

## A Case Study for Emissions Free CPC

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### Abstract

For aluminium smelters operating with emissions free power like hydroelectric, nuclear and renewables, the carbon raw materials supply chain accounts for around 15 % of the total smelter CO<sub>2</sub> footprint. The calcined petroleum coke supply accounts for 85 % with the balance from coal tar pitch. Work aimed at reducing CPC related emissions can have a meaningful impact on the smelter CO<sub>2</sub> footprint and this paper provides a review of calciner CO<sub>2</sub> emissions including a carbon capture solution.

The two primary contributors to CPC emissions are green petroleum coke (GPC) production (40 %) and calcination (60 %). Rain Carbon (RC) has done a substantial amount of work to quantify calciner process emissions. A key enabler was the development of a method which utilizes online CO<sub>2</sub> concentration and flowrate analyzers to quantify emissions in real time. Reducing GPC fines carryover during calcination is a key means of reducing CO<sub>2</sub> emissions. The calciner technology, operating conditions and GPC quality also play a key role.

CO<sub>2</sub> capture and storage can be used as a final reduction method. RC has undertaken a detailed capital and operating cost analysis to add a CO<sub>2</sub> capture system to its Lake Charles Calciner. The plant is located less than 20 km from a qualified CO<sub>2</sub> sequestration site in Louisiana and would qualify for US CO<sub>2</sub> sequestration tax credits. Relative to a smelter, CO<sub>2</sub> can be captured more efficiently at a calciner due to higher CO<sub>2</sub> concentrations. The technology exists today to execute a project like this, but the primary challenge is achieving a satisfactory return on investment. Without a price premium for low-CO<sub>2</sub> CPC, the investment return remains a major hurdle.

**Keywords:** Carbon, Anode, CO<sub>2</sub> Capture, Petroleum coke, Decarbonization.

### 1. Introduction

The amount of work being done around the world to decarbonize the primary aluminium production is growing rapidly. In its 2021 report [1], the International Aluminium Institute makes estimates of the emissions reductions needed by the aluminium industry to help the world achieve a 1.5 °C global warming limit by 2050. Collectively, the industry will need to reduce scope 1-3 emissions from 1.1 billion tonnes in 2020 to 53 million tonnes in 2050 representing a 95 % reduction. Decarbonizing the power supply represents the biggest opportunity but improvements will be required across the entire supply chain. Production of aluminium from recycled scrap will also need to grow to 81 million tonnes to support the 1.5 degree warming limit.

The contributors to scope 1-3 emissions for primary aluminium production have been well documented [2, 3, 4]. In a 2022 study [5], a detailed breakdown was provided for the Alouette primary aluminium smelter which operates with 100 % hydroelectric power. The total scope 1-3 emissions per tonne of aluminium were estimated at 3914 kg CO<sub>2</sub>. Smelter direct emissions from anode consumption, fluoride emissions, anode baking and casting represented 47 % of the total

and the alumina supply chain contributed 35 %. The next largest contributor was scope 3 emissions related to production of carbon raw materials used for anode production – calcined petroleum coke (CPC) and coal tar pitch (CTP). The paper provided a further breakdown that showed ~85 % of the carbon raw material emissions were due to CPC and GPC (green petroleum coke) production.

The purpose of this paper is to provide a more detailed review of the contributors to CO<sub>2</sub> emissions for CPC production. As more researchers undertake detailed CO<sub>2</sub> footprint studies, the need for reliable data on scope 3 emissions is increasing. Aluminium smelters making estimates of their scope 1-3 emissions are now turning to raw material suppliers to help provide this data. A recent paper [6] provided the first detailed product carbon footprint analysis of graphitized cathode blocks and this is a good example of the sort of data needed by aluminium smelters.

