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A Feasibility Study of Full Scale, Post Combustion, Amine Based, CO_2 Capture Retrofit Application in the Cement Manufacturing Sector at the Lehigh Hanson Materials Limited Facility

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Abstract

This paper will present the progress of a feasibility study, jointly conducted by Lehigh Hanson Materials Limited (Lehigh) and the International CCS Knowledge Centre, aimed at retrofitting a cement production facility at Lehigh (Edmonton, Alberta, Canada) with a full scale, post combustion, amine-based Carbon Dioxide (CO_2) capture system. This study is a major breakthrough for carbon capture and storage (CCS) as it represents a first in North America for CCS application in the cement industry. The main deliverable of the feasibility study is a Class 4 estimate to assist Lehigh in determining the economic viability of a potential CCS retrofit project. This feasibility study commenced in November 2019 and will be complete in the fall of 2021 and is projected to cost $3.0M CAD. Funding for this study has been contributed to by Lehigh and Emissions Reduction Alberta (ERA) with contributions by the International CCS Knowledge Centre. The study will examine both the carbon capture technology and the "balance of plant". Successful completion of this feasibility study could lead to a decision to carry out a Front End Engineering and Design (FEED) study and ultimately to a Final Investment Decision (FID) to implement a commercial scale project. A commercial project is projected to reduce emissions by approximately 600,000 tonnes of CO_2 per year. The commercial scale project is projected to reduce emissions in Alberta in excess of 13.1 M tonnes over a 25-year lifespan.

The International CCS Knowledge Centre who is providing project management and advisory services, has engaged an experienced CO_2 capture technology vendor, Mitsubishi Heavy Industries (MHI) Group, for the design of the CO_2 capture system. MHI is responsible for the scope of work that includes the flue gas pretreatment system, the CO_2 capture facility, and the CO_2 compression process. The International CCS Knowledge Centre is also engaging and directing engineering consultants or other solution providers as appropriate. This direction and guidance will utilize base learnings from both the fully integrated Boundary Dam 3 CCS Facility and the comprehensive second-generation CCS study, known as the Shand CCS Feasibility Study, engineering consultants are being engaged to provide preliminary process and equipment design and cost estimates within their assigned scopes of work or work packages.

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The captured CO_2 would be permanently sequestered and could be also used for Enhanced Oil Recovery (EOR). The Lehigh facility is located near potential storage locations, including being about 50 km away from the Alberta Carbon Trunk Line (ACTL) and nearby EOR opportunities. Lehigh, part of HeidelbergCement, will contribute to the company's goal of achieving CO_2-neutral concrete by 2050 at the latest and make it the most sustainable building material.

Keywords: CO_2 capture; CCS cement; heat recovery

Nomenclature

AC	Air Cooling
ACTL	Alberta Carbon Trunk Line
AQC	Air Quenching Chamber
DCC	Direct Contact Cooler
EPS	Electrostatic Precipitator
GHG	Greenhouse Gas
LP	Low Pressure
PH	Preheater
SP	Suspended Preheater
WHR	Waste Heat Recovery
WSAC	Wet Surface Air Cooler

1. Project overview

Cement is used to make concrete, the second most-consumed material in the world and the most consumed man-made material in the world. With a global annual production of more than 4 billion tonnes, the cement manufacturing industry contributes as much as 8% of global CO_2 emissions. With the demand of this material expected to increase between 12-23% by 2050, actions must be taken to reduce the CO_2 emissions profile of these facilities.

To achieve the sustainability commitment on CO_2 emission reduction and support Canadian policies on climate change protection, Lehigh Hanson, which is part of HeidelbergCement, is leading the development of the application of a large-scale, amine-based, CCS project at their cement manufacturing facility located in Edmonton Alberta. The facility emits 600,000 - 750,000 tonnes of CO_2 annually while producing 800,000 – 1,000,000 tonnes of clinker. This project is exploring:

- the economic and technical feasibility of capturing CO_2 produced both by the kiln during the production of clinker and the CO_2 produced from the thermal processes required for the regeneration of amine solvents
- the effects of cement plant flue gas contaminants on the CO_2 capture process and mitigation strategies
- the potential of heat recovery from the existing cement plant to fulfill the energy requirement of the CO_2 capture process (specifically amine regeneration)

A schematic diagram of the scope of the project is in Figure 1. Flue gas from the kiln is introduced to the flue gas pre-treatment process. At this stage the flue gas is preconditioned by cooling and removing impurities such as particulate, and sulfur oxides (SOx) before being fed to the CO_2 capture process. The CO_2 produced by the capture process is fed to a compression system which simultaneously compresses and dries the CO_2 before delivering it to off-takers for utilization or a CO_2 storage site.

