Decarbonizing the Cement Industry via Algae Cultivation

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Abstract

Concrete is an essential aspect of modern infrastructure, being a much-preferred construction material because it is long lasting and low maintenance. Concrete is produced through the creation of a paste comprised of cement and water that is mixed with aggregates such as sand and gravel. However, the production of one pound of cement emits 0.93 pounds of CO_2. Thus, concrete production is a major source of CO_2 emissions and accounts for approximately 8% of global carbon emissions. As the global demand for concrete continues to increase, it is evident that efforts must be made to reduce emissions associated with its production to mitigate climate change. This research proposes that the cultivation of algae can be integrated into the process of cement production so as to reduce the emissions associated with concrete. Algae uptake CO_2 through photosynthesis, having a CO_2 bio-fixation efficiency of 10-50 times higher than terrestrial plants. Algae have the ability to capture 1.8 kg of CO_2 per kilogram of algal biomass. Therefore, we hypothesize that, through the integration of algae cultivation and cement production, CO_2 can be effectively recycled through a closed-loop system. Algal biomass can be cultivated using the CO_2 emitted from cement flue gas. The cultivated algae can be harvested and used to produce methane gas (CH_4) via anaerobic digestion, which can in turn be used to power the cement plant, which will in turn produce more CO_2 to be captured through further algal cultivation.

Introduction

- Modern civilization is dependent upon energy consumption; therefore, the decarbonization of modern infrastructure is essential as greenhouse gas emissions continue to increase.
- Concrete is the second-highest consumed substance on the planet, second only to water (Hasanbeigi et al., 2012).
- Concrete is produced by creating a paste made from cement and water; this paste is then mixed with aggregates such as sand, gravel, and crushed stone to bind them together.
- In 2021, approximately 4300 Mt cement was produced. The top producers were China (55%); India (8%); Vietnam (3%); and the United States (2%), producing 92 Mt (USGS, 2021).
- In 2021, Florida was the fourth-highest state producer of cement, and the third-highest state consumer of cement (USGS, 2021).
- One metric ton (t) of cement can release approximately 0.73-0.99 t CO_2/t cement (Hasanbeigi et al., 2012).
- The kilns used to heat the ingredients of cement are powered by fossil fuels, and this process produces approximately 40% of the direct CO_2 emissions associated with cement production.
- The capture of CO_2 by technology has been studied, but this research proposes the use of algae biomass that can be directly used for energy production.
- Microalgal biomass contains ~50% carbon, and every kg of biomass can capture 1.83 kg CO_2.
- Algae can be anaerobically digested to produce biogas (CH_4) that can be used as a power source (Wilkie et al., 2011).

Objectives

- The primary goal of this research is to assess the possibility of creating a closed loop system of carbon capture at cement plants via the cultivation of algal biomass and the use of this biomass to produce methane in order to power cement plants.

