Molten Alkali Metal Borates for

High Temperature Carbon Capture

by

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Abstract

The value generated by industrial processes is undermined by the accumulation of CO_2 in the atmosphere and resulting damage from climate change. Carbon Capture, Utilization, and Storage (CCUS) intercepts CO_2 emissions, enabling the continued use of processes and resources that produce CO_2 while minimizing their environmental impact. This thesis discovers, demonstrates, and designs systems for molten alkali metal borates. These materials are positioned to benefit from both liquid phase and high temperature operation. By recovering heat more effectively from the process higher efficiencies and lower costs of capture are foreseen.

Material and chemical properties relating to CO_2 capture were explored, the ability to capture multiple acid gasses simultaneously proposed, and steam investigated as a sweep gas for isothermal operation, demonstrating ~90% capture in bench scale experiments. As liquids with inherent immunity to morphological degradation the molten alkali metal borates displayed stable performance over 1,000 hours of continuous operation. However, harsh conditions introduced material compatibility challenges such as corrosive and chemical degradation. A nickel alloy was identified as a suitable material of construction and a path forward has been proposed.

Techno-economic evaluation of a conceptual coal fired power plant confirmed the predicted benefits. Levelized cost of electricity increased 39% (25% to 49%) relative to that for the power plant without carbon capture. The expected cost of CO_2 avoided was $34/tonne ($18-56/tonne), 38% (27-50%) lower than that for the state-of-the-art amine process and competitive with the social cost of carbon ($50/tonne).

Bioenergy with Carbon Capture and Storage (BECCS) offered a unique opportunity to realize net-negative emissions while also producing reliable base-load electricity. BECCS could remove 300-850 kilograms of CO_2 from the atmosphere per megawatt hour of electrical output (kg_{CO_2}/MWh_e). The estimated cost of CO_2 avoided was $45-50/tonne relative to coal, and $80-100/tonne relative to a future, largely renewable, electrical grid. BECCS is seen as the most promising application with early adopters able to utilize low-cost resources and play an outsized role in climate change mitigation through net-negative emissions.

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