This study is being jointly conducted by Lehigh (including HeidelbergCement Technology Centre) and the International CCS Knowledge Centre. The International CCS Knowledge Centre has also engaged MHI, and engineering consultants (engaged to support the design the balance of the plant components).

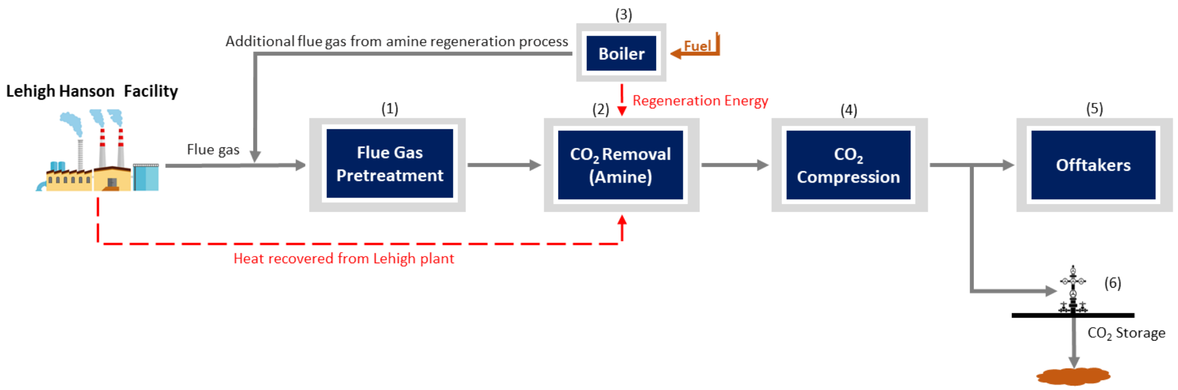

Fig. 1. A schematic diagram of the scope of the project

2. CO_2 emissions from Lehigh Edmonton plant

The majority of CO_2 emissions produced by a cement plant are derived in its kiln system, due to the combustion of fuel to heat the kiln, and the chemical conversion of limestone. Minor amounts of CO_2 emissions are also produced by the operation of mobile equipment and the cement milling process, in certain operating scenarios. While the energy used to fire the kiln could be switched to alternative or renewable sources, as adopted by the power generation and other industrial sectors, the emissions resulting from the chemical reactions in the cement production process cannot be similarly eliminated. Consequently, the greenhouse gas emissions associated with the chemical process continues to be a significant challenge in reducing the global CO_2 footprint of the cement industry. Cement plants are designed to allow for variability in their fuel sources. Availability and costs of fuel options often dictate the types of fuels used at a cement facility. This in turn affects the composition of the resulting flue gas that is to be treated by the CO_2 capture process. There can be a wide range in the composition of the flue gas. This variability adds a layer of complexity. The flue gas pretreatment, CO_2 capture and CO_2 compression processes must be designed to accommodate this variability in flue gas composition while also maintaining a desired degree of process efficiency over this compositional range.

The addition of post combustion amine solvent CCS technology to a cement facility would require energy for the regeneration of the amine. This energy would be supplied by steam to the reboilers of the CO_2 stripper column. The cement facility provides yet another obstacle as there are no existing steam sources that can be tapped into to provide this regeneration energy (as can be done with thermal electricity generating facilities). For this study, it was determined that this energy would be provided using a purpose-built auxiliary boiler. This auxiliary boiler would produce its own CO_2 emissions. To maximize the emission reduction potential of this project it was determined that capturing the CO_2 emissions from this boiler would also be desired. The flue gas pretreatment, CO_2 capture and CO_2 compression processes would be designed to accommodate emissions derived from combining the cement facility's kiln and the auxiliary boiler flue gas streams. The characteristic of the inlet flue gas to the flue gas pretreatment process inlet are summarized in Table 1.