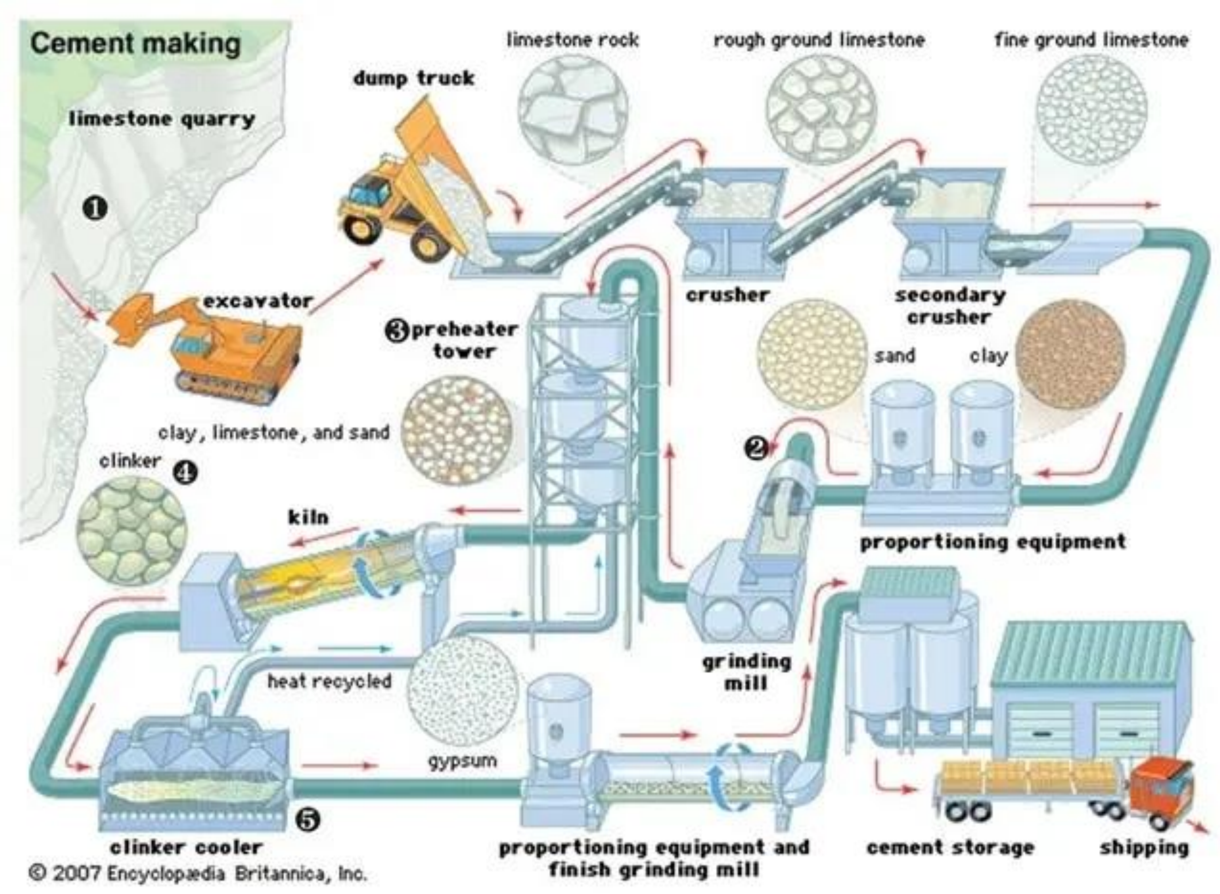

Fig. 1 depicts the process of cement production. First, the raw materials are quarried (primarily limestone and clays). These materials are crushed in a primary crusher to sizes of approximately 6 inches, and again in a secondary crusher to a size of 3 inches. The crushed ingredients are combined with materials such as iron ore or fly ash, and are then ground, mixed and fed to the cement kiln. The kiln heats the ingredients to 2700°F. As material moves through the kiln, some elements are driven off in the form of gases and the remaining mixture forms clinker. Clinker is cooled, ground, and mixed with gypsum to create a fine powder.

Methods

- This research is being conducted by reviewing the works and findings of previous studies on:

1. Algae cultivation using the CO_2 emissions from cement plants, and
2. Anaerobic digestion of algal biomass to produce biogas (CH_4) energy.

Results

- The results of this research indicate that algal cultivation from the flue gas associated with cement production is possible.
- Azari et al. (2020) found that the bio-fixation of carbon with algae aids in the conversion of polluted flue gases from large-scale industries into biofuels.
- However, despite the fact that cement flue gas can be used to cultivate microalgae, the presence of SO_2 will likely have adverse implications on growth rate due to pH changes (Azari et al., 2020).
- The pH of flue gas also affects algae cultivation, and it therefore must be maintained at a level of 6.0-8.0, with 7.0 being optimal, in order to maximize growth (Camargo & Lombardi, 2018).
- Bhola et al. (2014) found that algae of the types *Chlorella, Scenedesmus, Spirulina, Nannochloropsis,* and *Chlorococcum* are characterized by large and active growth, high tolerance of CO_2 concentrations, and different environmental conditions.
- The integration of algal bioresource generation into human activities has the potential to create an "algae-based bioresource cycle" (Wilkie et al., 2011).
- The cultivated algal biomass can be anaerobically digested to produce biogas, which can then be used to provide energy to power the cement plant (Wilkie et al., 2011).

