Design and cost optimization of Carbon Capture for H-class Gas Turbine

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ENGIE

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ENGIE IS LEADING THE ENERGY TRANSITION

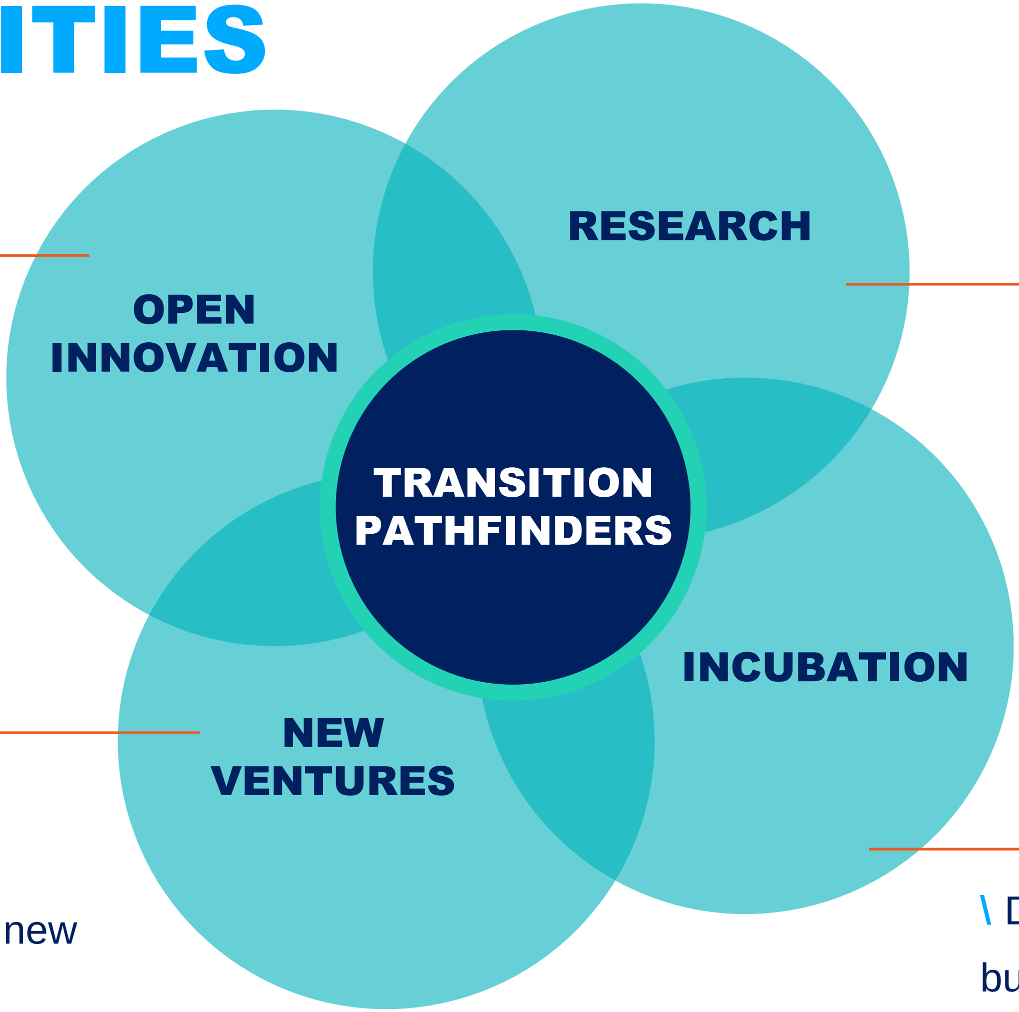
OUR PURPOSE

“ We act to accelerate the transition towards a carbon-neutral economy, through reduced energy consumption and more environmentally-friendly solutions.”

OUR COMMITMENT

“ We aim to be Net Zero Carbon by 2045 across all scopes following a well below 2° trajectory ”

Engie R&I CAPABILITIES



\ 600 experts working at Engie research centers

\ A €200 million venture capital investment fund

\ 25 active investments in startups (5 new investments in 2022)

\ 200 startups scouted each year

\ 4 R&D centres: Laborelec, CRIGEN, Cylergie, Singapore Lab

- R&D projects on Capture: CESAR, CASTOR, OCTAVIUS
- AEROSOLVE
- ROAD: Demonstration of CO_2 capture from a coal-fired PP (MPP3) + transport and storage

\ Develop innovative offers for Engie business units

\ Develop new adjacent businesses as growth drivers

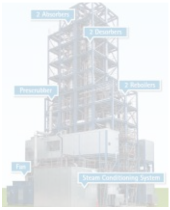
CO_2 Lab

Building technical and operational experience on Carbon Capture and conversion to support industrialization

CAPTURE

AeroSolve

Hitachi
(2010-2013)
5000 Nm_3/h
(1 t_{CO2}/h)



