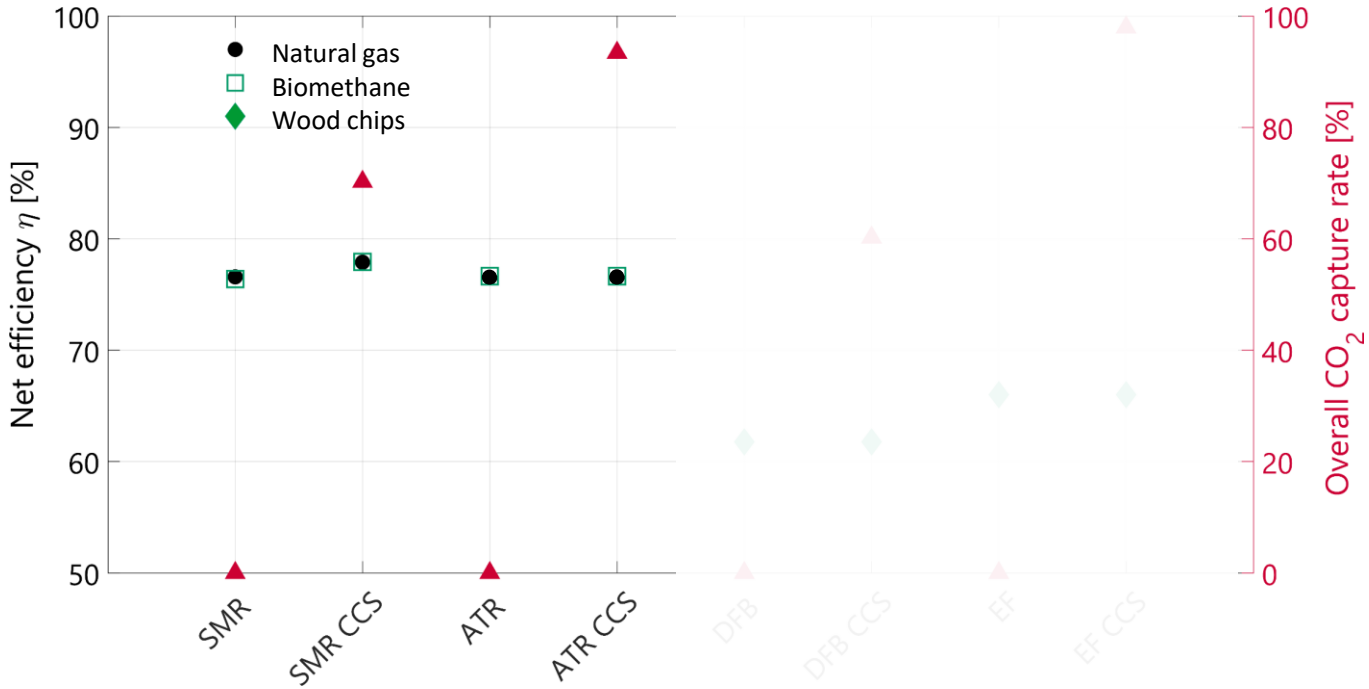

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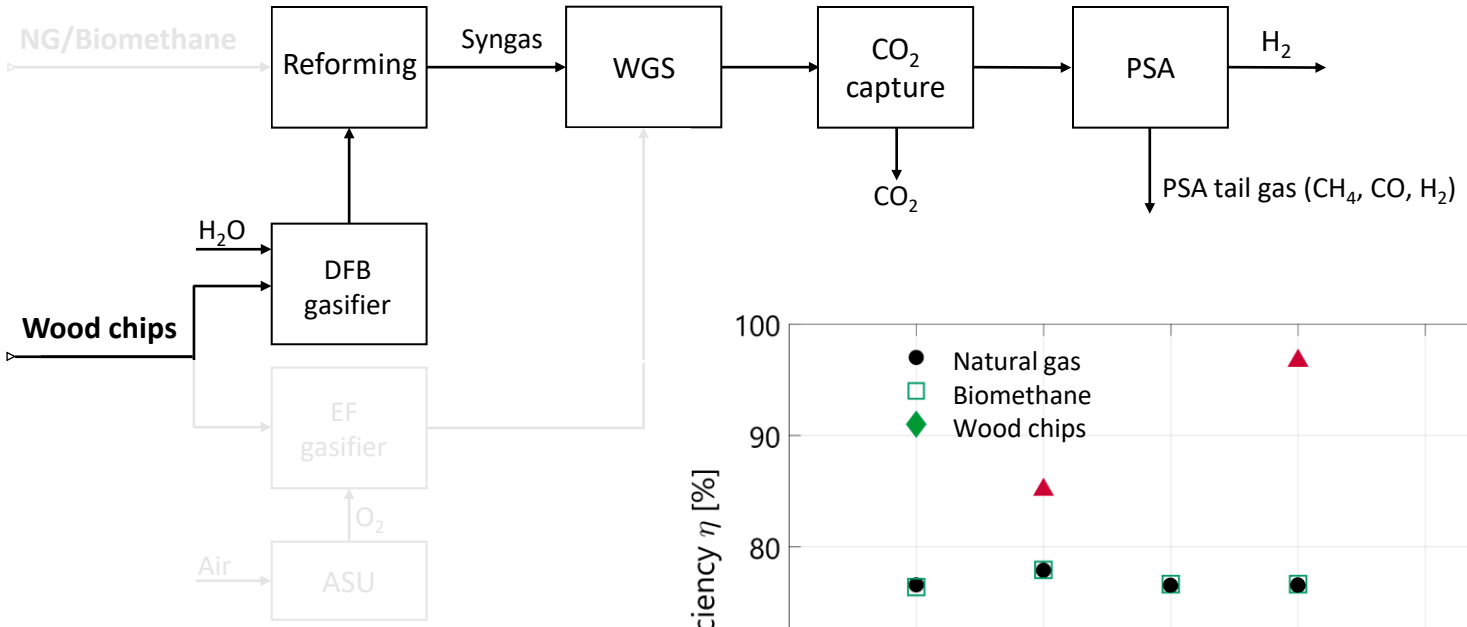
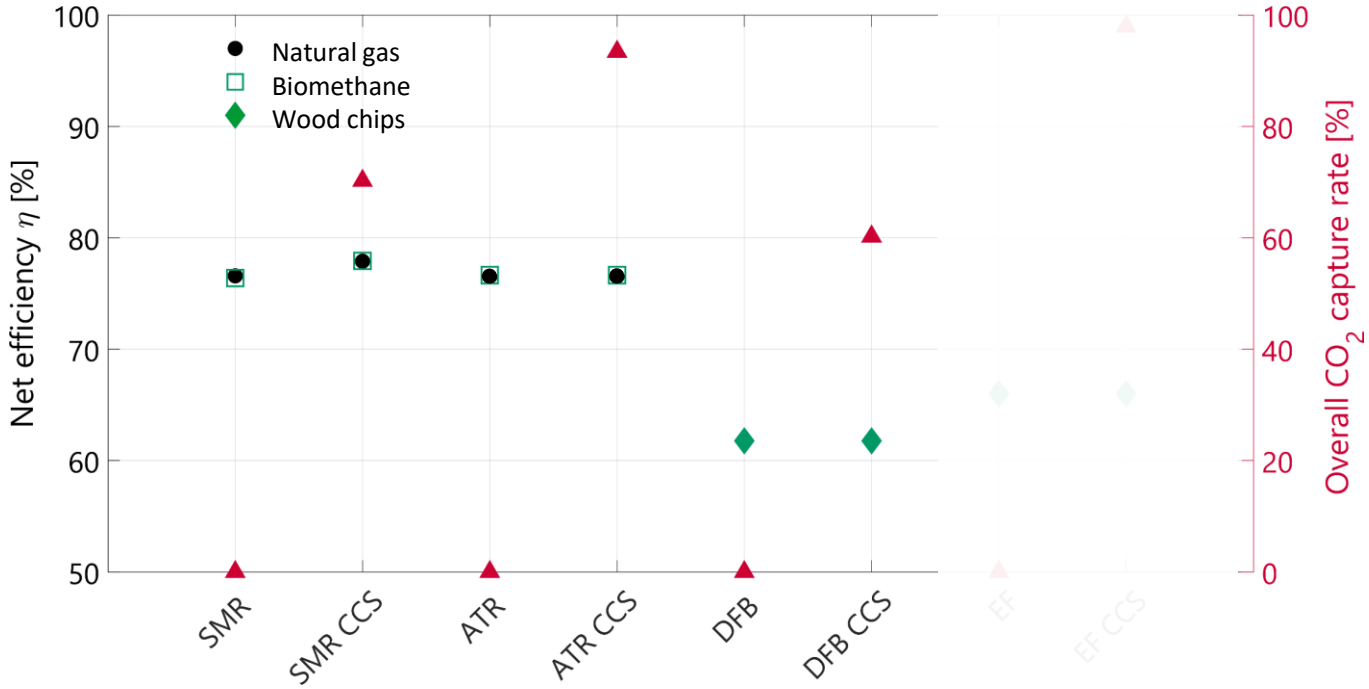
Low-C H_2 production - performance



$$\eta = \frac{E_{H_2}\,[\mathrm{MW}]}{E_{\mathrm{feedstock}}\,[\mathrm{MW}]}$$



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SMR: Steam methane reforming
DFB: Dual fluidized bed

