DMX DEMONSTRATION IN DUNKIRK (3D):

RELIABILITY ANALYSIS OF EXPERIMENTAL DATA

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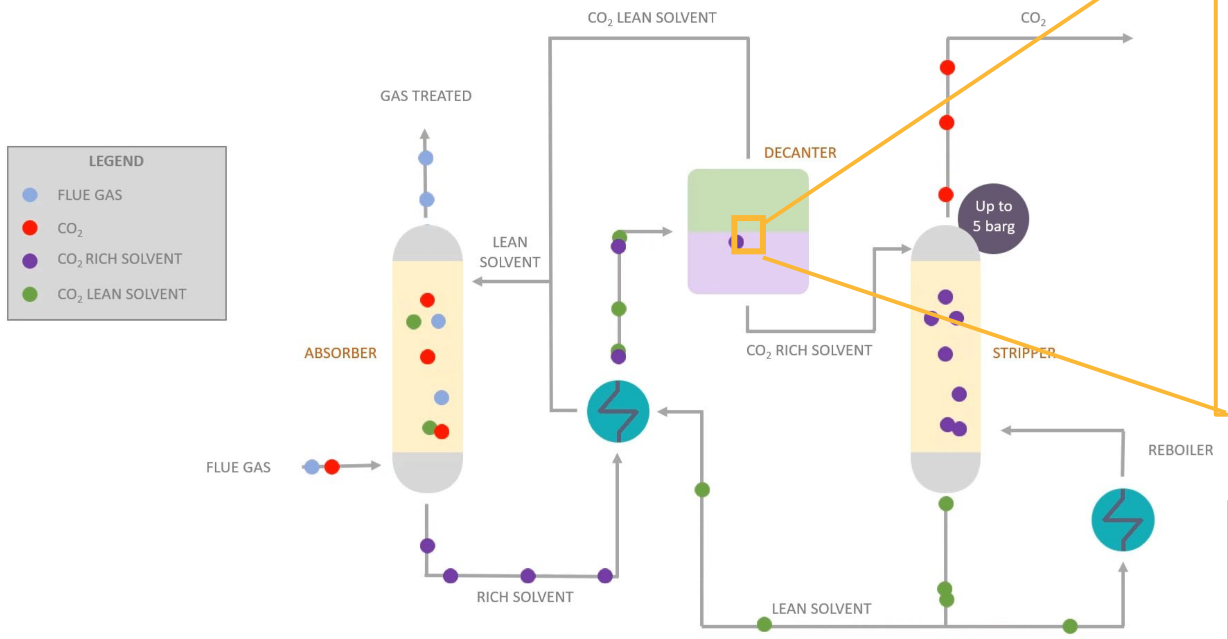
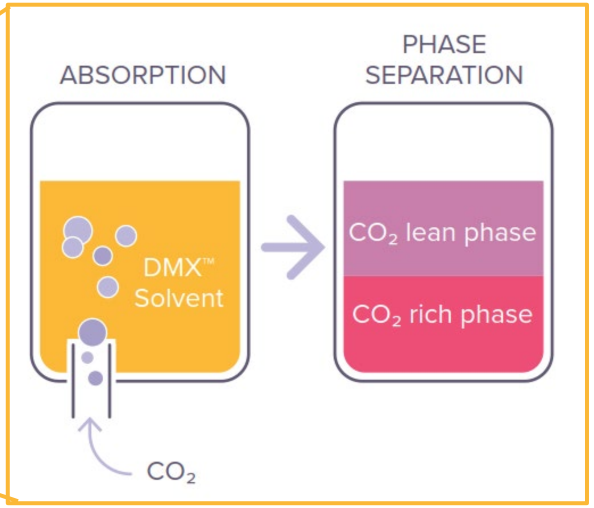
PLAN

- DMX technology
- 3D demonstrator
- Experimental plan of 2024 campaign
- Energy penalty uncertainty sources:
  - Reconciling mass balance discrepancies
  - Reconciling heat balance discrepancies
- Evaluation with inhouse simulator
- Conclusions

POST-COMBUSTION - FLUE GAS - DMX™ PROCESS

Flue Gas CO_2 capture - DMX™ Process





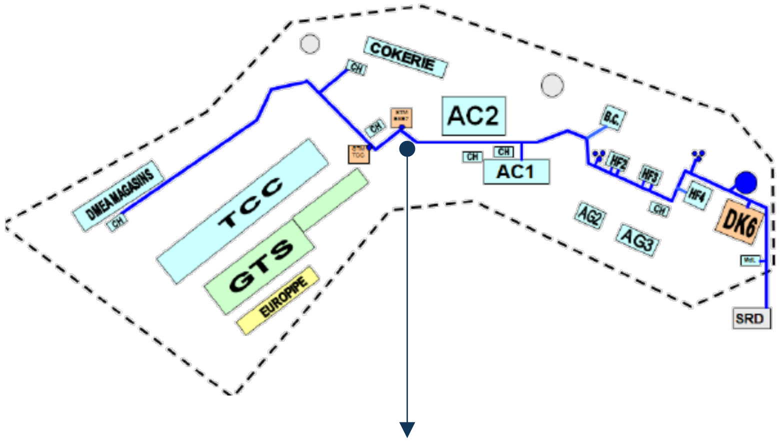
Axens
Powering integrated solutions

Benefits of DMX Solvent

I. Low energy consumption for capture rate > 90%
II. Thermally stable solvent with low sensitivity to oxygen
III. High purity of CO_2 produced at high pressure

THE 3D DEMONSTRATOR (1/2)

ArcelorMittal France (AMF) Blast Furnace Gas Network



Treating actual blast furnace gases to evaluate the solvent stability over time

Component	Unit	Value
CO	dry mol%	24
CO_2	dry mol%	25
H_2	dry mol%	4
N_2	dry mol%	47
Others	dry mol%	<0.3
Total	dry mol%	100.0

