18th September 2025

IEAGHG 8th Post-combustion capture conference, Marseille, France

Post-combustion capture for net-zero climate targets: What we know, what we need to do next?

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The UKCCSRC is supported by the EPSRC as part of the RCUK Energy Programme

Context & Background

- Net zero by 2050 is only an interim target
- The end goal is net-negative, with the magnitude of GHG removal yet to be determined
- Capturing (as close as possible to) all CO_2 from fossil fuel use
  - initially creates 'space' for harder-to-abate sectors in the 2030-2040s
  - displaces the deployment of more expensive GHG removal technology in the 2040s and beyond
- The long-term direction of travel for any CO_2 capture technology is 100% capture, all the time.
- Current tranche of (UK) CCS projects – 95% capture, but…

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Guidance

Post-combustion carbon dioxide capture: emerging techniques

Emerging techniques on how to prevent or minimise the environmental impacts of post-combustion carbon dioxide capture.

From: Environment Agency
Published 2 July 2021
Last updated 27 March 2024 — See all updates

https://www.gov.uk/guidance/post-combustion-carbon-dioxide-capture-best-available-techniques-bat

3. PCC plant design and operation

3.1 Purpose

The purpose of the PCC plant is to maximise the capture of CO_2 emissions for either use or secure geological storage.

You should aim to design your plant to achieve a CO_2 capture rate of at least 95% during normal operating conditions, although operationally this can vary, up or down.

Department for Business, Energy & Industrial Strategy

https://assets.publishing.service.gov.uk/media/6373993e8fa8f559604a0b8b/ccus-dispatchable-power-agreement-business-model-summary.pdf

Carbon Capture, Usage and Storage

Dispatchable Power Agreement business model summary

The Availability Payment is calculated for each AP Billing Period with the following formula:

$$AP = \sum (AG_i \times AC_i \times NDC \times APR_i) + TSCC + TSNC$$

Term	Definition
AC_i	Availability of Capture applicable to Settlement Unit i (%)
NDC	Net Dependable Capacity (MW)

- If capture rate were to increase by 1%, and
- Net power output were to decrease by less than 1%, then
- Payment for a gas CCS power plant would increase under the DPA UK business model
- <u>Incentive to increase capture rates operationally</u>

Post-combustion capture for net zero targets

- The focus today is on Combined Cycle Gas Turbine (similar principles apply for other applications)

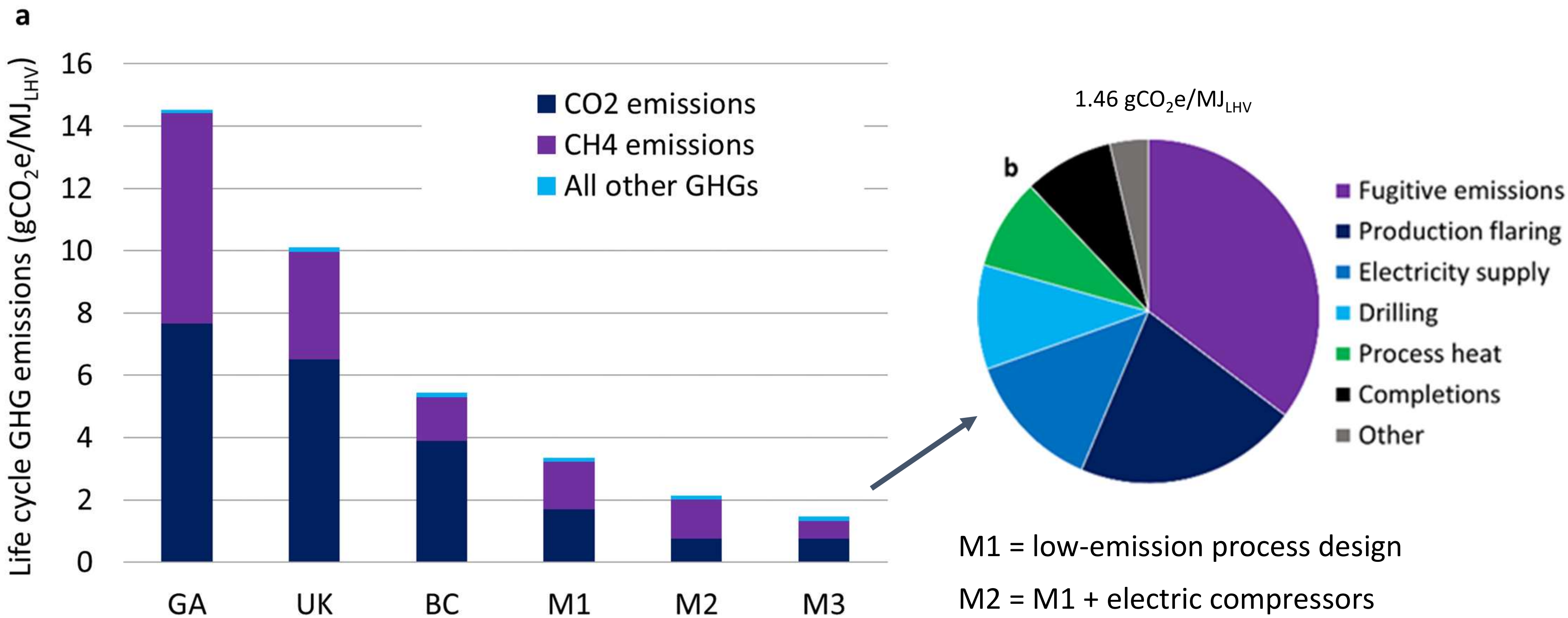
- Three principles for net zero

1. Use best practices for minimising lifecycle GHG emissions of gas supply

Zero residual CO_2 emissions (i.e. all of it, all the time):

2. 100% capture of fuel CO_2
3. Eliminate start up and shut down emissions in flexible gas power plants

NG supply chain GHG emissions



M1 = low-emission process design

M2 = M1 + electric compressors

M3 = M2 + 2030 fugitive CH_4 target

Cownden, R., Lucquiaud, M. (2024) Assessing best practices in natural gas production and emerging CO_2 capture techniques to minimise the carbon footprint of electricity generation, under review