ATR: Autothermal reforming
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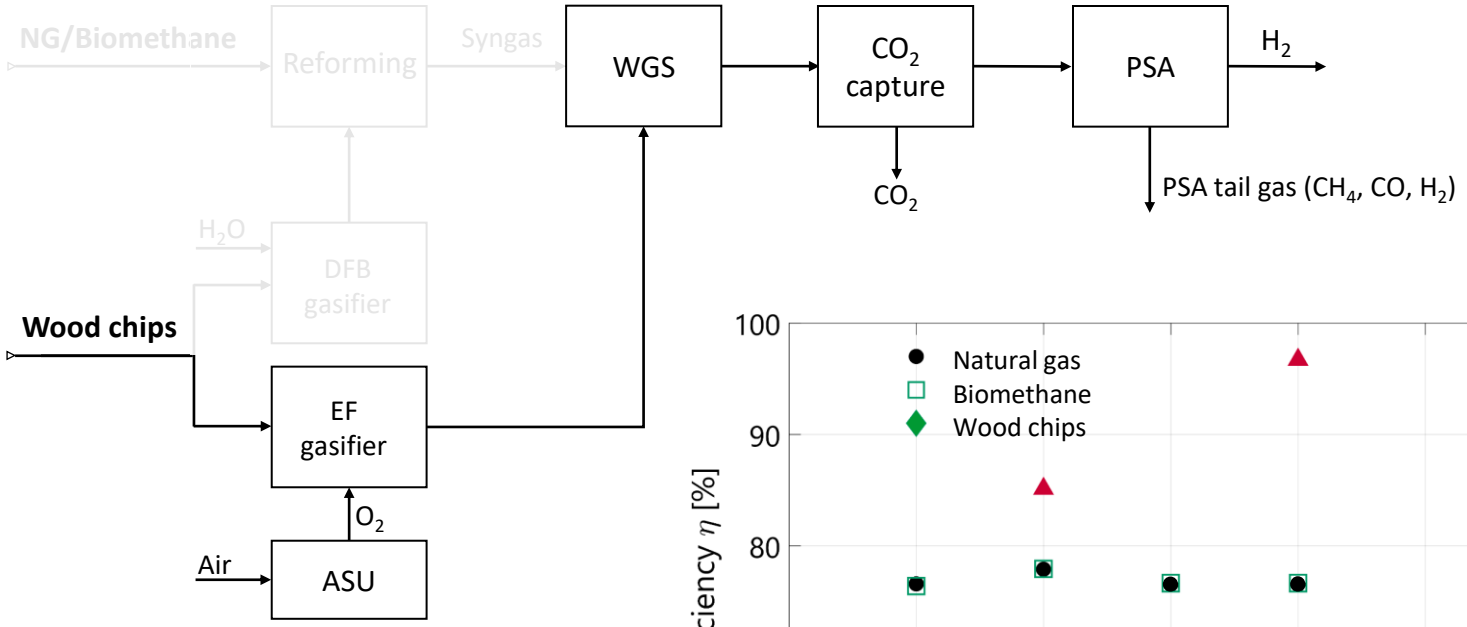
Low-C H_2 production - performance



