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Performance assessment of carbon capture applied to combined cycle gas turbine under part-load operation

5th Consortium Meeting - May 23th, 2022

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BEST

economie
FPS Economy, S.M.E.s, Self-employed and Energy

Objective

Assessment of the techno-economical feasibility of applying **Post Combustion Carbon Capture (PCCC)** to a **micro Gas Turbine (mGT)** and a typical Belgian **Combined Cycle Gas Turbine (CCGT)**

Workplan

1. Micro Gas Turbines
2. Combined Cycles Gas Turbines

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1. Micro Gas Turbines
2. Combined Cycles Gas Turbines

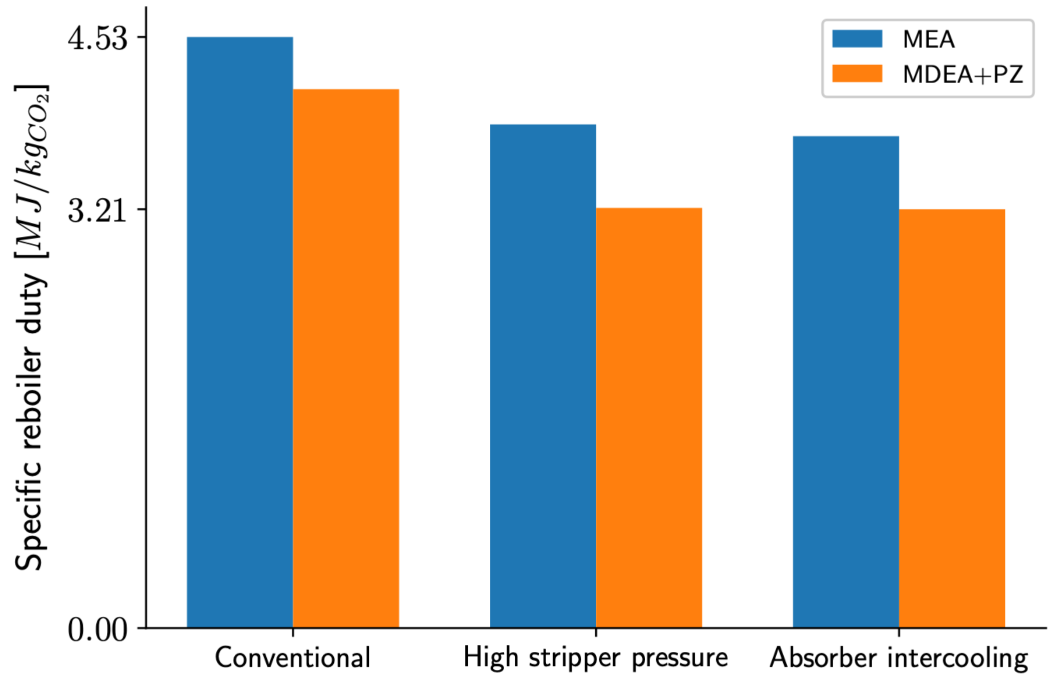
Carbon capture process improvement for mGT application

Carbon capture process improvement

Conventional MEA process optimisation

Implementation of another solvent MDEA/PZ

Implementation of more advanced configurations



Workplan

1. Micro Gas Turbines
2. Combined Cycles Gas Turbines

Problematic

CCGTs are increasingly used as peak units to back-up the intermittent renewable production

CGGTs operate mostly at partial load

The carbon capture design is typically based on the CCGT full load operation

The carbon capture performance is usually assessed at full load

The real impact of CCGT off-design operations on carbon capture performance and plant profitability is unknown

Objectives

Assessment of the performance of carbon capture plant applied to a typical CCGT power plant under various operation conditions

Assessment of the impact of realistic CCGT operating conditions over a year on the profitability of the plant

Approach

- The carbon capture plant is considered as an end-of-pipe unit without modifying the CCGT to retrofit existing power plants
- Steady-state thermodynamic cycle modelling

