UTCCS-3

The Third University of Texas Conference on Carbon Capture and Storage

Austin, Texas

February 17-19, 2016

POLYTECH MONS

UMONS Université de Mons

« Simulations of various configurations of the post-combustion CO_2 capture process applied to a cement plant flue gas: parametric study with MEA 30 wt.% »

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Partners: HEIDELBERGCEMENT Global Environmental Sustainability — NORCEM HEIDELBERGCEMENTGroup — ecra european cement research academy

In 2013, ECRA (European Cement Research Academy) and University of Mons signed an important scientific agreement related to the creation of a privileged partnership and the development, within the University, of an academic Chair financed by ECRA.

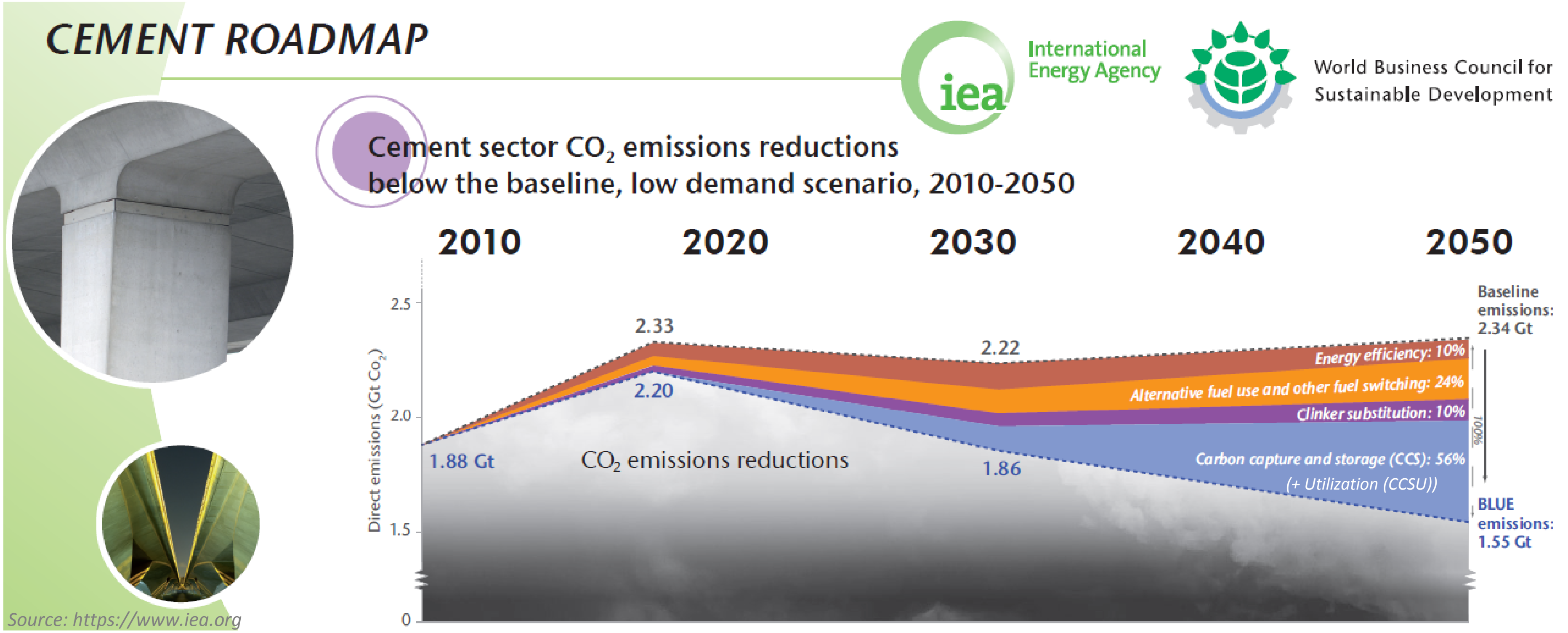
*The main objective of this academic Chair is to create a centre of scientific expertise in the specific field of "**carbon capture in cement production and its re-use**", and promote research and innovation.*

ECRA Chair prolonged until 2019!

http://hosting.umons.ac.be/html/ecrachair/

CO_2 emissions – Roadmap and actions

Cement plants ≈ 30% of the industrial CO_2 emissions



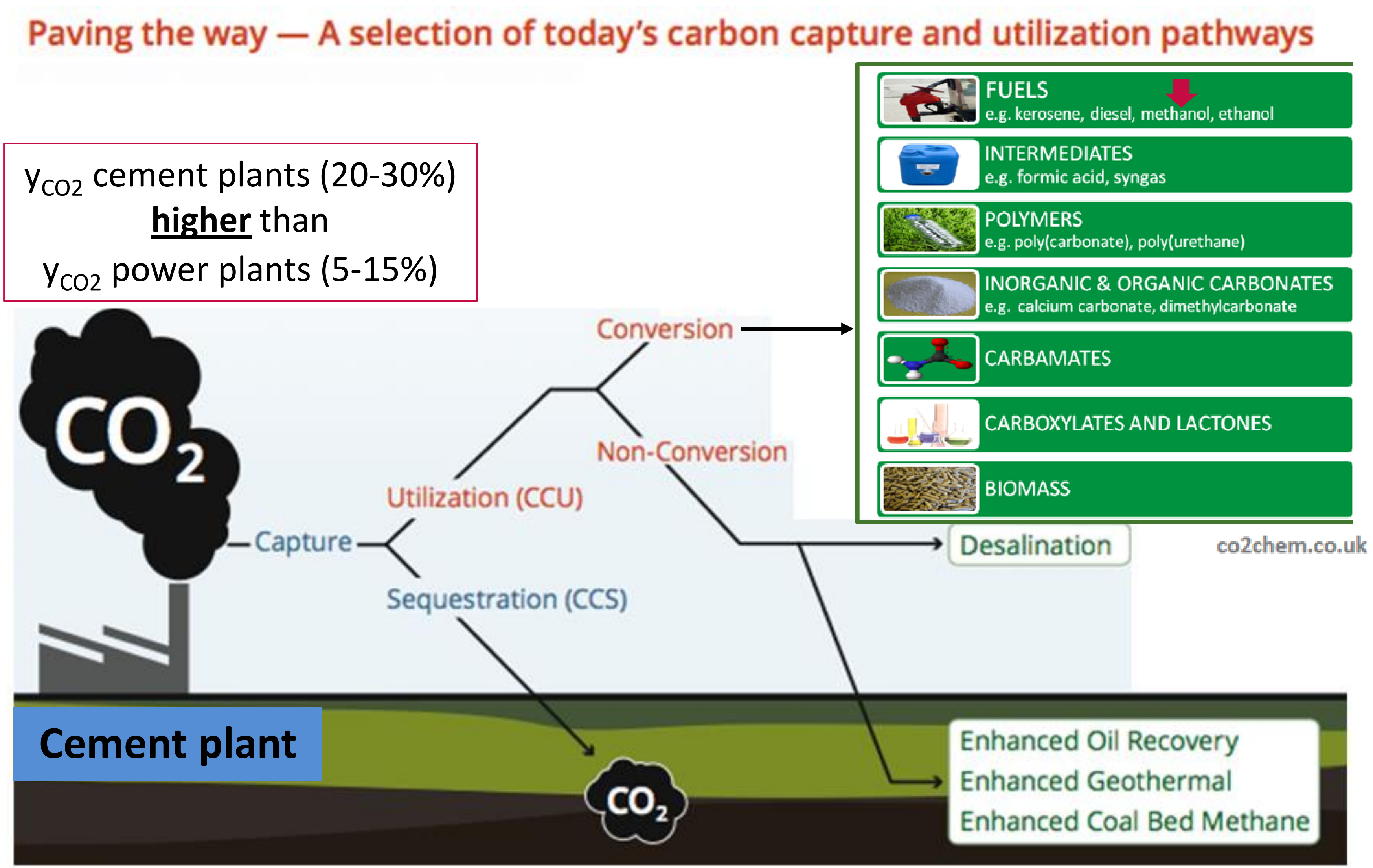
CO_2 emissions reductions

44% thanks to:
- Energy efficiency
- Alternative fuel
- Clinker substitution

56% thanks to Carbon Capture Storage/Utilization (CCSU)

