DECARBONISING WITH DUAL DYNAMICS

Jean-Michel Charmet, Fives FCB, outlines the potential of oxyfuel combustion and flue gas recirculation as scalable carbon capture strategies for deep decarbonisation in cement production.

For more than 20 years, Fives has had a comprehensive approach to provide viable, scalable decarbonisation solutions for cement manufacturers. While energy efficiency improvements and clinker substitutions remain foundational primary strategies, this article focuses on advanced carbon capture techniques – particularly tail-end and oxyfuel-based systems – positioned as key enablers for achieving final decarbonisation in cement plants.

Technological pathways for CO_2 mitigation

There are numerous carbon capture technologies that can be applied to cement manufacturing. They can be divided into two main groups: tail end systems, which do not require modification of the cement plant process

itself, and integrated systems, which induce more or less important modifications within the plant.

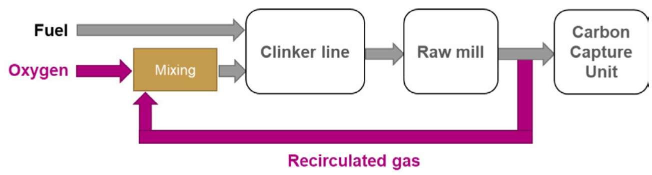
This article will focus on oxyfuel-combustion based solutions for concentration of the CO_2 in the process. Additionally, a comparison will be made with one of the most widely used carbon capture technologies, i.e absorption by amine type solvents.

Tail-end carbon capture using amine solvents

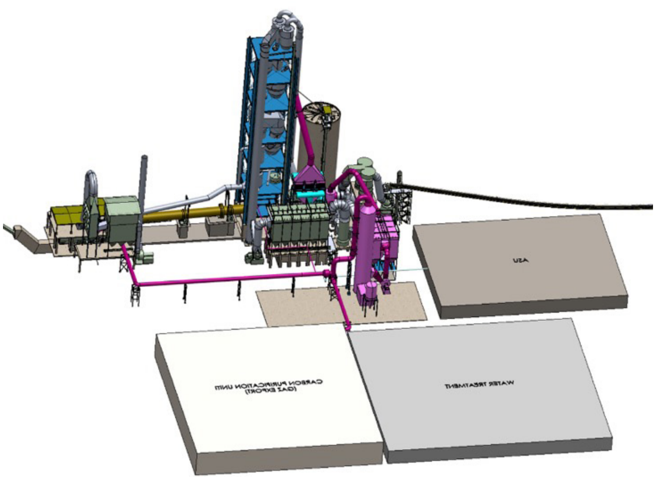
The main characteristics of carbon capture technologies using amines solvents can be outlined as follows. This mature and well-established technology, originally developed in the oil and gas industry for gas purification, is capable of capturing CO_2 from flue gas with very low concentrations up to a few dozen percent. Its adaptability makes it suitable for integration at the stack

	Energy Efficiency	Fuel Switching	Material Substitution	CO_2 Capture
FCB Horomill®	●		●	
FCB TSV™ Classifier	●		●	
FCB Aerodecantor	●		●	
FCB Rhodax®			●	●
FCB Carbonator				●
FCB calciners (Zero-NOx, In Line)	●	●		
FCB Preca-Max®	●	●		
FCB Pyro-line	●	●		
FCB Flash Calciner	●	●	●	
FCB By-pass	●	●		
Pillard NOVAFLAM® burner	●	●		
FCB Opti-Kiln™	●	●	●	
Oxyfuel-Combustion Process				●

Fives solutions for decarbonising the cement industry.



Oxyfuel combustion with FGR principle.



Plant layout with oxyfuel combustion and carbon capture footprint.

(tail-end) of any cement plant, requiring minimal modifications to the existing plant infrastructure.

Amine-based carbon capture systems have nearly 100 years performance history, mainly in the oil and gas sector, but their implementation in cement plants comes with specific challenges. One key element is the sensitivity of amines to pollutants present in the flue gas, such as dust, SOx, and NOx. To address this, additional gas treatment systems, such as scrubbers or filters, are required to ensure the flue gas is sufficiently clean before entering the capture system. Additionally, amines slightly degrade over time, necessitating a continuous supply of fresh amine solvent to maintain performance.