Rain Carbon (RC) operates six calcining plants in the US and two in India and has studied CO<sub>2</sub> emissions in detail to look for reduction opportunities. In 2022, RC started to investigate online measurement of CO<sub>2</sub> emissions for comparison against emissions calculated using a mass balance approach. The results of some of these studies will be presented in this paper. Carbon capture remains the only way to substantially reduce (> 90 %) calciner CO<sub>2</sub> emissions and the technology is available today, albeit at high capital and operating costs.

## 2. Review of Calciner Emissions

An overview of the calcining process and GPC production is provided in a 2015 review paper [7]. The primary goal of calcination is to remove volatile matter (VM) from GPC which is typically at levels of 9–13 %. At normal calcining temperatures (1250–1350 °C), the VM level is reduced to < 0.2 % in CPC. The VM level and composition varies by coke type, but all GPC contains carbon, hydrogen, nitrogen, oxygen, sulphur, and trace metals like vanadium and nickel. Table 1 shows some typical ranges for C, H, N, and S in GPC and CPC. Oxygen levels are not measured directly but calculated by subtracting the sum of C, H, N, S and ash levels from 100 %. The table also shows the average change in C, H, N, and S levels from GPC to CPC for a wide range of samples.

**Table 1. Typical ranges for GPC and CPC**

	<b>GPC %</b>	<b>CPC %</b>	<b>% Change GPC to CPC</b>
<b>Carbon</b>	86–92	92–97	+ 6.5
<b>Hydrogen</b>	3.4–4.4	< 0.2	- 98
<b>Nitrogen</b>	1.3–2.5	0.8–1.5	- 38
<b>Sulfur</b>	0.3–6.5	0.3–5.7	- 10

A detailed description of the chemical species generated during VM loss has been described previously [8] but the condensable tars, methane and hydrogen evolved are eventually combusted to form CO<sub>2</sub> and H<sub>2</sub>O in the kiln and pyroscrubber. As shown in Table 1, nearly all the hydrogen in GPC is lost during calcination. Some sulphur is also lost [9] and the amount varies as a function of the GPC S level and temperature and is typically 7–8 % for low S cokes and up to ~15 % for high S cokes (> 5 % S). The loss of nitrogen and oxygen varies by coke type but is significantly lower than the loss of H.

Most calciners operate with strict emission limits for SO<sub>2</sub> and many also have NO<sub>x</sub> emission limits. At RC, five of eight calcining plants use SO<sub>2</sub> scrubbers to reduce SO<sub>2</sub> to permitted levels. The extent of SO<sub>2</sub> removal varies by plant and depends on the permit limit and the sulphur level

of the GPC. The removal range is (40–99) % with the lower value for a plant that runs only low sulphur coke (< 2.5 %) and the higher value for RC’s two calciners in India.

In addition to VM, some GPC fines are also combusted during calcination – usually around 10 % for a rotary kiln calciner. The very finest particle size GPC can become entrained in the flue gas stream and carried into the pyroscrubber where it is combusted. Shaft calciners have lower fines carryover since there is no counter-current flue gas flow in contact with the coke bed. This has been documented in more detail previously [10].

The combustion of GPC fines increases the calciner CO<sub>2</sub> and SO<sub>2</sub> emissions. It also typically increases NO<sub>x</sub> emissions, but NO<sub>x</sub> can generally be controlled through the pyroscrubber temperature and combustion conditions. High temperatures and generation of “thermal” NO<sub>x</sub> [11] must be avoided to stay under emission limits.

The final source of CO<sub>2</sub> emissions in a calciner is combustion of any fuel used for supplemental heating. This is typically natural gas, but heavy fuel oil is used in some regions. The amount of CO<sub>2</sub> generated from the fuel can be calculated easily from the fuel volume used which is usually accurately known.

In summary the calciner CO<sub>2</sub> emissions are comprised of the following:

$$\text{Total CO}_2 \text{ emissions} = \text{CO}_2 \text{ from (VM combustion + fines combustion + fuel combustion)}$$

This looks to be a simple calculation, but it can be difficult to estimate CO<sub>2</sub> emissions from the first two sources due to variability in the green coke feed. The VM composition varies, particularly when the calciner uses a blend of different GPC. The level of fines carryover also varies significantly as a result of GPC particle size differences.