MCU
COD 2024
30-50 kg/h flue gas

ROAD
(2010-2017)
1.1 Mt_{CO2}/y

R&D → Pilot → Demonstration

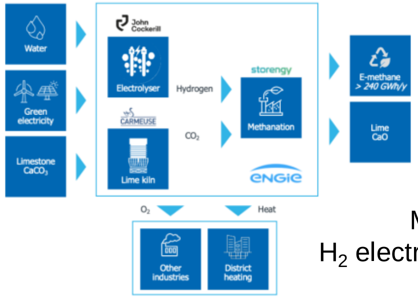
CONVERSION

PTM – Port of Antwerp

E-methanol

Thermocatalytic hydrogenation
H_2 electrolyser @ 3 MWe

Columbus **E-methane**



Methanation
H_2 electrolyser @ 100 MWe

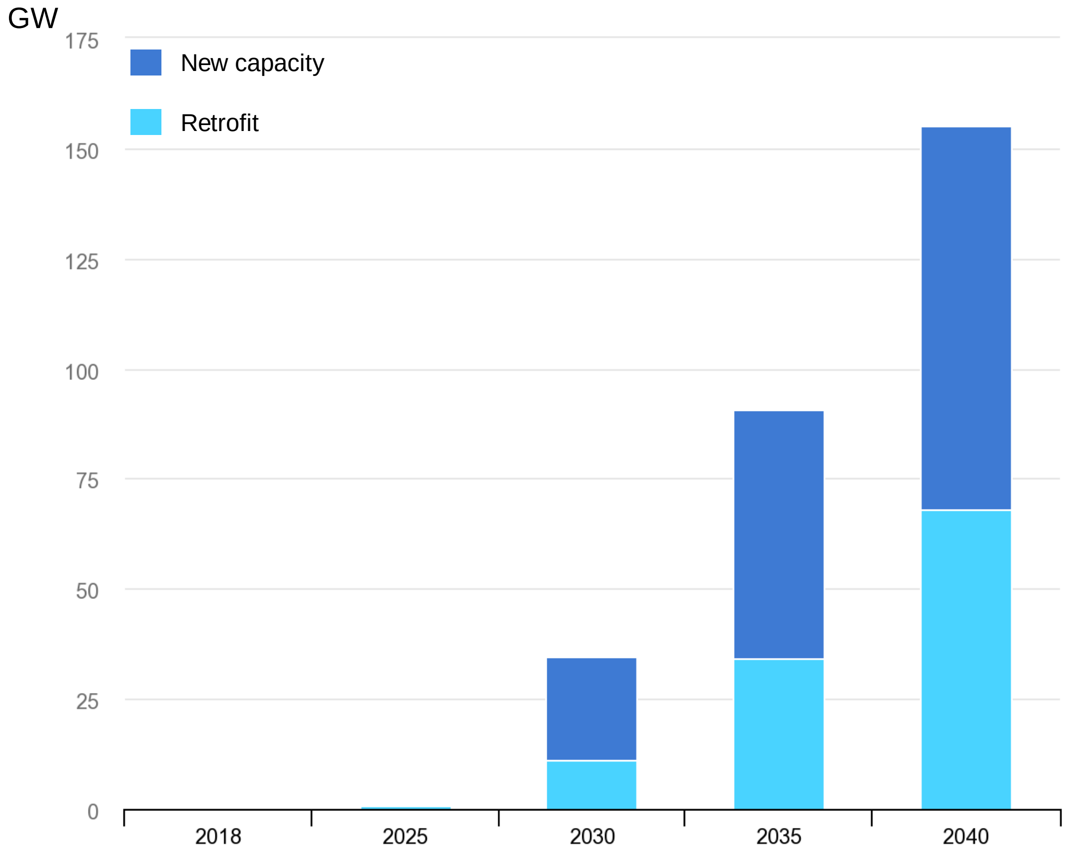
CCS+CCGT plays an important part in CO_2 emission reduction

By 2030, it is considered to increase the contribution of renewable energy from 21% to 43 % and decrease the CO_2 emission.

CCGT plants are part of the plan for increasing green energy and grid stabilization.

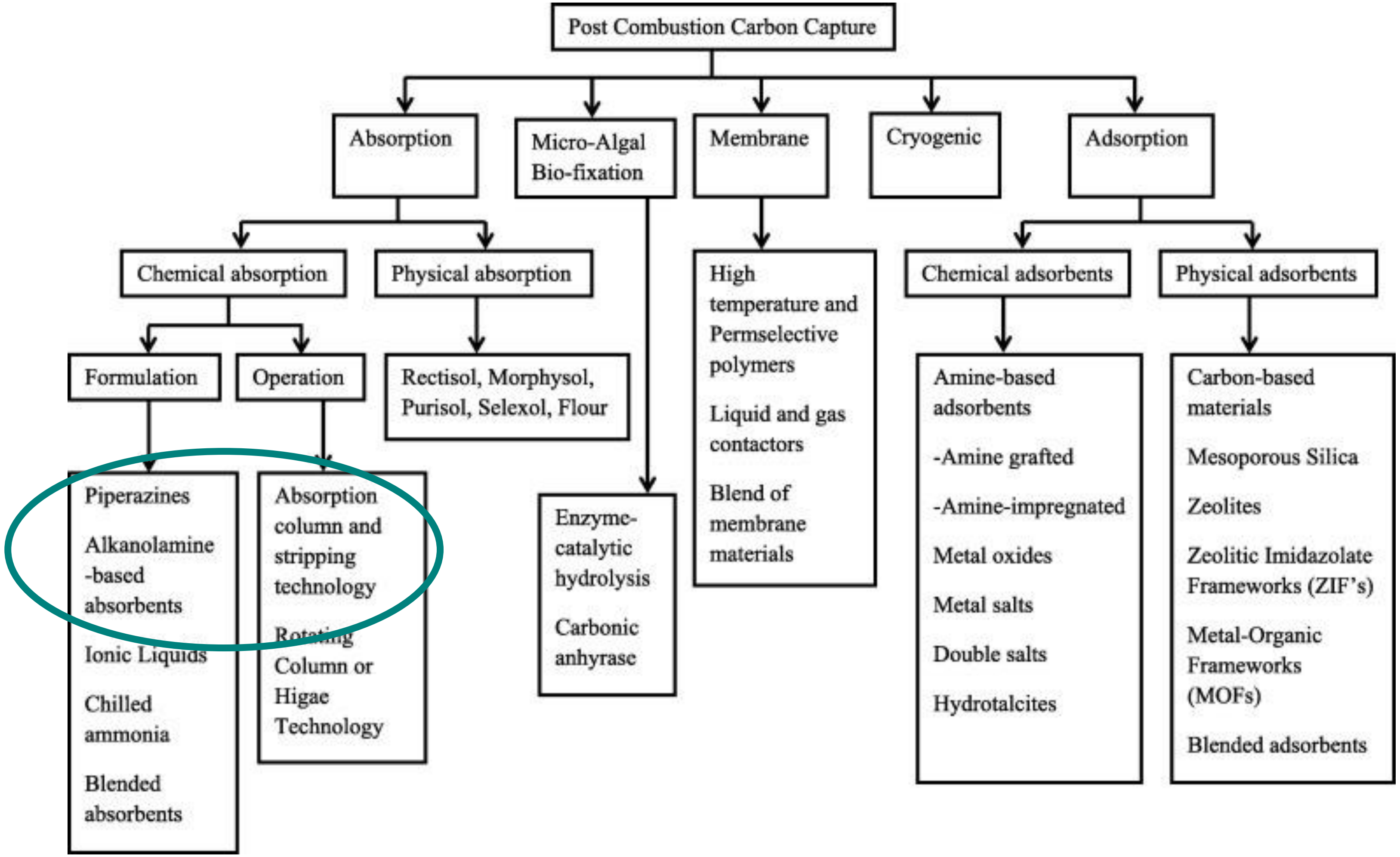
Benefits of using CCGT :

- Gas turbines in a combined cycle consume less and emit less carbon dioxide.
- Enabling grid flexibility and reliability.
- Low-cost conversion of fuel to electricity.
- Low emissions.

