Techno-Economic Analysis and Optimization of Integrated NGCC – MEA System at High CO_2 Capture Levels

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Motivation

Global economic development leads to increasing demand for energy and carbon intensive manufactured products (cement, steel, etc.). → Immediate requirement to accelerate large-scale industrial deployment of deep decarbonization technologies to reach U.S. DOE goals of net-zero emissions. → Need for rigorous economic analysis and risk assessment of carbon capture technologies at high capture levels.

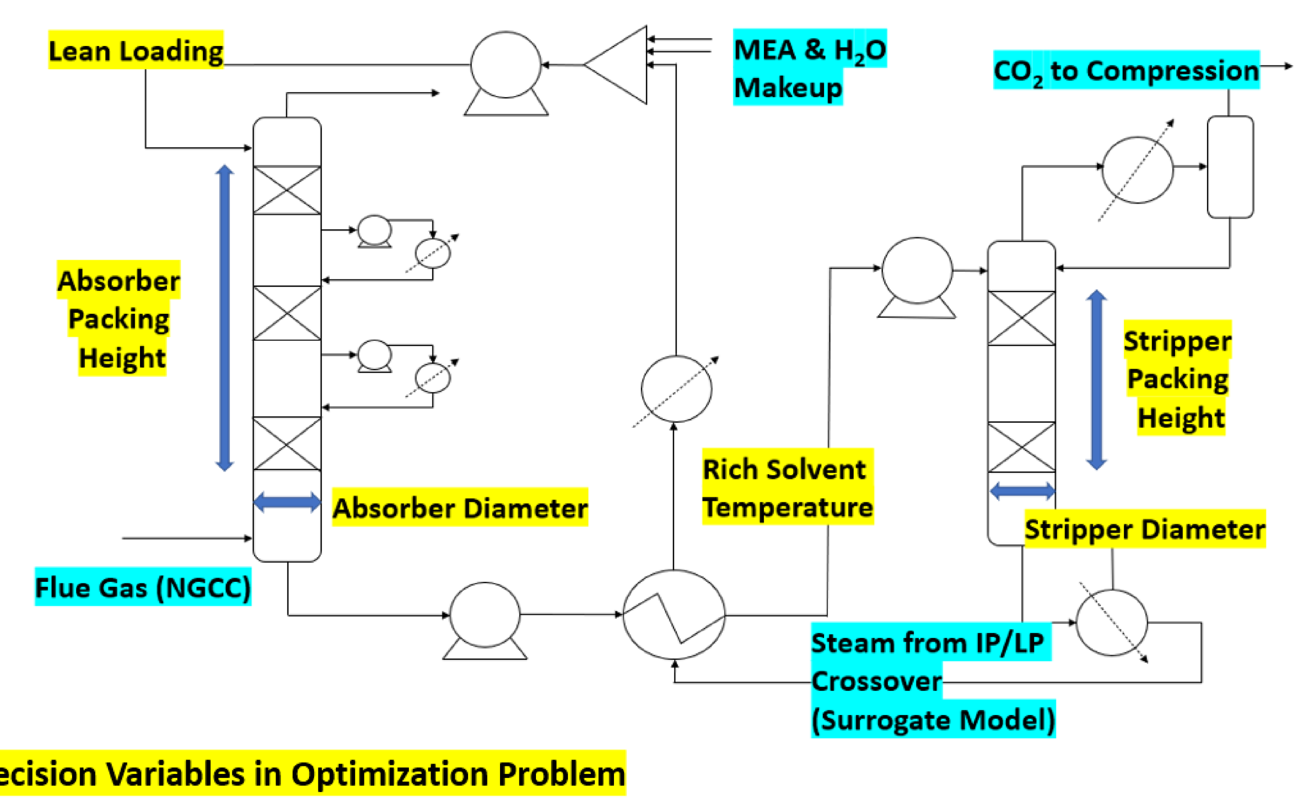
Project Objectives

- Optimize model of a natural gas combined cycle (NGCC) plant with aqueous monoethanolamine (MEA) solvent-based CO_2 capture system over a range of CO_2 capture levels beyond net-zero emissions.
- Understand incremental cost of high capture to compare with direct air capture and other net-negative emission technologies.
- Understand optimal operation and design of carbon capture and storage (CCS) unit to achieve high capture with minimal increase in cost.