Table 1. Summary of flue gas characteristics for the Lehigh cement facility

Source of flue gas	Kiln	Auxiliary Boiler	Combined
Temperature, °C	120	197	135
Pressure, bara	0.94	0.94	0.94
Mass Flow, kg/s	162.	37.	199.
Volumetric Flow (actual), m^3/h	707,000	198,000	906,000
Composition (mole %)			
H_2O	17.0	17.3	17.1
CO_2	12.36	8.74	11.67

O_2	10.38	2.04	8.79
N_2	60.26	71.06	62.32
Ar	0	0.86	0.16
Composition (ppm)			
NO	309.	29.	255.
NO_2	10.7	1.0	8.9
SO_2 (Raw Mill OFF)	64.5	0.00	52.15
SO_2 (Raw Mill ON)	6.29	0.00	5.09
Peak Condensable Particulates (mg/Nm^3 dry)	215.60	0.00	174.60
Peak Filterable Particulates (mg/Nm^3 dry)	6.40	0.00	5.20

3. Process flow description – flue gas delivery, pretreatment, CO_2 capture and compression

A process flow diagram for the retrofit of CCS to the Lehigh cement facility is depicted in Fig 2. Flue gas streams from the cement manufacturing process from the main stack and the auxiliary boiler (to be used to provide steam for regeneration) are diverted towards the Flue Gas Pretreatment and CO_2 Capture Process using flue gas ducting. The combined flue gas stream initially passes through the Flue Gas Pretreatment process which preconditions the flue gas while also removing flue gas contaminants that would adversely affect the CO_2 amines' health. Pretreatment is an important step in mitigating amine degradation which directly correlates to reduced CO_2 capture rates. Flue gas pretreatment can include flue gas cooling, particulate removal, and SO_2 abatement. Based on the combined flue gas composition, flue gas desulphurization and flue gas cooling would be required. During flue gas cooling, water vapor is condensed out of the flue gas which creates a condensate stream. This flue gas condensate stream would be directed to the water treatment plant. The treated water would be used in the heat rejection system.

Once the flue gas has passed through the pretreatment stage it enters the second stage - CO_2 Capture. During the CO_2 Capture stage, CO_2 is removed from the flue gas using amine solvent technology. This technology involves the use of two columns, one absorber and one stripper column, with a common amine solvent circulating in a continuous loop between them. Flue gas enters the bottom of the absorber while the amine is introduced at the top of the column. This enables counter current contact between the two fluids during which the CO_2 is selectively removed from the flue gas by reaction with the amine. The amine loaded with CO_2 then exists the bottom of the absorber column and moves onto the stripper column where heat is applied through a stream of low pressure (LP) steam fed to the stripper column's reboilers. The application of heat releases the CO_2 from the amine. The CO_2 then exits the top of the stripper column and proceeds onto the dehydration and compression stages.

CO_2 entering the compression and dehydration process is dehydrated and compressed in multiple stages. Moisture that is removed from the CO_2 during dehydration is sent to the water treatment plant. For this study a steam driven compressor is being evaluated. This compressor would require medium pressure (MP) steam which would be derived by using the auxiliary steam generator and a waste heat recovery boiler (PH and AQC boiler). The requirement of both MP and LP steams by the capture plant in two different areas of the process would require some integration techniques. To satisfy the MP steam needs of the compressor and the LP steam needs of the stripper column's reboilers in an efficient manner the steam path subsequently described was proposed. MP steam would be produced by the auxiliary boiler and the waste heat recovery boiler and would be initially supplied to the CO_2 compressor. Once utilized for compression the MP steam would be reduced to LP steam. This LP steam would then continue on to the CO_2 capture process and enter the stripper column's reboilers to provide the required amine regeneration energy. Once passing through the reboilers the steam would be further reduced into condensate. A portion of this condensate would circulate back to the auxiliary steam generator where the steam generation process would repeat while the remaining of this condensate would be supplied to the waste heat recovery units.

Due to the requirement of steam to the CO_2 capture and compression process, an auxiliary boiler system would be implemented to supply these needs. However, to satisfy these requirements at low costs while optimizing process efficiency, waste heat recovery methods were also explored alongside implementing an auxiliary boiler system.

As expected, additional cooling capacity would also be required for the CO_2 capture and CO_2 compression processes. This cooling could be provided by an air cooling (AC) system or by a hybrid system of air cooling (AC) in series with a wet surface air cooler (WSAC). At the time of this paper, evaluations of these two options are currently being conducted. The use of a WSAC will depend on water availability which will need to be determined.

4. Waste heat recovery from Lehigh's existing plant

Waste heat recovery provides opportunities to improve overall efficiency of a process while providing cost and energy savings by making use of lower quality heat that would otherwise be discarded. Two sources of useable waste heat were identified in this study 1) a portion of the flue gas exiting the conditioning tower of the cement facility and 2) the clinker cooling air. Two different types of boilers, with one to recover heat from each of the waste heat sources, would be needed. A preheater (PH) boiler would be utilized to recover heat from the portion of the flue gas from the conditioning tower while an air quench cooler (AQC) boiler would be used to recovery heat from the clinker cooler air. These two boilers would function together to produce steam which would then be fed to the required areas of the CO_2 capture and compression process. The thermodynamic evaluation, design, and cost estimation of these two boilers has been performed. The economic evaluation of waste heat recovery is ongoing.

