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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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Abstract

To be consistent with net-zero climate targets, it is evident that any residual (fossil) CO_2 emissions from CCS operation will need to be re-captured from the atmosphere. This creates an arbitrage between the marginal cost of increasing CO_2 capture rates from their design value, possibly up to 100% of added CO_2, and the accepted cost of removing CO_2 from the atmosphere, whether it is from BECCS, Direct Air capture or mineralisation of atmospheric CO_2. 100% capture of added CO_2 refers here to the capture of all non-atmospheric CO_2 entering the capture process. For example, it excludes atmospheric CO_2 entering power stations with combustion air. For CCS developers, it is likely that scrutiny of all residual stack CO_2 emissions and lifecycle emissions of fuel supply will increase in ways that are inversely proportional to the carbon intensity of economic activity.

This presentation gives a perspective on the relevance of ultra-high capture operation in post-combustion capture technology, i.e. with residual CO_2 emissions close to zero, taking fleixlbe operated Combined Cycle Gas Turbine (CCGT) power plants as a case study. It puts the relevance of capture rate in context by assessing their impact on the overall life cycle greenhouse gas (GHG) emission intensity of electricity generation from CCGTs along with supply chain emissions (Cownden and Lucquiaud, 2024).

It then presents a new analysis of the value of ultra-high capture rate operation of CCS to a future UK electricity grid using insights gained from the ESME model (Energy System Modelling Environment), a comprehensive, techno-economic whole-system model for design and planning of the UK energy system.

After examining how the existing regulatory regime in the UK may influence high capture rate operation (Environment Agency, 2024; DESNZ, 2022), it proposes a brief review of recent relevant additions to the literature:

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- Process modelling studies showing that, unlike previously reported, the energy of regeneration of 35%wt MEA is comparable at 95% and 100% capture with appropriate process modifications, i.e. additional absorber packing and increased desorber pressure for Steam Methane Reformers (Mullen et al., 2023; Cownden et al, 2023), CCGTs (Mullen and Lucquiaud, 2024), Steel, Cement, Energy from Waste and Fluid Catalytic Crakers (Michailos et al, 2025),
- Techno-economic studies showing that, with the process modifications above, key techno-economic metrics, such as the levelised cost of respectively electricity, hydrogen and capture, are higher at 100% capture by no more than circa 5% compared to 95% capture operation (Mullen et al., 2023; Cownden et al, 2023; Mullen and Lucquiaud, 2024)
- Pilot scale studies on open-art solvents 35%wt MEA and CESAR1 confirming process modelling results on energy of regeneration (Gibbins et al, 2025; Moser et al, 2024)

The presentation then shows how mitigating start-up and shutdown emissions, using solvent storage as proposed at this conference in (Mullen et al, 2025), can significantly reduce the overall life cycle greenhouse gas (GHG) emission intensity of flexibly operated CCGTs (Cownden and Lucquiaud, 2024) and compares it with studies where solvent storage is excluded to address start-up and shutdown emissions (Bui et al, 2023).

Additional solvent degradation is then discussed using the degradation model of MEA developed in (Braakhuis et al, 2022; Braakhuis et al, 2023). This arises from increased exposure to oxygen in taller absorber and from exposure to higher temperature (circa 135ºC) in the desorber. New insights are examining how operation with reduced lean loading (0.1 to 0.15 mol/mol compared to 0.25 mol/mol), a necessary requirement for ultra-high capture, mitigates additional solvent thermal degradation caused by higher desorber pressure (2.4 bara) and temperature (130-135ºC) (Mullen et al, 2024).

Finally, the presentation concludes by proposing a two-stage thermal reclaiming system for MEA as a method of solvent management for ultra-high capture operation, and the associated trade-offs with respect to water addition, MEA recovery, impurity recovery and electricity output penalty (Michailos et al, 2024). It ends by highlighting current gaps in knowledge and understanding of long term operation of MEA at ultra-high capture process conditions, and the necessary next steps to demonstrate two-stage thermal reclaiming as an effective solvent management method (Pokora et al. 2025; Ownsworth et al, 2025).

Keywords: post-combustion; amine technology; 100% capture; degradation; life cycle assessment; techno-economic assessment

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