The most significant challenge, however, lies in the new thermal energy demand required to regenerate the amine solvent. While some of this energy can be recovered from the waste heat recoverable at the cement plant, the majority must be supplied by an auxiliary steam generation system. This dependency on external thermal energy is particularly critical in regions like Europe, where waste heat availability is often limited due to integrated kiln production facilities and more limited access to combustible and low carbon fuels. To ensure the carbon footprint of the capture system is not compromised, it is essential to use a CO_2-neutral energy source for the steam boiler, such as biomass or even renewable fuels.

Despite these challenges, amine-based carbon capture can remain a viable and attractive solution for cement plants. Its ability to operate with low CO_2 concentrations and its compatibility with existing plant configurations make it a flexible and scalable option for reducing emissions in the cement industry.

Oxyfuel combustion with flue gas recirculation strategy

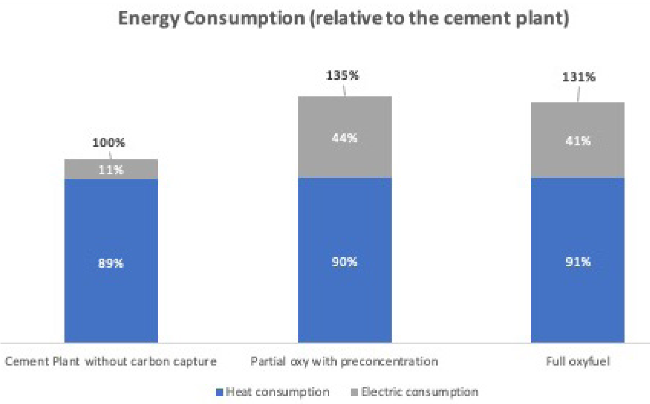
Main principles

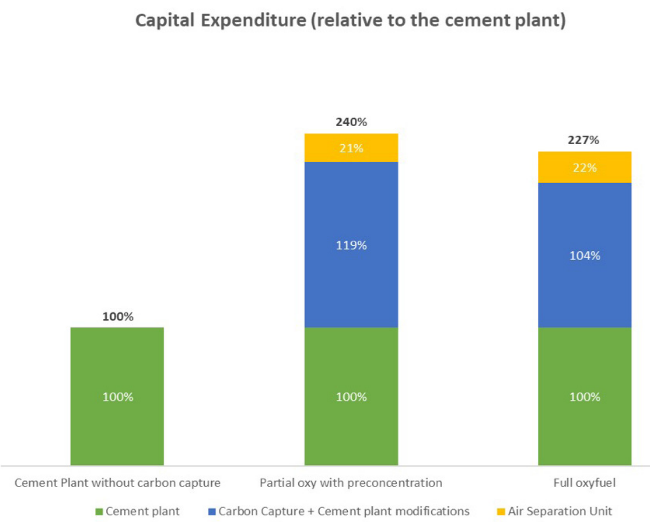
The CO_2 capture process using oxyfuel with flue gas recirculation technology relies on burning fuel in an oxygen and recirculated flue gas (mainly CO_2 and H_2O) atmosphere instead of air, in order to increase the CO_2 concentration in the flue gases and control the combustion temperature. This process simplifies the separation of CO_2 from the flue gases compared to traditional combustion methods that require, as previously explained, thermal energy-intensive post-treatment or preconcentration steps like CO_2 selective membranes or pressure swing adsorption process (PSA).

Testing, particularly the one conducted with ECRA in 2016 at Fives FCB R&D centre rotary kiln pilot, has shown that oxyfuel combustion does not significantly alter the composition, structure, or properties of the resulting clinker, maintaining product quality and process efficiency. However, the integration of this technology in cement plants necessitates careful optimisation of the entire process due to different gas properties.

After temperature quenching and abatement of the contaminants contained in the flue gases, they are directed to the CO_2 purification unit (CPU) to ensure the CO_2 meets the specifications for transport and storage, either in a liquid or gaseous condition.