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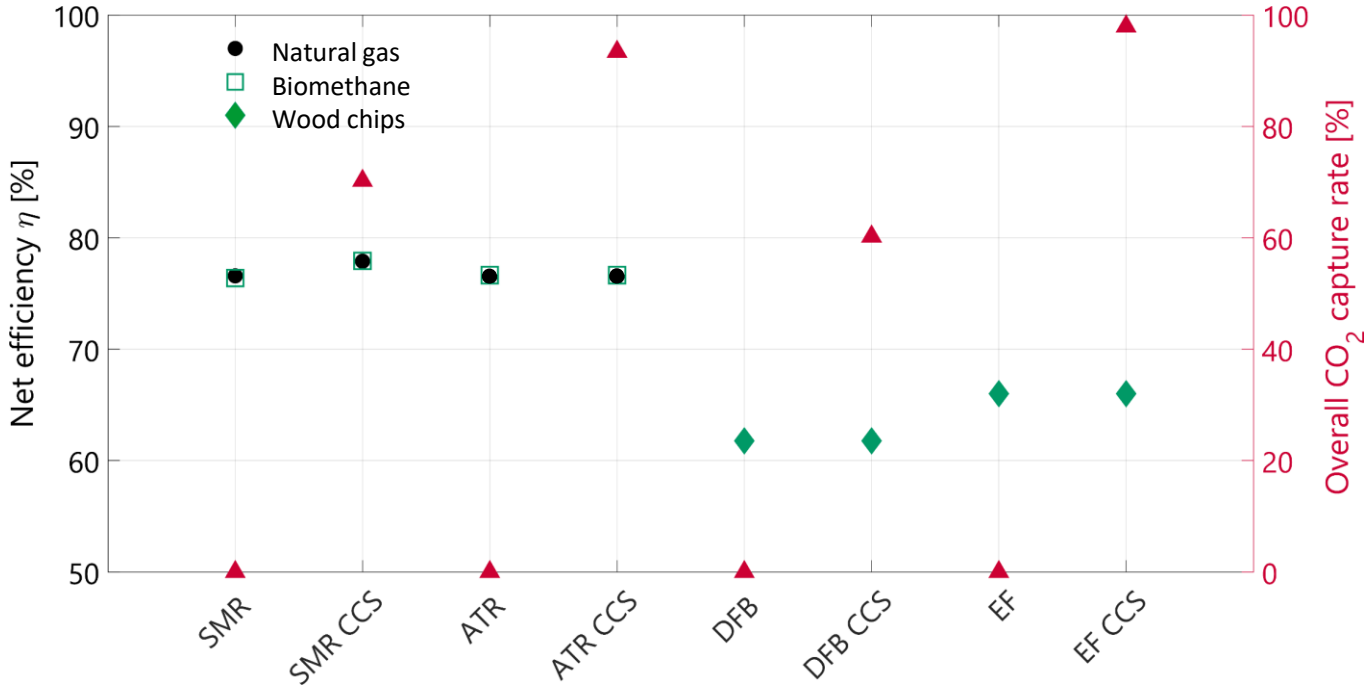

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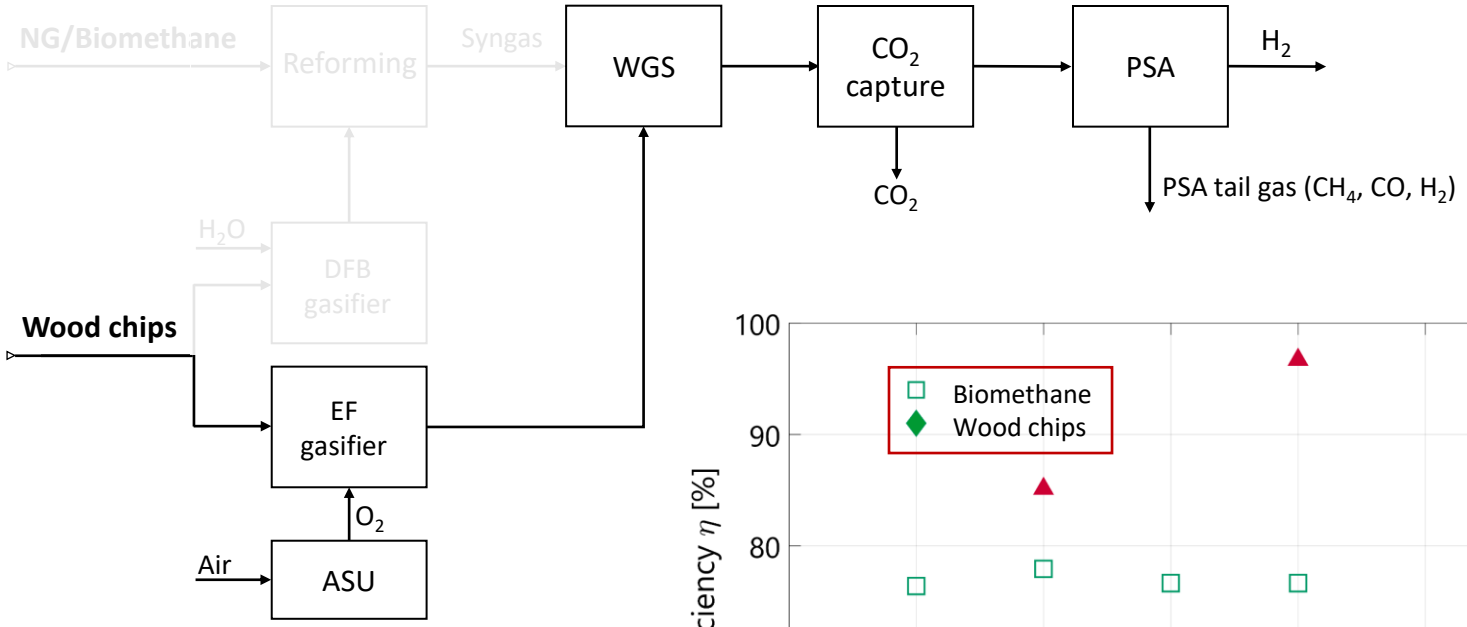