CCSU (Carbon Capture Storage Utilization)

y_{CO2} cement plants (20-30%)
higher than
y_{CO2} power plants (5-15%)



Source: The Pembina Institute with Integrated CO_2 Network (ICO2N)

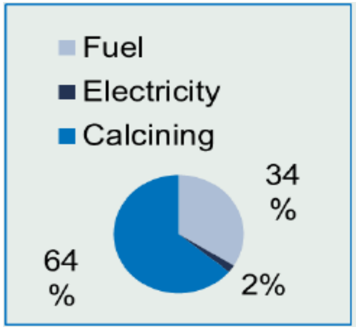
CO_2 Capture Techniques

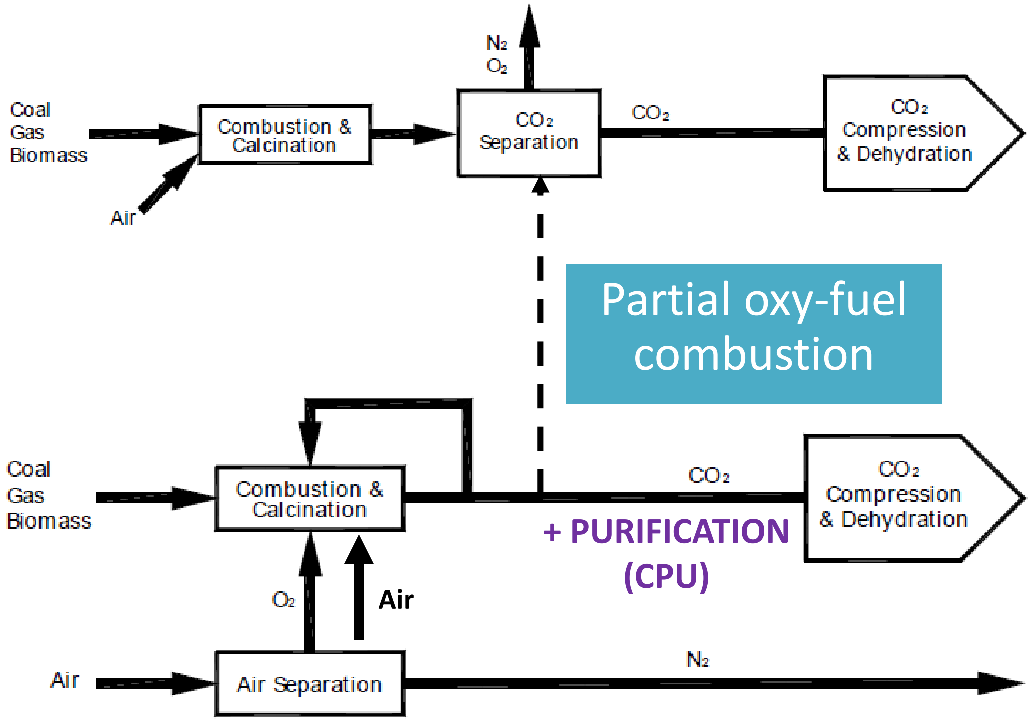
CO_2 Capture

- ~~Precombustion~~
- Postcombustion
- Oxycombustion

Not interesting for cement industry because most part of the CO_2 is coming from the calcining:

$$CaCO_3 + heat \rightarrow CaO + \uparrow \mathbf{CO_2}$$



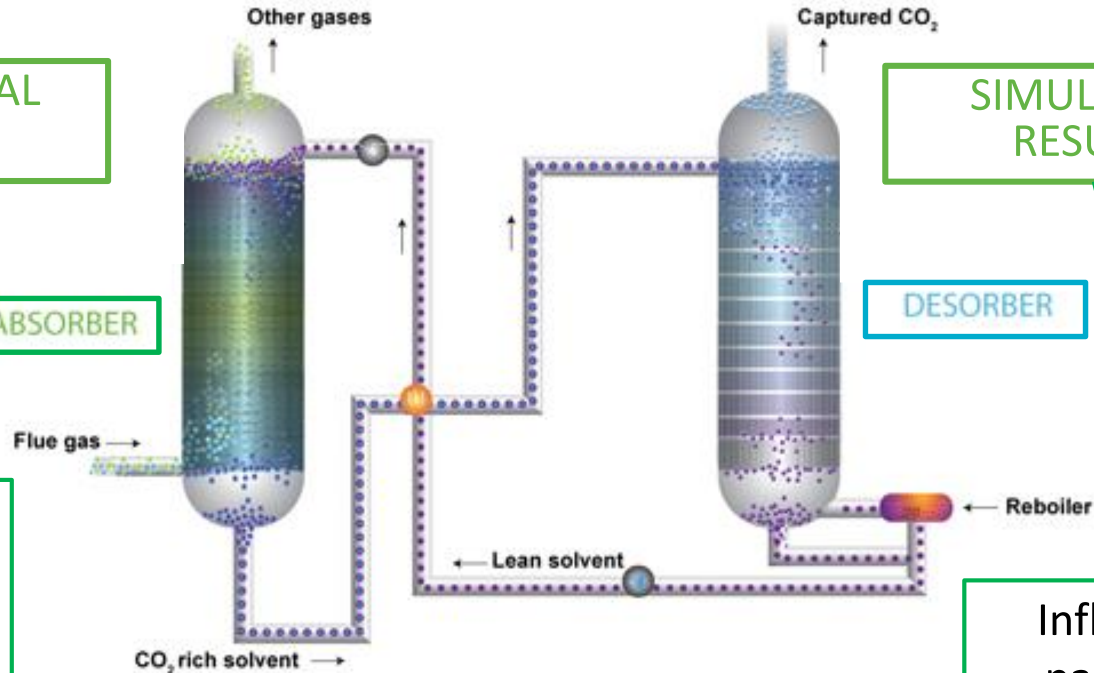


Experimental and simulation results

Absorption-regeneration process using amine(s) based solvents

EXPERIMENTAL RESULTS

SIMULATION RESULTS



From http://www.co2crc.com.au/

Evaluation of the absorption performances of a wide range of solvents in high CO_2 content conditions → Experimental screening of solvents

→ **Presentation by S. Laribi**

Influence of the partial oxy-fuel combustion conditions on the regeneration energy

Aspen Hysys™ simulations with alternative configurations
→ Current presentation

Context of the study: Brevik Project (Norway)

The Project

Including Aker Solutions amine based process

- ✓ Small scale test centre at Norcem Brevik
- ✓ 4 post-combustion CO_2-capture technologies
- ✓ Small scale testing → full scale perspective
- ✓ Kicked off in May 2013 – scheduled for 3,5 years

- ✓ Partners:
  - Norcem
  - HeidelbergCement
  - ECRA (European Cement Research Academy)

- ✓ **Project on behalf of the cement industry in Europe!**

- ✓ Total budget: 93 mill. NOK (11,7 M€)
- ✓ Gassnova / Climit-Program: 75% support

NORCEM
HEIDELBERGCEMENT Group

General principles of the simulations

NORCEM
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Brevik Cement plant

CASTOR/CESAR pilot

CO_2 recovery flow

$G_{CO_2,regen}$ = 1.5 t CO_2/h

G_{in} = 4000 m³/h
$y_{CO_2,in}$ = 20.4 mol.%
A = 90 mol.%
Purity of produced CO_2 = 98 mol.%

Brevik cement plant = ECRA reference
Single European project for testing
CO_2 capture from cement industry