Life cycle Greenhouse Gas Emissions of gas CCS electricity

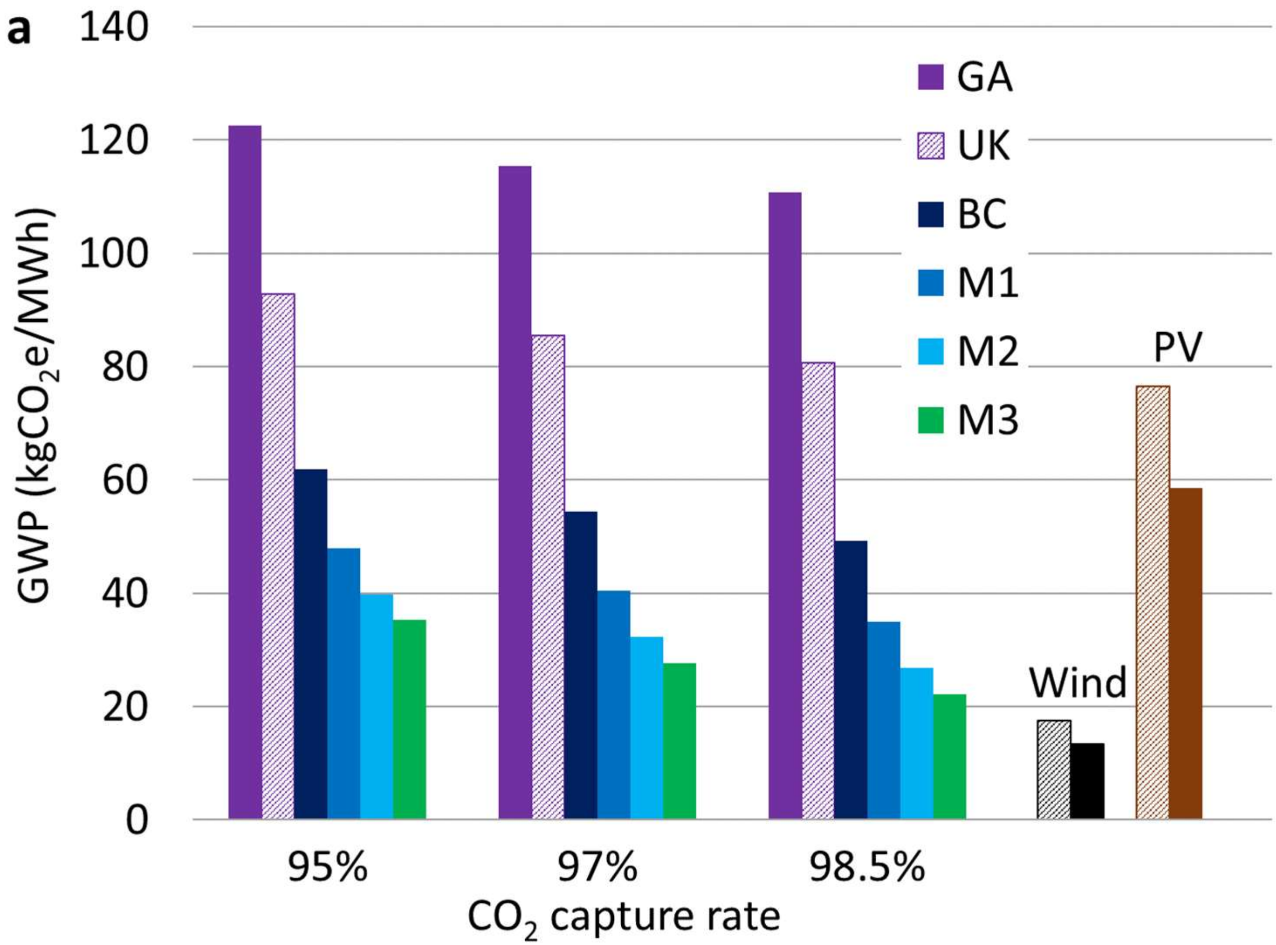


Figure 3. Life cycle GW intensity of electricity produced from CCGT with CCS. (a) Carbon footprint for six NG supply chain scenarios compared to wind and photovoltaic generation.
NG supply scenarios:
global average supply (GA),
UK average supply (UK),
BC average production in 2020 (BC),
BC Montney production with NG drive compressors (M1),
BC Montney production with electric drive compressors (M2), and
BC Montney production with electric drive compressors and 2030 fugitive methane emission reduction target achieved (M3).
Results for wind and photovoltaic shown for BC (diagonal hatch) and western USA (solid).

Cownden, R., Lucquiaud, M. (2024) Assessing best practices in natural gas production and emerging CO_2 capture techniques to minimise the carbon footprint of electricity generation, under review

What we need to do next?

- Develop and implement a strong policy framework to drive best practices in natural gas supply chain
- Efforts to achieve ultra-high capture/deep removal applications are otherwise meaningless

Post-combustion capture for net zero targets

- The focus today is on Combined Cycle Gas Turbine (similar principles apply for other applications)

- Three principles

1. Use best practices for minimising lifecycle GHG emissions of gas supply

Zero residual CO_2 emissions (i.e. all of it, all the time):

2. 100% capture of fuel CO_2
3. Eliminate start up and shut down emissions in flexible gas power plants

Caveat

- All results presented hereafter are a 35%wt MEA solvent, open-art technology

- Carbon accounting at ultra high capture rates:
  - Atmospheric CO_2 entering combustion & capture process is discounted
  - 100% capture of 'added CO_2' from
    - fuel (fossil or biogenic)
    - process emissions (e.g. limestone)

100% net capture of added CO_2 -> CCGT: ~99.2% gross absorber capture rate
EfW: ~99.7%
SMR: ~99.7%

This Session

PCCC-8

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A demonstration of the STRETCHER method for ultra-high capture rates with low energy requirements

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FCDO CLEEN Project:

COGENT – Capture Operation with Greater Economy for Net-zero Targets

中英（广东）CCUS中心
UK-China (Guangdong) CCUS Centre

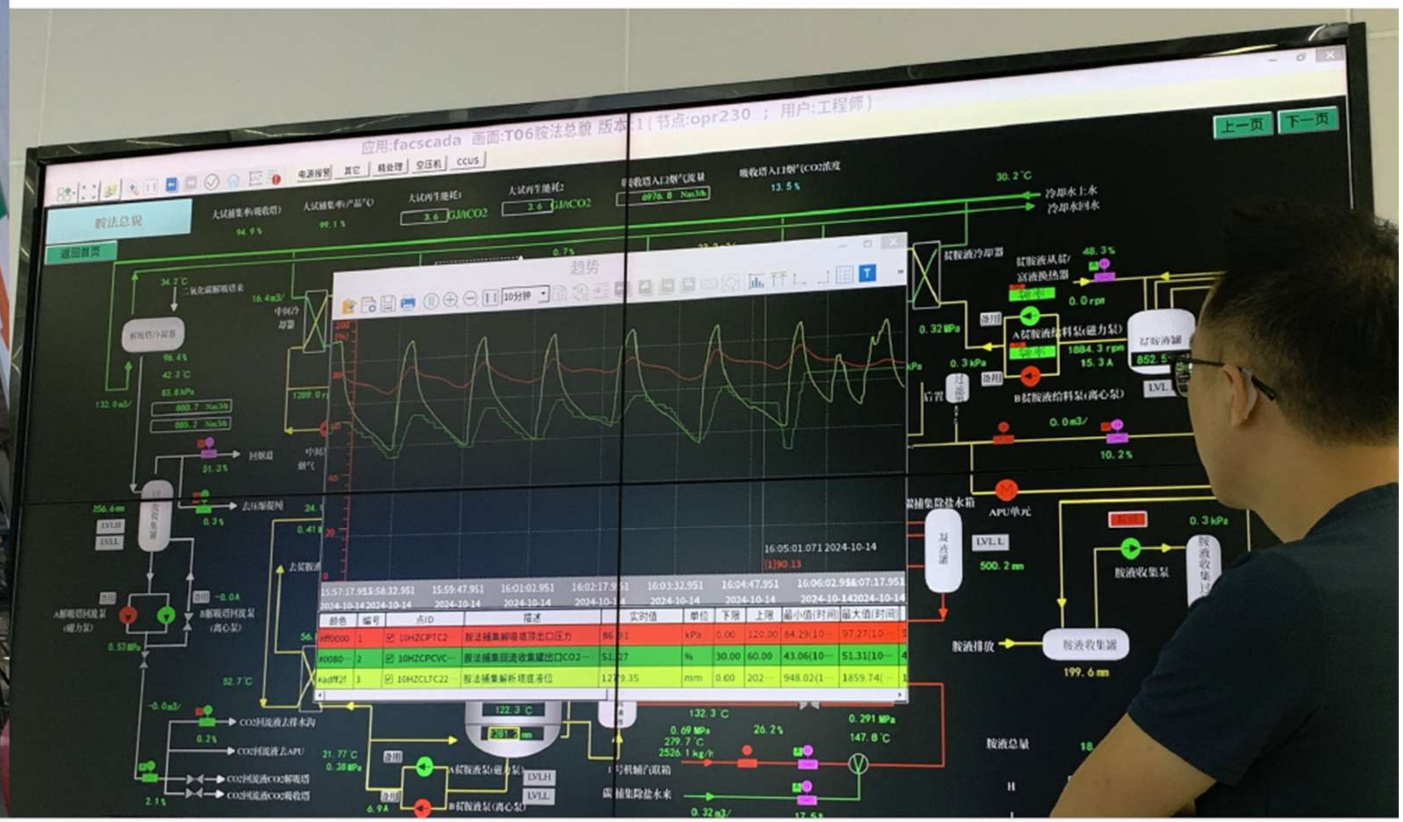
The University Of Sheffield. Energy Institute

UKCCS RESEARCH COMMUNITY

GD UK-China CCUS Centre

University of Sheffield/UKCCSRC

Guangdong Carbon Capture Test Platform



Achievements for COGENT project

- 97-99% capture achieved in a large 50 tonne CO_2/day capture plant with low additional energy requirements
- New desorber optimization method shown to be entirely suitable for industrial use
- Absorber optimization through precise capture liquid flow control also demonstrated, but would be facilitated by adding direct loading measurements
- Immediate impact in supporting 95% capture targets for new UK CCS projects
- Excellent working relationships established, with plans for further work

What we need to do next?