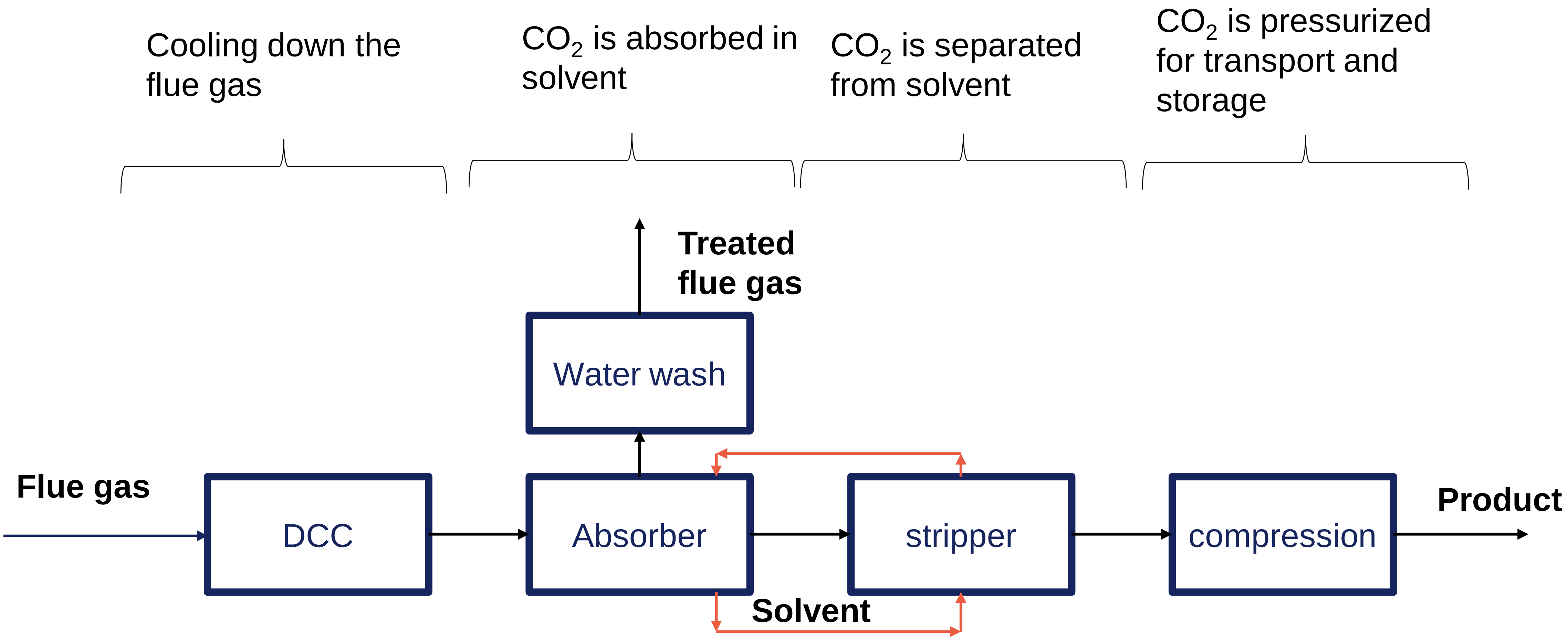


IEA, Natural gas-fired power plants equipped with carbon capture in the Sustainable Development Scenario, 2018-2040, IEA, Paris

CO_2 capture processes overview:
Amine-based absorption is the most mature process



Simplified representation of the main blocks of the CO_2 Capture Plant



Challenges of carbon capture on CCGT

High energy requirements and large CAPEX of the amine-based process are obstacles to its deployment

Large volume of flue gas with low CO_2 partial pressure and high O_2 content

- Large quencher / absorber

→ Trade-off between equipment size and pressure drop

- Handling of large volumes of process condensates

Following the flexible operation of CCGT

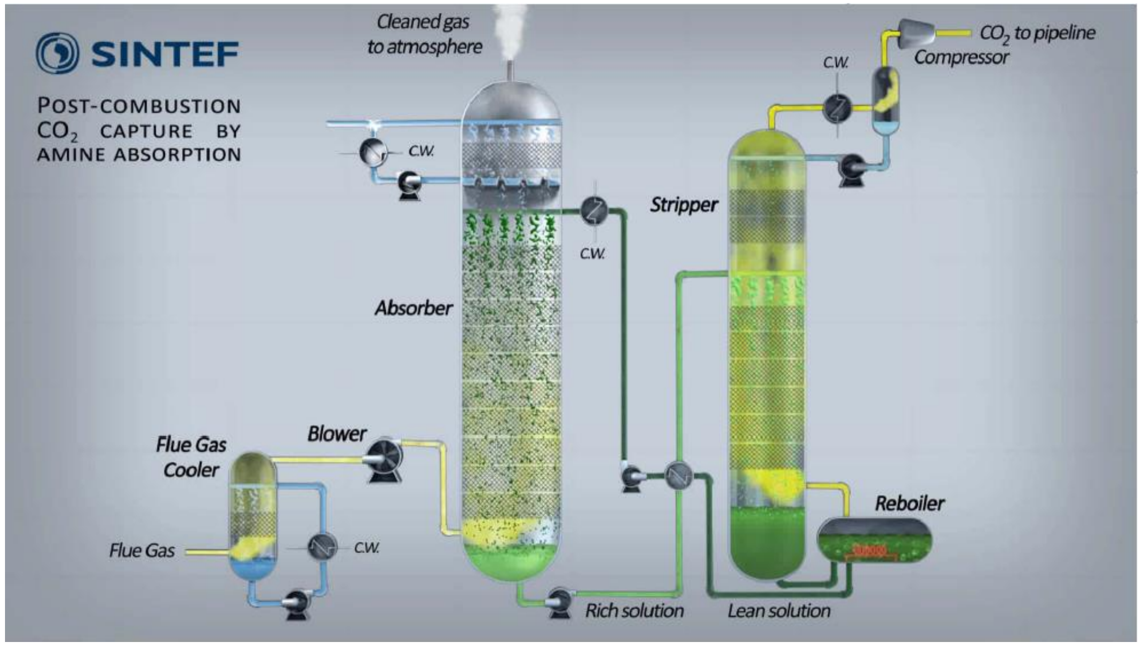
- Match CCGT design and CO_2 Capture process requirements: steam / power

