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Impact of fuel selection on the environmental performance of post-combustion calcium looping applied to a cement plant

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HIGHLIGHTS

- The environmental performance of calcium looping applied to clinker production is studied.
- Replacing coal with natural gas or biomass improves the performance of calcium looping.
- Using biomass to drive calcium looping can lead to net negative life cycle CO_2 emissions.
- Using alternative fuels avoids environmental repercussions associated with coal production.

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ABSTRACT

Calcium looping CO_2 capture is a promising technology to reduce CO_2 emissions from cement production. Coal has been seen as a logical choice of fuel to drive the calcium looping process as coal is already the primary fuel used to produce cement. This study assesses the impact of using different fuels, namely coal, natural gas, woody biomass and a fuel mix (50% coal, 25% biomass and 25% animal meal), on the environmental performance of tail-end calcium looping applied to the clinker production at a cement plant in North-western Europe. Process modelling was applied to determine the impact of the different fuels on the mass and energy balance of the process which were subsequently used to carry out a life cycle assessment to evaluate the environmental performance of the different systems. Using natural gas, biomass or a fuel mix instead of coal in a tail-end calcium looping process can improve the efficiency of the process, as it decreases fuel, limestone and electricity consumption. Consequently, while coal-fired calcium looping can reduce the global warming potential (life cycle CO_2 emissions) of clinker production by 75%, the use of natural gas further decreases these emissions (reduction of 86%) and biomass use could results in an almost carbon neutral (reduction of 95% in the fuel mix case) or net negative process (−104% reduction in the biomass case). Furthermore, replacing coal with natural gas or biomass reduces most other environmental impact categories as well, mostly due to avoided impacts from coal production. The level of improvement strongly depends on whether spent sorbent can be utilized in clinker production, and to what extent sequestered biogenic CO_2 can reduce global warming potential. Overall, the results illustrate the potential of using alternative fuels to improve the environmental performance of tail-end calcium looping in the cement industry.

1. Introduction

Carbon capture and storage (CCS) is an important technology to reduce greenhouse gas (GHG) emissions and mitigate climate change, and is considered essential in limiting the global temperature increase to 2 °C [1–4]. Although CCS is often associated with power plants, CCS is essential to achieve deep CO_2 emission reductions in industry as the effects of alternative climate change mitigation options e.g. energy efficiency improvement and the use of renewable fuels) are limited [5,6].

Global cement production accounts for about 1.4 Gt of CO_2 emissions per year [7], corresponding to roughly 5.8% of global anthropogenic emissions [8]. Established measures, such as improving energy

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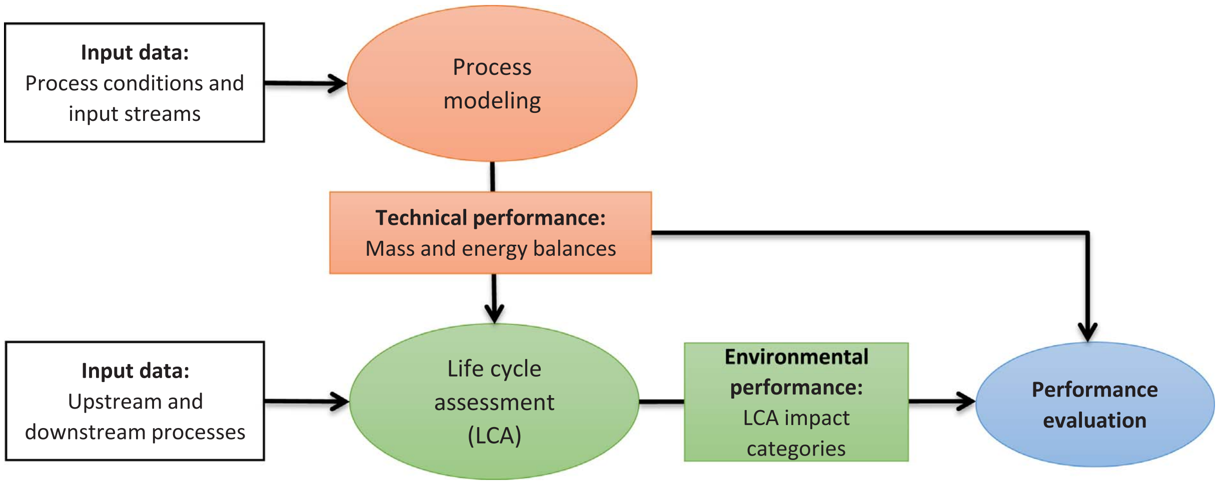