- Demonstrate extended controlled operation at close to 100% capture for > several 100s of hrs

- Demonstrate ultra-high capture on CCGT CO_2 flue gas concentration

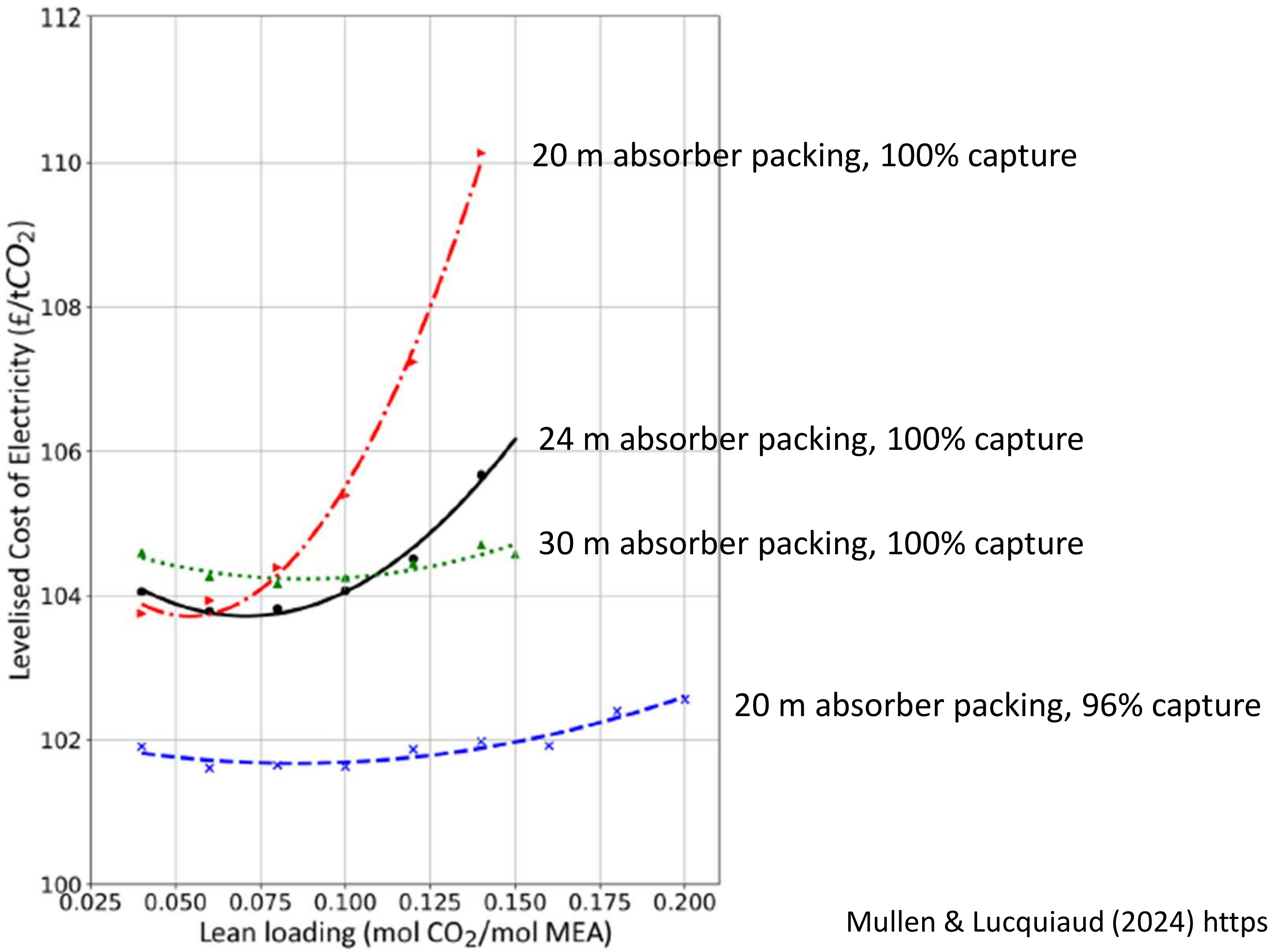
100% CO2 capture: design and operation on CCGT

Table 6
Plant performance for 100% fossil CO_2 capture, 96% fossil CO_2 capture and a no CO_2 capture case.

Parameter	Unit	100% fossil CO_2 capture	96% fossil CO_2 capture	No CO_2 Capture
Scope 1 specific carbon intensity	gCO_2e/kWh	0.0	15.1	320.5
Fossil CO_2 Capture fraction	%	100	95.8	0
Gross CO_2 Capture fraction	%	99.16	95	0
Net Output	MW_e	587.5	593.0	663.3
Natural Gas $_{(HHV)}$	MWh_{th}/s	0.319	0.319	0.319
Thermal Efficiency $_{(LHV)}$	%	56.7	57.2	64.0
Specific Reboiler Duty	GJ/tCO_2	3.67	3.52	-
CO_2 Export	kg/s	59.0	56.6	-
CO_2 Stack Emissions	kg/s	0.5	3.0	59.5
[a] Flue Gas Flow Rate	kg/s	792	792	792
CO_2 Concentration	Mole Frac	4.9	4.9	4.9
Absorbers	-	2	2	
Packing Stages	-	3	2	
Packing Height	m	24	20	
Diameter	m	11.4	11.3	
Absorber Flooding	%	<80	<80	
Lean Loading	mol CO_2/mol MEA	0.10	0.10	
Rich Loading	mol CO_2/mol MEA	0.44	0. 46	
L/G	kg/kg	0.88	0.81	
Reboiler Temp	°C	136	136	

Mullen & Lucquiaud (2024): On the cost of zero carbon electricity: A techno-economic analysis of combined cycle gas turbines with post-combustion CO2 capture, Energy Reports 11 (2024) 5104–5124, https://doi.org/10.1016/j.egyr.2024.04.067

What is the additional cost of 100% CO_2 capture on CCGT (UK)?



Mullen & Lucquiaud (2024) https://doi.org/10.1016/j.egyr.2024.04.067

Additional solvent consumption from 100% capture operation

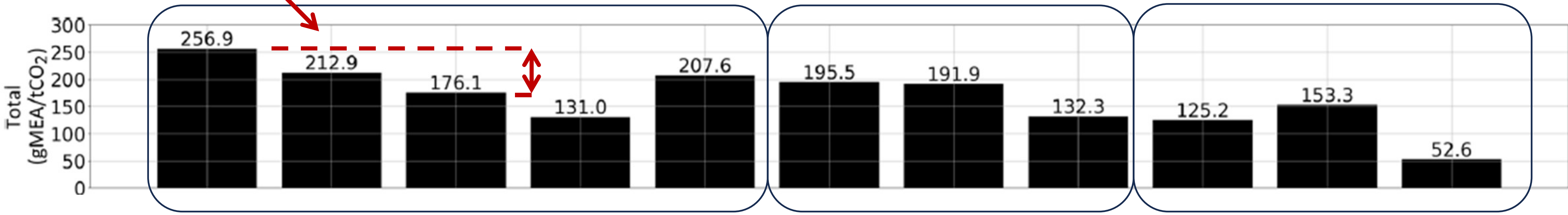
- low lean leading – 0.1 mol/mol vs 0.2 mol/mol at 95% capture
- Increased exposure to oxygen: 24m packing height vs 20m at 95%
- Higher desorber pressure - 2.7 bara vs 1.5 bara at 95%
- Higher reboiler temperature – 135ºC vs 115ºC at 95%
- Additional MEA consumption: 23-138%

Model limitations
Oxidative and thermal degradation only
No HSS or other degradation products
No interaction between degradation compounds
No data on emissions to air and waste

Additional degradation at 100% capture for a CCGT
NB - Baseline is not representative

application & capture rates, * indicates the use of intercooling

CCGT: 100/100*/95/95*/95 EfW: 100*/95/95* SMR: 100*/95/95*



Mullen, D., Braakhuis, L. Knuutila, H.K., Gibbins, J., Lucquiaud, M. (2024) Monoethanolamine Degradation Rates in Post-combustion CO_2 Capture Plants with the Capture of 100% of the Added CO_2, *Industrial & Engineering Chemistry Research 63* (31), 13677-13691, DOI: 10.1021/acs.iecr.4c01525