  → Impact on Energy efficiency

- Operability and efficiency of the capture with flexible operation of CCGT

  →From low to high load with possibly quick ramp-up/down

  Transient phases: start/stop, hot standby / cold standby of the CCGT



Simplified representation of an amine-based absorption CO_2 capture process

High capture level, a potential strategy to reach carbon neutrality

Balancing costs between a higher CO2 capture rate and Carbon offsets credit for residual CO2 emissions

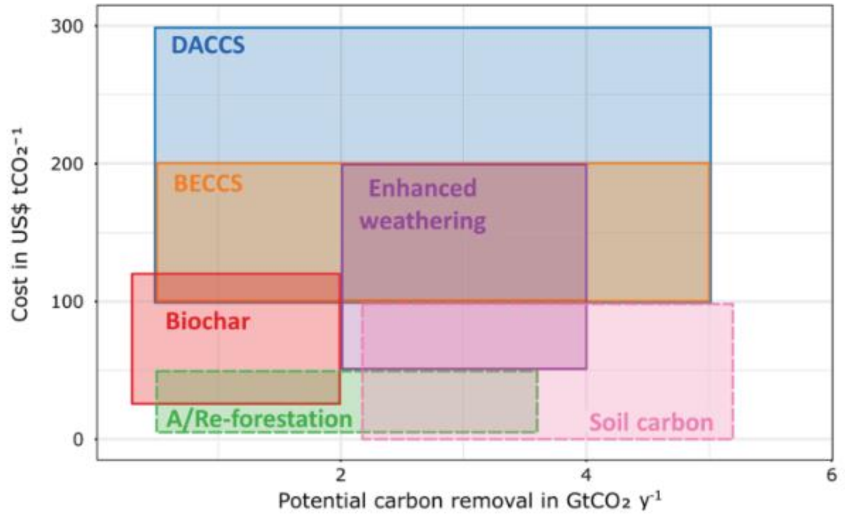
High capture levels seem to be the **new target** for future Carbon Capture demonstration projects.

→ While today there is no legal requirements for a minimal capture rate, in recent UK BAT guidance [Gibbins, 2021] and US DoE funded projects, a capture rate of 95% is recommended

High capture levels can be the **most effective approach to reach carbon-neutral** power production rather than purchasing Carbon offset credits from Carbon Dioxide Removal projects?

→ Uncertainties remain on the CO_2 removal price

High capture levels at base load to **compensate** for reduced CO_2 capture efficiency during **transient phases** and **start-up** and to maximize power production.



Cost and potential of deployment of Negative Emission Technologies [Fuss S., 2018]

Finding a cost-effective method to increase the capture rate

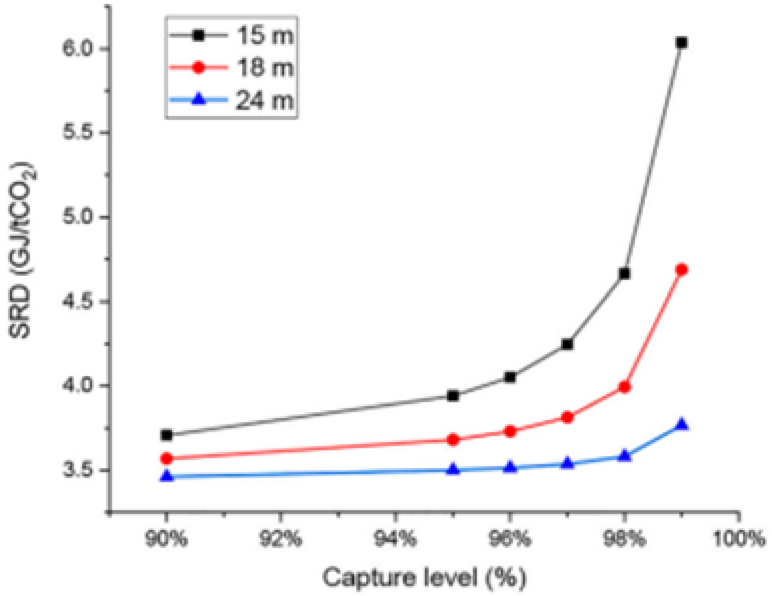
Different parameters can influence the overall CO_2 capture rate, either by increasing the solvent absorption capacity or by enhancing CO_2 desorption. However, all these strategies do not have the same impact on both CAPEX and OPEX.

The impact of the following parameters has been evaluated.

- Effect of **reboiler duty**: increasing steam input leads to an enhanced solvent regeneration and thus CO_2 recovery in the stripper.

- Effect of **flue gas temperature** at absorber inlet (30 to 50°C) : as CO_2 absorption is an exothermic reaction, a lower flue gas temperature is beneficial for increasing the CO_2 absorption rate in the absorber.

- Effect of **absorber height**: increasing absorber packing height enables to increase in the gas/liquid contact favorable to increase the CO_2 absorption rate.



Reboiler duty for different capture levels and absorber heights [Michailos,2022]