Most calciners do a good job of quantifying the tonnes of GPC fed to the kiln but accurate, real-time measurement of CPC production is more difficult. The temperatures and process conditions can make this quite challenging when conveyor belt weigh scale systems are used. A recent publication [12] proposed an alternative method to quantify CPC production rates and kiln yields based on measuring particle size changes between GPC and CPC.

CPC production can be better quantified over longer time periods based on the use of more accurate measurement systems for transferring and shipping the CPC product. Most calciners closely track the recovery or yield of CPC per tonne of green coke fed to the kiln. Since GPC always contains moisture (usually 6–9 %), dry yields are calculated to remove the impact of moisture. For a rotary kiln, typical dry yields are in the 77–82 % range depending on the green coke type and kiln operating conditions. Alternate kiln technology such as rotary hearth or shaft calciners will have different yield ranges. The GPC variables that influence the yield are the VM content, moisture content (wet yield), particle size distribution and sulphur content.

Assuming a calciner can accurately measure CPC production on a daily, weekly, monthly, or quarterly basis, the simplest mass-balance calculation to estimate CO<sub>2</sub> emissions is as follows:

$$\text{Total calciner CO}_2 \text{ emissions} = [(\text{Dry Tonnes GPC Fed to kiln} \times \text{Carbon Content}) - (\text{Tonnes CPC Product} \times \text{Carbon Content})] \times 44/12 + \text{Fuel related CO}_2 \text{ Emissions}$$

In the US, RC collects monthly GPC and CPC composite samples for each plant (daily samples) and measures the carbon content of each using a CHN analyser. This is a standard piece of analytical equipment that can be kept well calibrated using reference standards. The CO<sub>2</sub> emissions for any fuel consumed can be calculated easily using standard formulas.

### 3. Use of Online CO<sub>2</sub> Analysers and Flow Meters

Three RC calciners in the US have waste heat recovery (WHR) and flue gas desulfurization systems (SO<sub>2</sub> scrubbers) that use continuous emissions monitoring systems (CEMS) to measure SO<sub>2</sub>, NO<sub>x</sub> and CO<sub>2</sub> concentrations in real time. The WHR system cools the flue gases to less than 160 °C which are then exhausted from a “cold” stack which is the final emissions source for the plant. The CEMS measures both the concentration and flow rate which is necessary to meet concentration (ppm) and mass flow permit limits (kg/h) which are common in the US.

Figure 1 shows some photographs of the CEMS units. The systems are monitored and maintained independently by a third-party company and used for reporting data to environmental agencies like the EPA (Environmental Protection Agency). The systems are sophisticated and frequent calibration checks are performed (typically every 4 hours) with certified calibration gases (shown in the left corner of the middle photo in Figure 1). The probes in the stack which sample the gas and measure the flow rate are regularly pulsed with air to prevent blockages. An annual RATA (relative accuracy test analysis) is also a permit requirement to validate the CEMS data against stack test data.



**Figure 1. Left: CEMS analysers, Middle: CEMS room, Right: stack probe.**

Whilst a CEMS operates well in a “cold” stack, it is more difficult to make measurements reliably in plants without WHR systems where “hot” stack exhaust temperatures are typically > 1000 °C. The hot gases can still be sampled at these temperatures, but it is more difficult to maintain the probes for flow rate measurements. RC has not succeeded in finding a reliable system but it may be possible using water cooled probes.

RC uses the CEMS for measuring and reporting SO<sub>2</sub> and NO<sub>x</sub> emissions to ensure compliance with permitted limits. While no plants have CO<sub>2</sub> permit limits, annual CO<sub>2</sub> emissions are reported to the US EPA as part of a national GHG (greenhouse gas) reporting program.