Continuous two-stage thermal reclaiming for 100% capture operation

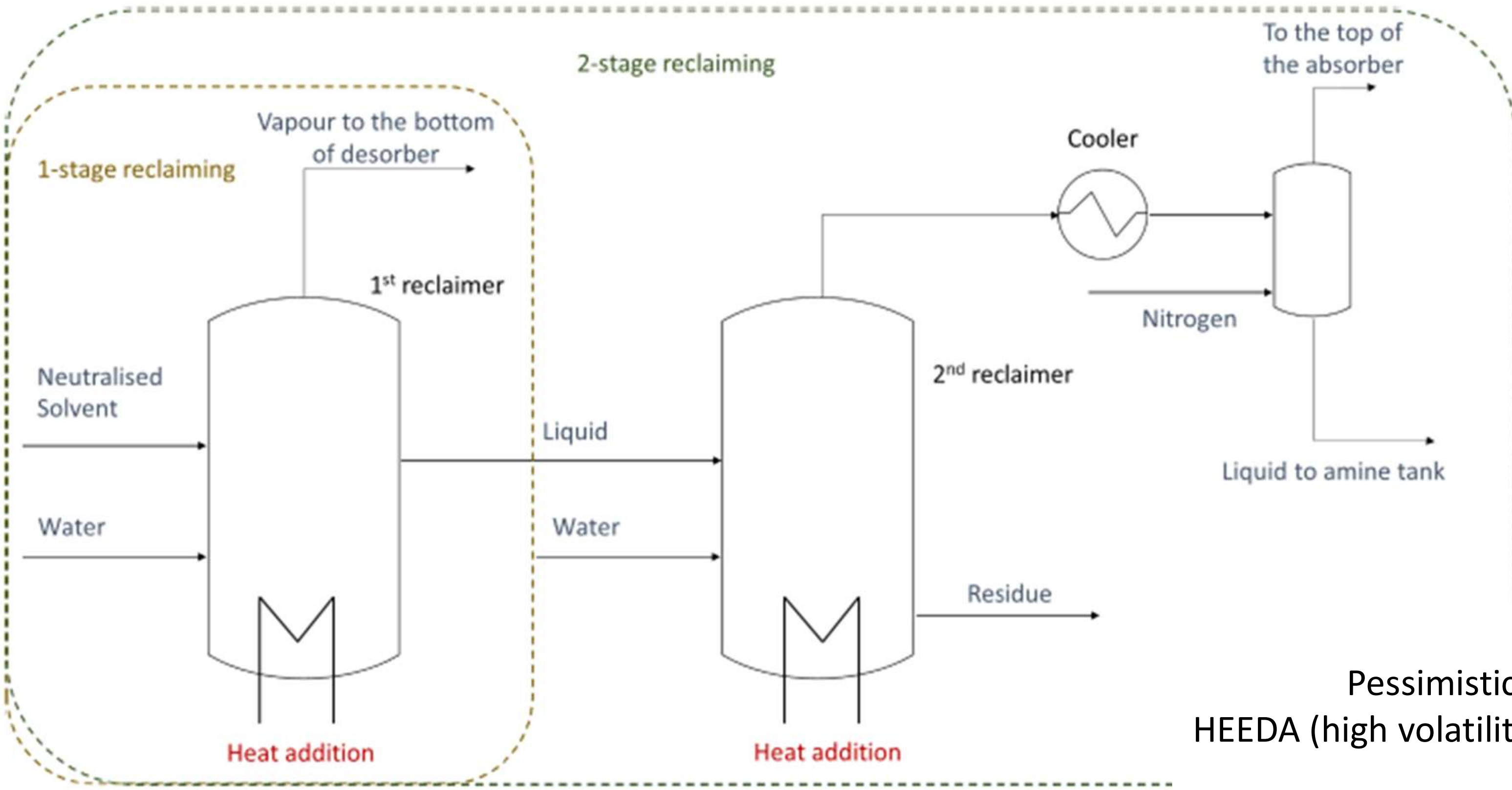


Figure 3. Process flow diagram of the thermal reclaiming configurations. Vapour from the 1st reclaimer is sent to the bottom of the desorber for energy recovery.

<u>ASPEN Model limitations</u>

Pessimistic rates of MEA degradation

HEEDA (high volatility) is used as a proxy for all degradation products

-> Worst case scenario

Michailos, S., Lucquiaud, M., Benz, A., Mullen, D., Elliott, W., Gibbins, J. (2025) A Performance Modeling Study for Zero Fossil CO_2 Stack Operation and Solvent Thermal Reclaiming in Post-Combustion Capture Industrial Applications, Ind. Eng. Chem. Res., 2025, https://doi.org/10.1021/acs.iecr.4c04530

Continuous two-stage thermal reclaiming for 100% capture operation

Table 3. Summary of the thermal reclaiming results

Reclaiming temperature	135°C		140°C		145°C	
	HEEDA recovery (%)	MEA recovery (%)	HEEDA recovery (%)	MEA recovery (%)	HEEDA Recovery (%)	MEA recovery (%)
Water added*	**1-stage reclaiming**					
100%	1.84	26.12	5.30	52.92	14.21	76.89
150%	2.85	36.39	9.23	67.49	24.73	86.27
200%	4.13	46.12	14.68	77.77	35.33	90.89
300%	7.77	63.11	27.94	88.37	52.42	94.97
400%	13.17	75.58	40.52	92.78	63.78	96.67
Water added*	**2-stage reclaiming**					
0%	11.39	76.07	15.25	80.66	23.34	87.43
10%	11.71	76.87	15.94	81.95	24.88	88.99
20%	12.01	77.62	16.66	83.19	26.51	90.41
30%	12.30	78.33	17.41	84.38	28.22	91.68
40%	12.59	79.02	18.19	85.51	30.01	92.81
50%	12.87	79.69	19.02	86.60	31.86	93.81

**water added in the 1st reclaimer as a percentage of the reclaimer input mass flowrate. For the 2-stage configuration a fixed amount of water, equal to 30% of the reclaimer feed, is added in all cases.*

Trade-off between
HEEDA (degradation products) recovery
MEA recovery
Water consumption
Energy requirements

Michailos, S., et al. (2025)
https://doi.org/10.1021/acs.iecr.4c04530

Electricity output penalty of thermal reclaiming is half to ¾ of a percent of plant electricity penalty

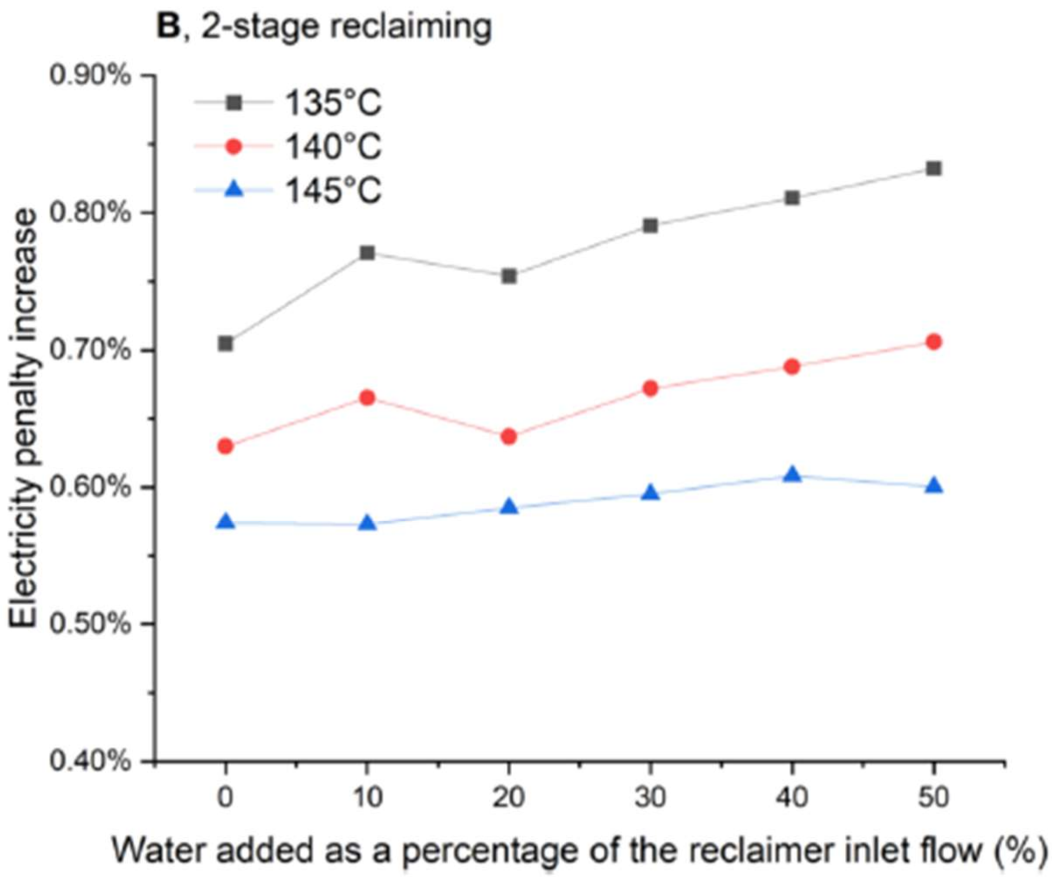


Figure 13. The %increase of the equivalent electricity lost, due to thermal solvent reclaiming, from the electricity lost in the desorber reboiler without reclaiming for A) 1-stage reclaiming and B) 2-stage reclaiming for the EfW operating case. Equivalent electricity lost due to desorber reboiler duty is 41.35 MWe without reclaiming.

Michailos, S., et al. (2025)
https://doi.org/10.1021/acs.iecr.4c04530

What we need to do next?