Methodology

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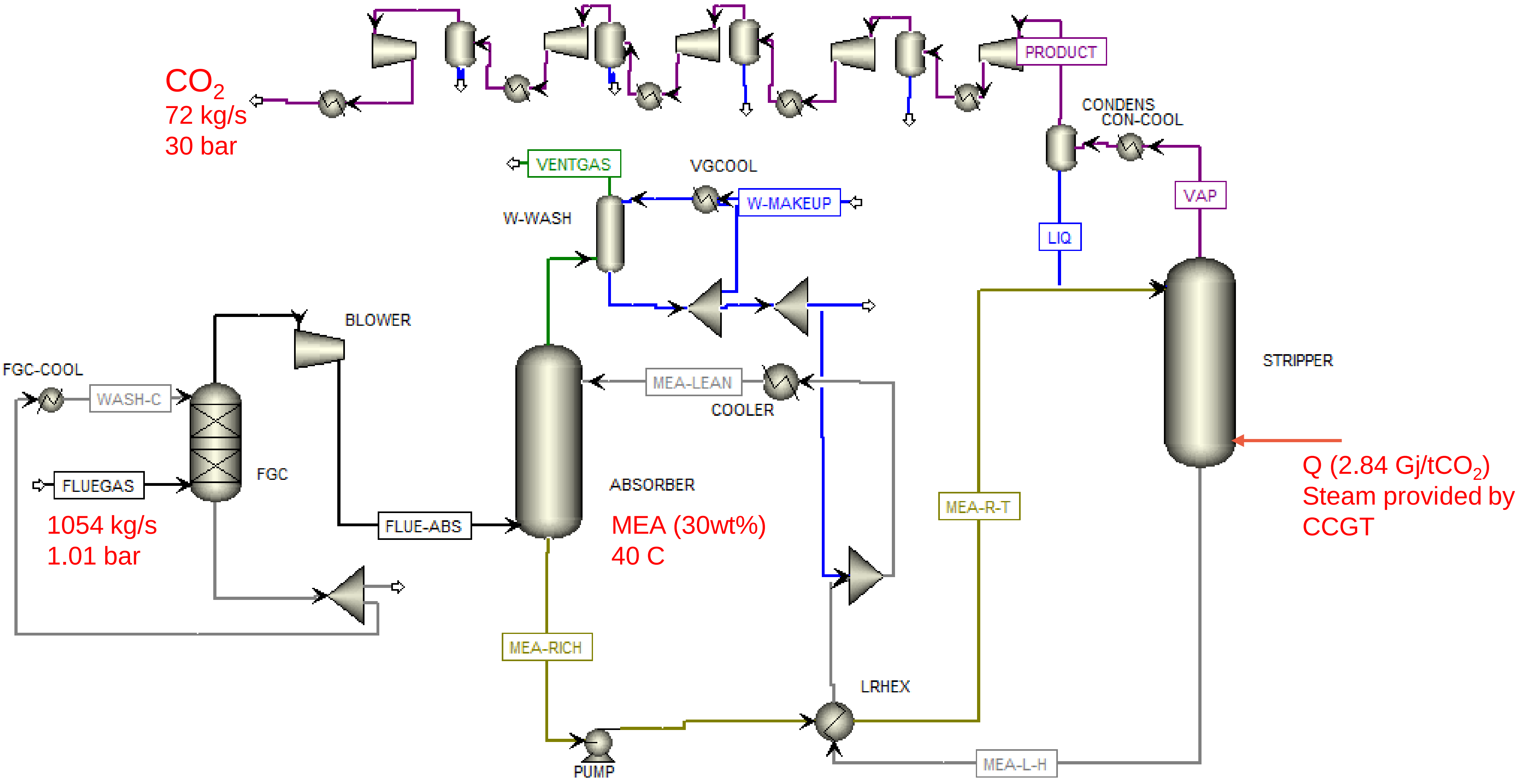
Aspen Plus was used to simulate the capture plant.



Key assumptions and economic indicators

Assumptions considered for CAPEX:

- Plant lifetime: 20 years
- Yearly operation hours for CCGT: 4500 h (base load)
- Yearly operation hours for CCS+CCGT: 6500 h (base load)
- Annual CO_2 production capacity: 1.6 Mt CO_2/y (90% capture rate)
- Lang factor: 4

Parameters considered for opex:

- Raw materials (water, MEA, NaOH, etc.)
- Utilities (cooling water, electricity and steam)
- Waste treatments
- The steam and electricity consumptions are considered as loss of CCGT plant efficiency

Operational fixed costs includes:

- Labor
- ISBL (inside battery limit costs) (7% of interest)
- Depreciation (20 years)

Results and discussion

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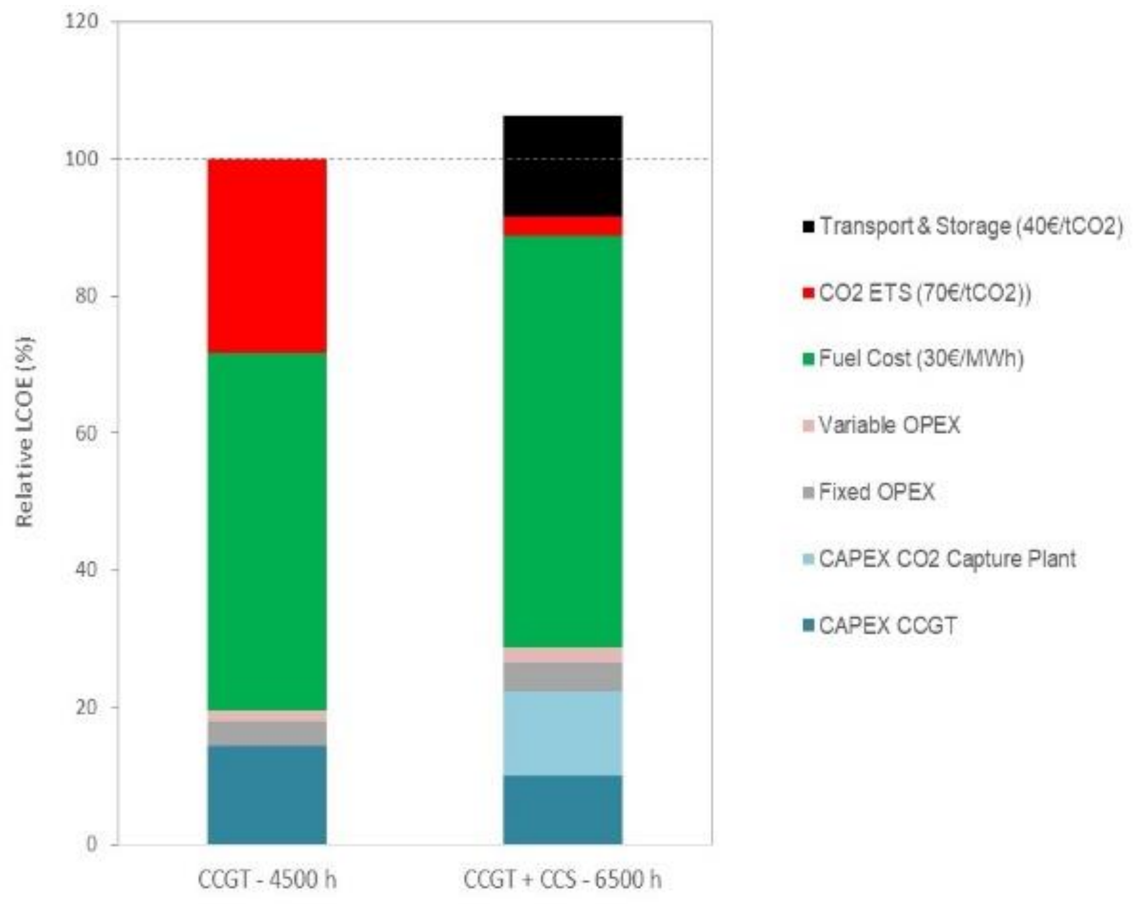
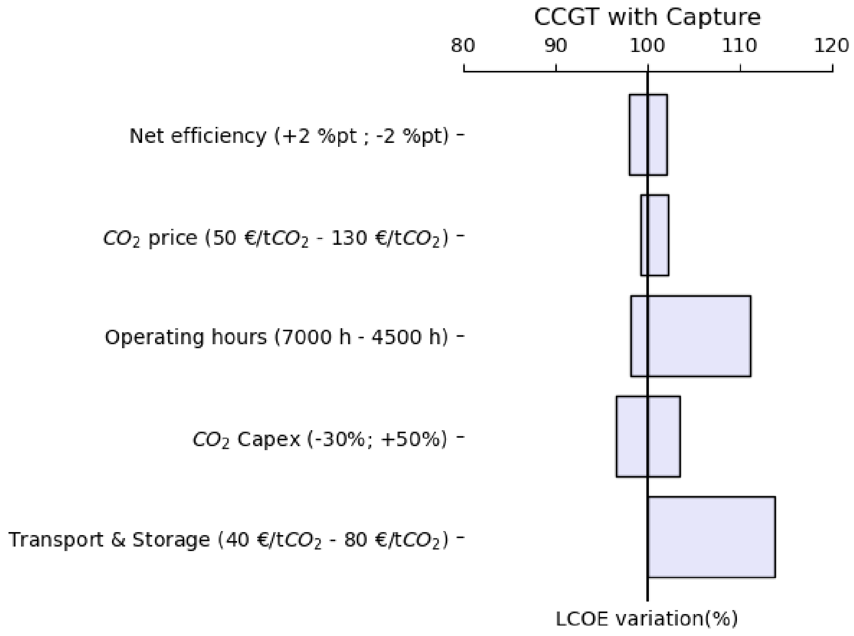
Base case study results for 90 % capture rate