Methodology

CCGT flue gas properties prediction with Thermoflow

Carbon capture modelling approach

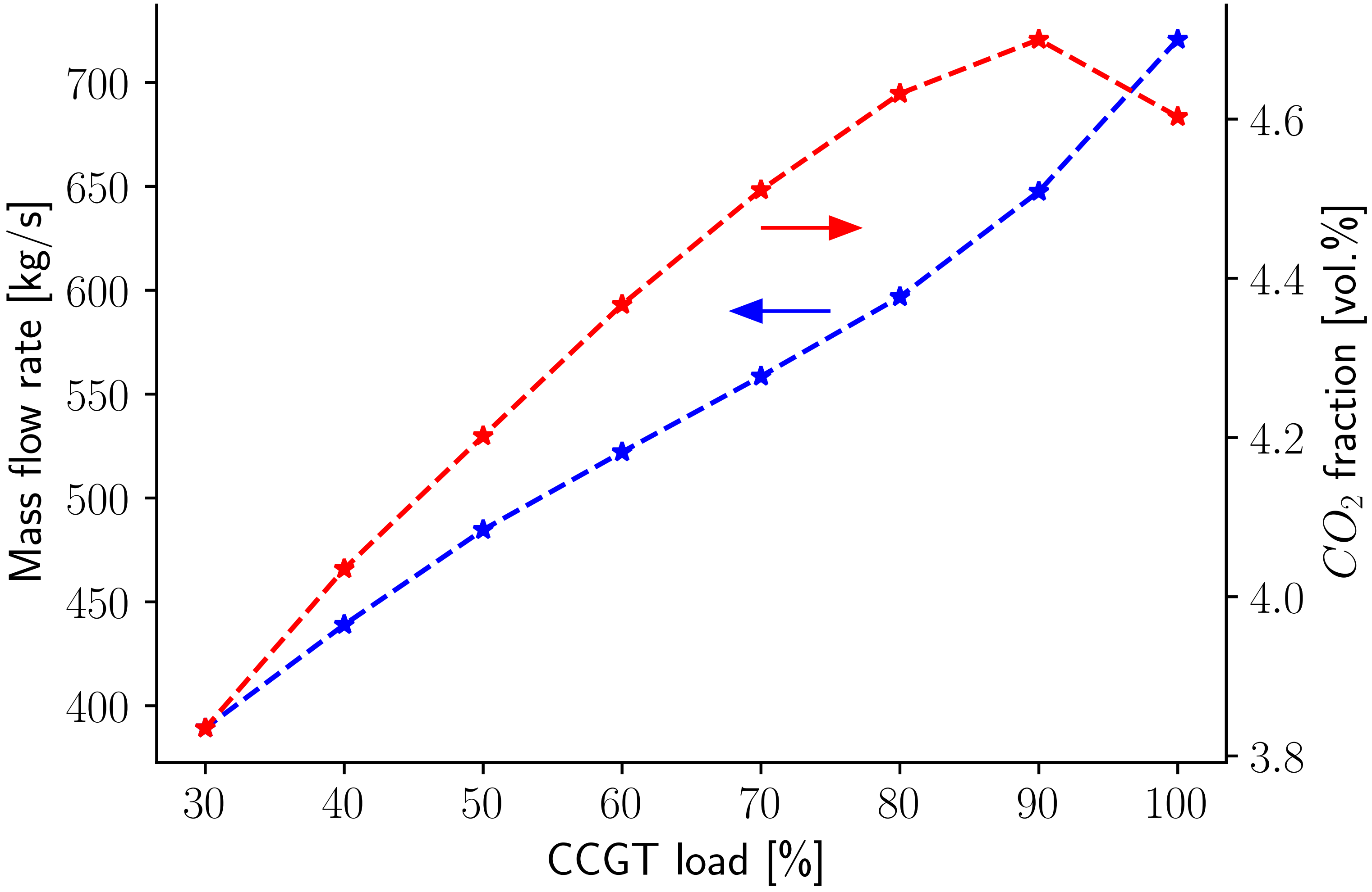
- Pilot-scale carbon capture modelling and validation
- Scale-up of the carbon capture plant
- Optimisation of the carbon capture process