In 2022, RC looked at the CO<sub>2</sub> data being collected by the CEMS to determine if there was enough sensitivity to monitor the impact of process changes on CO<sub>2</sub> emissions. As a first step, the data were compared to engineering stack test results to ensure that measured CO<sub>2</sub> concentrations and flowrates were accurate. The results were found to be within 5 % of stack results. This gave RC the confidence to use online CO<sub>2</sub> monitors to study calciner emissions in real time. What follows is a review of some of the studies undertaken with these analysers to better understand the drivers for CO<sub>2</sub> emissions during calcination.

#### 4. CO<sub>2</sub> Emissions Process Studies

##### 4.1 Passive Process Monitoring Trial

As a first step, RC passively monitored CO<sub>2</sub> emissions from a plant in Norco, Louisiana running a single source, low sulphur GPC with a low VM content (9.0–10.5 %). Over a 2-week period, extra sampling was conducted to measure the daily carbon content of the GPC feed and CPC product. Every tonne of CPC was also accurately weighed using trucks passing over a certified truck weigh scale. This allowed comparison of the mass balance estimated CO<sub>2</sub> emissions with the measured CO<sub>2</sub> emissions.

The plant has a dry lime, SO<sub>2</sub> scrubber downstream of the pyroscrubber and a baghouse removes the reacted or spent lime which is used as a soil stabilization material. The carbon content of the scrubber lime byproduct was measured daily to account for carryover of any un-combusted carbon fines.

Figure 2 shows a plot of the total CO<sub>2</sub> emissions in TPH (tonnes per hour) during the monitoring period along with the feed rate to the calciner. There were several periods of feed rate changes for various reasons and at the midpoint of the trial, feed was stopped completely for a short period to resolve an equipment maintenance problem.

What was surprising, was the level of variation in the CO<sub>2</sub> emissions even during periods when the operation appeared stable. The average CO<sub>2</sub> concentration for the period was 4.63 % but the range was (3.53–6.38) %. Some of this variation was attributed to, for example, significant feed rate changes but much of it was not (the period where the feed was stopped was not included in the range above). The equivalent values for the mass flow rates were an average of 16.0 t/h with a range of (11.1–22.1) t/h.

