Deep decarbonisation of cement: Oxyfuel burners and hydrogen electrolysers show the way

By Stephen B. Harrison | 15 February 2021

Some industries are considered 'difficult to decarbonise'. Iron and steelmaking is one example. Cement is another.

The challenge of decarbonisation in these industries is that carbon dioxide emissions result from the process itself, in addition to combustion of fuels for heat and energy.

In the case of ironmaking, carbon in the form of coke is used to draw oxygen out of the iron ore. Carbon dioxide (CO2) gas is the result. In cement making, calcium carbonate in the form of limestone is chemically reduced to form calcium oxide. Again, carbon dioxide is produced from the process chemistry.

In the case of ironmaking, coke can be substituted with hydrogen as a reducing agent to drive the oxygen away from the iron ore. Water is produced in the form of steam and the process is called Direct Reduction of Iron, or DRI. If the hydrogen has been produced using a renewable source, then decarbonisation of the ironmaking process is possible.

In the case of cement, there simply is no alternative way to produce calcium oxide from limestone. Carbon dioxide production cannot be avoided. However, there are many things that can be done to mitigate carbon dioxide emissions to atmosphere. Decarbonisation may be 'difficult', but it is possible.

Industrial gases hold the key to several incremental and deep decarbonisation technologies which can minimise greenhouse gas emissions from cement production. Oxygen and hydrogen have leading roles to play.

Reducing indirect carbon dioxide emissions

Limestone, clay, and sand are the main ingredients for cement making. Other materials can be added, but these minerals make up the biggest tonnages that are moved from quarries to the cement plant.

"Hydrogen-powered fuel cell trucks to replace diesel mining vehicles are an option," says Xavier d'Hubert of XDH-energy. d'Hubert is a sector coupling expert with a depth of expertise in cement and other energy intensive industries.

It is estimated that 10% of CO2 emissions related to cement production result from transportation and electrical power required to operate machinery within the cement making process. Fans to move hot gases consume power, as do the limestone crushers and cement clinker grinding mills. The sintering process operates in a huge rotary kiln, which requires a beefy motor, also drawing electrical power.

Altogether, a standard 3,000 tonnes per day (tpd) cement plant will require between 20 and 25 MW of power. d'Hubert says, "Waste heat recovery from the flue gases for an Organic Rankine Cycle (ORC) or steam plant for electricity self-generation is highly relevant for cement plants. Energy efficiency results in a reduction in total system carbon dioxide emissions."

Renewable electricity generation is also an option and some cement plants have installed PV solar or wind farms.

Oxyfuel burners and alternative energy sources

The first stage of cement making takes place in a tall vertical tower where multiple cyclones and often a calciner are located. Crushed limestone and clay are heated to 1,000°C. Calcium Carbonate ($CaCO_3$) is converted to carbon dioxide and calcium oxide (CO_2 + CaO). The mineral mixture then passes through a horizontal rotating kiln at 1,450°C where clinker is formed.

d'Hubert adds that, "Every industry has specific terminology. It might be helpful to explain that clinker is what comes out of the cooler located at the discharge of the kiln system. Cement is produced when you mix clinker with other additives such as gypsum. Concrete is produced by mixing cement with aggregate and allowing that to harden, or cure."

The limestone and clay require a tremendous amount of energy to heat them in the process. Furthermore, the calcination reaction is endothermic and requires energy to liberate the carbon dioxide from the limestone. Heating typically accounts for 30-35% of the carbon dioxide emissions related to cement production.

In locations where natural gas is cheap, it can be used to fire burners on the cement plant. d'Hubert comments that, "In many countries natural gas is a premium fuel and coal or petcoke have traditionally been used to ensure the cement is affordable in the local market. However, this is changing. Increasingly, refuse derived fuels and biomass are used to generate heat for cement making."

Xavier d'Hubert

Refuse derived fuels, or RDF, can include scrapped tyres and mixed plastic waste. Combustion of waste materials does produce carbon dioxide, but the International Panel on Climate Change (IPCC) regards incineration of the biogenic fraction of waste as carbon dioxide neutral. Animal carcasses, scrap wood, waste vegetable oils and post-consumer wastepaper meet this definition.

Oxygen enriched combustion can be implemented on many existing cement plants to support the decarbonisation of heat generation. The use of full oxyfuel combustion is also possible on new-build cement plants or can be incorporated into existing plants with appropriate process modifications.

d'Hubert adds that "when oxygen is added to the combustion air, several decarbonisation benefits arise. Firstly, the flame temperature increases which means that a higher fraction of biogenic waste can be burned." This is because the extremely high temperature will ensure complete combustion of most wastes.

"Secondly there is less gas entering the process and less heat is required to warm the gas up to the high temperatures in the calciner and kiln. This saves energy." Cement production can also be increased by 5-10% due to process intensification. This can offset some of the costs of the oxygen supply and equipment modifications.

d'Hubert declares that the third reason is because, "using less air means that the carbon dioxide concentration in the flue gases can be increased which makes carbon capture much more cost effective." With full oxyfuel combustion the carbon dioxide concentration in the off-gases could approach 85%.

Mitigation of pollutant emissions such as NOx, SOx and particulates can be simplified using oxygen enriched air, because the flue gas treatment equipment can be downsized. Also, the fans that are used to move hot gases around within the process can be smaller and will draw less power.

Deep decarbonisation within the process

The formation of carbon dioxide during the calcination reaction is unavoidable and can account for up to 65% of carbon dioxide emissions from cement production.

"Capture of the carbon dioxide is an option and retrofitting carbon capture equipment to cement plants is conceivable," says d'Hubert. "The question then becomes: what to do with the captured carbon dioxide?"

In some cases, transportation of captured carbon dioxide to a CCS pipeline for permanent underground storage will be possible. This process is being used at Norcem's Brevic cement plant in Norway. The plant is located on the banks of a Fjord which allows the carbon dioxide to be transported by ship to an offshore terminal where it will be permanently sequestered underground at high pressure.

If there is no CCS scheme close by, the captured carbon dioxide could be reacted with green hydrogen, produced by an electrolyser, to generate methane. The methane can then be used within the cement making process to fire the burners. "People sometimes ask why we would not simply use hydrogen on the burners or direct electrical heating," says d'Hubert. "Good questions. Conversion to methane is a much better fit for the heating requirements of cement making."

Both hydrogen and oxygen can be used to support decarbonisation of cement production. This means that there is a perfect fit with electrolysis which generates both gases simultaneously. d'Hubert adds that, "One of the challenges of electrolyser schemes that are driven by the growing demand for hydrogen, is to find a use for the oxygen. In the cement plant the answer is clear: use an oxygen enriched combustion process."

Decarbonisation in the cement value chain

Working to decarbonise the existing cement production process is one option. Beyond that, additional routes to decarbonisation exist. One emerging trend is to replace cement with less carbon-intensive binders such as calcined clay to make concrete.

Changes to the way concrete is made and used will also support decarbonisation. For example, fly-ash from coal combustion can partially replace clinker in cement. Less clinker production means reduced carbon dioxide emissions. Binding carbon dioxide into concrete during the curing process is also a way to utilise captured carbon dioxide.

d'Hubert concludes by saying, "The clinker – cement – concrete value chain will become less carbon intensive by taking incremental steps in addition to deep decarbonisation initiatives such as full oxyfuel combustion."

About the author

Stephen B. Harrison is Managing Director of sbh4 Consulting.