Comparison of CCS costs for Class H – Base Case (Aspen model)
Base load operation, 4500 h/y (CCGT only) – 6500 h/y (CCGT + CCS), 20 years, WACC : 8%, Tax rate : 30%

Implementing a CCS to a CCGT is translated in the electricity production costs by:

- ETS cost of residual CO_2 emissions
- more than doubling the CAPEX of the CCGT
- a higher fuel cost: +17% per MWh: and power consumption for the Carbon Capture Plant (CCP)



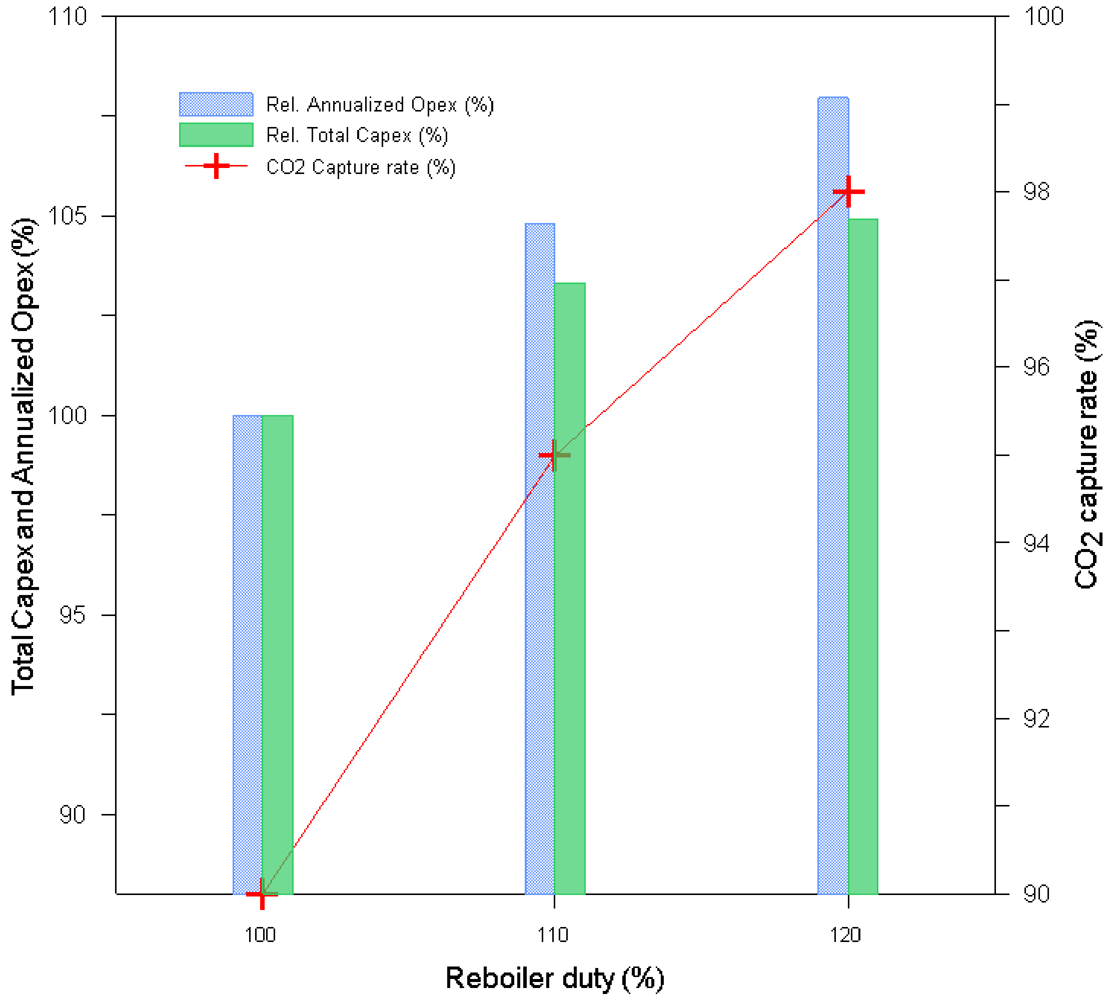
Increasing reboiler duty to reach 95% capture rate leads to limited capture cost increase

- To reach 98% capture efficiency, this leads to an exponential increase in reboiler duty by 20%