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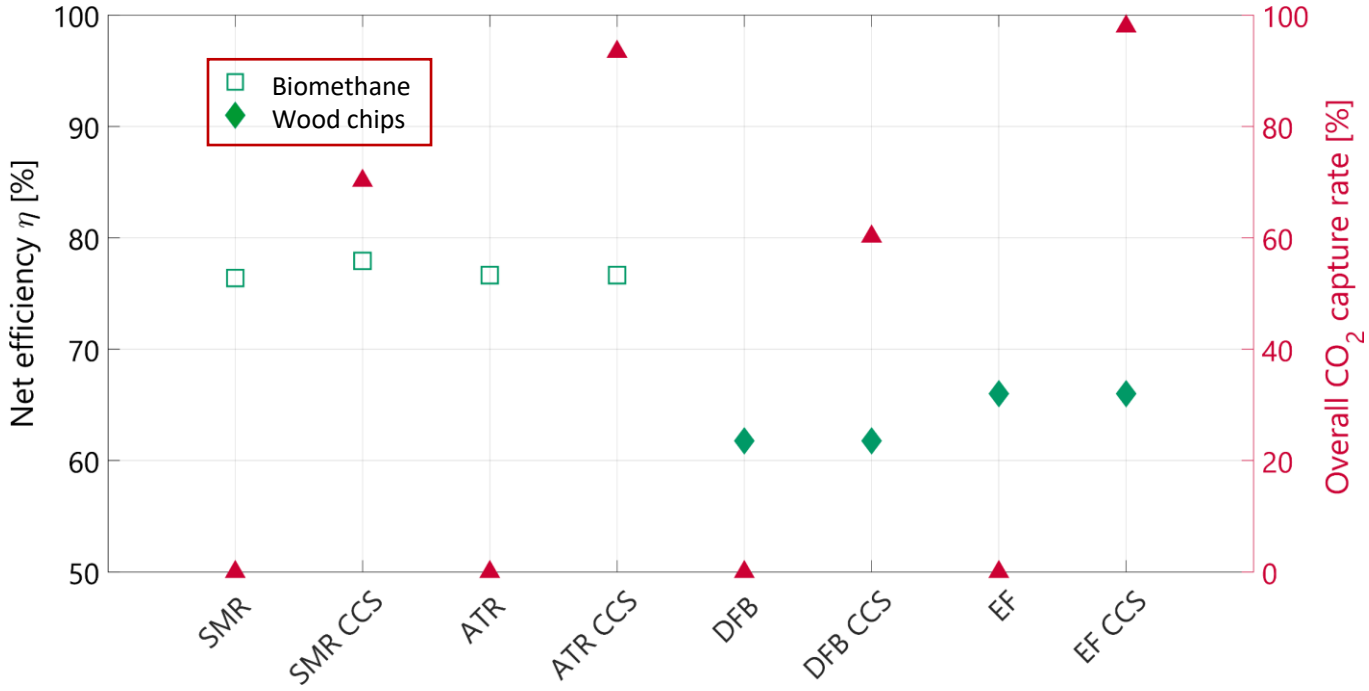