CASTOR/CESAR pilot = reference
European projects
All data available

- Aspen Hysys V8.6
- Acid gas package
- Thermodynamic models: Peng-Robinson (gas) and e-NRTL (liquid)
- Reactions sets included in the package (validated by literature)

→ Simulations for different process configurations

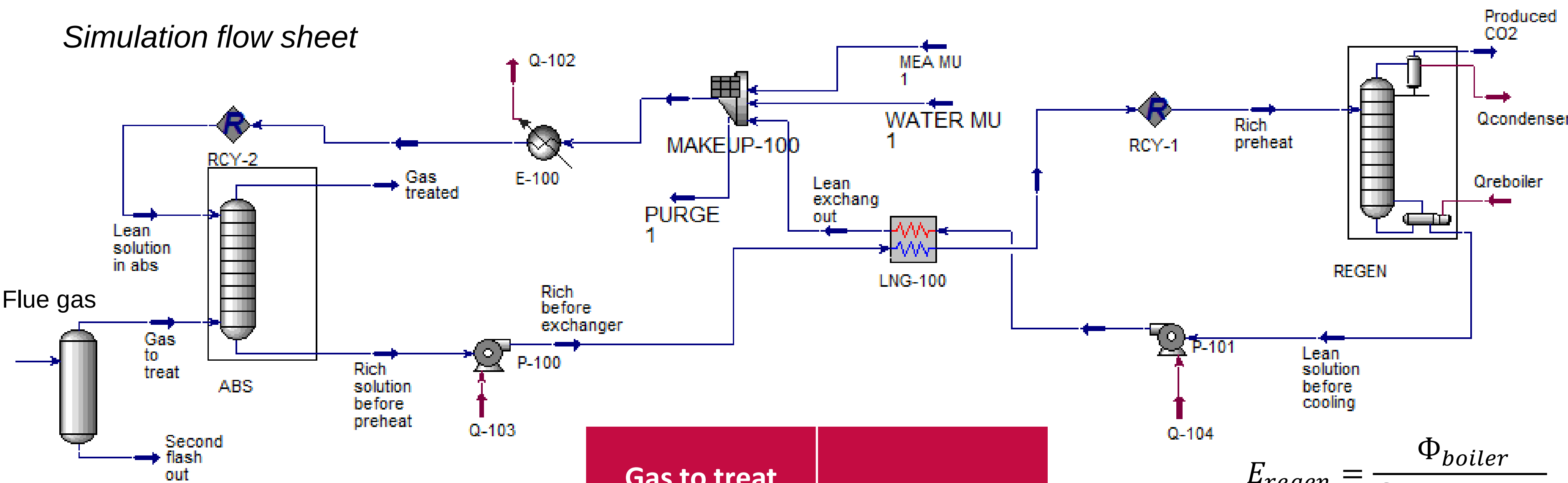
Comparison of Aker's MTU and CASTOR/CESAR pilot

Parameters	MTU from Aker tested at Brevik Cement plant	CASTOR/CESAR pilot used for the simulations
Absorber diameter	0.40 m	1.10 m
Absorber packing height	max 18.00 m	max 17.00 m (N_{stage} = 17)
Absorber pressure	-	1.2 bar
Desorber diameter	0.32 m	1.10 m
Desorber packing height	8.00 m	10.00 m (N_{stage} = 10)
Desorber pressure	-	2 bar
Packing type	MellapakPlus	Random packing IMTP 50
Gas flow rate	450 m^3/h	4000 m^3/h
Solvent circulation rate	max 4 m^3/h	max 40 m^3/h
CO_2 capture efficiency	90%	90%
Captured CO_2 flow from Brevik flue gas	≈ 0.15 t_{CO2}/h	≈ 1.5 t_{CO2}/h

≈ x 10

Simulation parameters

Simulation flow sheet



Master Thesis of G. Pierrot, 2015

$$E_{regen} = \frac{\Phi_{boiler}}{G_{CO_2,produced}}$$

Gas to treat Brevik cement plant	mol fraction
CO_2	0.2040
N_2	0.6470
H_2O	0.0622
O_2	0.0860
CO	1.33E-03
NO_2	1.77E-06
SO_2	1.11E-04
NO	4.74E-04
Ar	/

Process configurations

Improvements of the process:

A

Promoting absorption

thanks to temperature levels adjustments

B

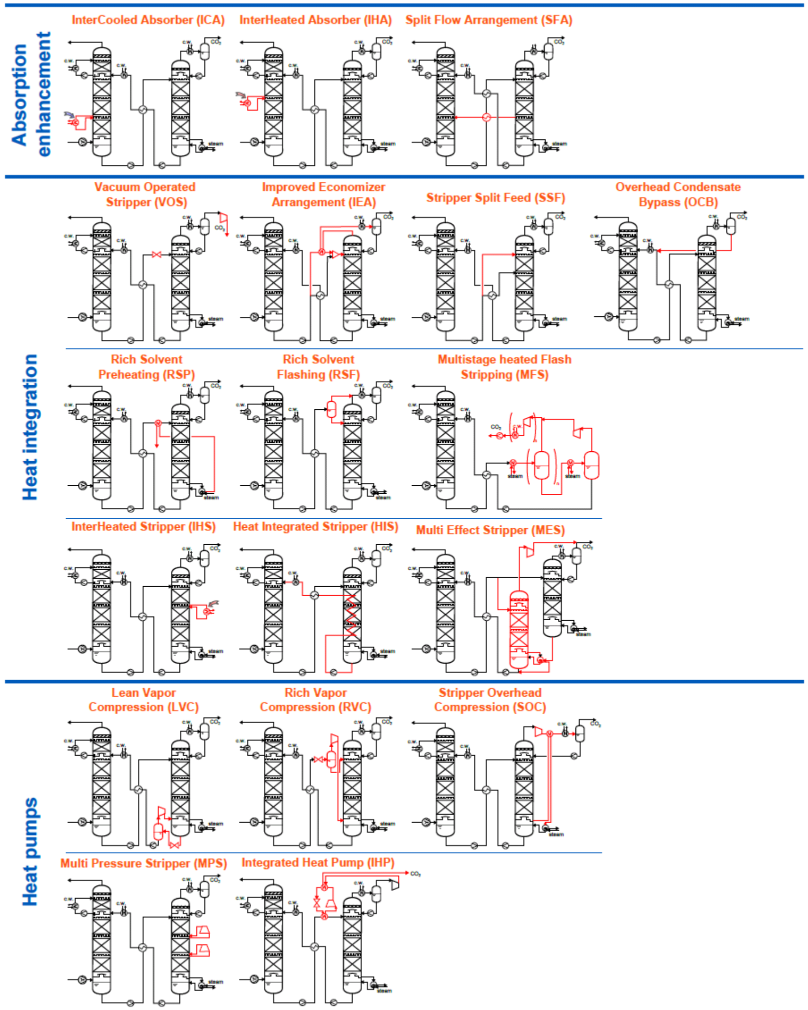
Promoting energy integration

thanks to enhancement of the heat exchanges between the fluids

C

Promoting heat recovery

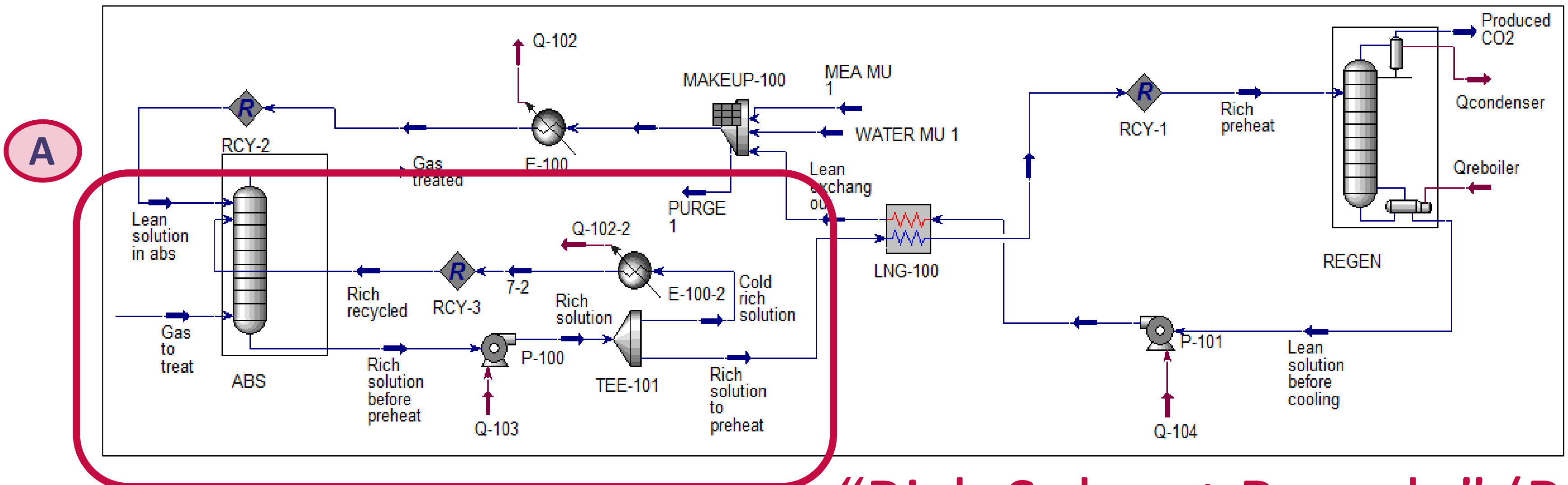
thanks to heat quality adjustments



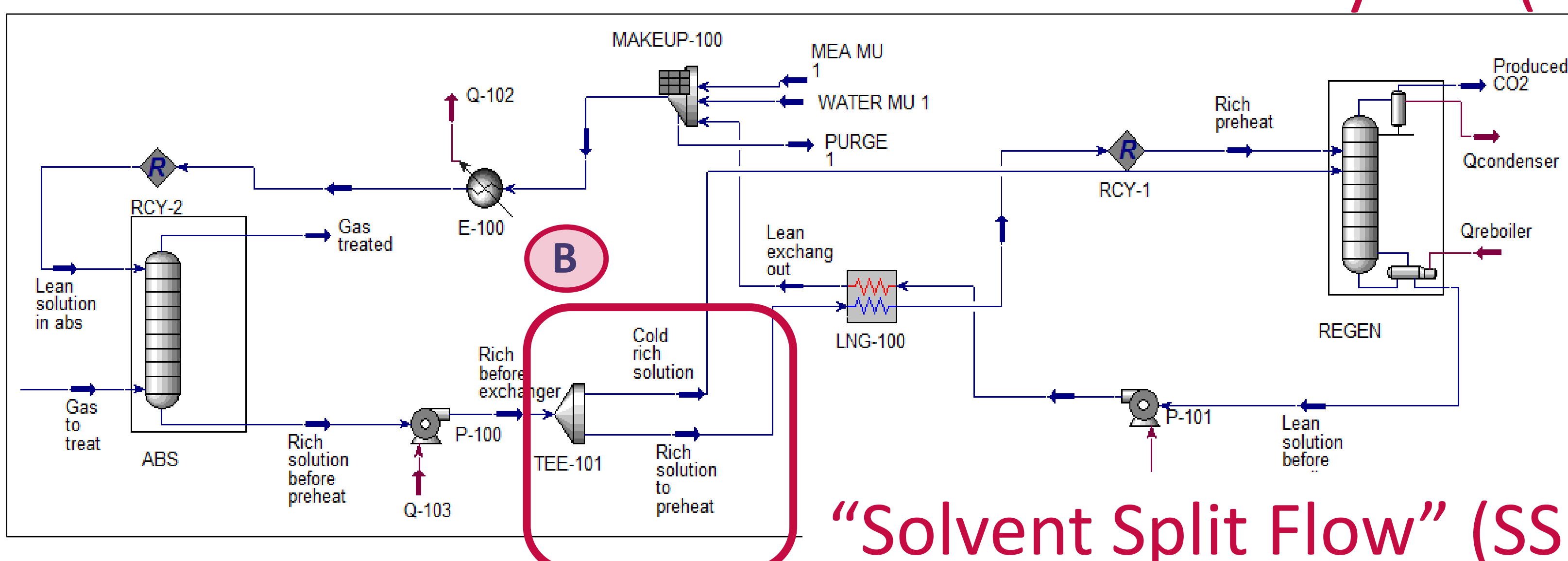
Classification des modifications individuelles de procédés (Le Moullec, Neveux, Hoff, et Chikukwa, 2013)

Simulation parameters

Alternative configurations:



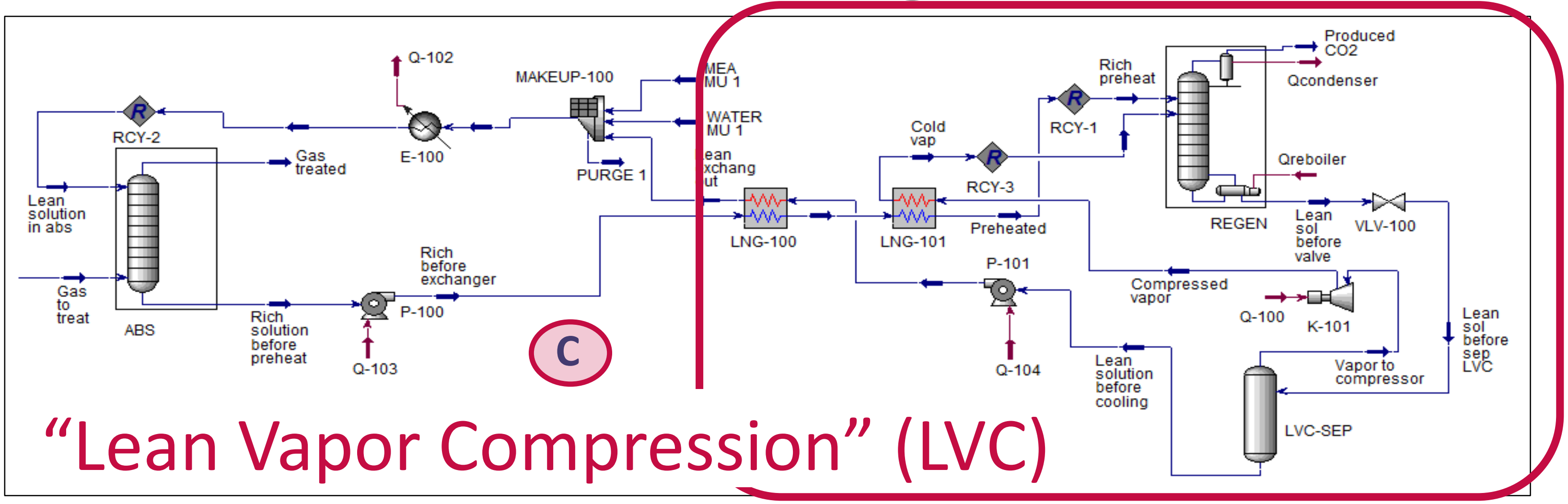
"Rich Solvent Recycle" (RSR)