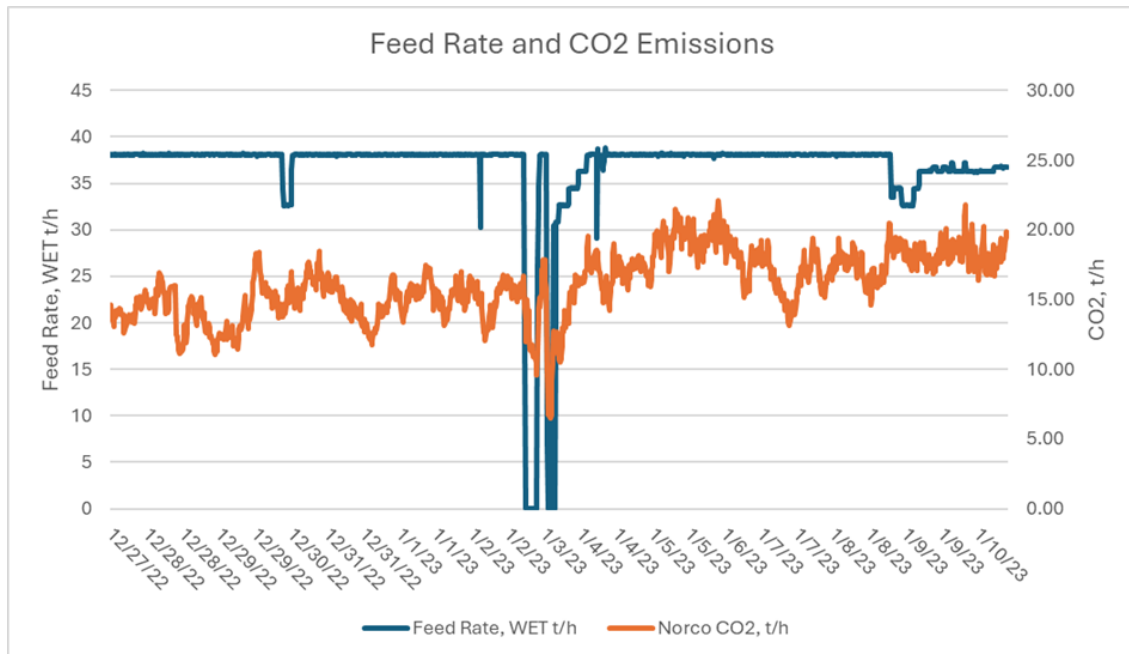


Figure 2. Calciner cold stack CO<sub>2</sub> emissions and feed rate.

The Norco calciner uses a natural gas burner to supplement process heat and the CEMS data includes the CO<sub>2</sub> from fuel combustion. The plant operators adjust process variables like tertiary air flows, kiln draft levels, pyroscrubber combustion air flows and natural gas and primary air flows and all of these impact the total flow rate which underscores the importance of the flow rate measurement for accurate calculation of the mass flow rate.

The CO<sub>2</sub> emissions from the CEMS were used to back-calculate the product recovery or yield assuming that 100 % of the fines carried over from the kiln were fully combusted to CO<sub>2</sub>. CO<sub>2</sub> from gas combustion was subtracted from the total. The measured physical yield over the 2-week trial was 79.5 % (dry basis) and the CEMS calculated yield was 80.9 %. The relative difference of less than 2 % is well within the measurement accuracy of the various systems including the GPC weigh scales, the truck weigh scales, the CO<sub>2</sub> analyser and the stack flow rate.

Key data from the 2-week trial are summarized in Table 2 and broken into first week and second week averages. The level of variation in some process parameters like the feed rate and steam flow was higher in week 2 vs week 1. The reduction in the kiln yield in the second week measured by the CEMS was matched by an increase in steam flow, consistent with a change in GPC quality and additional fines carryover to the pyroscrubber. Calculation of the online yield is not trivial since it requires accurate data for the GPC tonnes, GPC moisture level, GPC and CPC carbon content and removal of CO<sub>2</sub> generated from natural gas combustion. Once an algorithm is developed in the control system however, it can be calculated in real time as long as the carbon content variation is known.

