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RESEARCH PAPER · CARBON CAPTURE

Direct Air Capture Energy Intensity: Process Pathways and Scale-Up Economics

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EXECUTIVE SUMMARY

We model energy intensity and cost across liquid solvent and solid sorbent DAC process pathways under varying heat source assumptions, finding that heat source carbon intensity, not just process energy efficiency, is often the dominant factor in a DAC facility's net carbon removal effectiveness, a distinction that published cost figures frequently obscure.

Abstract

This paper models process energy intensity and levelized capture cost for representative liquid solvent and solid sorbent direct air capture pathways, decomposing total energy demand into electrical and thermal components and evaluating net carbon removal effectiveness under a range of heat source carbon intensity assumptions. We find that a DAC facility's net removal effectiveness, gross CO2 captured minus emissions associated with process energy supply, is highly sensitive to heat source selection, to the point that a technically efficient DAC process paired with a high-carbon heat source can achieve substantially lower net removal effectiveness than a less efficient process paired with a low-carbon heat source.

Introduction

Direct air capture cost and performance figures published by different developers are difficult to compare directly, in part because different process pathways rely on different mixes of electrical and thermal energy, and different heat source assumptions carry very different embedded carbon intensity. This paper aims to provide a consistent modeling framework for comparing DAC pathways on a net carbon removal basis, not simply gross CO2 captured.

Methodology

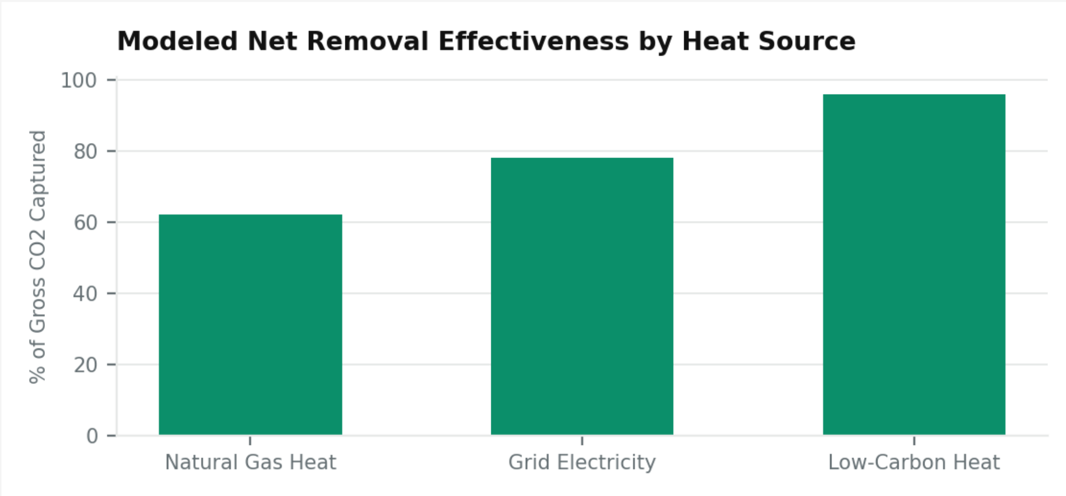
We model representative liquid solvent and solid sorbent DAC process pathways using published process energy and material balance data, decomposing total energy input into electrical energy, for air contactors, fans, and compression, and thermal energy, for sorbent or solvent regeneration. We then evaluate net carbon removal effectiveness under three heat source scenarios: natural gas combustion, grid electricity at a representative average carbon intensity, and a dedicated low-carbon heat source such as geothermal or renewable-powered electric heating.

Levelized capture cost is modeled using a discounted cash flow approach incorporating capital cost, energy cost under each heat source scenario, and sorbent or solvent makeup cost, to evaluate cost alongside net removal effectiveness rather than either metric in isolation.

Results

Under a natural gas heat source assumption, modeled net carbon removal effectiveness for both DAC pathways falls meaningfully below gross capture, in some scenarios by more than a third, once the heat source's own combustion emissions are netted against gross CO2 captured. Under a dedicated low-carbon heat source assumption, net removal effectiveness for both pathways approaches gross capture, with solid sorbent DAC showing a modest net removal advantage in our central scenario due to its lower absolute thermal energy requirement.

Levelized capture cost is lowest under the natural gas heat source scenario in absolute dollar terms, reflecting natural gas's lower delivered energy cost relative to renewable electricity or dedicated low-carbon heat in most modeled regions, which creates a direct cost-versus-net-effectiveness tradeoff that DAC project developers and, importantly, carbon removal credit purchasers evaluating claimed removal volumes should explicitly account for rather than comparing cost or removal volume figures in isolation.



Modeled net carbon removal effectiveness after accounting for heat source emissions, central scenario across both DAC pathways evaluated.

Discussion

These findings suggest that carbon removal credit buyers and DAC project developers should evaluate and disclose net removal effectiveness alongside gross capture volume and cost, since heat source selection alone can shift net effectiveness by a wide margin at comparable capital cost. We recommend that DAC procurement standards and credit verification frameworks require explicit disclosure of heat source carbon intensity alongside gross capture claims.

This analysis is based on representative published process parameters rather than a specific commercial facility's proprietary performance data, and actual facility-level results will vary with site-specific engineering and heat integration choices.

References

• IEA, Direct Air Capture technology reports

• Global CCS Institute, DAC facility technical database

• Journal of Cleaner Production, DAC lifecycle assessment literature

Suggested Citation

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