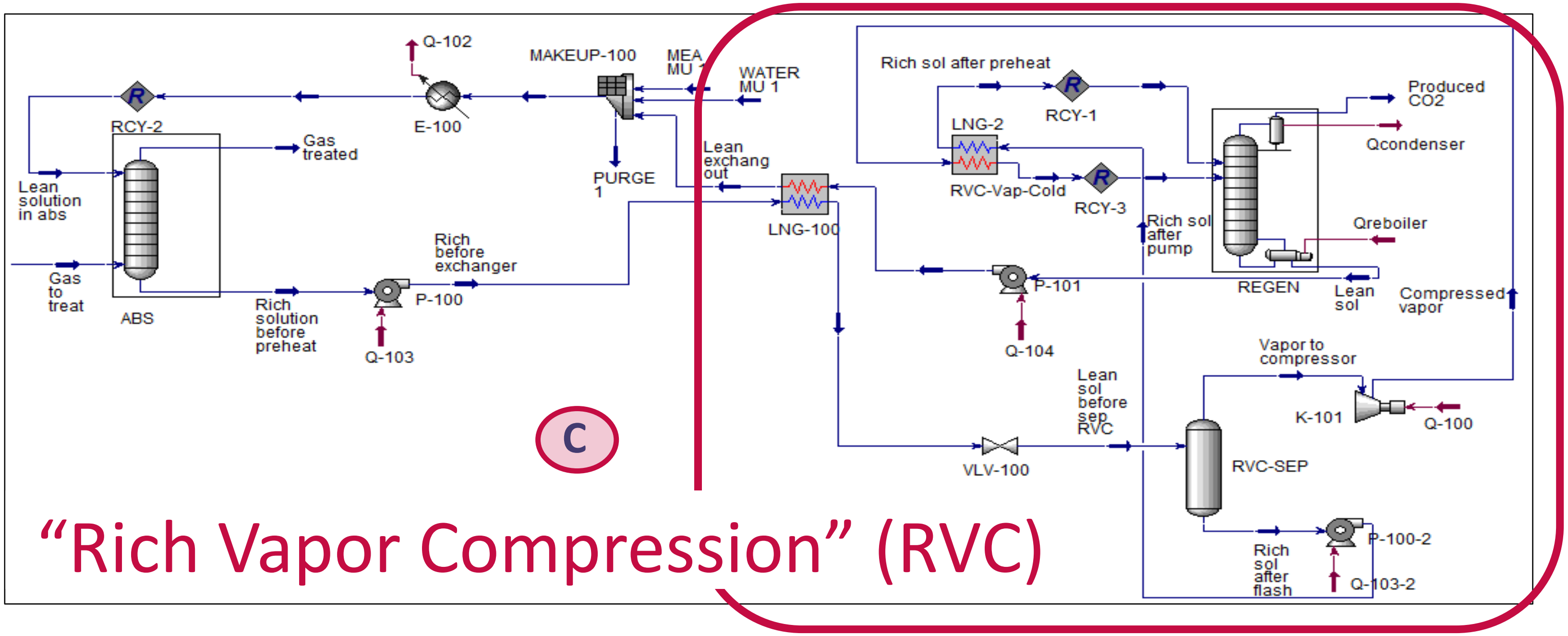
"Solvent Split Flow" (SSF)

Simulation parameters

Alternative configurations:



"Lean Vapor Compression" (LVC)



"Rich Vapor Compression" (RVC)

Simulation parameters

Parametric study: parameters considered

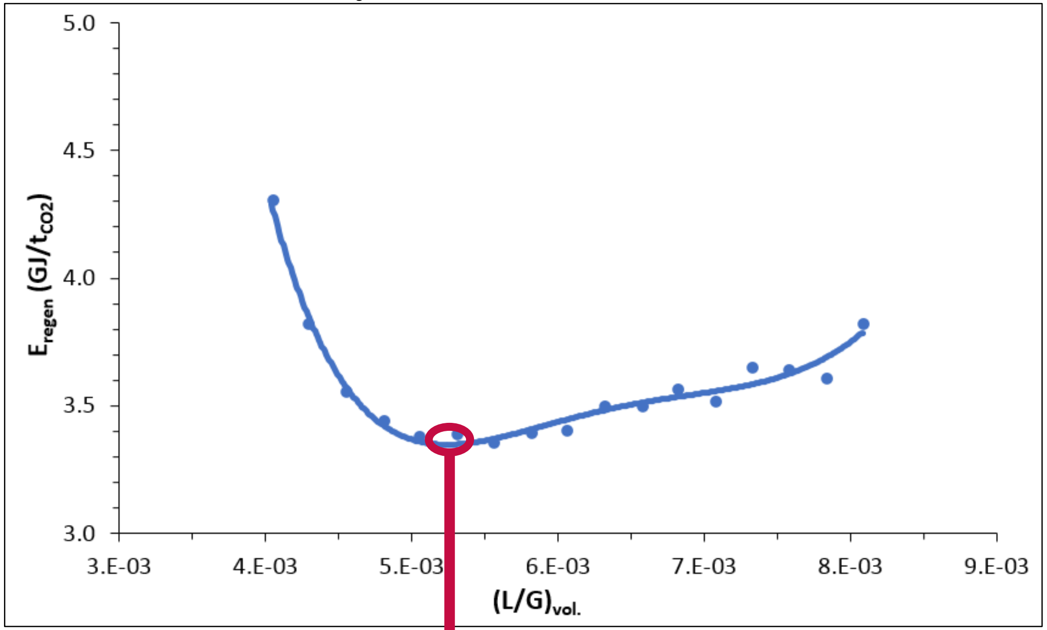
Base case	RSR	SSF	LVC	RVC
L/G	L/G	L/G	L/G	L/G
Injection level into the stripper	Re-injected fraction	Split fraction	Flash pressure drop	Flash pressure drop
	Re-injection level into the absorber	Injections level of the cold solution into the stripper		
	Re-injection temperature into the absorber	Injections level of the preheated solution into the stripper		

➔ Each parameter varied separately in a first step and then cross variation in a second step

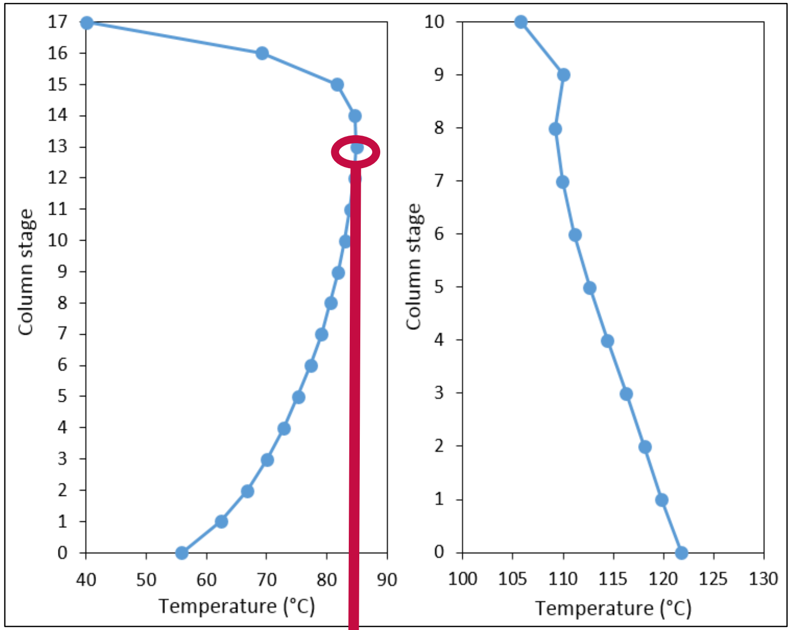
Simulation results

Conventional configuration:

E_{regen} as a function of the $(L/G)_{vol.}$ values



Temperature profiles into the absorber and the stripper



Minimum E_{regen} for $(L/G)_{vol.}$ = 5.56 10^{-3} (L = 22 m^3/h):

E_{regen} = 3.36 GJ/t_{CO2}

Due to the higher CO_2 partial pressure into the absorber: temperature reaches higher values than for power plants