CCGT flue gas properties were obtained using Thermoflow

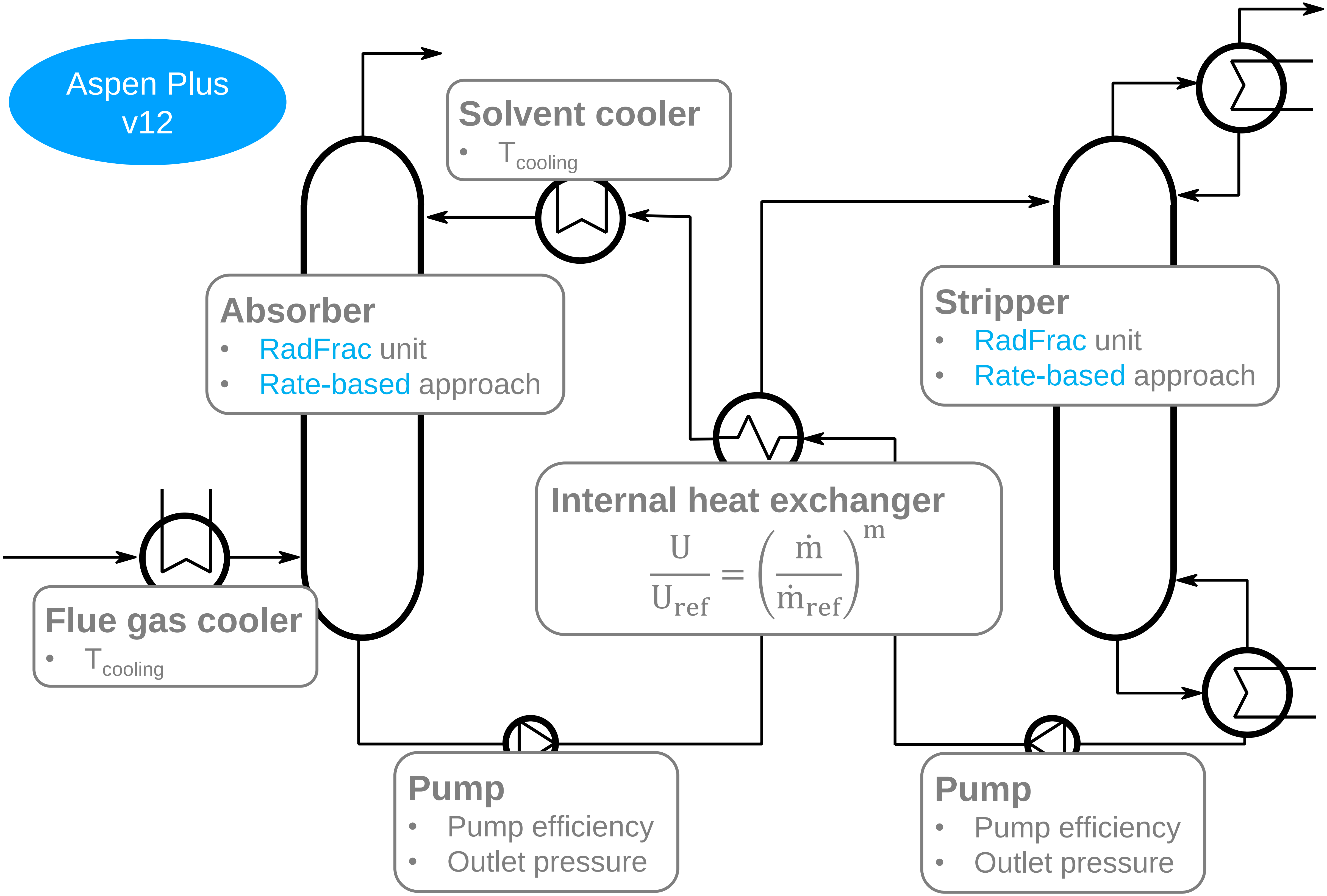
Generic H-class GT and 3 pressure level steam with reheat

Thermoflex simulation

CCGT load: from 100% to 30%



Themodynamic cycle modelling of the CC plant with Aspen Plus



The numerical model is validated

Pilot-scale Advanced Capture Technology (PACT) at UK Carbon Capture and Storage Research Centre (UKCCSRC)