- Demonstrate solvent stability with two stage thermal reclaiming at increased pressure (2.4bara) and reboiler temperatures (>130C)

  for a period long enough to coincide with major plant outages (>15-20,000 hrs)

Session 7A

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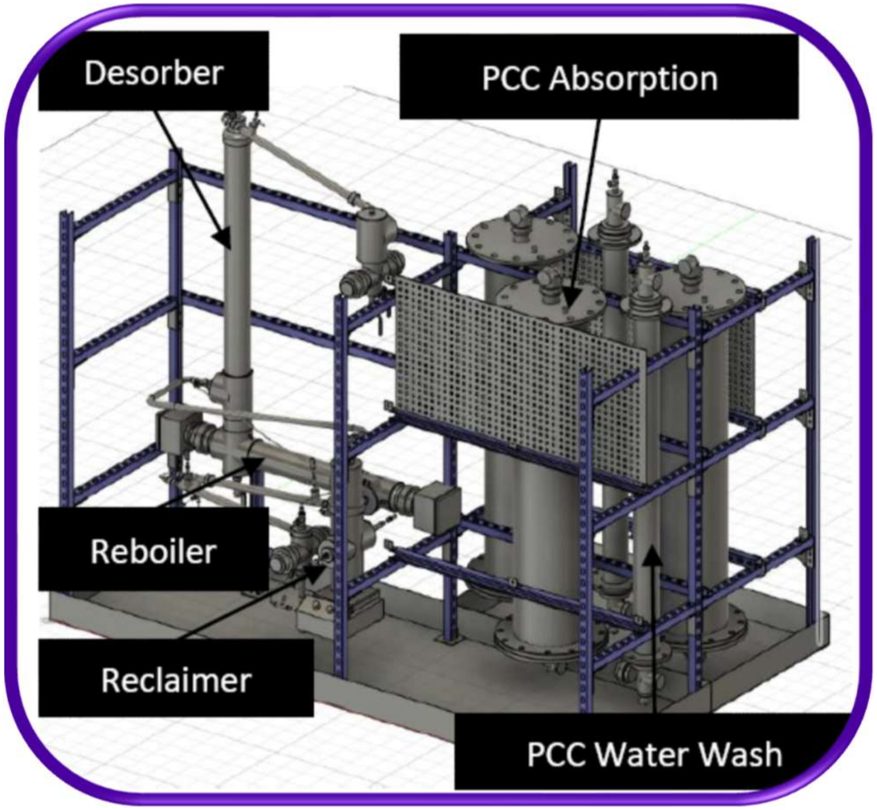
Final Design and Initial Operation of a SMART Test Unit

Mike Ownsworth[a,*], Lucas Joel[a], Mathieu Lucquiaud[a], Jon Gibbins[a]

[a]University of Sheffield, Sheffield S7 3RD, UK



CAD Design of SMART Lab Rig
(Joel et al., 2024)


SMART Lab Rig at University of Sheffield
(Frame - W:1.7m; L:2.7m; H:2.5m)

Session 7C

PCCC-8

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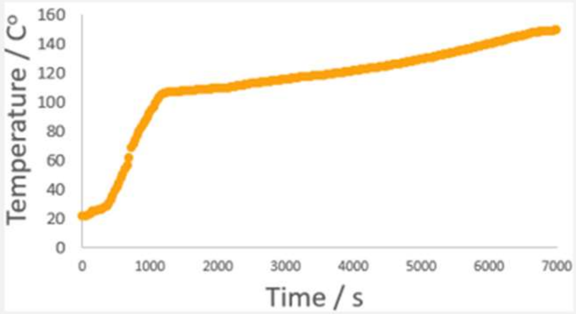
Continuous Two Stage Thermal Reclaiming of Monoethanolamine

Marcin Pokora[1*], Lucas Joel[1] , Mathieu Lucquiaud[1] and Jon Gibbins[1]

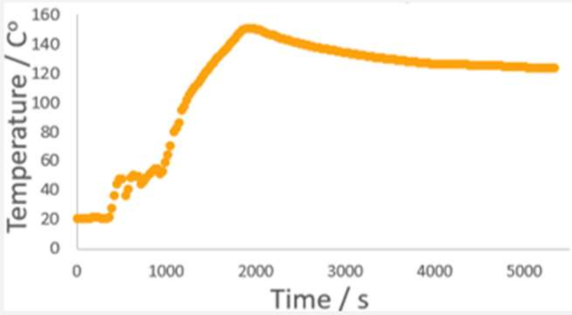
[1] *University of Sheffield, Sheffield S7 3RD, UK2*

Lab Batch Thermal Reclaimer

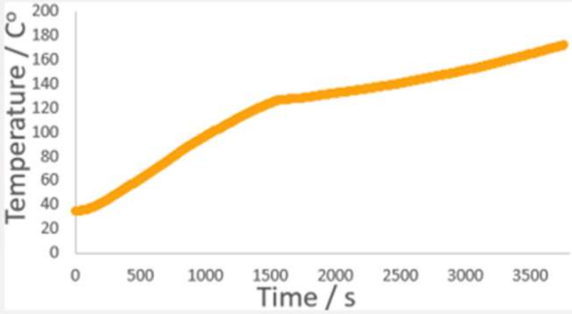
- Step 1: Solvent Feed



- Step 2: Water Feed



- Step 3: Residue Reduction



Temperature was used as an indicator to determine the endpoint of step 1 & 2

Post-combustion capture for net zero targets

- The focus today is on Combined Cycle Gas Turbine (similar principles apply for other applications)

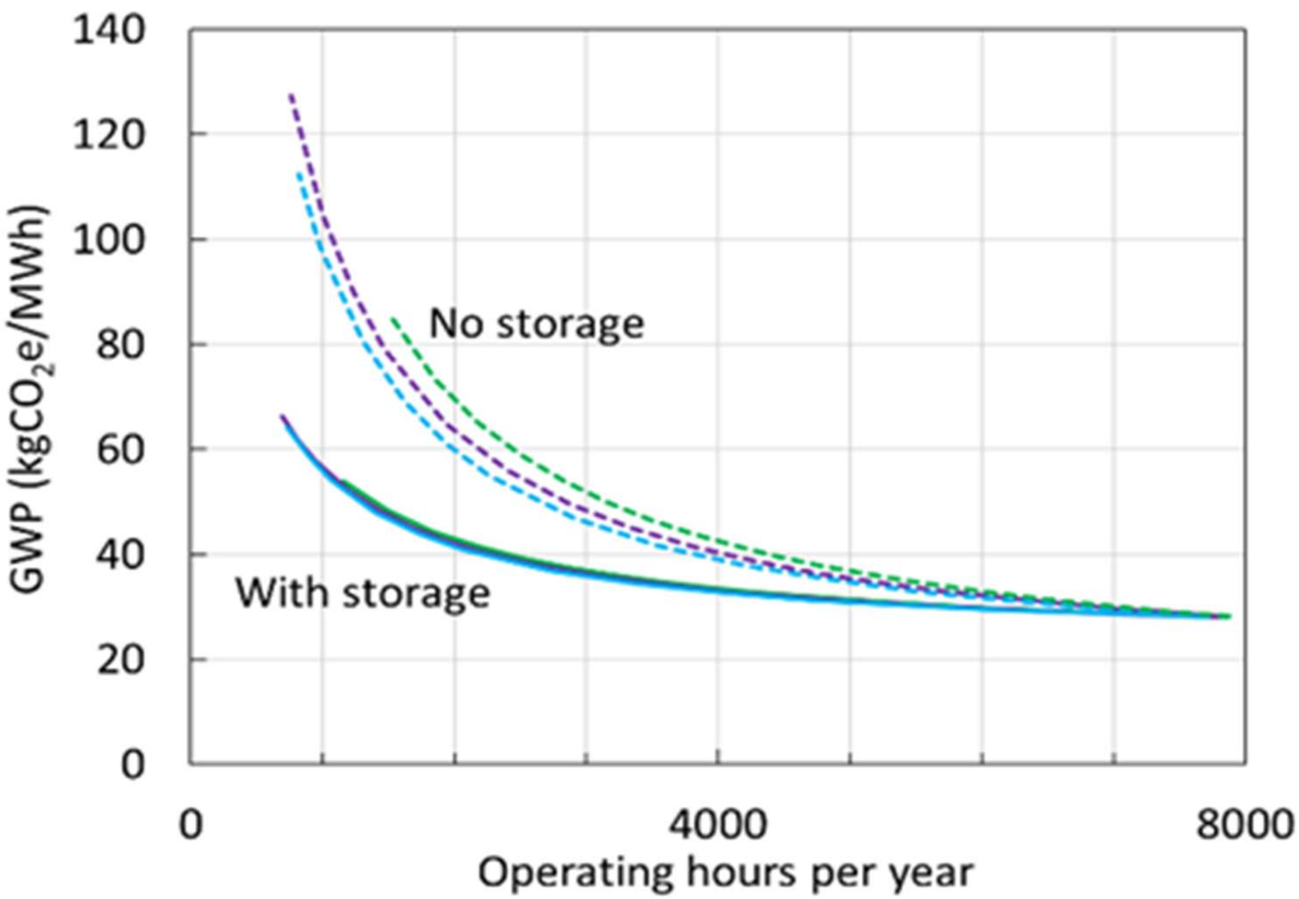
- Three principles for net zero

1. Use best practices for minimising lifecycle GHG emissions of gas supply

Zero residual CO_2 emissions (aka all of it, all the time):