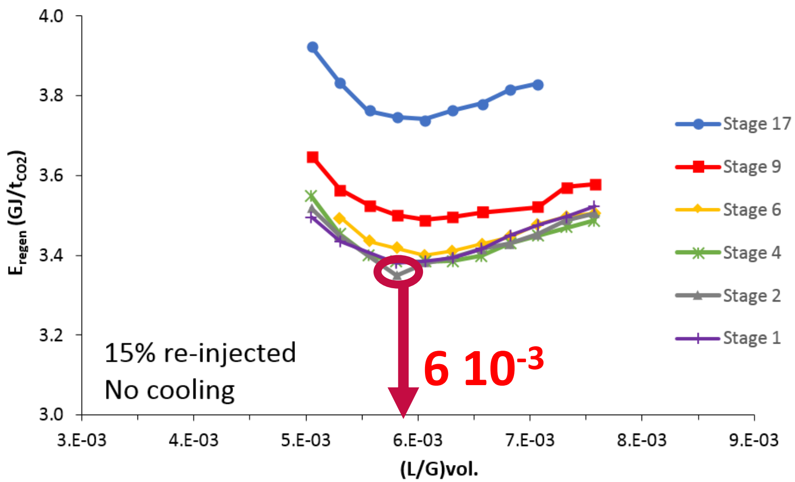
Note: optimum injection level into the stripper is 9/10 (allows a small decrease of $E_{condenser}$)

Simulation results

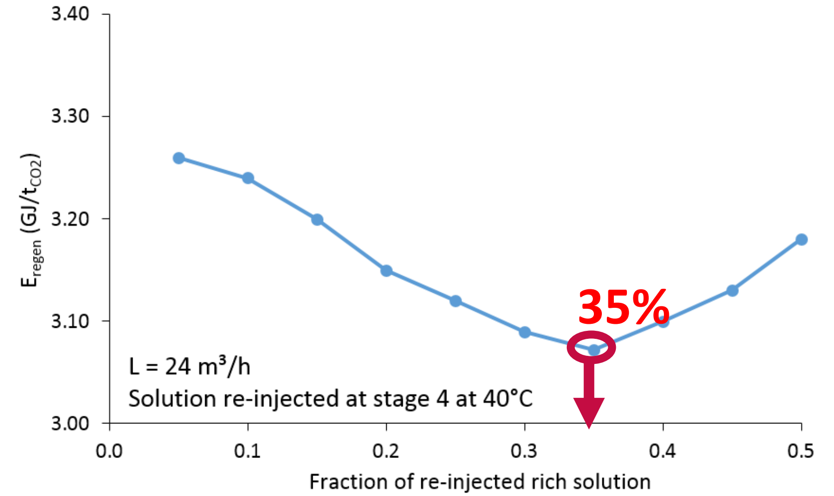
RSR configuration:

E_{regen} = 3.07 GJ/t_{CO2}

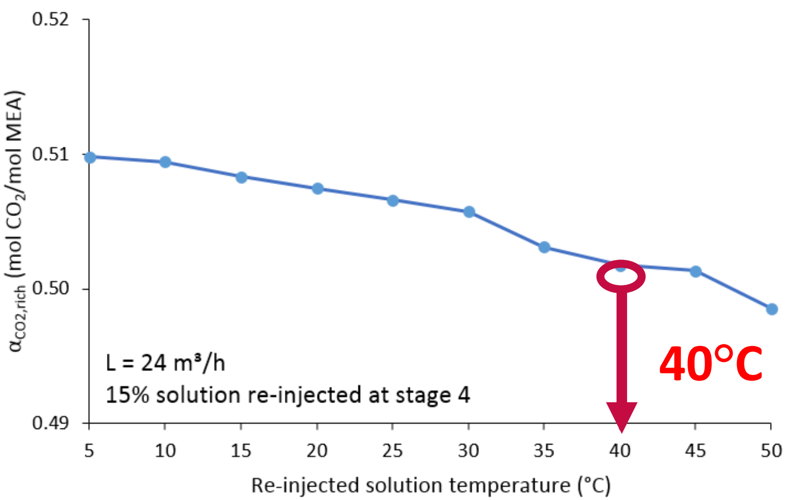
E_{regen} as a function of the re-injection level of the rich solution into the absorber for different $(L/G)_{vol.}$ values

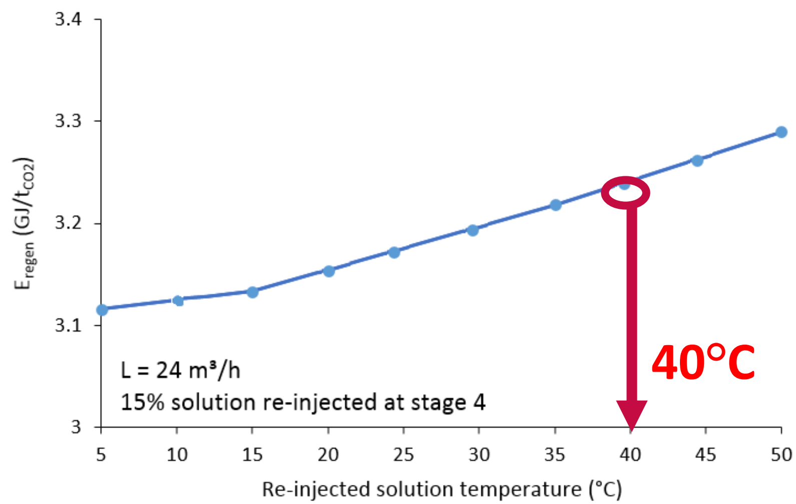


E_{regen} as a function of the percentage of re-injected solution into the absorber



$\alpha_{CO2,rich}$ and E_{regen} as a function of the re-injected solution temperature into the absorber





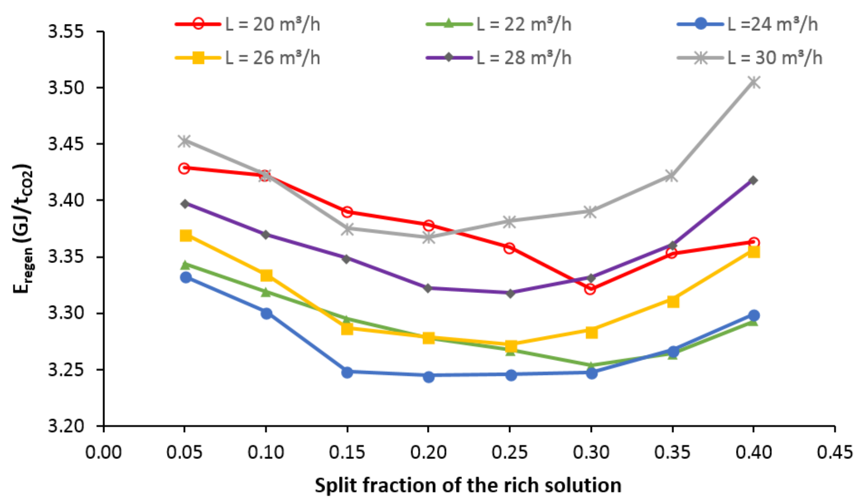
Simulation results

SSF configuration:

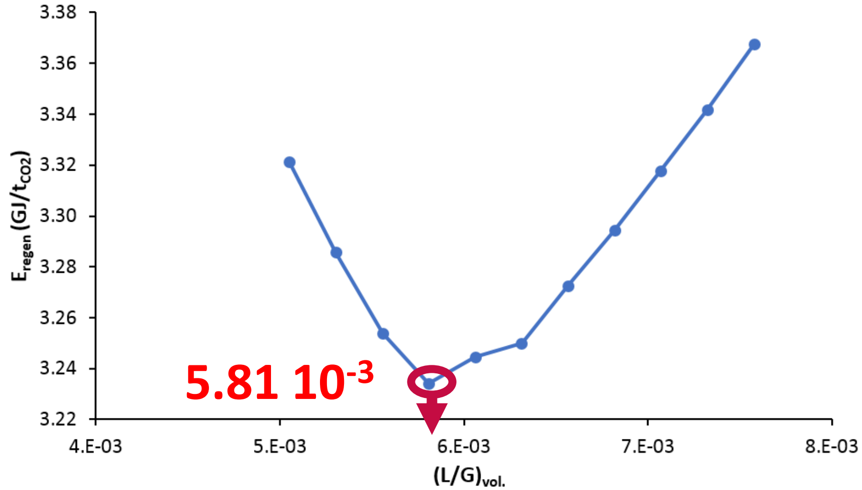
in the stripper:
cold solution injected at stage 10
hot solution injected at stage 8