Large enough to be representative for industrial scaling-up

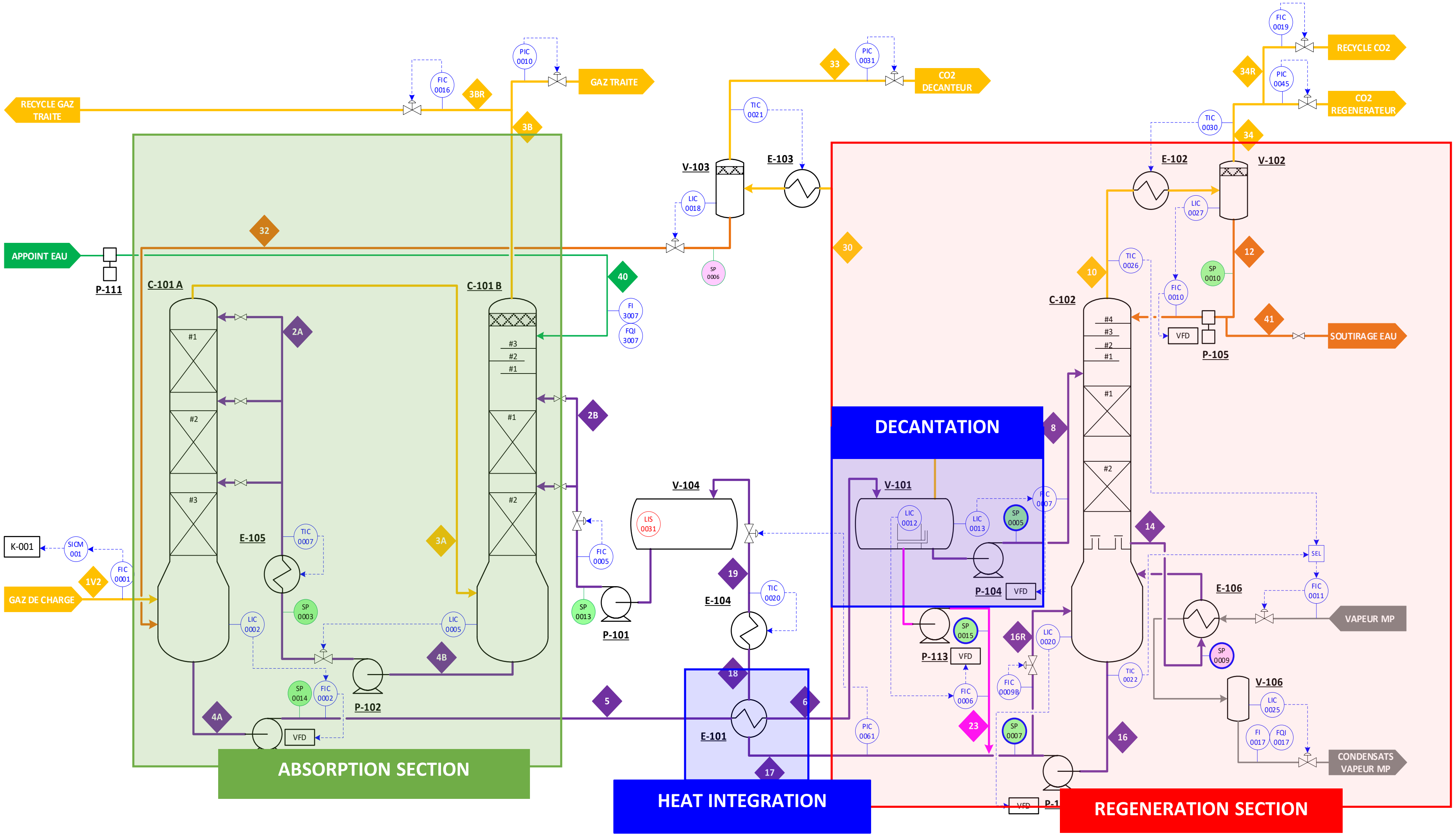
	Key values
Columns height	**30 m**
Columns diameter	**350 - 450 mm**
Absorption pressure	**0.1 – 1.8 barg**
Regeneration pressure	**2 – 5 barg**
Gas flowrate	**200 – 1100 Nm3/h**
Solvent flowrate	**2500 – 7500 kg/h**
Design capacity	**0.5 tCO_2/h**

Small enough to not perturb industrial activity

	Ratio 3D/AMF
BF Gas	**0.1%**
MP steam	**0.6%**

THE 3D DEMONSTRATOR (2/2)

Climate, Environment and Circular economy



THE 3D DEMONSTRATOR (2/2)

Climate, Environment and Circular economy

Utilities from AMF :

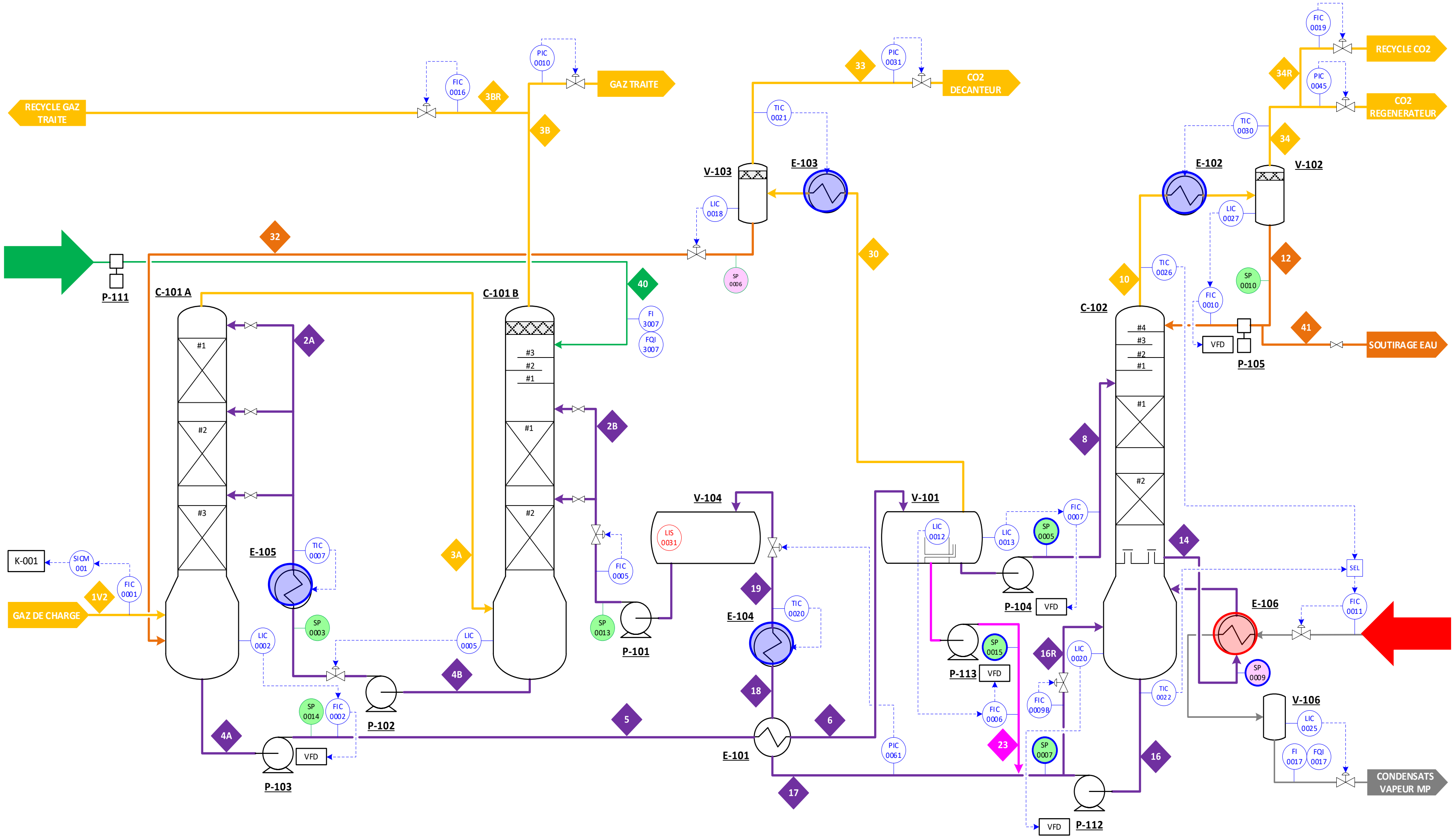
- Steam
- Water
- Electricity
- Nitrogen
- Air instrument