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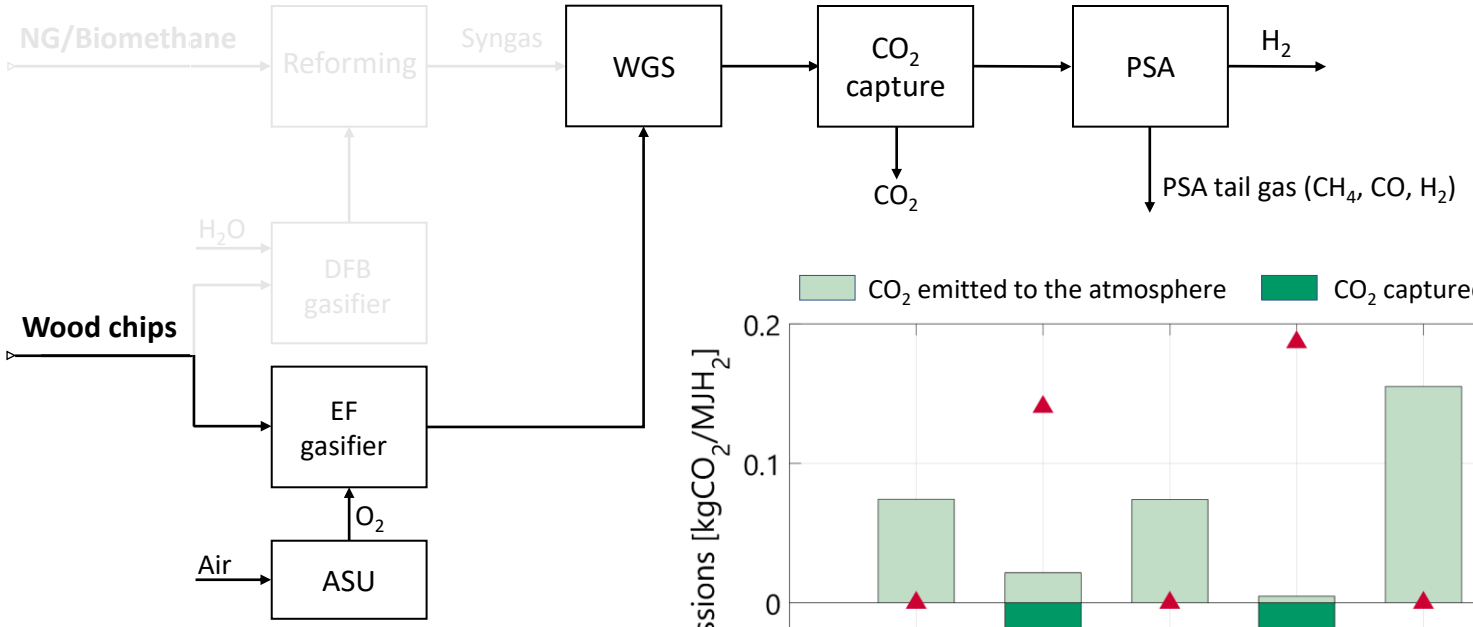