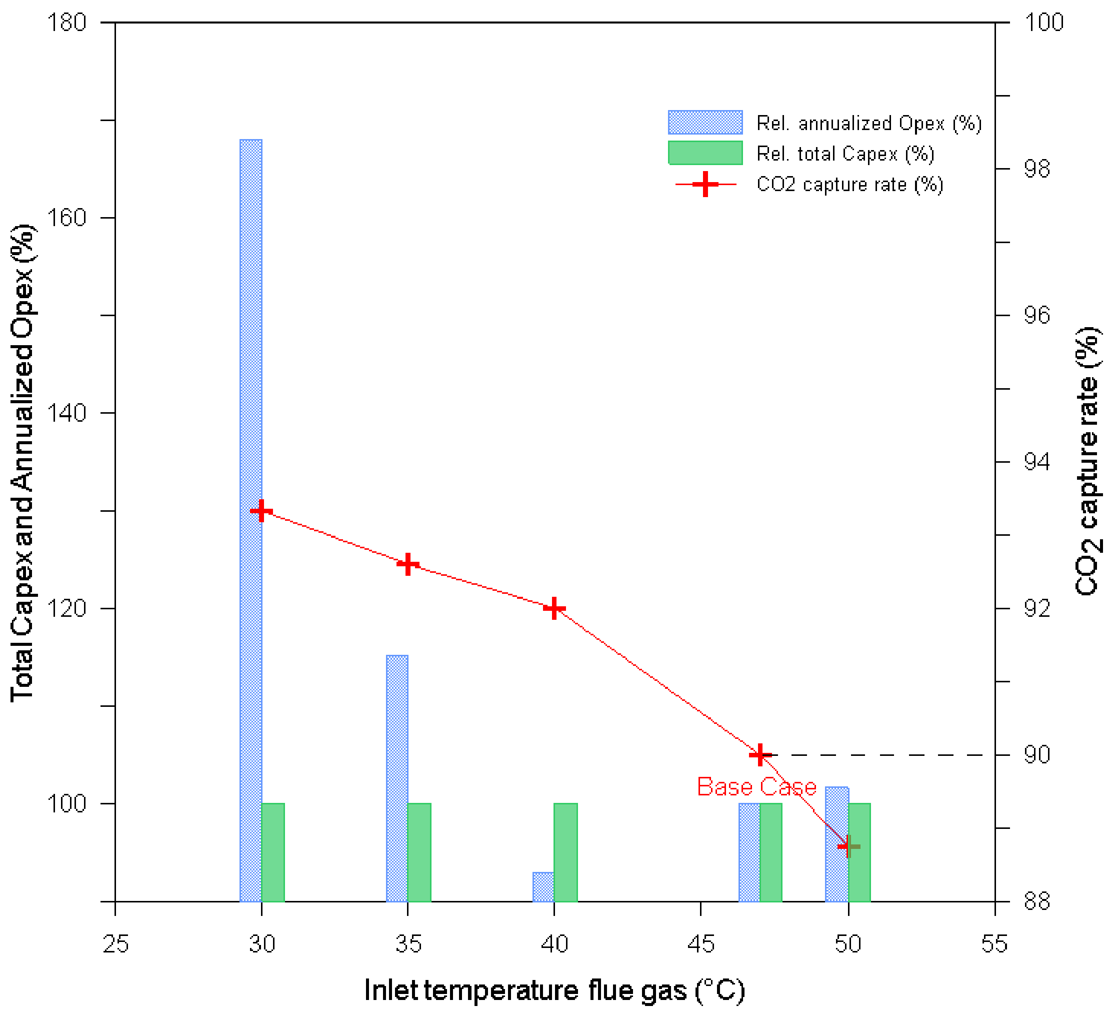
  → This translates into an 8% increase of opex

- The impact on CAPEX is limited to the reboiler and compressors (+3%)

→ Based on current results, increasing the capture rate up to 95% would lead to a relatively limited cost (energy demand) increase.



Decreasing flue gas temperature at absorber inlet to increase capture rate: optimum T is 40°C



- Decrease of the flue gas temperature
  - Assumed no effect on the capital costs
  - results in higher cooling duty and use of electricity
- Lower flue gas inlet T to absorber results in higher capture rate, up to 93%
- The optimal T is 40°C for MEA.
- Going below 40°C might not be technically feasible for some solvents

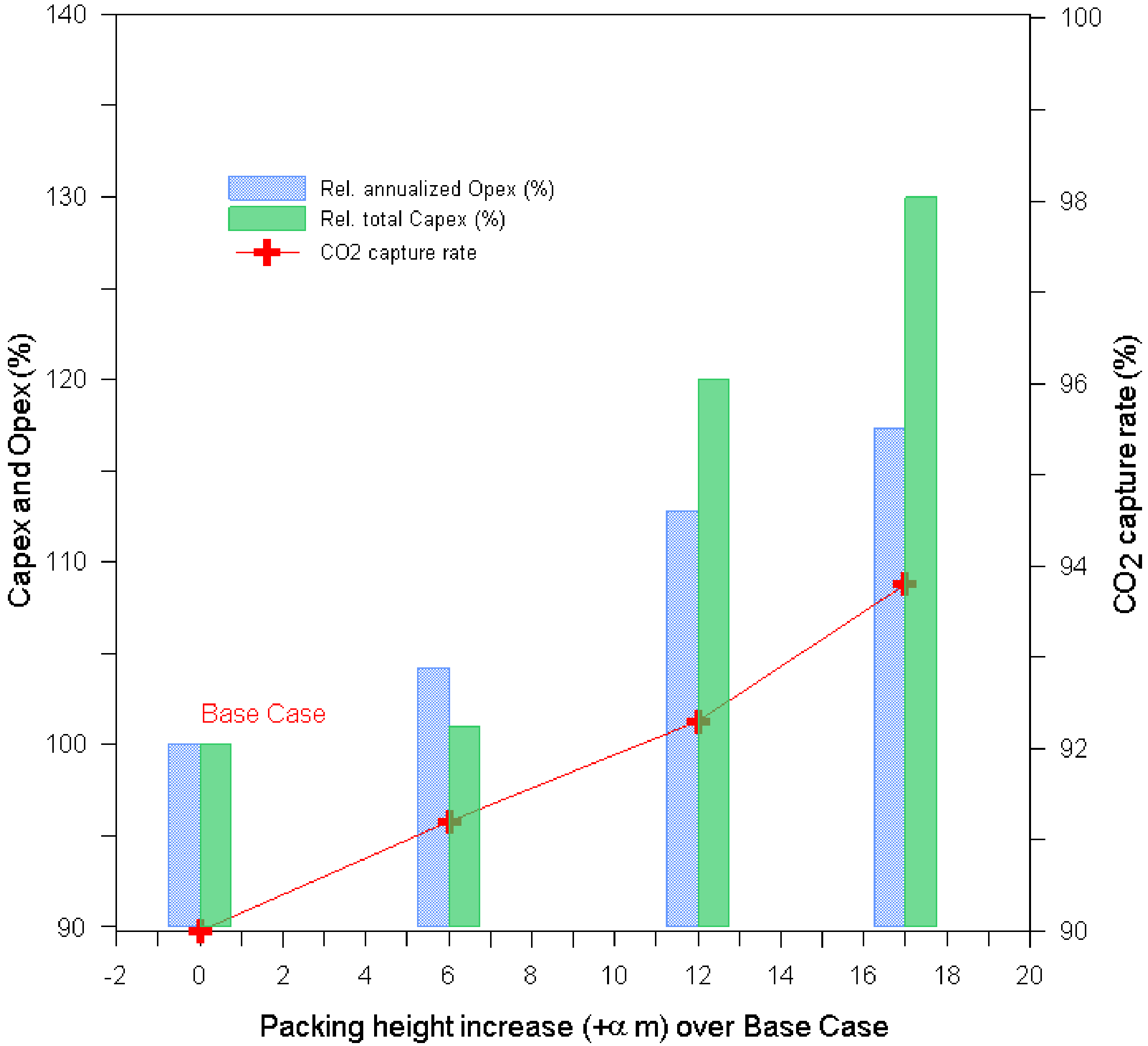
Increasing the packing height is not the best strategy