Demineralized water production package

Cooling water package (closed loop)

Auxiliaries

- Solvent filtration
- Closed solvent drain network
- Anti-foam injection



Steam from AMF network

THE 3D DEMONSTRATOR (2/2)

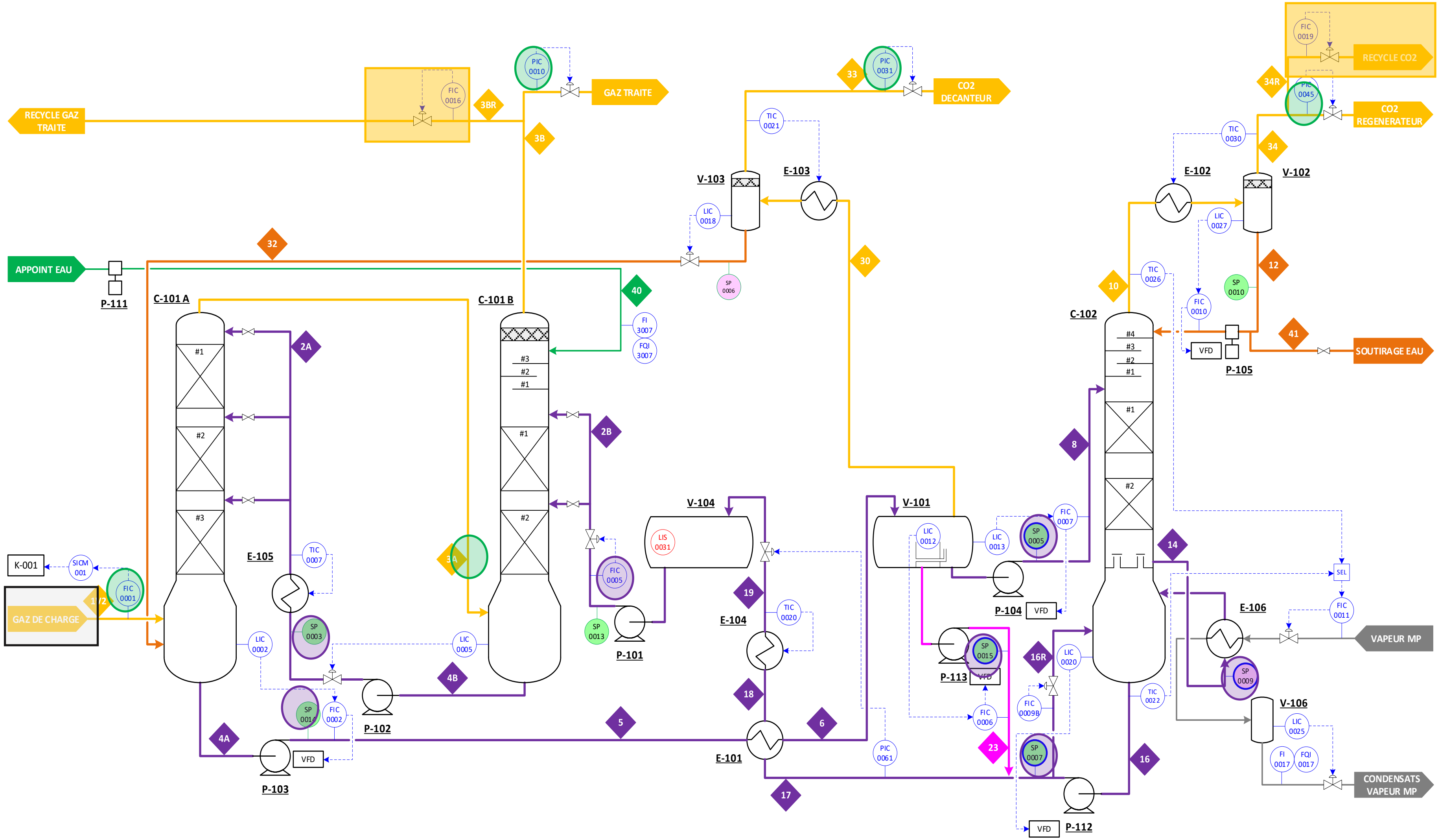
Climate, Environment and Circular economy

Compressor:
To study different absorption pressures

Gas recycling lines:
To study different CO_2 concentrations in the feed gas

Online Gas follow-up:
Flowmeter (vortex)
Composition (FTIR & µGC)

Liquid follow-up:
Flowmeter (Coriolis)
Liquid sampling and on-site lab. analysis :
- Amine content
- CO_2 loading