	Absorber	Stripper
Diameter (m)	0.303	0.303
Packed height (m)	6	6
Packed type	IMPT#40	IMPT#40

L/G=1.86 kg/kg		Experimental data	Numerical model	Relative difference [%]
Rich CO_2 loading	[molCO$_2$/molMEA]	0.409±0.001	0.411	0.56
CO_2 captured	[kg/h]	16.47±0.4	16.48	0.07
CO_2 capture efficiency	[%]	90.35±3	90.38	0.04
Specific reboiler duty	[MJ/kg$_{CO_2}$]	5.92±0.8	5.81	1.77

L/G=3.77 kg/kg				
Rich CO_2 loading	[molCO$_2$/molMEA]	0.247±0.001	0.246	0.4
CO_2 captured	[kg/h]	16.3±0.59	16.09	1.31
CO_2 capture efficiency	[%]	94.93±4.2	93.73	1.27
Specific reboiler duty	[MJ/kg$_{CO_2}$]	13.27±2.21	15.67	**18.09**

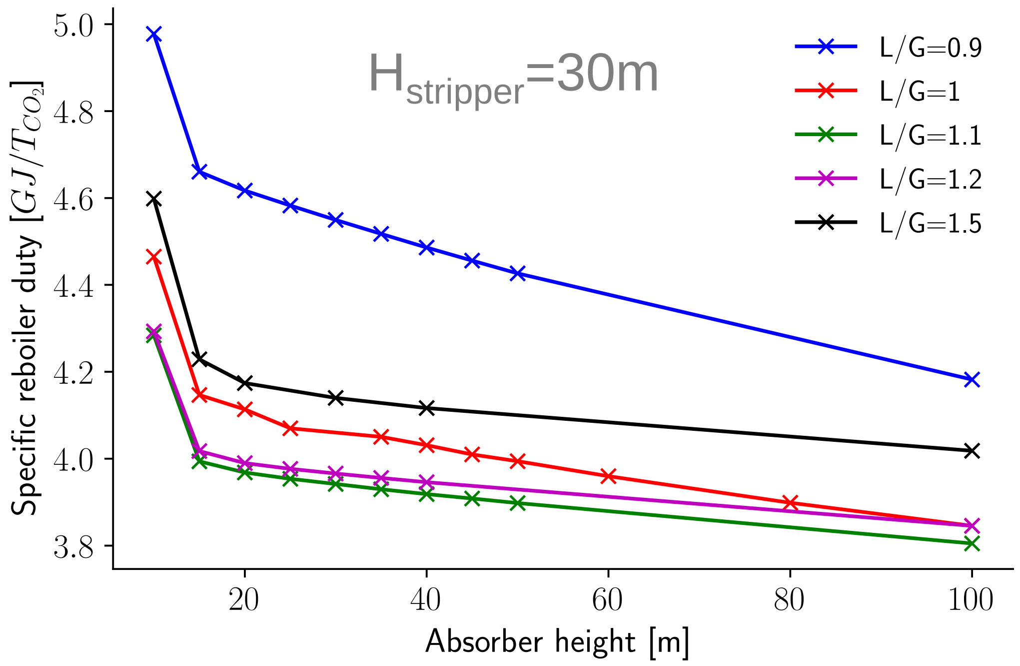
Scale-up of the carbon capture plant for CCGT application