E_{regen} = 3.22 GJ/t_{CO2}

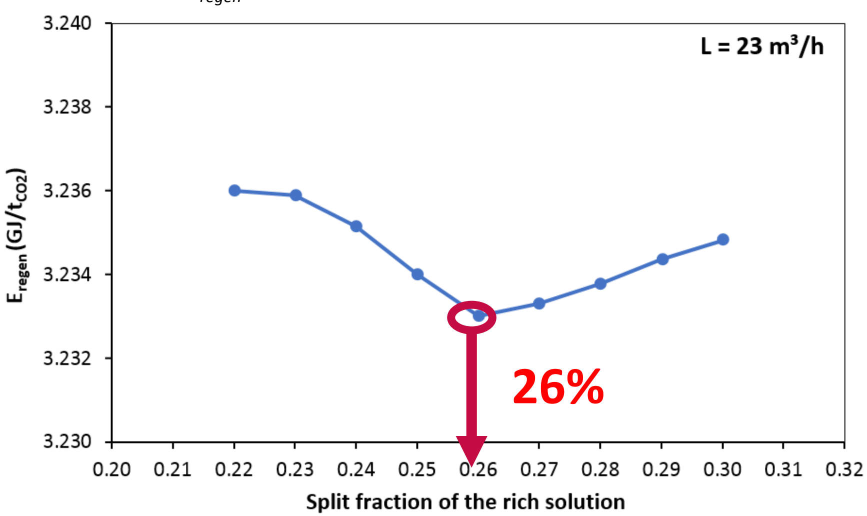
E_{regen} as a function of the split fraction for different liquid flow rates



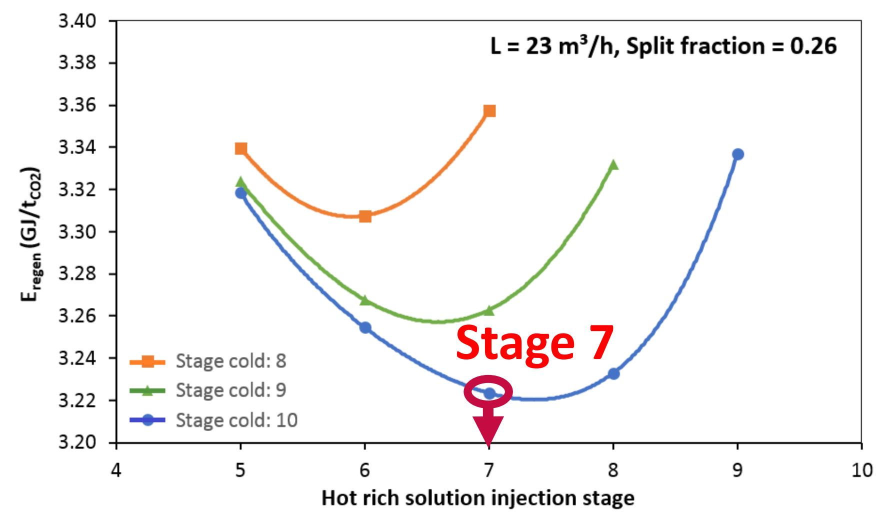
E_{regen} as a function of the $(L/G)_{vol.}$ ratio considering the optimum split fraction for each liquid flow rate value



E_{regen} as a function of the split fraction for L = 23 m³/h



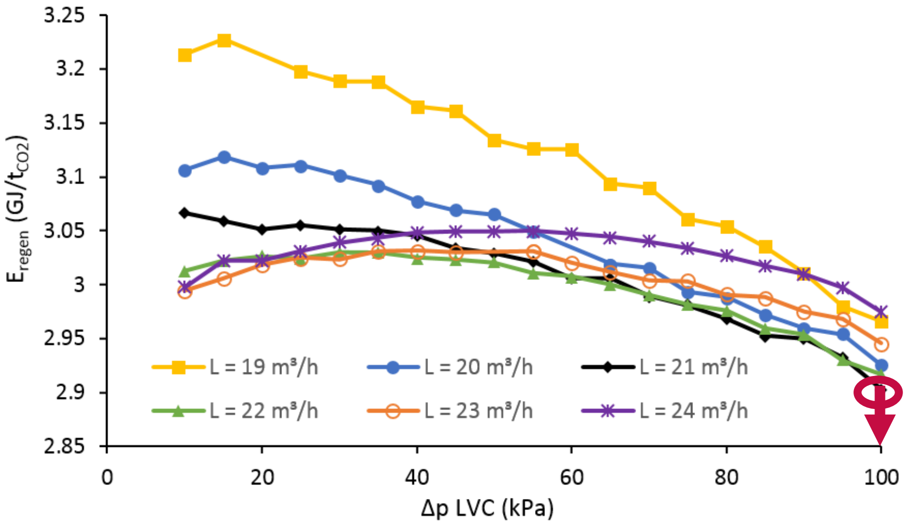
E_{regen} as a function of the injection stage of the hot solution into the stripper for different injection stages of the cold solution



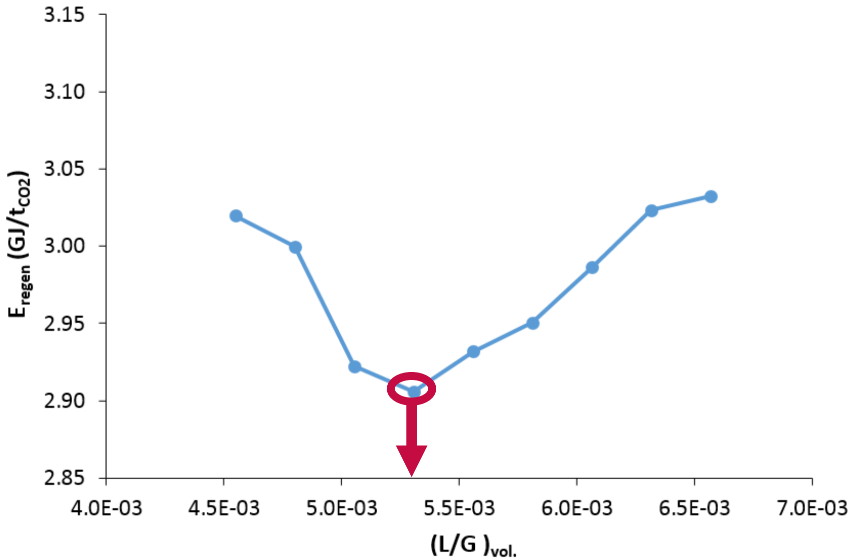
Simulation results

LVC configuration:

E_{regen} as a function of the LVC flash pressure drop (Δp) for different liquid flow rate