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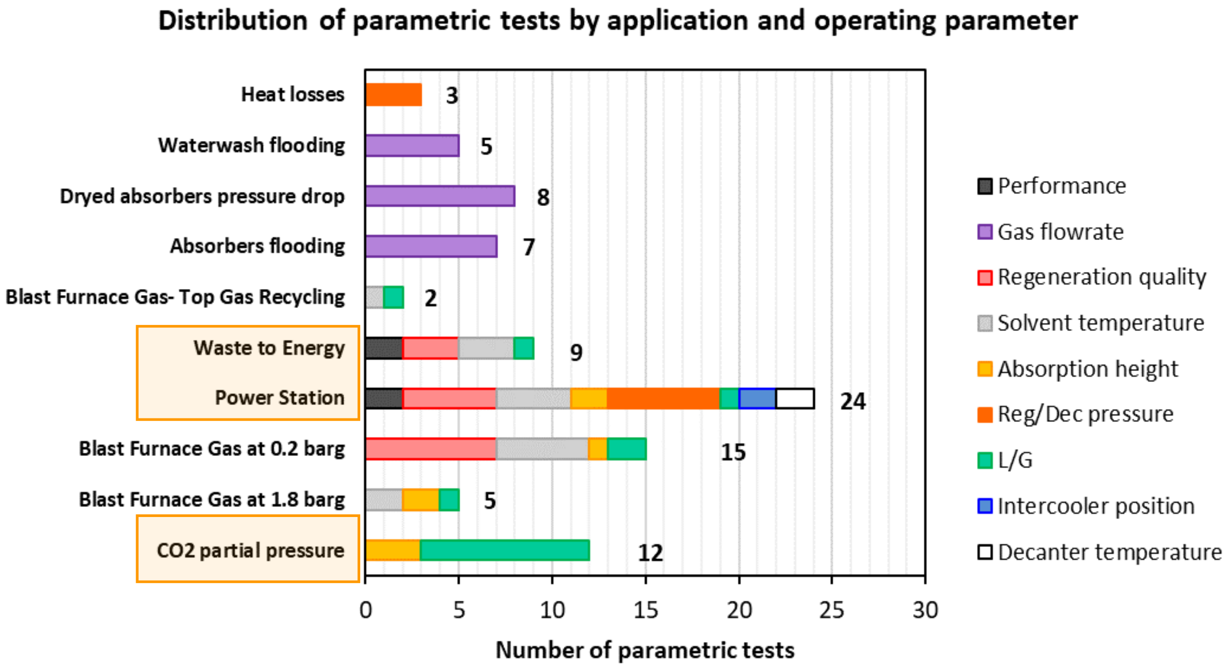
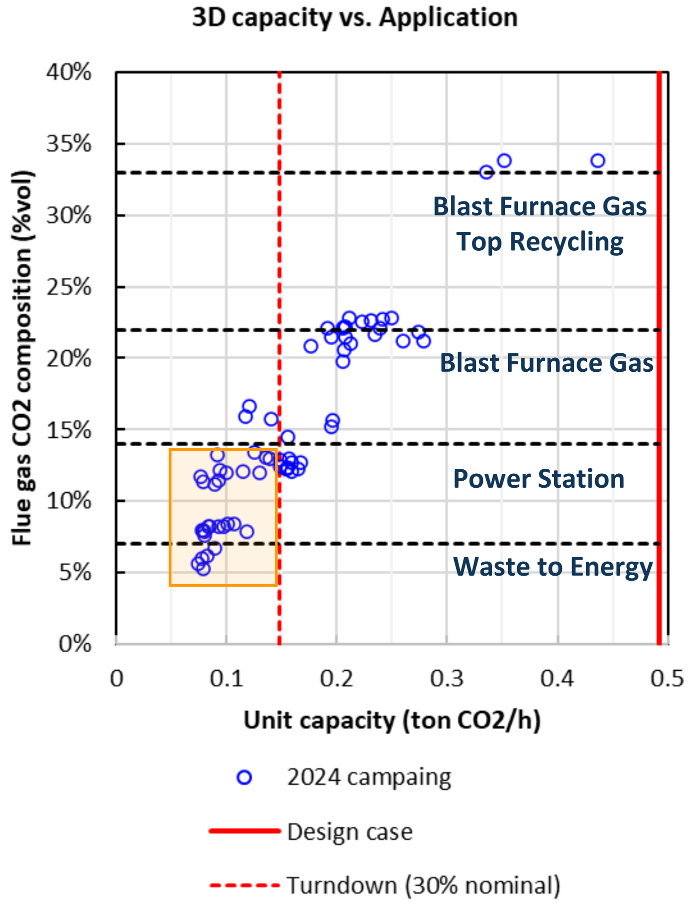
TOPOLOGY OF EXPERIMENTAL CAMPAIGN IN 2024

Climate, Environment and Circular economy

- Over 90 Test-Runs performed in which several operating parameter studied. Regeneration quality, L/G ratio and solvent temperature being the most important. **CO_2 capture** ratio and **energy penalty** amongst the most relevant performance indicators
- Motivation to enlarge DMX validation for <u>low CO_2 content emitters</u>, leading to operate at very low capacities (below turndown capacity, 30% of design capacity)

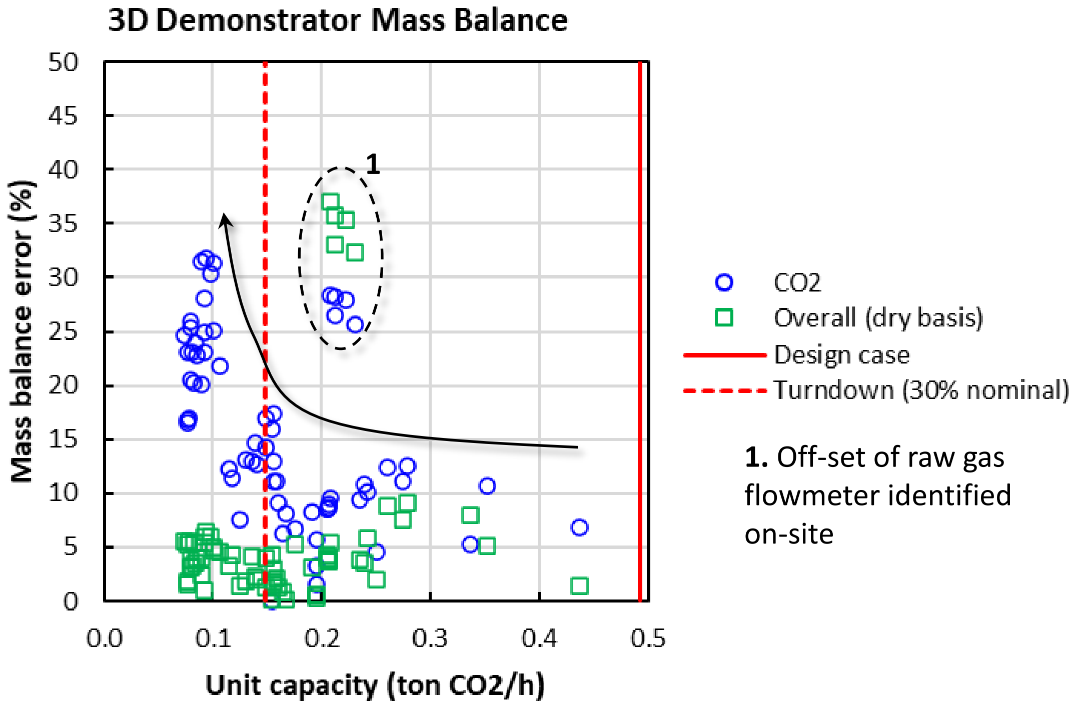




ENERGY PENALTY UNCERTAINTY SOURCES

$$\text{Specific Reboiler Duty} = \frac{\text{Effective Reboiler Duty}}{\text{Captured } CO_2 \text{ capacity}}$$