2. 100% capture of fuel CO_2
3. Eliminate start up and shut down emissions in flexible gas power plants

Impact of SUSD on GHG emissions



Hot/warm/cold start distributions:
80/15/5% (green)
60/30/10% (purple)
40/40/20% (blue)

Cownden, R., Lucquiaud, M. (2024) Assessing best practices in natural gas production and emerging CO_2 capture techniques to minimise the carbon footprint of electricity generation, under review

Session 4C

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Flexibly operated capture using solvent storage (FOCUSS): Test data and application to commercial dispatchable power-plants

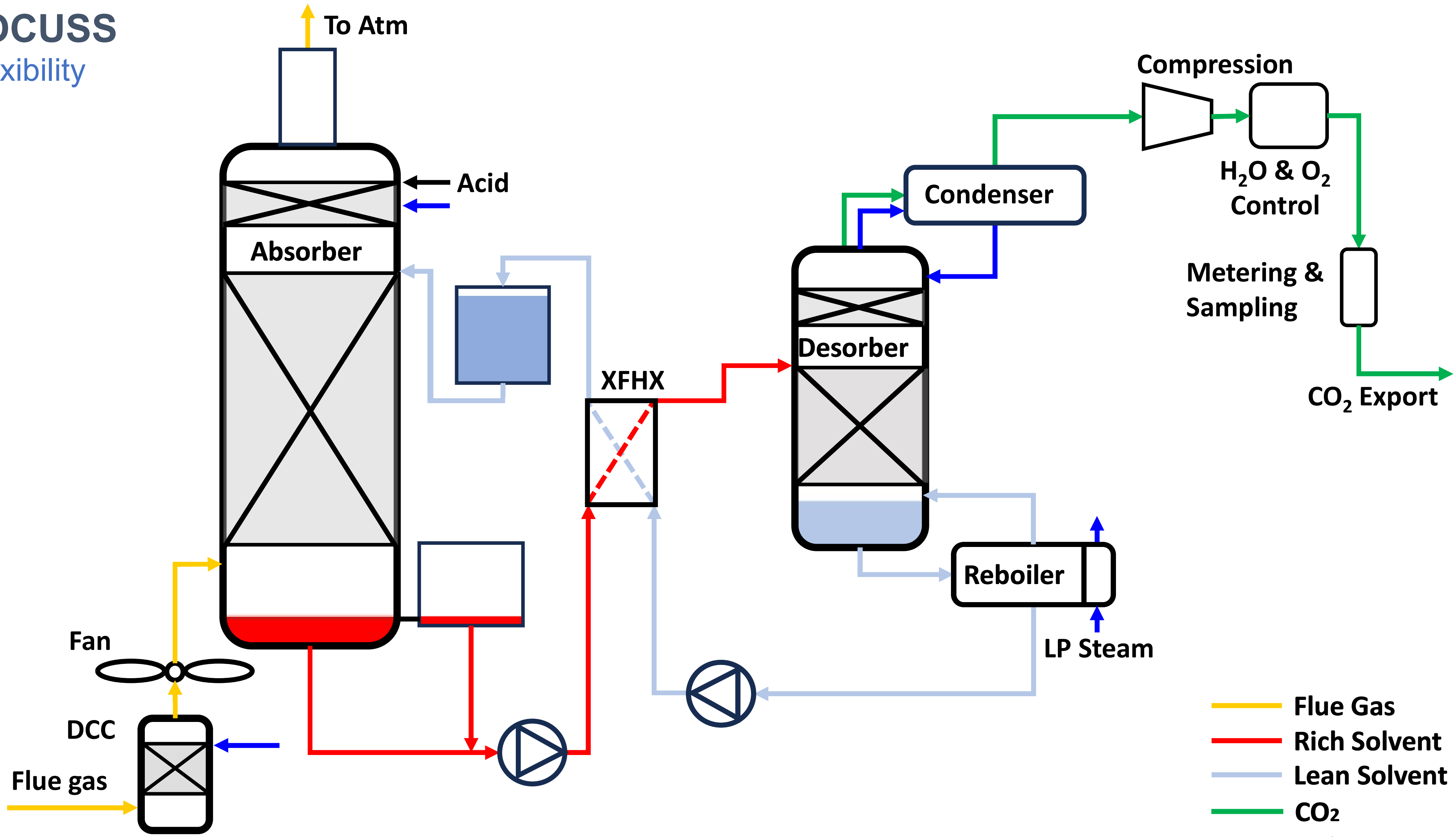
Daniel Mullen[1,*], Xiaomian Baxter[1], James Bowers[1], Harry Ellicott[1], Paul Kerian[1], Tom Ilett[2], Sam Atkinson[2], Mathieu Lucquiaud[3], Jon Gibbins[3]

[1]SSE Thermal, One Forbury Place, 43 Forbury Road, Reading, RG1 3JH, UK

[2]AECOM, London, Aldgate Tower, 2 Leman Street, London, E1 8FA, UK

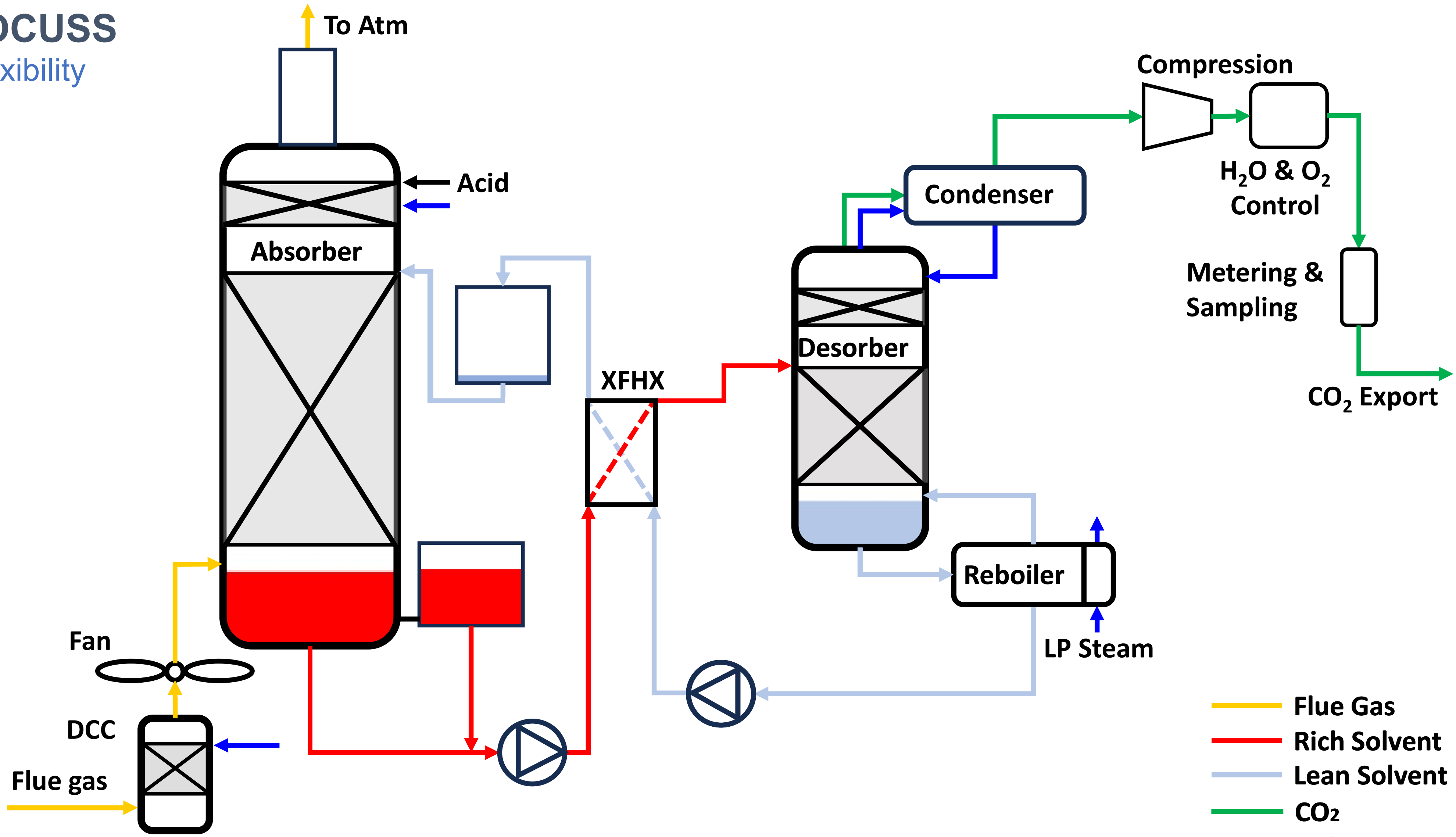
[3]University of Sheffield, Faculty of Engineering, Sir Frederick Mappin Building, Mappin Street, Sheffield, S1 3JD, UK