**Table 2. Summary data from 2-week monitoring trial.**

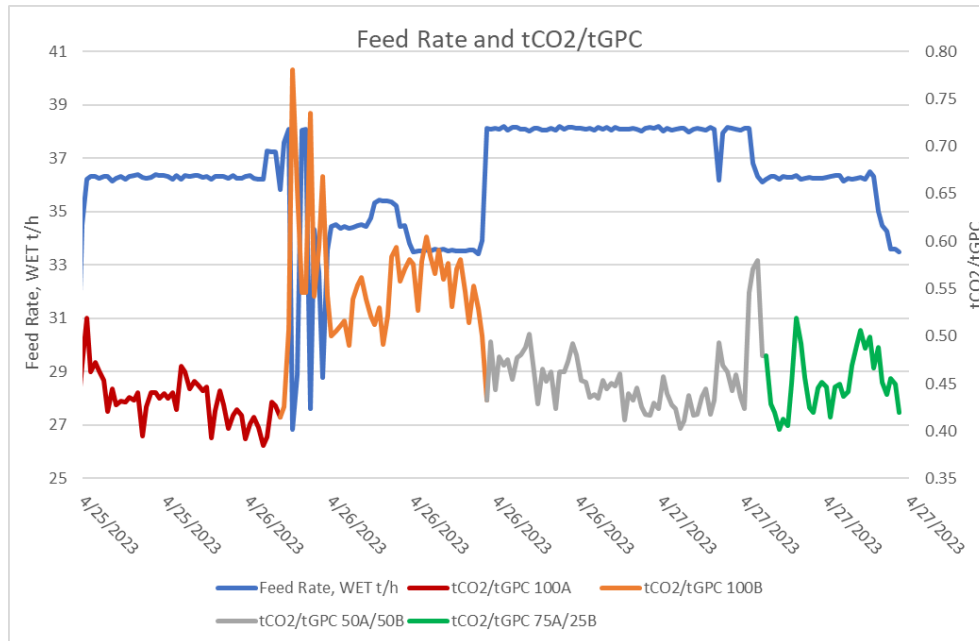
	Average		Standard Deviation	
	27 Dec–3 Jan 24	4–9 Jan 24	27 Dec–3 Jan 24	4–9 Jan 24
Kiln Feed Rate (wet t/h)	37.9	37.4	0.95	1.5
Steam Flow (kg/h)	56 977	65 347	10 603	13 182
Stack Flow (Nm <sup>3</sup> /h)	251 868	251 604	13 148	12 394
SO <sub>2</sub> Concentration (ppm)	530	532	13	17
CO <sub>2</sub> Concentration (%)	4.41	4.84	0.35	0.43
CO <sub>2</sub> (t/h)	15.1	17.3	1.6	1.5
CEMS Yield (%)	82.6 %	79.2 %	1.5 %	1.6 %

In all cases where CO<sub>2</sub> calculated yields are compared to physical yields, the CO<sub>2</sub> estimated yields are slightly higher. This is because a small amount of CPC product is lost as dust in the process, through spillages and sometimes as un-combusted carbon dust leaving the process through the lime byproduct removed from the baghouse. During the initial 2-week trial, the average carbon content in the byproduct lime was 5 % but it increased to 30 % one day after a process excursion which resulted in insufficient combustion air in the pyroscrubber. VM is combusted instantly when it comes in contact with oxygen in the kiln and pyroscrubber, but coke fines require more time to combust. A shrinking core model has been used in previous kiln modelling studies [13] to describe the combustion kinetics.

The development of an online yield measurement has provided RC with a powerful tool to optimize the calciner operation. Maximizing the kiln yield reduces the specific CO<sub>2</sub> emissions and is also favourable from an economic perspective (less tonnes GPC needed per tonne of CPC).

#### 4.2 Test with Finer Particle Size GPC

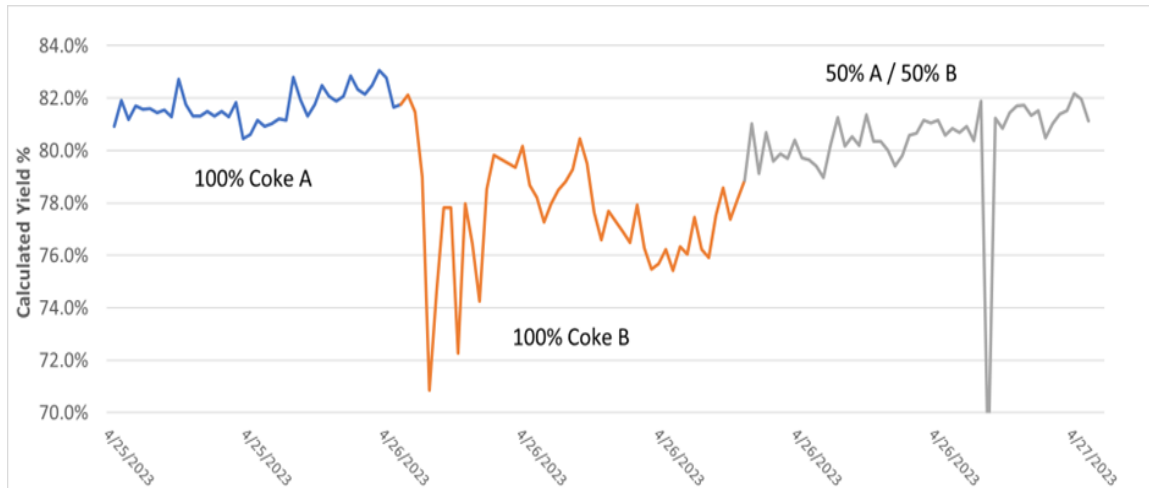
To quantify the impact of calcining GPC with a different particle size, a test was conducted at the Norco calciner by introducing a GPC with a significantly finer size. The results of this trial were quite dramatic and Figure 3 shows the CO<sub>2</sub> emissions before, during and after the trial. Coke A represents the standard GPC used by the plant and Coke B represents the finer particle size coke. This coke is never typically used as a straight run coke due but as a blend component at 10-30 %.