Fig. 1. Schematic overview of the general approach.

efficiency, using alternative raw materials and/or fuels, and reducing the clinker to cement ratio, are increasingly being used to lower CO_2 emissions from cement production [9]. However, these measures are expected to reduce the CO_2 emissions of cement production by only 20–25% by 2050 [10]. Deployment of CCS is thus necessary to achieve deeper emission reductions in the cement industry [11]. The main component of cement is clinker (usually over 90%), and clinker production is also the most energy- and CO_2 intensive process in cement manufacturing. Therefore, capturing the CO_2 emissions from clinker production is generally the point of focus when considering CCS in the cement industry.

Post-combustion CO_2 capture and oxy-fuel combustion are the preferred technologies for CO_2 capture in clinker production, as pre-combustion capture cannot capture the CO_2 from the calcination process [11]. Calcium looping is considered an especially favourable CO_2 capture technology for the cement industry, as cement plants already have experience with solids handling, have limestone handling infrastructure in place, and can potentially utilize the resulting spent solids in the cement production process [12–15]. Calcium looping CO_2 capture can be applied at the tail-end of the clinker production process post-combustion capture) or integrated with the calcination process. Integration of the calcium looping process with clinker production has been shown to be more efficient [16,17]. However, tail-end calcium looping can still be a valid retrofitting option for existing plants [18].

Traditionally, coal is used in the production of cement due to its high heating value, homogeneous composition, favourable radiative heat transfer characteristics, and relatively low costs. Although an increasing amount of cement plants has started to co-fire less carbon intensive fuels, such as waste streams and biomass to reduce CO_2 emissions, coal is still the most dominant fuel used in cement production [11]. Consequently, coal is generally selected as the fuel to also cover the heat demand of the calcium looping CO_2 capture processes. However, additional coal consumption can have significant repercussions for the environmental footprint of a cement plant as emissions associated with coal production and transport are reported to dominate the life cycle impact of calcium looping [19].

Other fuels than coal, e.g., natural gas or biomass, could also be used to deliver the heat demand of calcium looping. The performance of using natural gas for calcium looping has been studied for natural gas fired power plants [20,21] and natural gas fired industrial processes [22,23]. Besides, the feasibility to apply calcium looping to biomass fired power plants has been analysed [24]. To date, no publicly available literature addresses the environmental performance of other fuels driving the calcium looping CO_2 capture process at a cement plant. The required additional fuel input to drive tail-end calcium looping is in the same order of magnitude as the required fuel input for clinker production. Therefore, additional investments will be needed in clinker plants to increase fuel handling capacity, regardless of the type of fuel that is considered, and coal does not need to be selected as the fuel driving the calcium looping in the decision making process.

The possibility of using alternative fuels than coal for calcium looping can be interesting as environmental repercussions associated with coal production can be avoided. The goal of this study is to investigate whether, and if so by how much, using fuels with low carbon intensity might provide a low-hanging fruit to improve the environmental performance of calcium looping in cement plants.

Table 1
Kiln fuel mix of the clinker production process under study.

Fuel	Mass fraction (%)	Lower heating value (MJ/kg)	C content (%)
Coal	41.7%	27.2	72.9%
Refuse derived fuel	18.5%	10.3	43.1%
Solid hazardous waste, coarse	13.6%	14.7	35.9%
Solid hazardous waste, fine	1.1%	14.2	35.9%
Liquid hazardous waste	4.8%	14.2	43.7%
Waste carbon	10.6%	31.4	72.9%
Animal meal	4.5%	17.6	47.1%
Plastic	3.5%	27.2	58.7%
Waste oil	1.4%	39.8	86.5%
Fuel oil	0.3%	41.9	86.5%

Table 2
Cement plant flue gas characteristics.

Parameter	Unit	Average value	Wet/dry
Temperature	°C	165	–
Pressure	bar	1	–
Gas flow	Nm^3/h	330,000	Wet
Mole fraction O_2	%	7.5	Wet
Mole fraction H_2O	%	18.2	Wet
Mole fraction CO_2	%	17.8	Wet
Mole fraction N_2	%	56.5	Wet
Dust	mg/Nm^3	8.7	Dry
CO	mg/Nm^3	1470	Dry
NO_x	mg/Nm^3	250	Dry
SO_2	mg/Nm^3	25	Dry
HCl	mg/Nm^3	10	Dry