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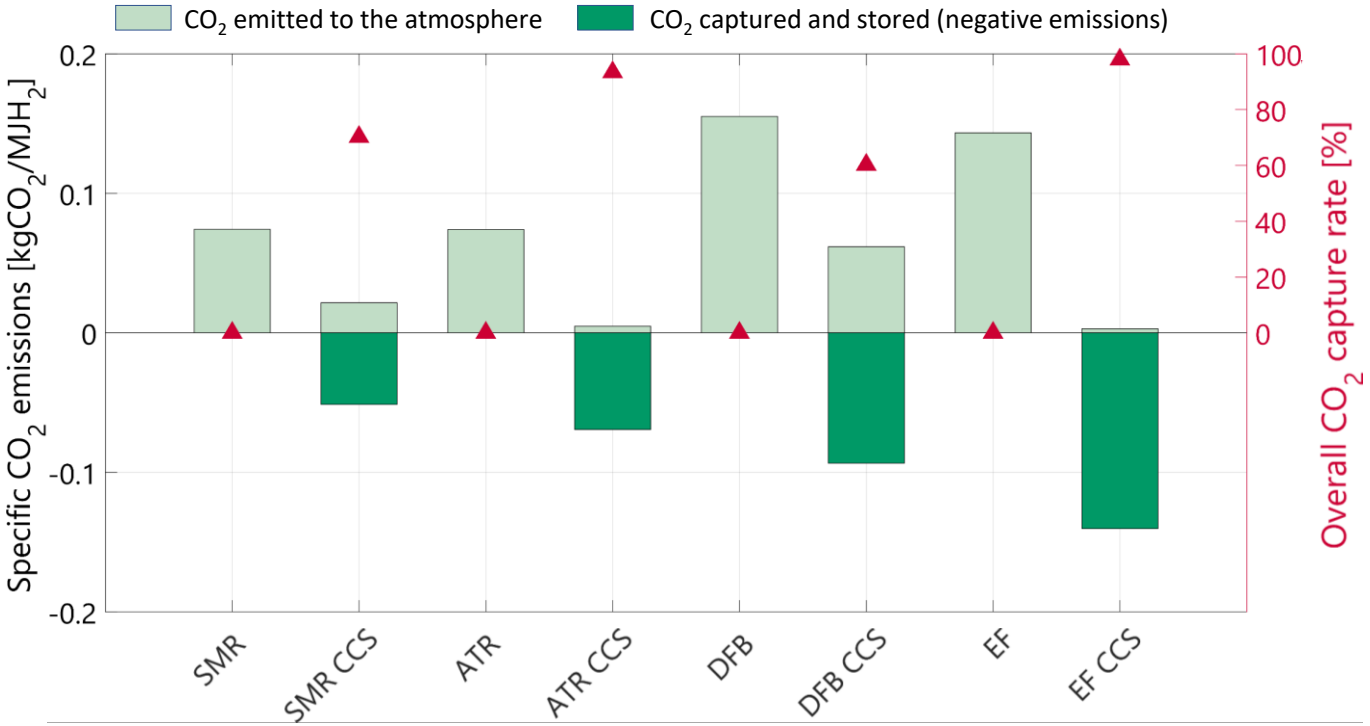

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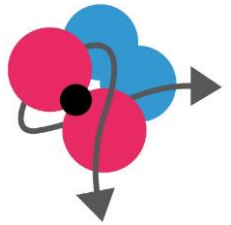
Conclusions