**Figure 3. CO<sub>2</sub> Emissions before, during and after particle size trial.**

After the plant switched from 100 % Coke A to 100 % Coke B and ran for 12 hours, the plant moved to a blend of 50 % Coke A/50 % Coke B. The initial plan was to operate with Coke B for 24 hours, but the plant struggled to maintain stability when running 100 % Coke B. Feed rates were unstable initially after switching to Coke B due to emptying and filling of the GPC bin. The pyroscrubber temperatures increased significantly after Coke B was introduced and it was difficult to keep them within the operating temperature limits due to combustion of additional fines. This was the primary reason for cutting short the trial and moving to a 50/50 blend.

Figure 4 shows the kiln yield trend for the trial with CO<sub>2</sub> from gas combustion removed. Coke B has a lower sulphur content and higher carbon content than Coke A and average carbon content data was used for the both the GPC and CPC forms of both cokes to allow calculation of the kiln yield. The chart highlights the value of online CO<sub>2</sub> analysers for estimating the kiln yield in real time.



**Figure 4. Kiln yield trend from particle size trial.**

Table 3 summarizes key data from the trial where averages were calculated for each period. The CO<sub>2</sub> emissions increased by ~30 % on average when Coke B was introduced. This was driven by the significantly higher GPC fines carryover to the pyroscrubber. The emissions decreased when the amount of Coke B was reduced to 50 % and again when the plant reverted to 100 % Coke A. It took several days for the plant to recover from the trial due to carbon fines buildup in the pyroscrubber from incomplete combustion due to a lack of combustion air. Table 4 shows the difference in particle size between Coke A and Coke B.

**Table 3. Summary data from particle size trial.**

	12 h Before Coke A	12 h Trial Coke B	12 h After Coke A/B
Feed Rate (wet t/h)	36.3	33.9	37.9
Pyro Temperature (°C)	1 309	1 378	1 340
Boiler Inlet Temp (°C)	966	1 054	1 022
Steam Flow (kg/h)	65 896	74 203	74 254
SO <sub>2</sub> Concentration (ppm)	500.2	171.3	381.6
CO <sub>2</sub> Concentration (%)	4.0	4.8	4.2
CO <sub>2</sub> (t/h)	15.6	18.8	17.1
CEMS Yield (%)	81.6 %	77.6 %	80.4 %

**Table 4. Particle size of coke A and coke B samples collected during trial.**

	Particle Size %		
	+4.75 mm	-1.00 mm	-0.25 mm
<b>Coke A</b>	75	15	7
<b>Coke B</b>	20	50	15

### 4.3 Waste Heat Recovery Systems

As mentioned in two previous papers [5,14], WHR systems provide a mechanism to indirectly reduce calciner CO<sub>2</sub> emissions. When these systems are installed, no additional CO<sub>2</sub> emissions are generated during calcining. The steam or power produced is classified as emissions free power/steam and is formally recognized by regulatory agencies like the US EPA. At RC’s Lake

Charles calciner for example, the ~27 MW of power exported to the local power grid forms part of Entergy's Renewable Energy portfolio [15].