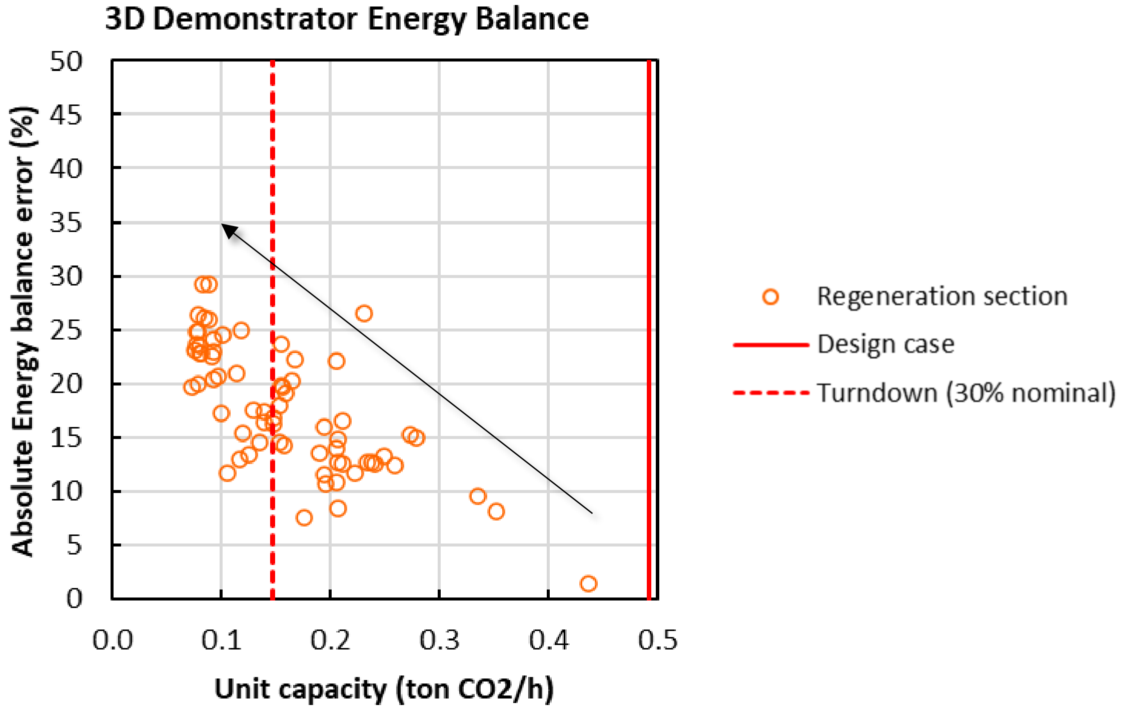
- CO_2 capacity uncertainty evaluation through mass balances



1. Off-set of raw gas flowmeter identified on-site

Trend matches with CO_2 gas flowrate measurements falling below 10 % of full scale

- Effective Reboiler duty uncertainty evaluation through energy balance



Trend matches with thermal losses from the facility to the environment

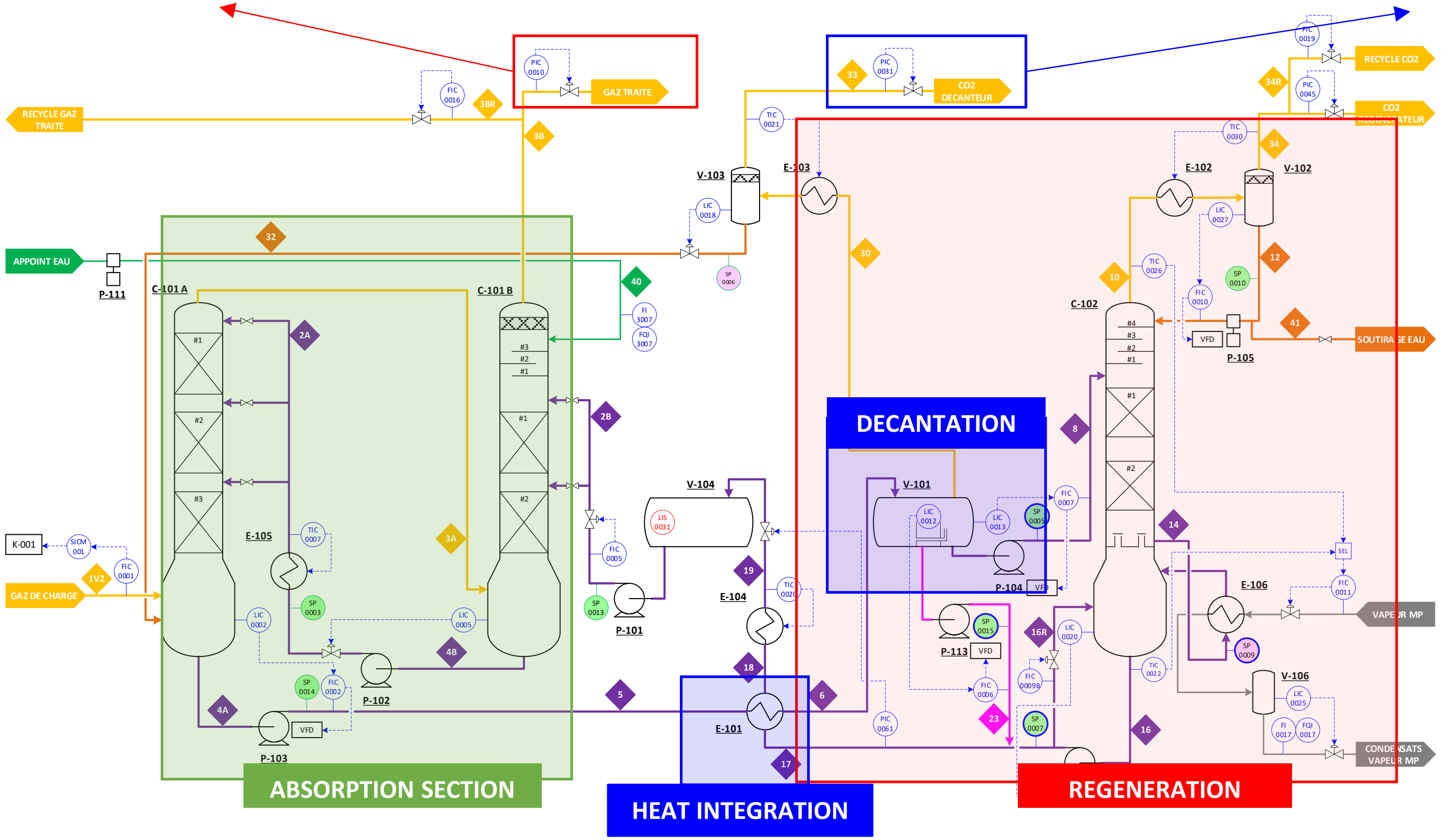
RECONCILING MASS BALANCE DISCREPANCIES (1/2)