Methodology

Problem Formulation in FOQUS (Framework for Optimization, Quantification of Uncertainty, and Surrogates)

Carbon Capture System Process Model (Aspen Plus®)



Variable Transfer

Economic Model (Python)

Calculates levelized cost of electricity (LCOE) for integrated NGCC-MEA system. Developed from information provided in NETL cost and performance baseline [1] for NGCC system and CSIRO study [2] for capture unit.

Optimization Formulation

$\min_{\tilde{x}} f(\tilde{x})$	Minimize LCOE.
s.t.	
$\tilde{x}^L \leq \tilde{x} \leq \tilde{x}^U$	Bounded decision variables: design and operation of capture unit.
$h(\tilde{x}) = 0$	Fixed level of CO_2 capture and material/energy balances.
$g(\tilde{x}) \leq 0$	Maximum flooding in columns: 80%.

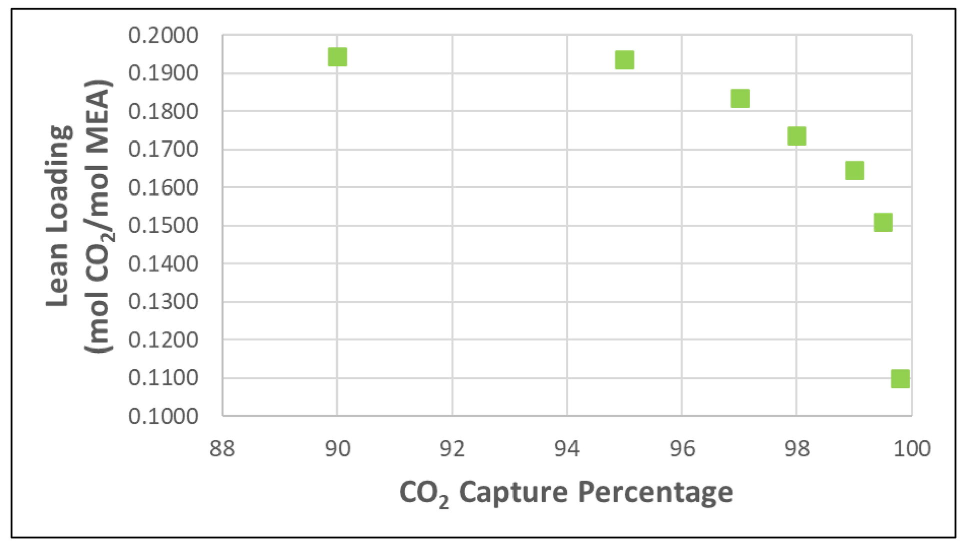
References

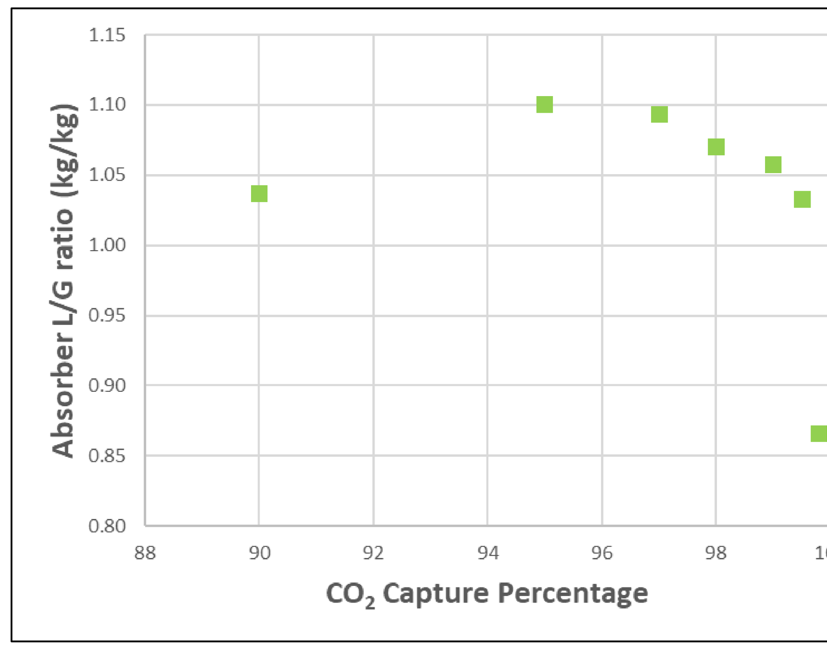
[1] James, R., Zoelle, A., Keairns, D., Turner, M., Woods, M., Kuehn, N., 2019. Cost and Performance Baseline for Fossil Energy Plants Volume 1: Bituminous Coal and Natural Gas to Electricity. NETL-PUB-22638