5. Future work and reports

This feasibility study is expected to be completed the fall of 2021. Completion of this study will aid in further decisions and whether to move towards an implementation of CCS to the Lehigh Edmonton facility. A public report is anticipated to be released which will detail the non-confidential findings of this study. The future of industrial scale applications of CCS lies in the industries that do not have renewable alternatives.

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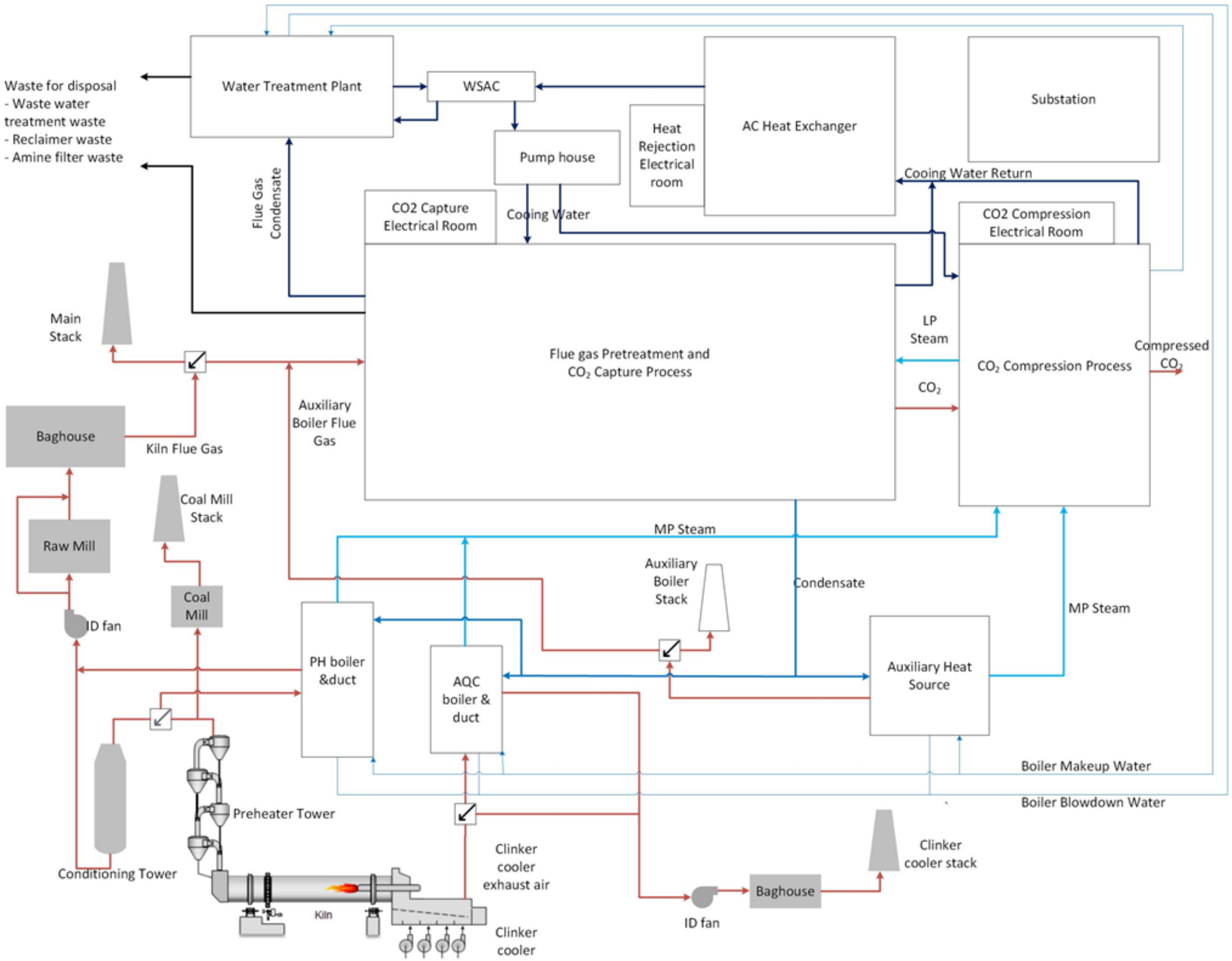

Fig 2. Overall process flow diagram of the CCS retrofit of the Lehigh Cement facility