Climate, Environment and Circular economy

- Closing material balances loops leads to two alternatives :

Treated gas flowrate measure reliable,
CO_2 flowrate measure rejected
(Rec_ABS)

CO_2 flowrate measure reliable,
Treated gas flowrate measure rejected
(Rec_REG)



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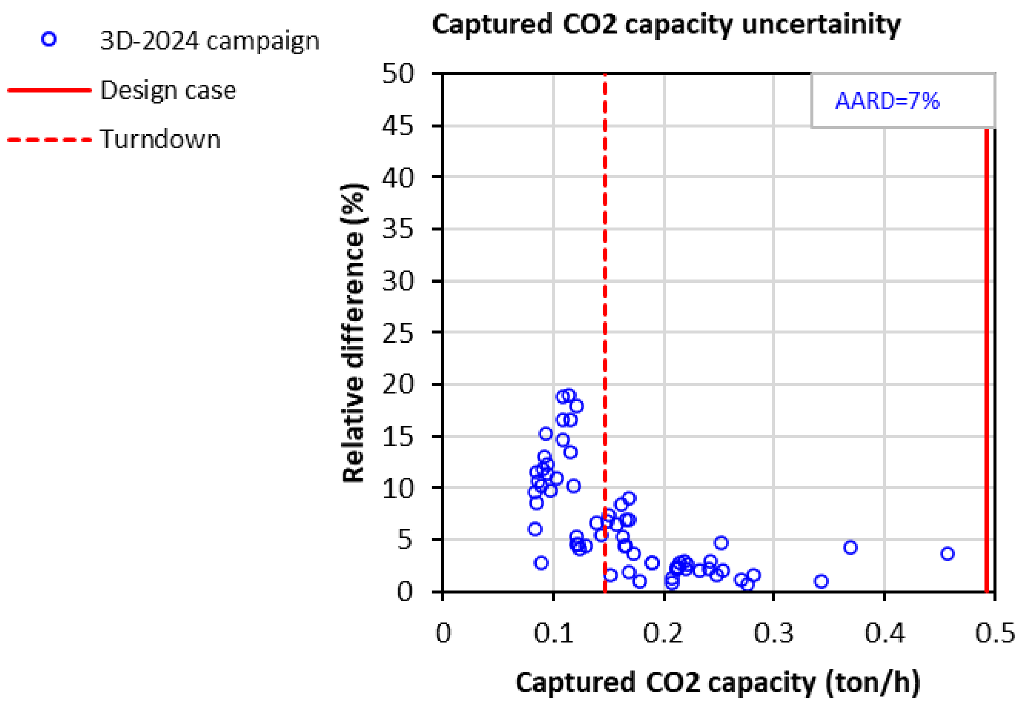
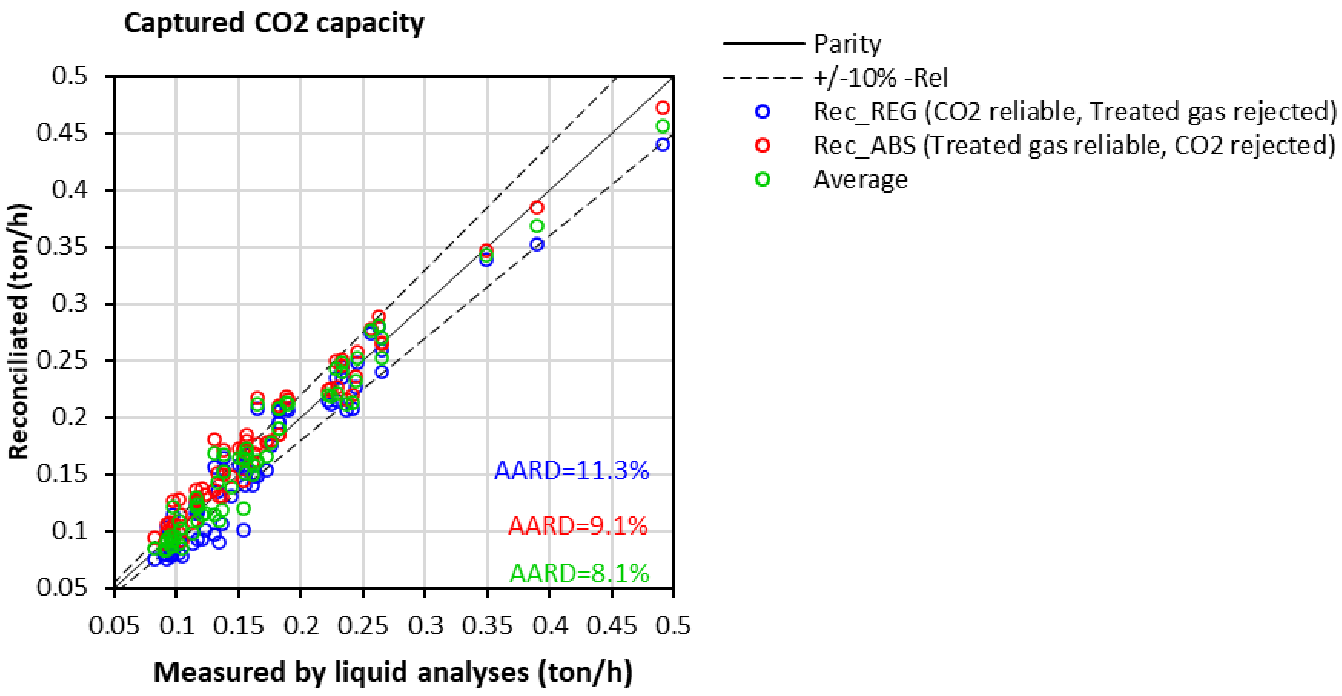
RECONCILING MASS BALANCE DISCREPANCIES (2/2)