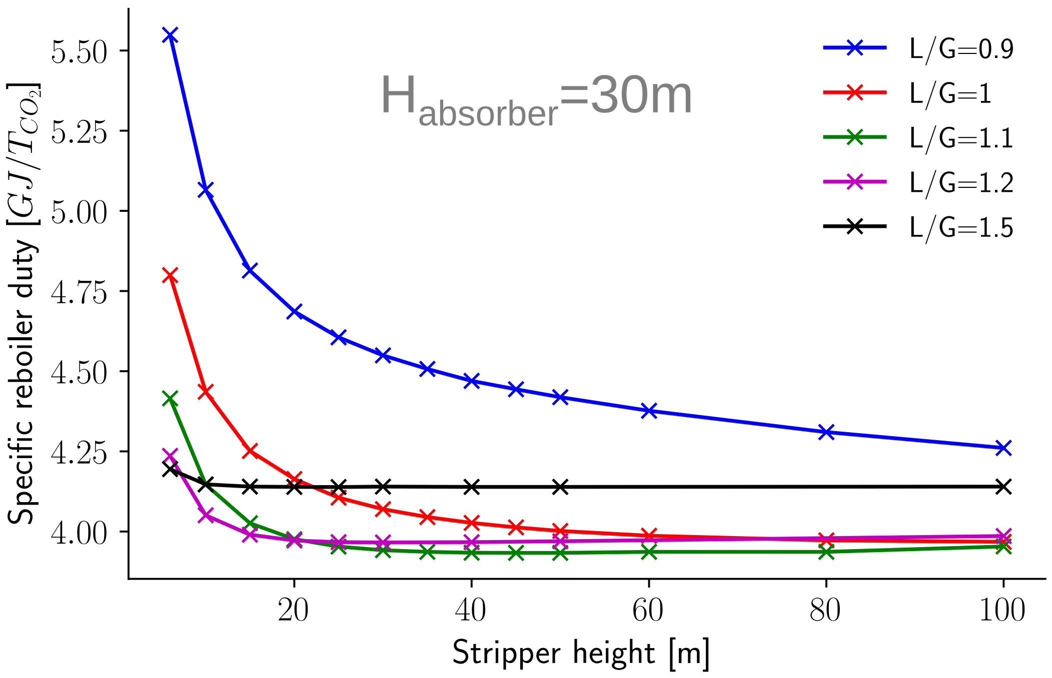
	Absorber	Stripper
Diameter [m]	18	8.5
Height [m]	30	30

Columns diameter?

Avoid flooding in the absorber and the stripper

Columns height?



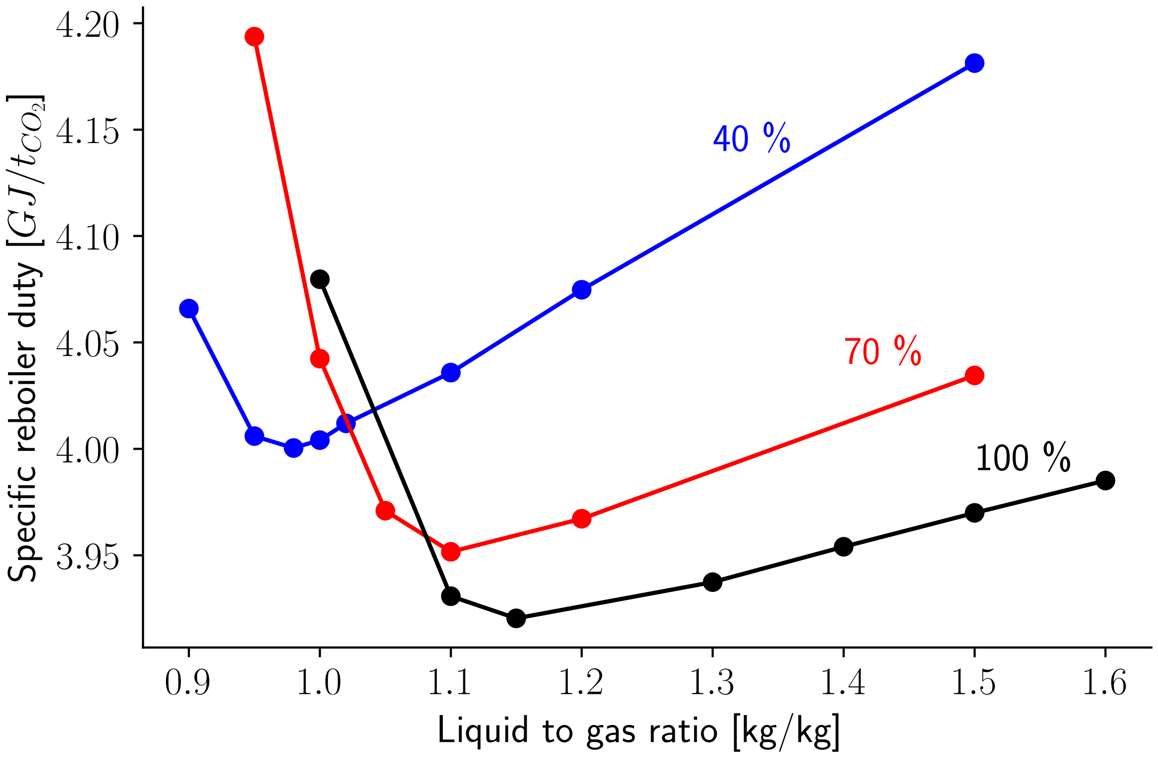


The CC process is optimized to minimize its energy consumption for each CCGT load