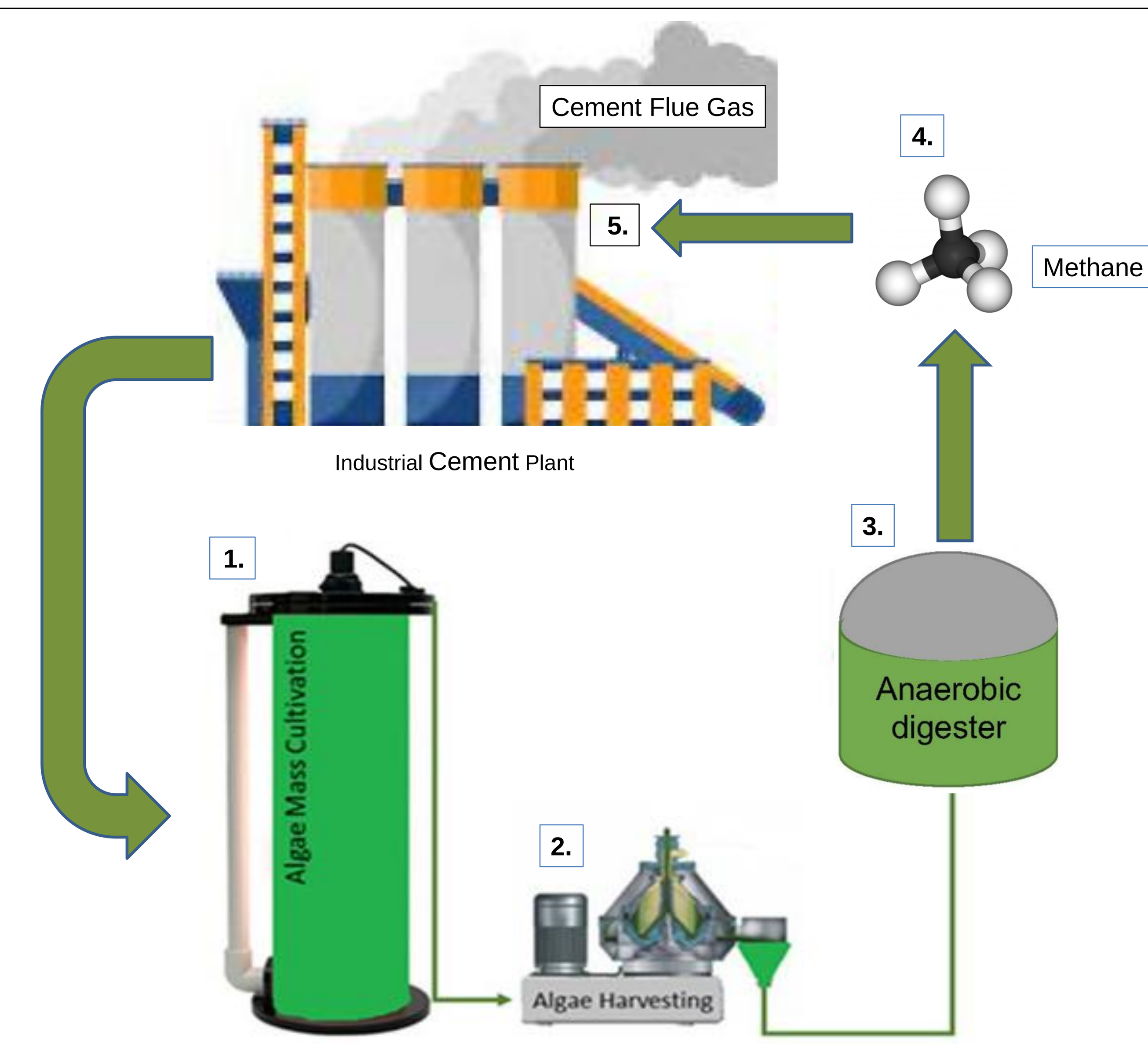

Fig. 2 depicts an integrated, closed-loop cement/algae production process. Step 1 is to cultivate microalgae from the flue gas emitted from the cement plant. Step 2 depicts the harvesting of the cultivated algal biomass. Step 3 depicts the process of anaerobic digestion that the biomass will undergo to produce the methane (CH_4) depicted in Step 4. Step 5 is to use this CH_4 to power the cement plant.

Conclusions

According to the results of available literature, the cultivation of microalgae from cement flue gas is possible, as is the ability to produce biogas (CH_4) from algal biomass via anaerobic digestion.

This study provides evidence to support the concept of an integrated, closed-loop cement production/algae cultivation process. The next step would be a "proof of concept" study to conduct a pilot-scale feasibility demonstration project. Ultimately, by integrating algae cultivation and cement production, the greenhouse gas footprint of the cement industry can be reduced.

References

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