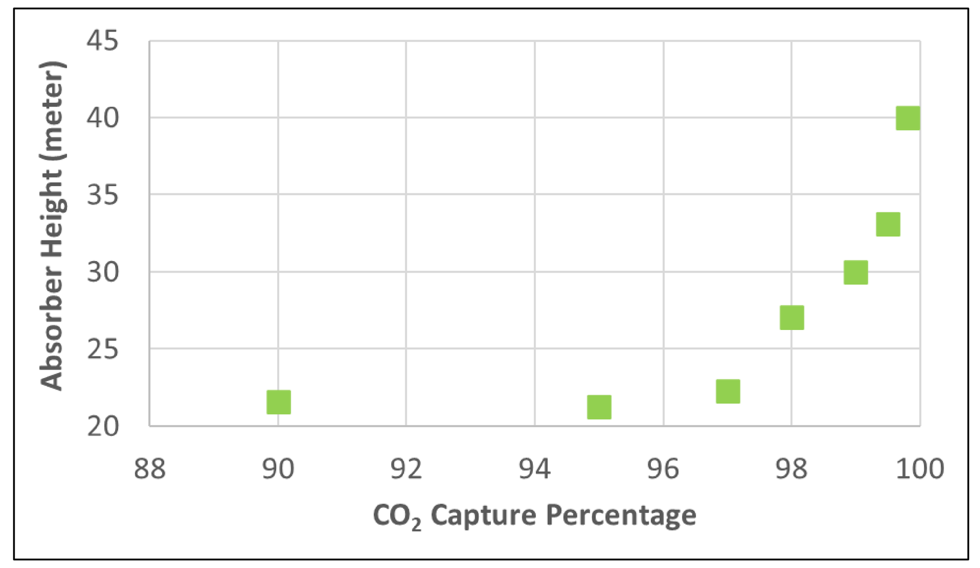
[2] Li, K., Leigh, W., Feron, P., Yu, H., Tade, M., 2016. Systematic study of aqueous monoethanolamine (MEA)-based CO_2 capture process: techno-economic assessment of the MEA process and its improvements. Applied Energy 165: 648-659.