Regeneration energy as function of the $(L/G)_{vol.}$ ratio for a Δp of 100 kPa

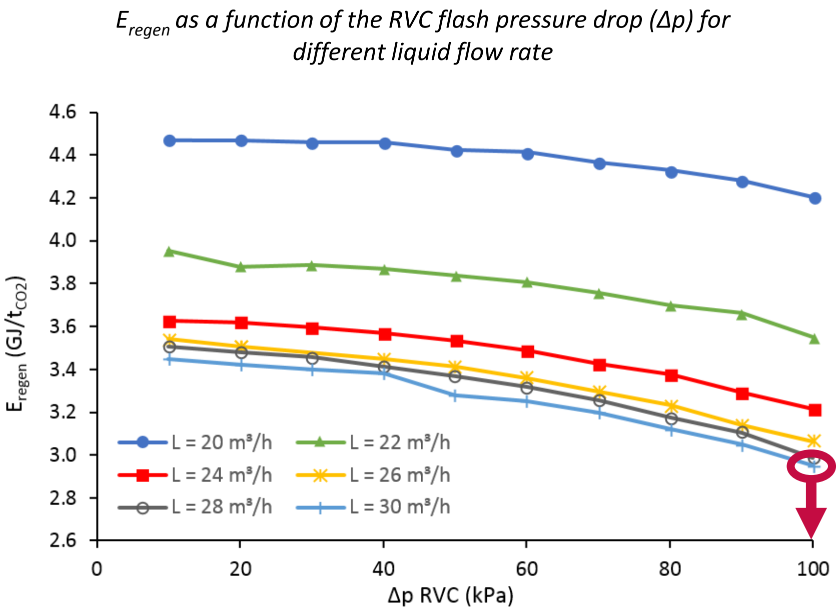


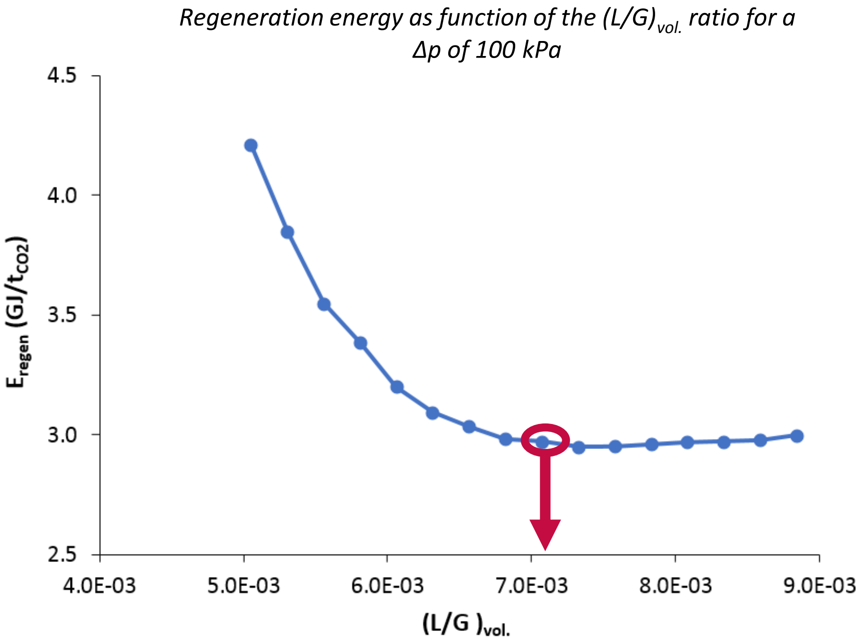
Minimum E_{regen} for Δp = 100 kPa and $(L/G)_{vol.}$ = 5.3 10^{-3} (L = 21 m^3/h):

E_{regen} = 2.91 GJ/t_{CO2}

Simulation results

RVC configuration:





Minimum E_{regen} for Δp = 100 kPa and $(L/G)_{vol.}$ = 7.33 10^{-3} (L = 29 m³/h):

E_{regen} = 2.95 GJ/t_{CO2}

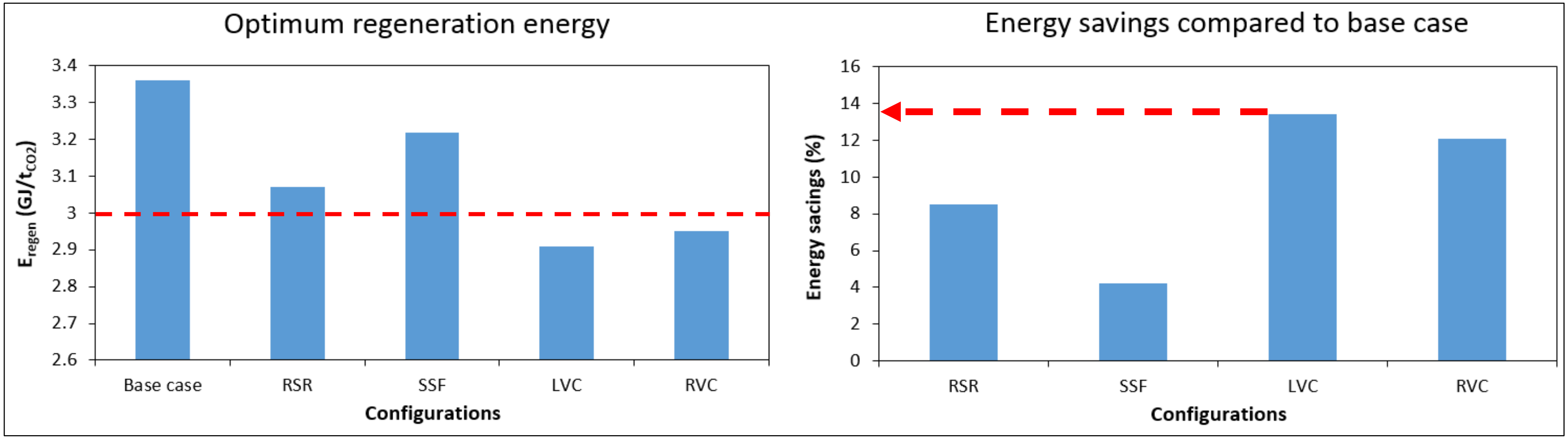
Simulation results

Global comparison of the simulation results

MEA 30 wt.%	Base case	RSR	SSF	LVC	RVC
Operating conditions					
$(L/G)_{vol,opt}$ (m^3/m^3)	$5.56\ 10^{-3}$	$6.06\ 10^{-3}$	$5.81\ 10^{-3}$	$5.30\ 10^{-3}$	$7.33\ 10^{-3}$
Split fraction rich sol. (%)	-	35	26	-	-
Re-injection sol. temp. (°C)	-	40	-	-	-
Re-injection abs. stage (N°)	-	4	-	-	-
Hot sol. stripper stage (N°)	-	-	7	-	-
Cold sol. stripper stage (N°)	-	-	10	-	-
Flash pressure drop (kPa)	-	-	-	100	100
$\alpha_{CO2,rich}$ (mol/mol)	0.51	0.51	0.50	0.51	0.47
$\alpha_{CO2,lean}$ (mol/mol)	0.21	0.24	0.22	0.20	0.25
Energy consumptions					
E_{pump} (GJ/t_{CO2})	$1.57\ 10^{-2}$	$1.57\ 10^{-2}$	$1.57\ 10^{-2}$	$1.58\ 10^{-2}$	$1.58\ 10^{-2}$
$E_{condenser}$ (GJ/t_{CO2})	-1.94	-1.89	-1.02	-0.91	-1.52
$E_{LVC/RVC\ compressor}$ (GJ/t_{CO2})	-	-	-	$8.28\ 10^{-2}$	$13.57\ 10^{-2}$
E_{regen} (GJ/t_{CO2})	3.36	3.07	3.22	2.91	2.95
E_{regen} savings /Base case (%)	-	8.5	4.2	13.4	12.1

Conclusions

Global comparison of the simulation results



➔ **Best results with "heat recovery" modifications (C): RVC and LVC**

- **E_{regen} < 3 GJ/t_{CO2}** is possible with MEA 30 wt.% (even if $y_{CO2,cement\ plants} > y_{CO2,power\ plants}$)
- **Almost 14% energy savings** in comparison with the conventional configuration
- Detailed results for MEA 30 wt.% in a forthcoming publication
- <u>Next step:</u> detailed results for both **MEA**, **PZ** and **aMDEA**
  → will be presented at GHGT-13 Conference in November 2016

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Thanks very much for your attention !

Questions?

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