Compared to the other strategies capex and opex increased more significantly

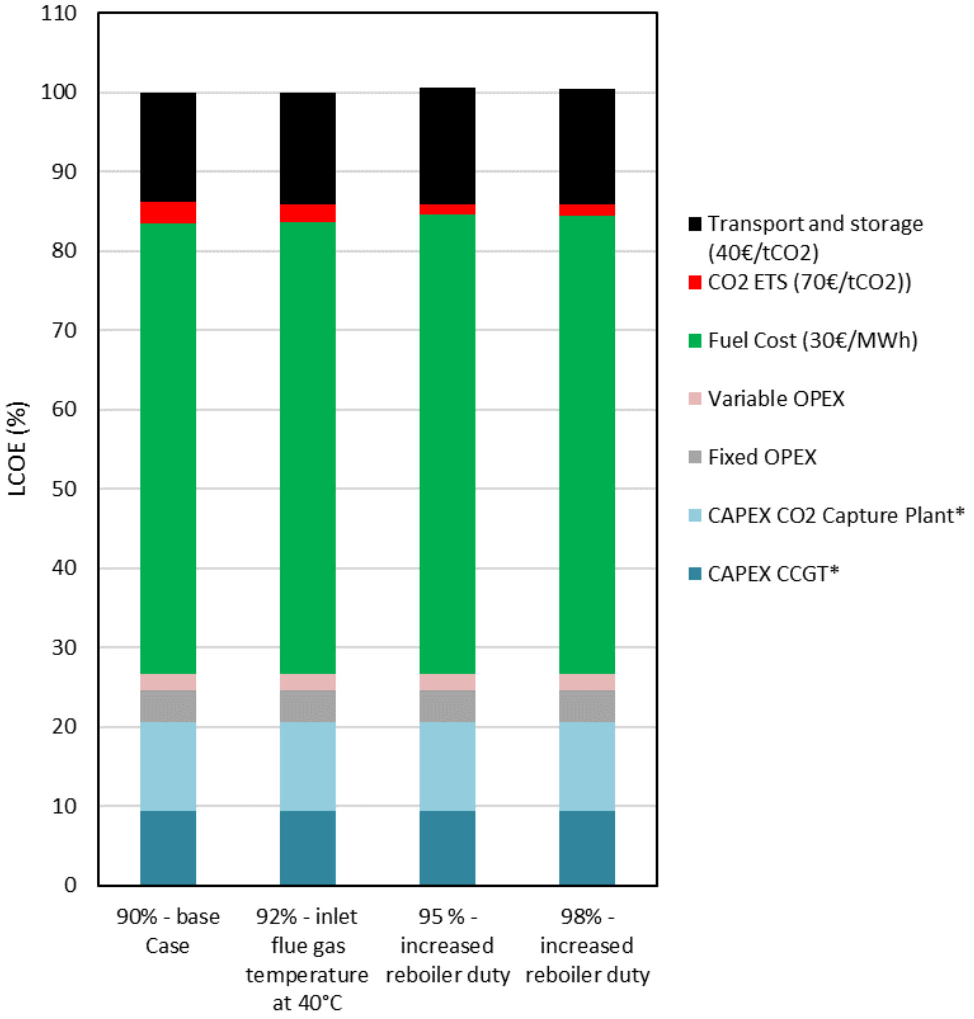
- Increasing the packing height by 17 meters from the base case leads to a +18% increase in opex and a +30% rise in capex

- The improvement in capture rate from 90 to 94% is unremarkable given the significant rise in capex and opex.

- Based on the current design, the solvent's capacity is approaching its maximum level, thus increasing the mass transfer with more packing does not address the other limitation in the process



Higher capture rates are achievable with limited impact on LCOE



- The impact on the costs is limited in LCOE, considering not all strategies have equal potential in terms of both cost and capture rate.

- Economics of high capture rate are driven by:
    - Cost of fuel
    - CO_2 ETS

- Among the different strategies evaluated, for MEA solvent, the merit order is:

  1) Inlet Flue Gas temperature decrease,

  2) Reboiler duty increase,

  3) Increase absorber height

Conclusion

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Conclusion

This study is centered on achieving a higher capture rate. While today, there are no legal requirements to reach 95%, increasing the capture rate can be beneficial to overcome reduced efficiency during transients and start-up and to reach carbon neutrality.
This study showed that achieving a higher capture rate is technically feasible with limited impact on the costs.

The main strategies considered to overcome the challenges are:

1. Decrease of flue gas temperature → with an optimal temperature (40 C)

2. Increase of reboiler duty→ economically acceptable until 95 % capture rate

3. Increase of the packing height → but limited improvement and high costs

Additionally, other options such as increasing the solvent concentration, absorber intercooling, and alternative solvents could be studied.

The optimal design would be a mix of different strategies.

Thank you for your attention