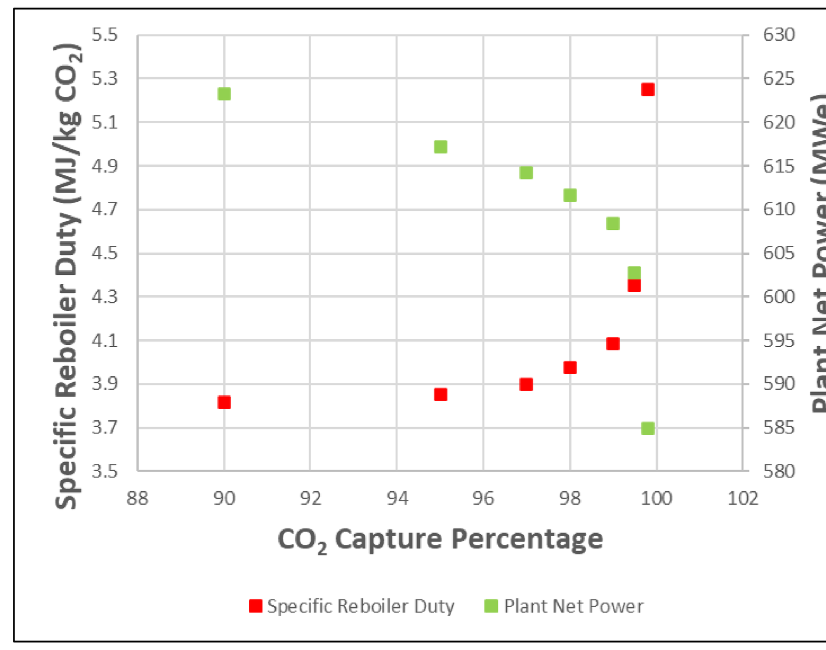
Results and Conclusions

Capture System Model Variables



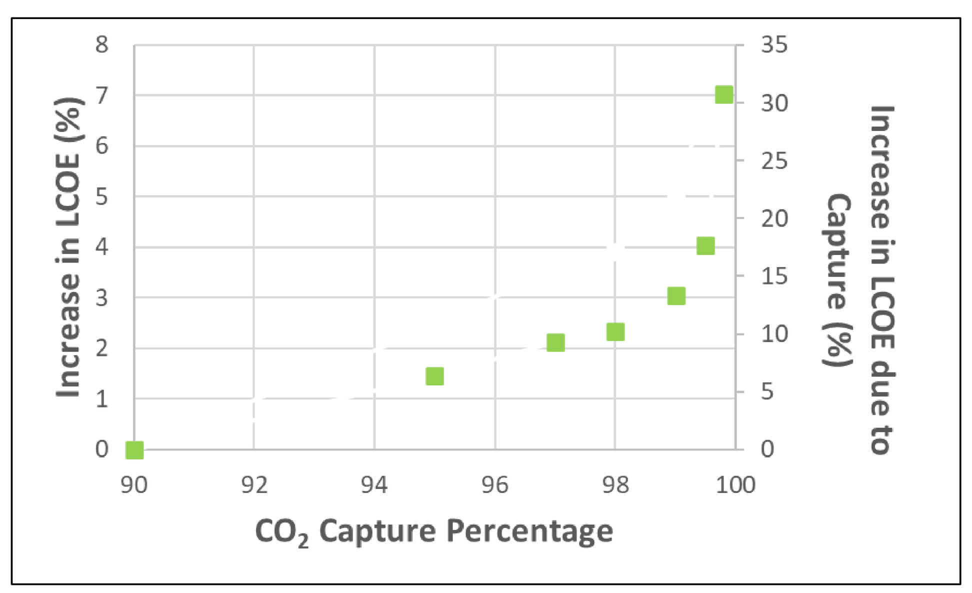


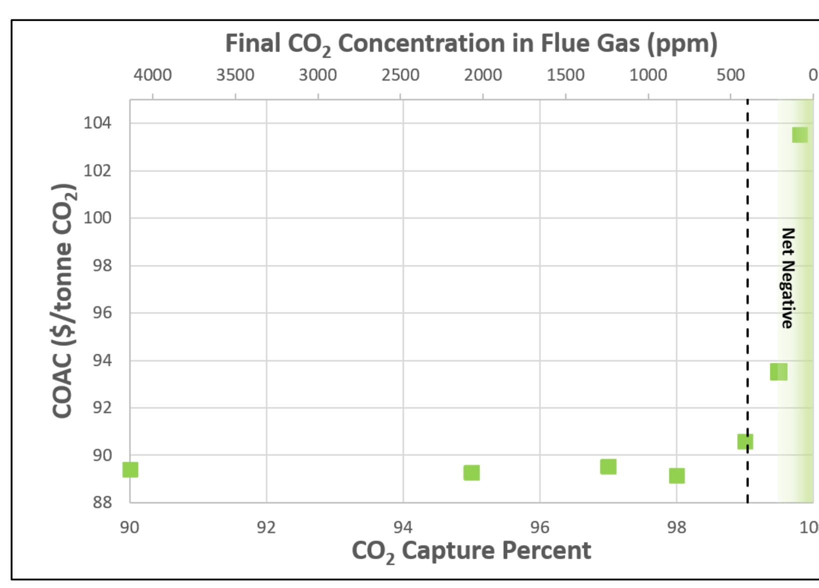




Optimal lean loading remains flat for 90–95% CO_2 capture and then decreases with increasing CO_2 capture to alleviate the rapid rise in reboiler duty and steam extraction. As a result, the solvent circulation rate drops, and the absorber height increases. Higher working capacity of solvent is favored over higher liquid flux (higher mass transfer rates) for high levels of CO_2 capture.

Economic Variables





- **COAC for optimal cases: Rises from $90.59 to $103.52/tonne CO_2 from 99 to 99.8% CO_2 capture.**
- **LCOE rises from $73.9 to $78.12/tonne CO_2.**
- **Results subject to uncertainties in capital cost of CCS unit equipment.**

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