FOCUSS
Flexibility



FOCUSS

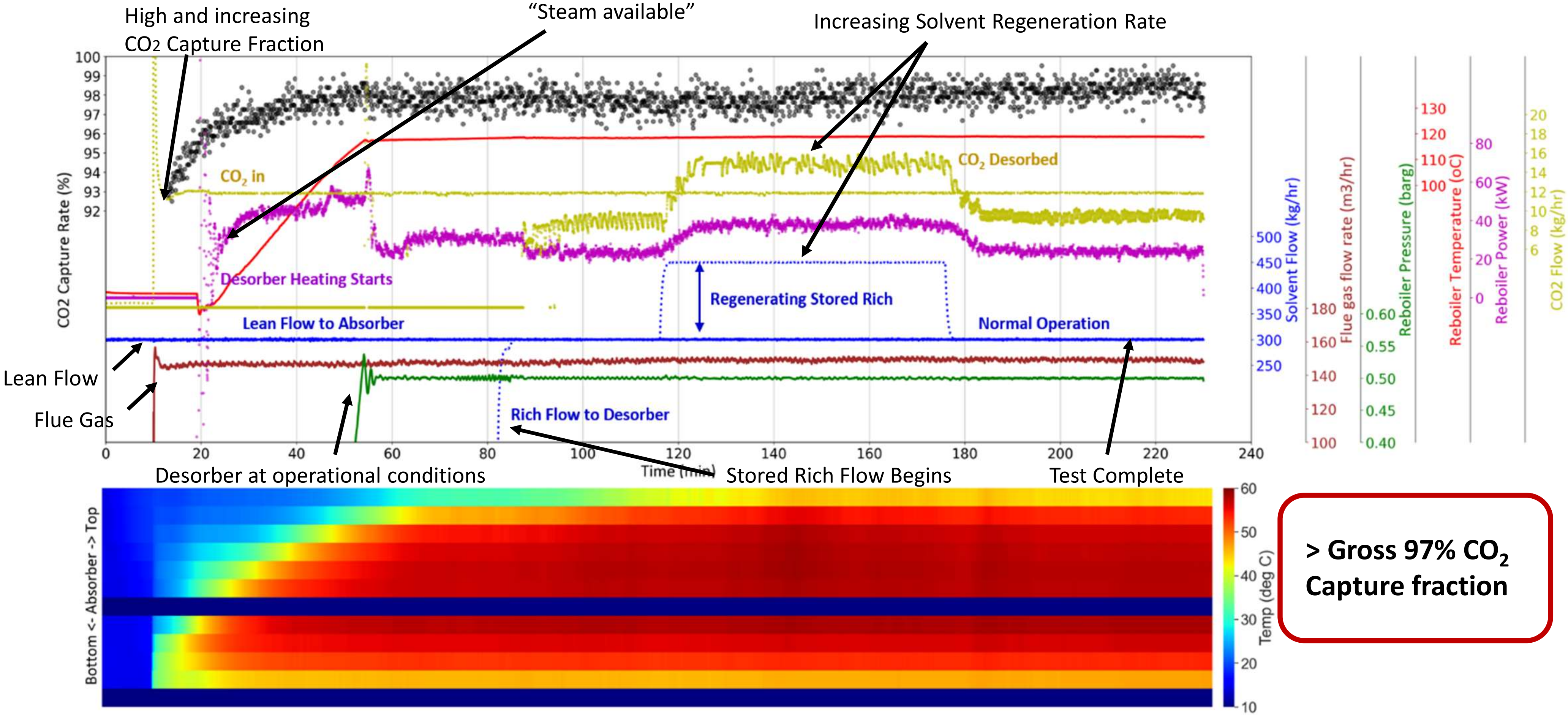
Flexibility



FOCUSS Amine Capture Plant Upgrades


Lean storage tanks adjacent to (L to R) Desorber, Absorber 1 and Absorber 2 columns

FOCUSS Phase 2 Test Campaign



> Gross 97% CO_2 Capture fraction

AECOM

The University Of Sheffield. Energy Institute

Translational Energy Research Centre.

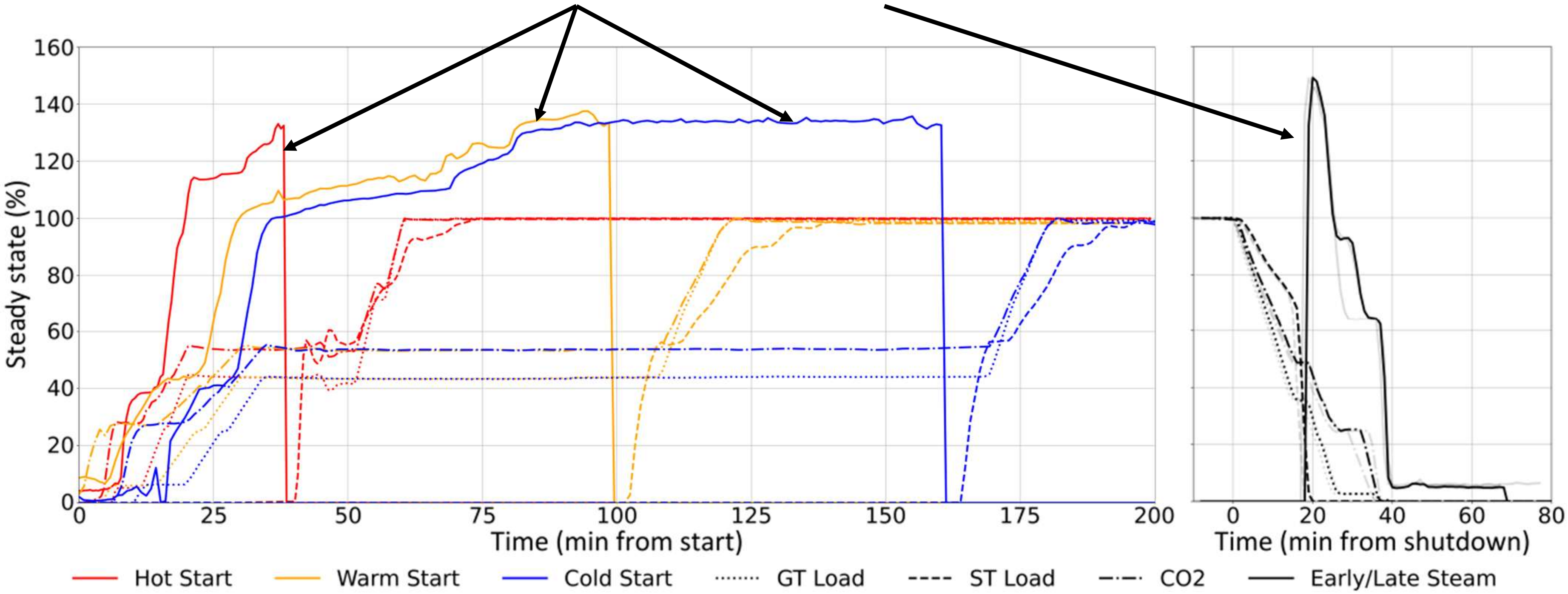
FOCUSS

Early Steam

A CCGT start-up sequence produces steam that that cannot be admitted into the steam turbines

Normally bypassed and dumped into the condenser.