- Relatively good quality of operation with an average relative uncertainty of +/-7 % of the CO_2 capacity (below 5% for the test-runs operated above the turndown capacity)
- For test-runs with high uncertainty (>10%), an average reconciliated capacity leads to better agreement with experimental measures from liquid analyses

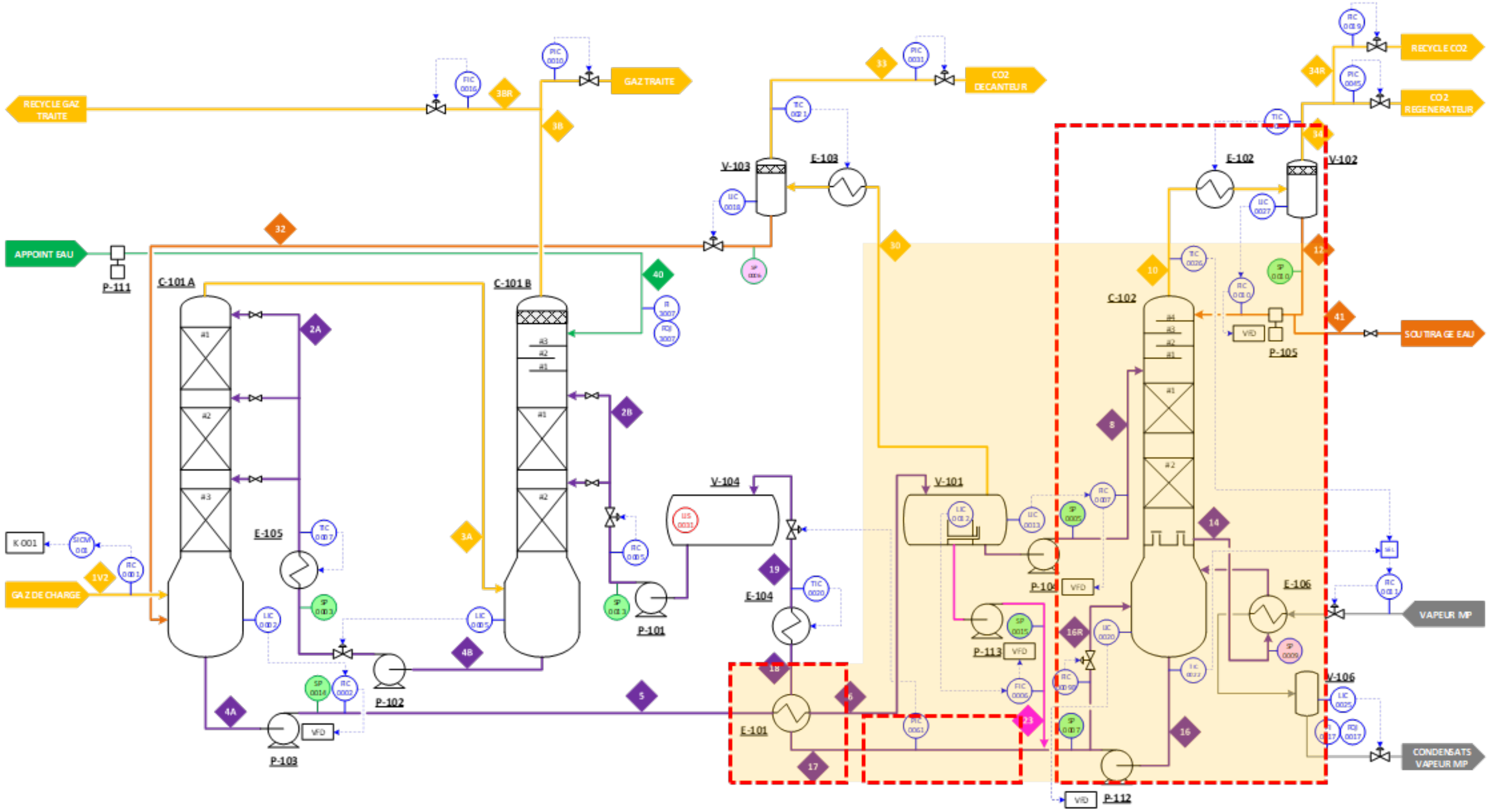




RECONCILING ENERGY BALANCE DISCREPANCIES (1/2)

Climate, Environment and Circular economy

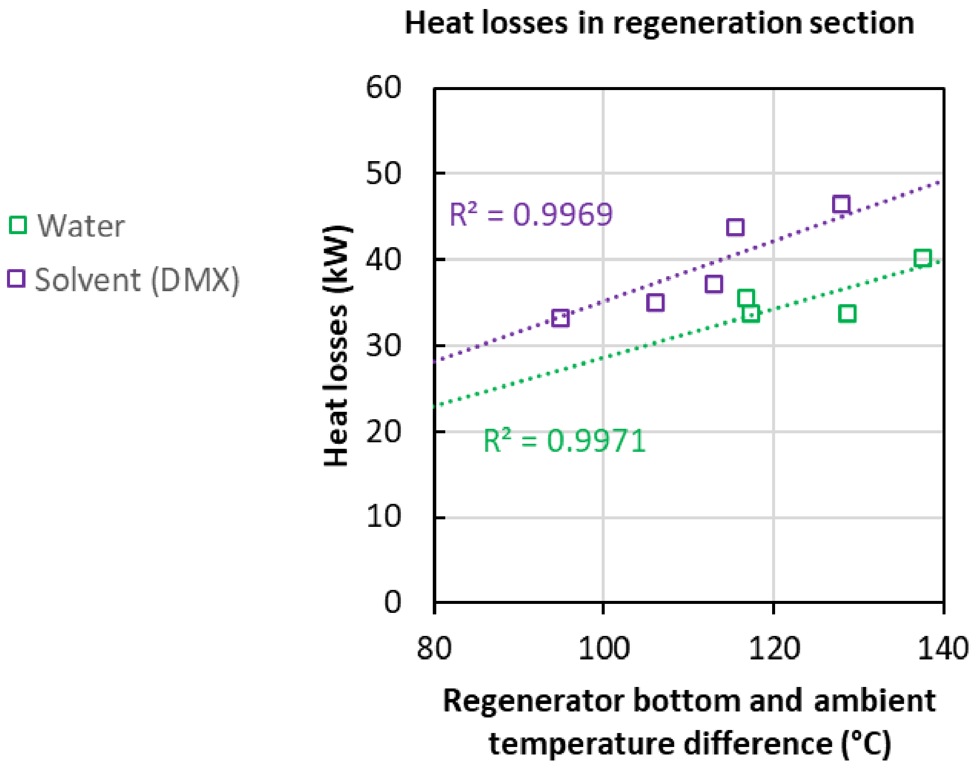
- Specific campaigns for heat loss accounting were performed without gas circulation and for DMX solvent and water, to avoid uncertainties related to CO_2 (mass balances, thermodynamics…)
- Only heat balances around the regeneration section were performed (highest temperatures of the demonstrator)