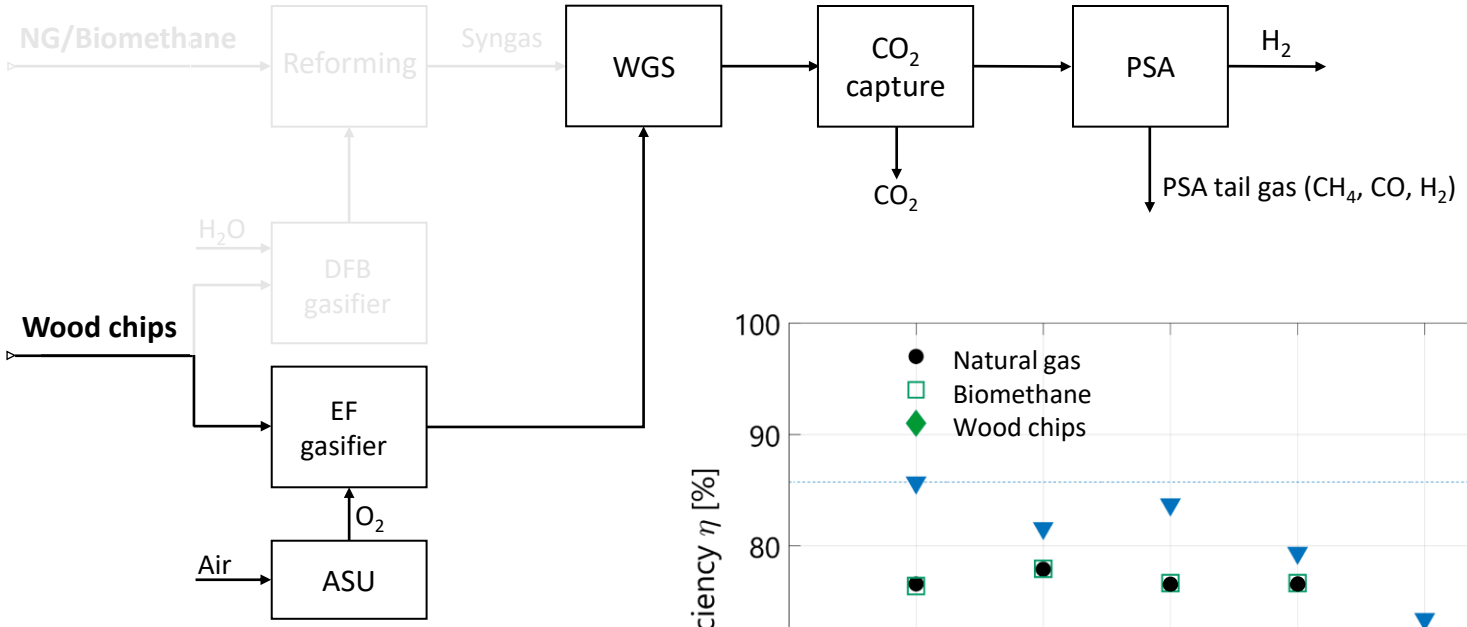


- Producing low carbon hydrogen is possible
  - Combining production from natural gas with CCS
  - Using biomass either wet or dry
  - Negative emissions can be obtained when combining hydrogen production from biomass with CCS
- The availability of biomass will be a critical factor and will vary from region to region
- The overall environmental performance that depends on the type of feedstock and production chain selected has to be evaluated via LCA
  - Karin will present the overall environmental performance of low-C hydrogen production

Acknowledgement

ACT ELEGANCY, Project No 271498, has received funding from DETEC (CH), BMWi (DE), RVO (NL), Gassnova (NO), BEIS (UK), Gassco, Equinor and Total, and is cofunded by the European Commission under the Horizon 2020 programme, ACT Grant Agreement No 691712. This project is supported by the pilot and demonstration programme of the Swiss Federal Office of Energy (SFOE).

Low-C H_2 production - performance



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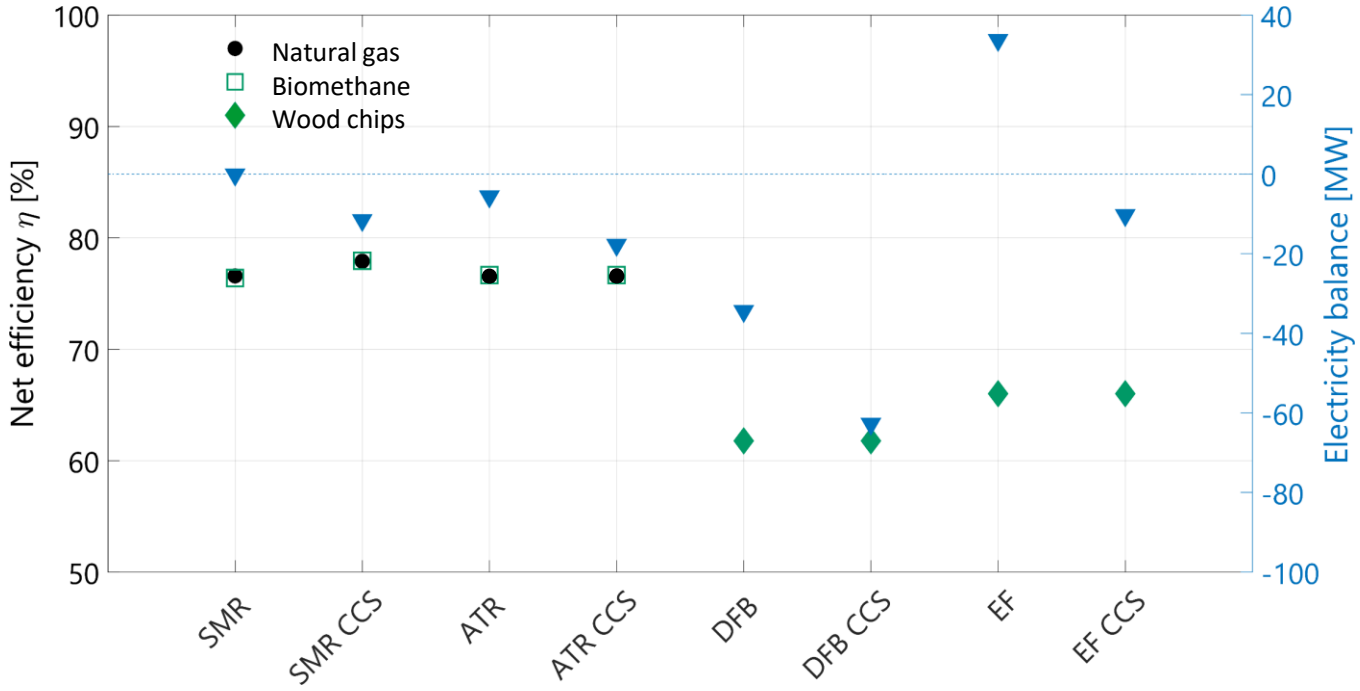

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