Investigates utilising this “Early Steam” & “Late Steam” for startup acceleration



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Early Steam

Rich solvent storage/required increase in solvent inventory[1]

Start	Without the use of Early Steam	With the use of Early Steam
Hot	+89%	**+24%**
Warm	+226%	**+40%**
Cold	+344%	**+49%**

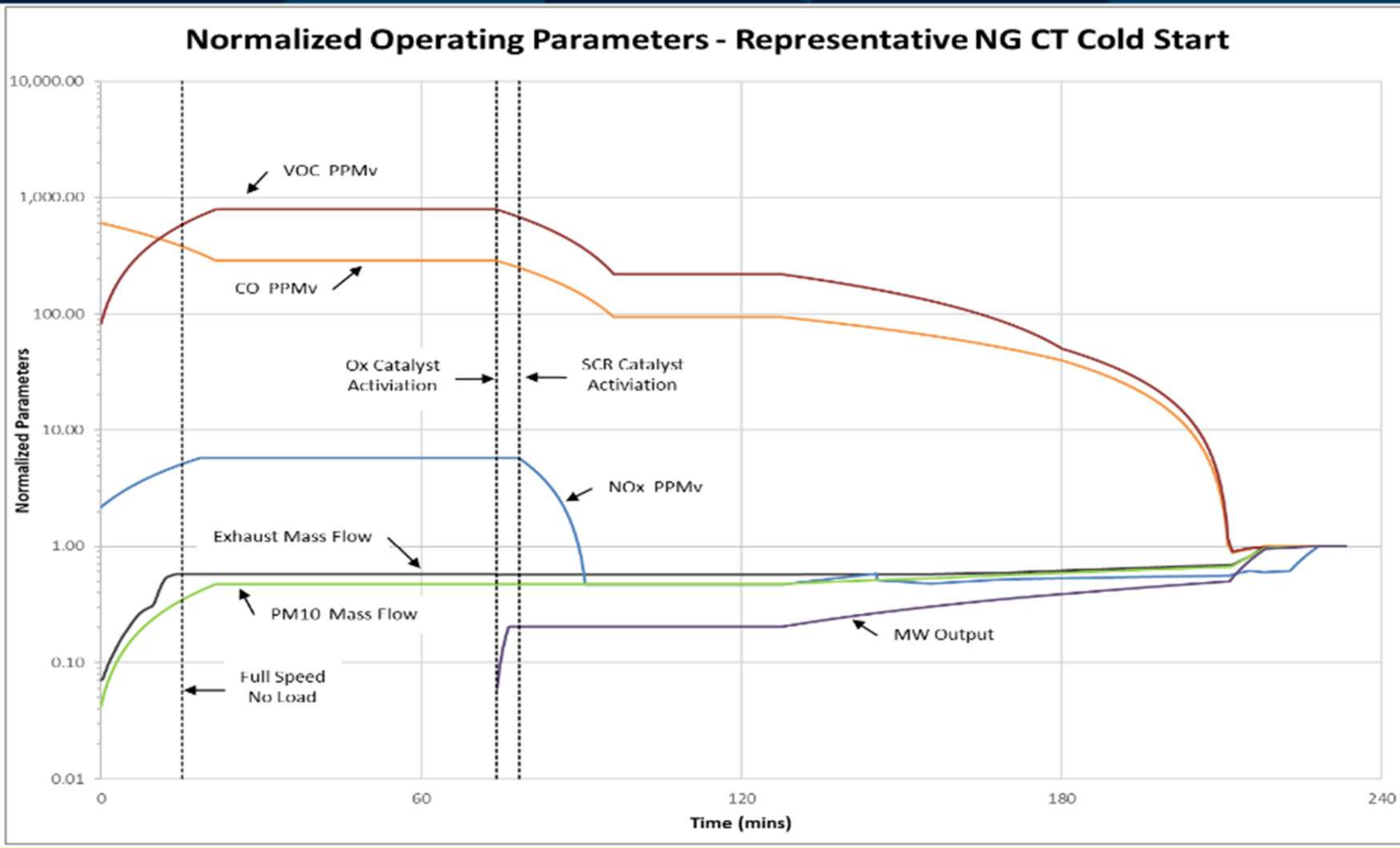
Circa 72 - 84% CO_2 capture possible with early steam but without enhanced solvent storage/increased inventory

[1] Expressed as a percentage of CO_2 free solvent inventory.

What we need to do next?

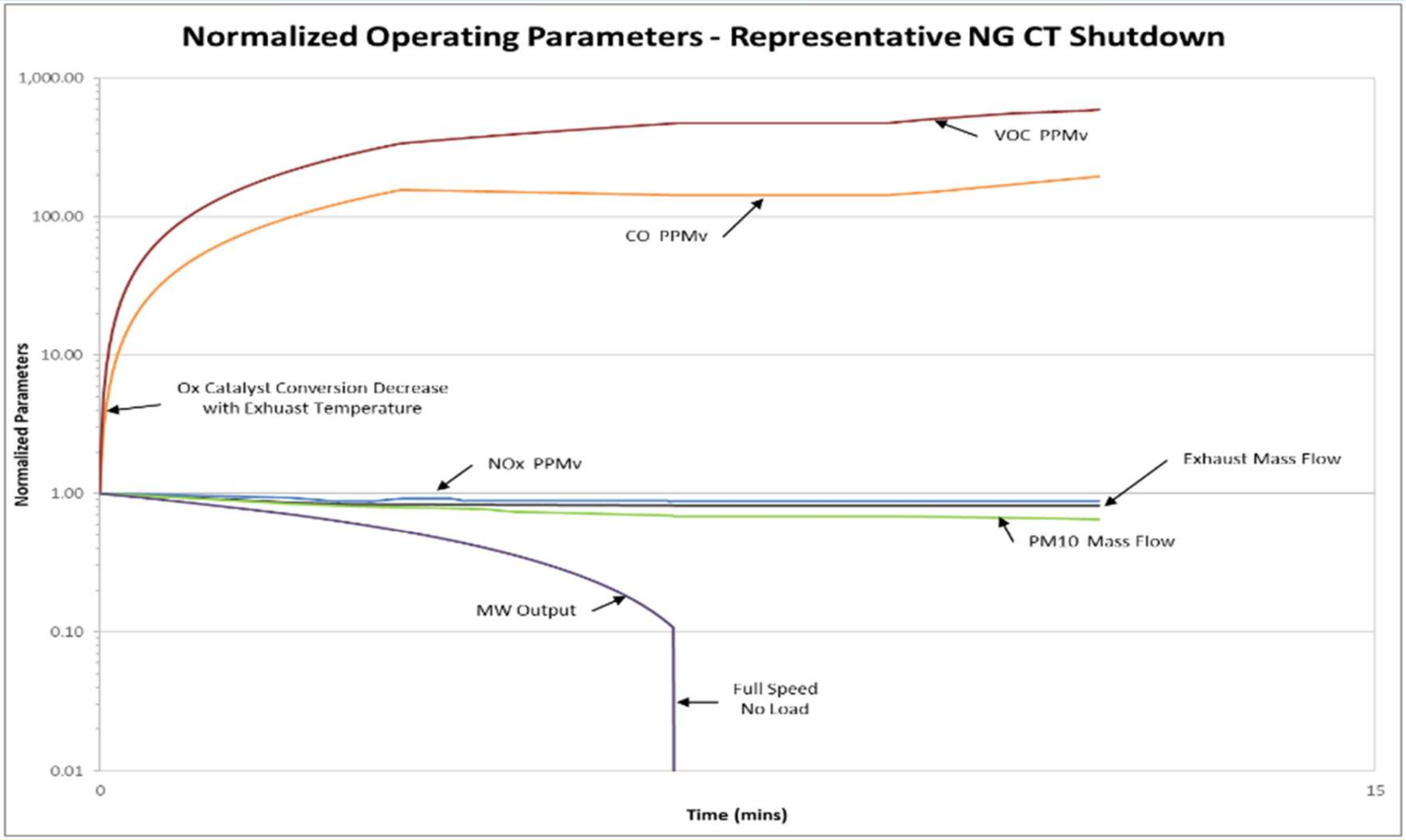
- Demonstrate solvent storage for start-up/shut down at 40-50 tCO_2/day scale
- Demonstrate 100% capture during start-up/shut down with warm solvent
- Demonstrate solvent management (two stage thermal reclaiming) to handle short periods of high level of exposure with NOx and CO

Example of NGCC Cold Start Up – Normalized Parameters



https://usea.org/sites/default/files/event-/Lunsford%20-%20Startup%20Shutdown%20Emissions%20considerations%202023%2006%2005.pdf

Example of NGCC Shut Down – Normalized Parameters



https://usea.org/sites/default/files/event-/Lunsford%20-%20Startup%20Shutdown%20Emissions%20considerations%202023%2006%2005.pdf

Conclusions – for CCGTs

- None of the below matters without best practices in NG supply chain
  - Long term Target is <20 kgCO_2eq/MWh
- 100% capture is possible at moderate additional costs
  - Moderate increase in packing height,
  - Increase in desorber pressure & temperature
- Trade-offs between the marginal cost of capture and carbon dioxide removal must be explored further

- For MEA, two stage thermal reclaiming must demonstrate long-term solvent stability with increased degradation

- Start Up and Shut Down emissions: increase TRL by testing at 40-50 t/day scale
- Understand exposure of solvent to short periods of high levels of Nox, CO and VOC

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Post-combustion capture for net-zero climate targets: What we know, what we need to do next?

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[1] SSE Thermal

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