Novel Use of Concentrated Solar Thermal Energy for Producing Highly Thermal Activated Materials for CCUS via Mineral Carbonation of Mine Waste

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1. Introduction

Carbon capture, utilisation and storage (CCUS) refers to a suite of technologies that can play a diverse role in meeting global energy and climate goals. In the IEA Net-Zero Scenario [1], CCUS can facilitate the transition to net-zero CO_2 emissions by tackling emissions from existing assets, particularly large CO_2 point sources from hard to abate sectors, by providing a pathway to produce low-carbon hydrogen, and/or by allowing CO_2 removal directly from atmosphere. Among all CCUS technologies proposed to date, ex-situ mineral carbonation (MC), a process mimicking natural weathering phenomena, offers unique advantages of permanent disposal via geologically stable and environmentally benign materials (e.g., carbonates and silica) [2] while also providing recovery of valuable by-products.

Magnesium and calcium-rich minerals are ideal candidate feedstock for MC processes, with serpentine-type minerals found in both readily minable deposits and ultramafic mine waste/tailings (e.g., from nickel processing), at relatively low-cost. At global scale, the annual amount of mining tailings (mainly serpentine and olivine) produced could potentially offset some 1.5% of current global CO_2 emissions [X]. At site level, the Mount Keith Nickel mine (owned by BHP Billiton) in Western Australia has been among the most studied mines globally for potential MC integration, [3], with the mine producing some 11Mt per year of ultramafic tailings per year. The full MC capacity of these tailings represents some 4MtCO_2/year, which is approximately 10 times the annual emissions of the mine, making the mine a carbon sink. Serpentine typically requires thermal activation to produce an activated feedstock for MC. While the majority of R&D work has focused on optimizing the heating step to maximise activation and enhance rate of kinetics, there is only a limited understanding of the impact of the heating source selection on the overall techno-economics and emissions of the thermal activation step. In particular, no data are available for hydrogen-based and concentrated solar thermal-based (CST) heating, with no information on the impact of solar plant type, scale and location on process performance. Therefore, the present paper aims to meet this need by providing the very first techno-economic assessment and emission analysis of a CST-based heating plant for serpentine activation to produce activated feedstock materials for CCUS processes via mineral carbonation. A comparison with fossil fuel-based, and hydrogen-based heating is also considered in this work.

2. Methodology

Two main technological scenarios were assessed here, based on either direct fuel sources heating or indirect, CST-based heating with a back-up burner and storage to provide continuos operations (Figure 1). A first-order mass/energy balance, a transient system modeling using an expanding solar vortex receiver (SEVR) as solar receiver technology [4], and techno-economic assessments (TEA) were then developed and used to systematically analyse the process performance. A baseline reference employing non-solar energy sources (natural gas, hydrogen from different production methods) to provide the heat required for the thermal activation was also developed and performance compared against the solar route. The effect of scale, and the distance between mine and the heat activation site on the final cost of heat activation and net CO_2 sequestered were also considered and assessed here. For all cases, it is assumed that the source of mine waste is located at the BHP Mount Keith Nickel mine, with the plant scale varied in the range 200-1000 ton/h (of serpentine).

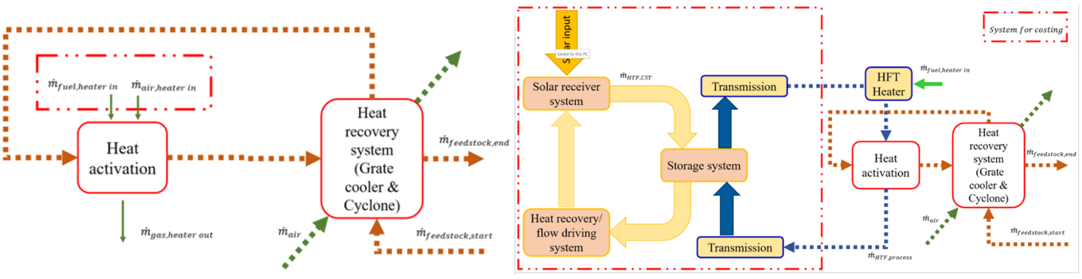

Fig. 1: Process diagram for the thermal activation of serpentine waste, with left) fuel-only (either NG or H_2), and right) CST with back-up fuel hybrid system.

4. Summary of key outcomes

The key outcomes from this study are as follows:

- **A potential, attractive business case for CST:** use of CST as major source of heat avoids reduction in the net CO_2 sequestration efficiency of some 10% in comparison with fuel-only cases (due to avoidance of CO_2 emissions associated with fuel supply chain). By selecting an appropriate ratio between scales of the CST system and the thermal activation plant, the overall cost of heating for a CST-hybrid plant is similar to that of fuel-only cases, but with lower CO2-equivalent emissions
- **Role of CST in a thermally assisted CCUS process**: the solar route can provide the heat required to sustain activation of serpentine for CO_2 mineral carbonation processes. An indirect (with the solar heat collector system being different from the thermal activation device), hybrid (CST with back-up burner and thermal storage) approach was identified as a potential, preferred route to achieve 24/7 continuos heat supply while retaining fine tuning of activation temperature process.

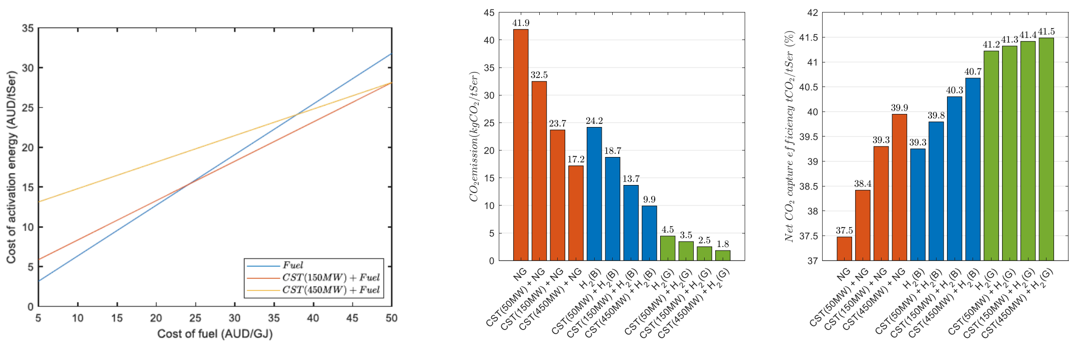

Fig. 2: Left) effect of cost of fuel and source on activation cost. Comparison of middle) CO2-equivalent emissions from activating a tonne of serpentine, right) net CO_2 capture efficiency using various heating methods. H_2 (B) and H_2 (G) represent blue hydrogen (from methane reforming with CCUS with 90% capture rate), and electrolytic H_2 from renewable electricity. All calculations for 200 ton/h of serpentine.

References

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