When plant retrofitting limits CO_2 concentration – typically to less than 65% – and thus the oxygenation intensity of combustion, pre-concentration is required using PSA or membrane separation to enrich flue gases to levels compatible with cryogenic purification.





The two graphs above present a detailed comparison of both energy consumption and CAPEX (Capital Expenditure) estimations. Note: Country-specific factors, such as energy prices and carbon pricing mechanisms, must be considered for precise financial modelling. Transportation and storage of CO_2 are not considered in this study.

Key benefits

Switching between air and oxyfuel modes is crucial for retrofitting existing plants without significant modifications to the pyro-process system. It is also very important for a new plant designed for oxyfuel operation to come back to air mode in order to maintain its production during a downtime of the air separation unit (ASU) or the CO_2 capture plant (no recirculation of CO_2).

This is achievable through the adjustment of flue gas recirculation (FGR), which ensures that gas flows and velocities within the system remain consistent with those in air mode, thereby maintaining meal lifting and process stability.

However, a high CO_2 concentration may impact combustion and limestone calcination. Flue gas recirculation (FGR) mitigates these negative effects by introducing recirculated H_2O, which lowers the CO_2 concentration. Water (as vapour) is then easily and inexpensively separated through condensation.

Another benefit is that by limiting the flame temperature, compared to pure oxygen combustion, FGR does not impair the refractory lifetime nor impact the volatiles phenomena within the kiln.

Additionally, CFD modelling conducted by Fives has demonstrated that FGR can enhance heat transfer – due to higher emissivity of CO_2 and H_2O molecules – and reduce specific fuel consumption, showcasing the robustness and flexibility of the oxyfuel combustion process with recirculation. The ease and flexibility of switching to air mode combustion is achieved through adjustments of axial and swirl air at the main burner.

Case study-economic assessment

A comparative analysis was conducted in collaboration with a consultant with specific knowledge in the field of carbon capture.

To ensure a thorough understanding of the parameters affecting the performances of the carbon capture plant and their implication for modifications to the cement plant, a European based facility was selected as the reference with a CO_2 recovery rate of >95%.

Two scenarios were evaluated: a full oxyfuel combustion revamp and an intermediate case involving more limited modifications to the cement plant, such as a lower degree of oxygen enrichment and partial CO_2 recirculation.

In the partial oxyfuel combustion scenario with pre-concentration and purification, a moderate level of plant modification is required, enabling CO_2 concentrations of up to 50%. Key changes in this scenario include:

- Recirculation of stack gas to the clinker cooler.
- Reduction of false air infiltration in the plant.
- Adaptation of burners.
- Adjustment of process parameters to optimise performance.
- Installation of new equipment, such as scrubber and ASU.

In contrast, the full oxyfuel combustion scenario with cryogenic purification involves the most extensive modifications. This option is suitable for new plants or major retrofits and enables CO_2 concentrations of 90% or higher. Key modifications in this scenario include:

- Recirculation of kiln gas to the clinker cooler.
- Reduction of false air infiltration in the plant, including the injection of dry CO_2.
- Recirculation of clinker cooler exhaust gases.
- Recirculation of the raw mill drying circuit and gas conditioning with heat exchanger.
- Adaptation of burners to handle the new combustion environment.
- Adjustment of process parameters to align with the oxyfuel system.
- Installation of new equipment, including a scrubber, bag filter, fan, heat exchanger, and ASU.

Each scenario progressively increases the complexity of the modifications and equipment requirements for the cement plant.

Conclusion

The decarbonisation of the cement industry is essential to meeting international climate targets. This article highlights the technical maturity and economic potential of combining oxyfuel combustion with CO_2 purification.

A joint effort between Fives FCB and a carbon capture technology specialist highlights how combining expertise can lead to the development of customised, cost-effective (both CAPEX and OPEX), and scalable solutions for this emerging application.

Considering the diverse designs and operational characteristics of cement plants, tailored strategies – leveraging modular technologies and iterative integration processes – will be critical to achieving significant and sustainable emission reductions. ■