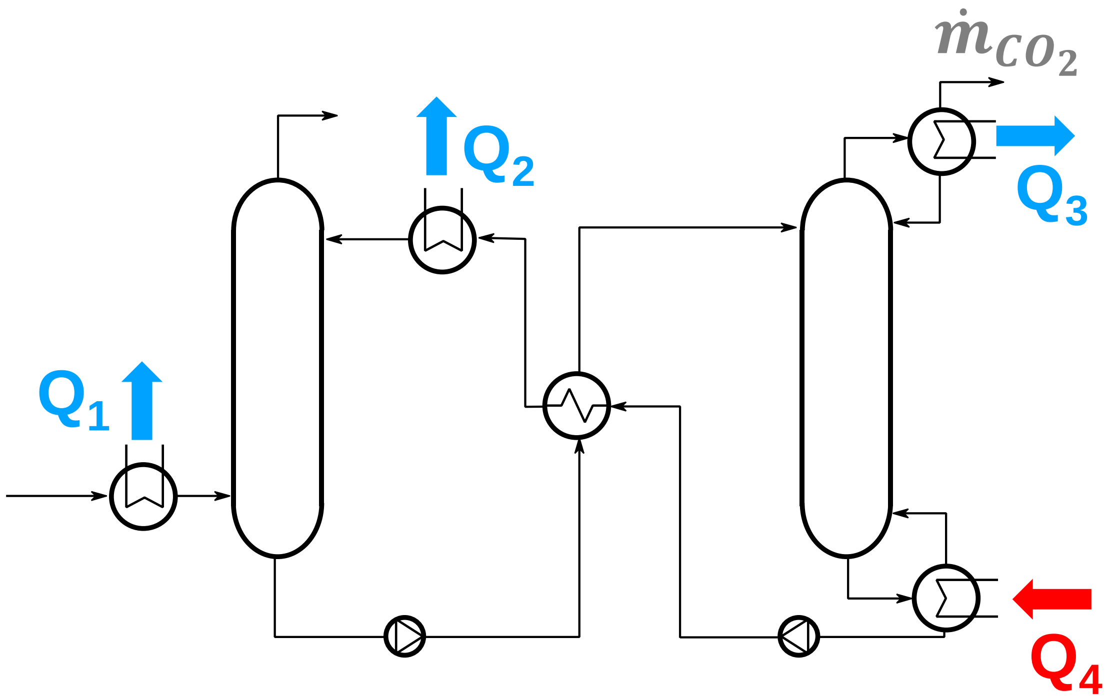
The L/G ratio has a high influence on the SRD for each CCGT load

If the CCGT load decreases:

- Optimal L/G decreases
- SRD increases

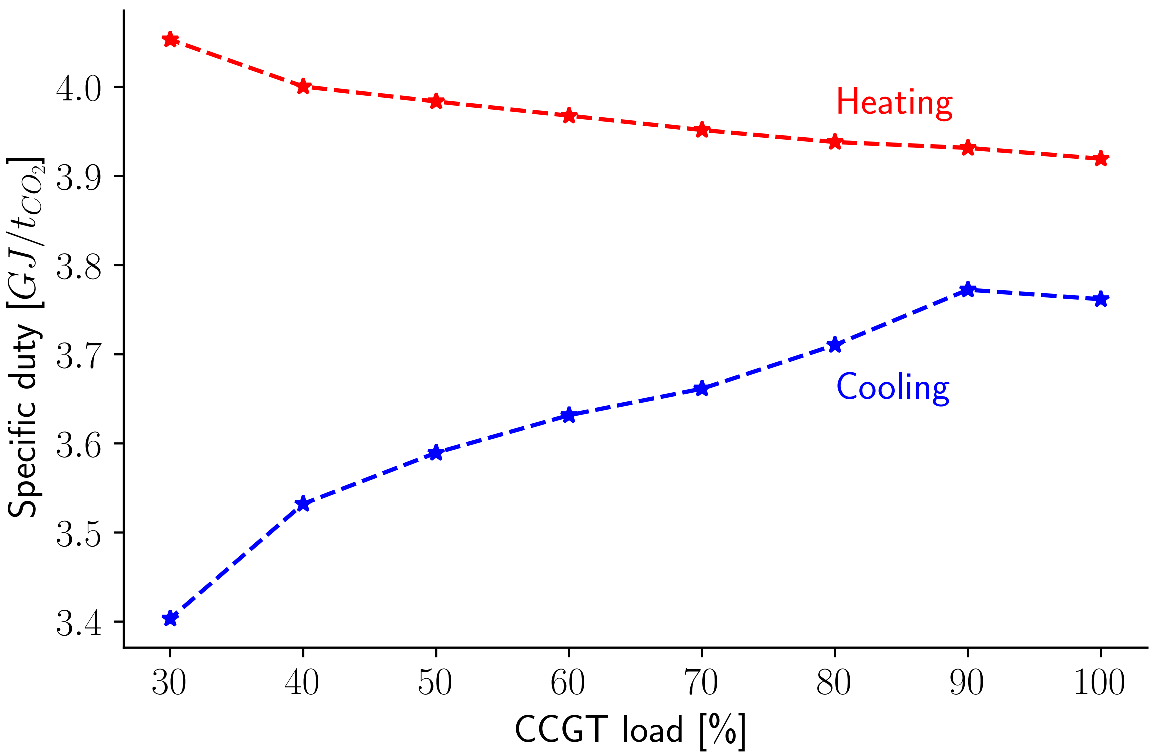


The heating duty increases, while the cooling duty decreases when the CCGT load is reduced



$$SCD = \frac{Q_1 + Q_2 + Q_3}{\dot{m}_{CO_2}}$$

$$SHD = \frac{Q_4}{\dot{m}_{CO_2}}$$



Different CCGT annual operations scenarios are analysed

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual load factor	1	0.5	0.5	0.75
Net electrical production [GWhe/y]	2109	2098	1050	2105

CCGT load	**30%**	**40%**	**50%**	**60%**	**70%**	**80%**	**90%**	**100%**
Scenario 1 [h]	-	-	-	-	-	-	-	4000
Scenario 2 [h]	3000	-	3000	2000	-	-	-	-
Scenario 3 [h]	1000	1000	1000	1000	-	-	-	-
Scenario 4 [h]	-	600	-	1500	-	2200	-	1000

CCGT part-load operations impact negatively CC performance

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual load factor	1	0.5	0.5	0.75
Net electrical production [Gwhe/y]	2109	2098	1050	2105
Energy input without CC [kWh/kWhe]	1.64	1.86 **+12%**	1.86 **+12%**	1.71 **+4%**
Energy input with CC [kWh/kWhe]	2.12	2.44 **+15%**	2.44 **+15%**	2.22 **+5%**
Increase in energy input due to the CC [kWh/kWhe]	0.48	0.58 **+21%**	0.58 **+21%**	0.51 **+6%**
CO_2 emissions without CC [g/kWhe]	326	370	370	341
CO_2 emissions with CC [g/kWhe]	35	40	40	37

Conclusions

Most of the studies evaluate carbon capture performance at full-load CCGT operation

Carbon capture performance negatively impacted by part-load CCGT operation

Useful insight for a thorough economic analysis

Decision-making about carbon capture should be based on analysis considering realistic CCGT operating conditions

Next steps

Micro Gas Turbine (mGT)

- Other advanced CC configurations (in progress)
- Energy integration between the mGT and the CC

Combined Cycle Gas Turbine (CCGT)

- Impact of Exhaust Gas Recirculation (EGR)
- Energy integration between the CCGT and the CC

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