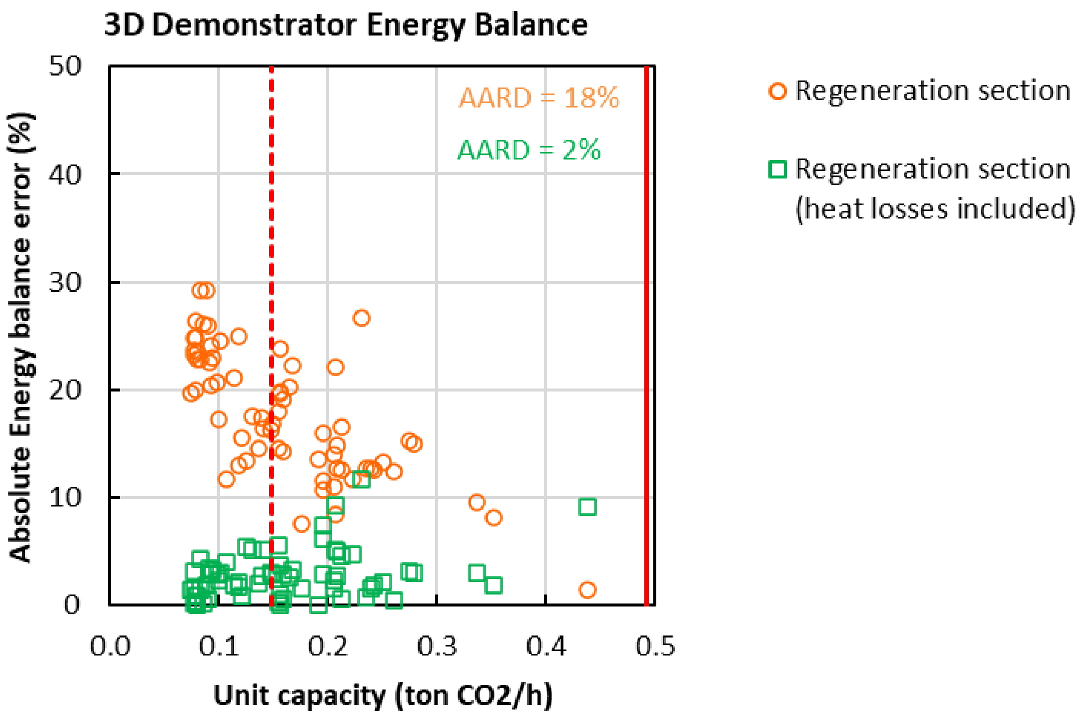


RECONCILING ENERGY BALANCE DISCREPANCIES (2/2)

Climate, Environment and Circular economy

- Results of both campaigns were consistent. The outcome from water campaign was prioritized to avoid any uncertainty related to the thermodynamic model of the DMX solvent.
- Accounting for thermal losses reduces heat balance uncertainty from 18 % to 2 % overall
- Mass balance reconciliation has a small influence on energy balance

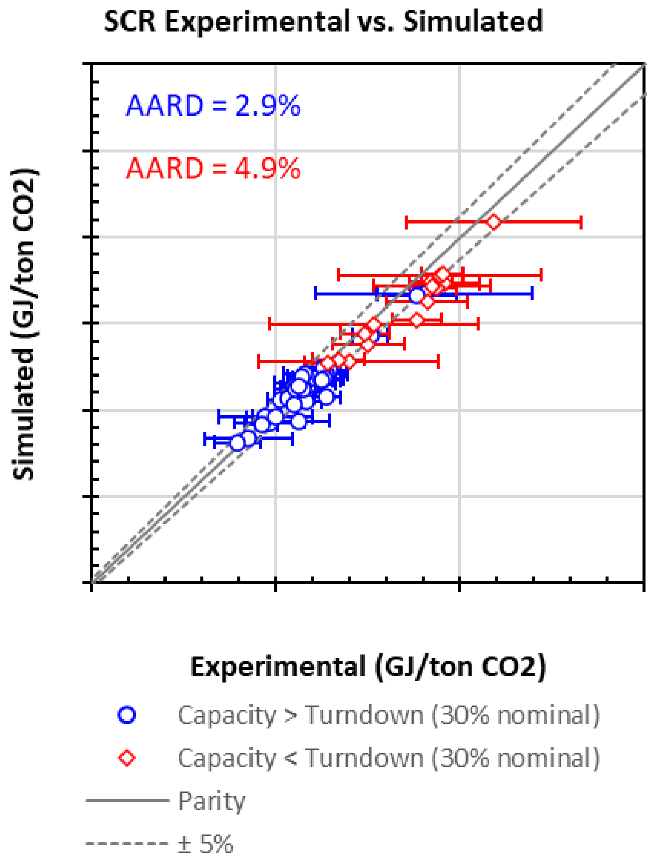




SIMULATOR PREDICTION OF 3D DEMONSTRATOR DATA

Climate, Environment and Circular economy

- Simulations with in-house model led to good agreement with experience in overall
  - Very good agreement for TR with low uncertainty (+/- 3%), demonstrating the high performance of the simulator
  - Good agreement for TR with high uncertainty (+/-5%), supports the consistency of the selected reconciliation strategy



CONCLUSIONS

- DMX technology for low CO_2 content emitters has been validated
- Uncertainties of mass and heat flows for the 2024 campaign at 3D were identified and quantified:
  - The most preponderant source of uncertainty was to operate below 10 % of full scale of one of the CO_2 gas flowmeters.
  - Overall relative uncertainty of ±7 % of the CO_2 capacity (below ±5% for the TR operated above the turndown capacity, 30% nominal)
  - It is not very misleading to consider an uncertainty of 5 to 10% on the energy penalty for the 3D operation
- The high confidence we have on the 3D experimental data relies on :
  - Reconciliation offers good agreement with liquid analysis
  - Good prediction by in-house simulator
- Take away messages :
  - Reconciling mass balances is a relevant step to evaluate the experimental data consistency
  - When varying the operating CO_2 capacity…
    - Do not forget flowmeters metrology !
    - Do not underestimate thermal losses !

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