



Limestone quarry

Reducing scope 3 emissions for green steel

Scope 3 emissions take place in the supply chain. They are not directly emitted from the iron or steelmaking plant (scope 1), nor do they account for emissions from power generation for the plant (scope 2). Production of green steel will require a reduction in all categories of greenhouse gas emissions.

One contributor to scope 3 emissions is over-the-fence oxygen supply for basic oxygen furnaces and reheating burners. Lime production by a third party is also responsible for scope 3 emissions. Lime is used for slagging in the blast furnace to remove impurities in the ore.

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Oxygen is produced in power-hungry air separation units. The emissions from off-site oxygen production with pipeline supply are related to electricity generation. But when the power is used by a third party, the emissions are categorized as scope 3.

When lime is made offsite and sourced through the supply chain,

carbon dioxide (CO₂) emissions from the lime kiln are categorized as scope 3. Other feedstocks procured for use at iron and making steel plants will also contribute to the overall scope 3 emissions.

Green power for green oxygen

The core process for making oxygen is cryogenic air

separation. Ambient air is drawn into the process and pressurized using a large air compressor. To serve an ironmaking plant equipped with a blast furnace and multiple basic oxygen furnaces, the air separation unit (ASU) may require an air compressor that continuously draws 20MW of power.

Within the ASU, warm incoming air is cooled against cold air leaving the cryogenic core of the ASU. This cold air is fed to the base of a distillation column where it rises up through refluxed liquid air. The progressive contact between the rising air and the falling liquid separates oxygen and nitrogen due to vapour-liquid equilibrium differences between these two gases.

Within the ASU, a stream of high-pressure air is expanded across a high-speed rotating turbine to cool it. Electrical power is recovered from the turbine to maximize the energy efficiency of the ASU. However, this amount power is not sufficient to drive the main air compressor.

To ensure that the oxygen and nitrogen separation takes place effectively, argon must be removed from the system with an additional distillation step. Argon is present in air at less than 1%, but it accumulates in the distillation columns and inhibits the separation of oxygen from nitrogen.

The recovered argon has many commercial applications, including stainless steelmaking. The sale of argon is important in the air separation business model to offset the cost of the power consumed to make oxygen and nitrogen.



One contributor to scope 3 emissions is over-the-fence oxygen supply for basic oxygen furnaces and reheating burners.

Once the air is separated to yield oxygen, argon and nitrogen the oxygen gas must be compressed to around 20 to 40 bar and supplied by pipeline to the iron processing facility. High pressure is required to blow the oxygen through the pipeline and ensure there is sufficient pressure to drive the oxygen into the furnaces. An oxygen compressor with an additional power draw of around 10MW may be required.

To supply the air and oxygen compressors, renewable power generation from wind, solar any hydropower is a clear alternative to using electricity generated from the combustion of fossil fuels. Low-carbon nuclear power or biomass as a feedstock to thermal power generation can also be used.

With so many options open to produce green electricity, decarbonizing the air separation unit may appear to be simple from a technological perspective. However, the challenge is related to assigning the green power production to the ASU, since the biomass-fired power plant or wind farm is unlikely to be adjacent to the gas compressors.

Power transmission over the grid will generally be required, and a power-purchase agreement (PPA) must be put in place to assign the appropriate quantity of green power to the ASU operator so that their oxygen can be certified as 'green'.

Low-carbon lime making

Lime making results in geogenic CO₂ emissions which are



generated through baking calcium carbonate in the limestone ore (CaCO_3) to generate lime (CaO). The heat required to bake the limestone rock is also a source of CO_2 emissions.

Heat for the lime kiln can be theoretically be decarbonized using biogas, biomass or biocarbon as a fuel source. Alternatively, electrical heating could be used and a PPA put in place to ensure the consumed power is green. However, while these options may look good on paper, the reality is that a huge amount of heat is required.

The geogenic CO_2 emissions from the lime baking chemistry are unavoidable. To mitigate these, CO_2 capture equipment

must be used. There is no alternative. This feeds back into the decision-making process for decarbonizing the heat to the lime kiln.

The lime kiln burner flue gases are generally produced with the geogenic CO_2 emission from the process. This offers the potential to capture CO_2 from the fuel combustion and heat generation alongside the unavoidable geogenic CO_2 emissions. A similar situation arises in the cement industry, where CO_2 capture is being adopted as a decarbonization solution on several plants.

The CO_2 concentration in the flue gas from the kiln is elevated beyond that of a typical

combustion process since it also contains geogenic CO_2 from the lime making. This influences the technology selection for the CO_2 capture process.

Other factors that are key when considering the most appropriate CO_2 capture technology include the presence of moisture, oxygen and sulphur compounds in the flue gas and the pressure of the flue gas stream.

Liquid solvent-based CO_2 capture systems are being deployed for cement and lime-making decarbonization. The solvent is often an amine-type solution. Liquid absorbents are sprayed onto a rising plume of flue gas and absorb CO_2 from



Lime is required for slagging in ironmaking.

the flue gas as the gas and liquid come into contact with each other. This process takes place in an absorber tower.

The CO₂-rich solvent is then pumped to a second tower called a stripper. At the base of the stripper, heat is introduced to boil CO₂ out of the solvent. The regenerated CO₂-lean solvent is pumped back to the absorber tower and re-used to capture more CO₂.

The CO₂ from the top of the stripper is yielded as a high purity stream which is dried using cooling and condensation. The dry CO₂ can either be compressed to transmit it by pipeline to a sequestration scheme or liquefied for transportation by rail or ship to a CO₂ storage location.

Solid adsorbents are also penetrating this CO₂ capture application. These may be molecular sieves, solid amines or metal-organic-frameworks (MOFs). In this technique, CO₂ from the flue gas is chemically or physically adsorbed onto a bed of solid material at an elevated pressure.

The bed of adsorbent material is contained within a simple pressure vessel. A number of vessels containing adsorbents are connected in parallel with a manifold and change-over valves to control the direction of gas flow. When the adsorbent



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material is saturated with CO₂, the flue gas is diverted to another bed of adsorbent.

The bed of adsorbent that is saturated with CO₂ is then depressurized. This pressure reduction, or pressure swing, causes the CO₂ to be desorbed. The adsorbent is regenerated through this process and the beds can then be switched again. The pressure swing (PSA), or vacuum swing (VSA)

process alternates between adsorption and desorption over cycles that may last several minutes.

The CO₂ released from the PSA or VSA system is typically less pure than that from a liquid solvent process. However, it can generally be recovered at 95% purity or more and will be suitable for compression and pipeline transmission or can be fed to a CO₂ liquefier.