In principle, this allows a CO<sub>2</sub> offset to be taken for the waste heat recovery system and the magnitude depends on the average CO<sub>2</sub> footprint of the avoided energy production. In India, the national average CO<sub>2</sub> footprint for power [16] is 0.65 t CO<sub>2</sub>/MWh (2020 data) compared to 0.40 t CO<sub>2</sub>/MWh in the US Gulf region [17] (2024 data). This is due to the higher percentage of natural gas, wind, solar and nuclear capacity in the US vs coal fired power generation in India.

When the GRI (Global Reporting Initiative) standard is used for GHG emissions reporting, no offset/reduction can be taken for avoided CO<sub>2</sub> emissions from waste heat power or steam generation unless 100 % of this is used by the plant. In RC's 2023 Global Sustainability Report (under publication), total scope 1 & 2 emissions of 1.197 Mt are reported along with specific emissions of 0.512 t CO<sub>2</sub> per tonne of product. Most of the emissions (83 %) are generated by RC's calcining plants. The report highlights that 0.46 million tonnes of CO<sub>2</sub>e are avoided with these WHR systems that generate a combined 913 GWh of energy.

From a societal perspective, it is much better for calciners to operate with WHR systems. Power or steam generated from these systems reduces the need to produce this energy elsewhere.

## 5. Carbon Capture

### 5.1 Process and Equipment Overview

The ultimate solution to reducing calciner process emissions is through carbon capture and storage (CCS). With typical calciner CO<sub>2</sub> concentrations in the (3.5–5.5) % range, technology exists to remove CO<sub>2</sub> from the calciner exhaust stack. RC completed an engineering study on a carbon capture option for its Lake Charles calciner in 2021 but has recently updated this as a result of changes to tax credits available for CO<sub>2</sub> sequestration in the US.

In 2022, the US Government passed the BIL (Bipartisan Infrastructure Law) which increased the tax credit available under the 45Q program for CO<sub>2</sub> storage to 85 USD/t at qualified sequestration sites. The previous level was 25–35 USD/t subject to other qualifying requirements. For companies sequestering CO<sub>2</sub> via DAC (direct air capture) the 45Q tax credit is even higher at 180 USD/t.

RC has been working with a US company, Verde CO<sub>2</sub>, who have a CO<sub>2</sub> sequestration site about 20km from RC's Lake Charles calciner. The site is technically qualified and has the capability to sequester up to 1 million tonnes of CO<sub>2</sub> per year over a 20-year period in a geologically stable formation. With a large base of industrial plants in the area, it would be possible to build a CO<sub>2</sub> pipeline to aggregate a volume of 1 million tonnes of CO<sub>2</sub> for permanent sequestration.

Whilst there are many new CO<sub>2</sub> capture technologies under development, RC considered only commercially proven technologies as the basis for this study such as Mitsubishi Heavy Industries, Shell Cansolv, and others. All these technologies use amine-based solvents and are similar in design with an absorber and stripper/regenerator on the front end and multi-stage CO<sub>2</sub> compression on the back end for a pipeline offtake. A capital cost estimate was prepared for a system capable of removing up to 330 000 t of CO<sub>2</sub> from the calciner flue gas. The annual CO<sub>2</sub> emissions from the plant vary as a function of the production rate and coke quality calcined and the above represents an upper limit. The carbon capture plant is capable of a ~90 % removal rate.

A schematic layout of the RC Lake Charles calciner is shown in Figure 5 with the location of the carbon capture plant highlighted. A flowsheet showing key process equipment is shown in

Figure 6. Although the Lake Charles plant operates with a dry lime SO<sub>2</sub> scrubber, higher SO<sub>2</sub> removal rates are needed for the carbon capture plant to avoid excess amine solvent consumption. The flowsheet therefore includes additional scrubbing capacity using a NaOH spray solution to reduce the SO<sub>2</sub> concentration from 150 ppm down to 2 ppm.

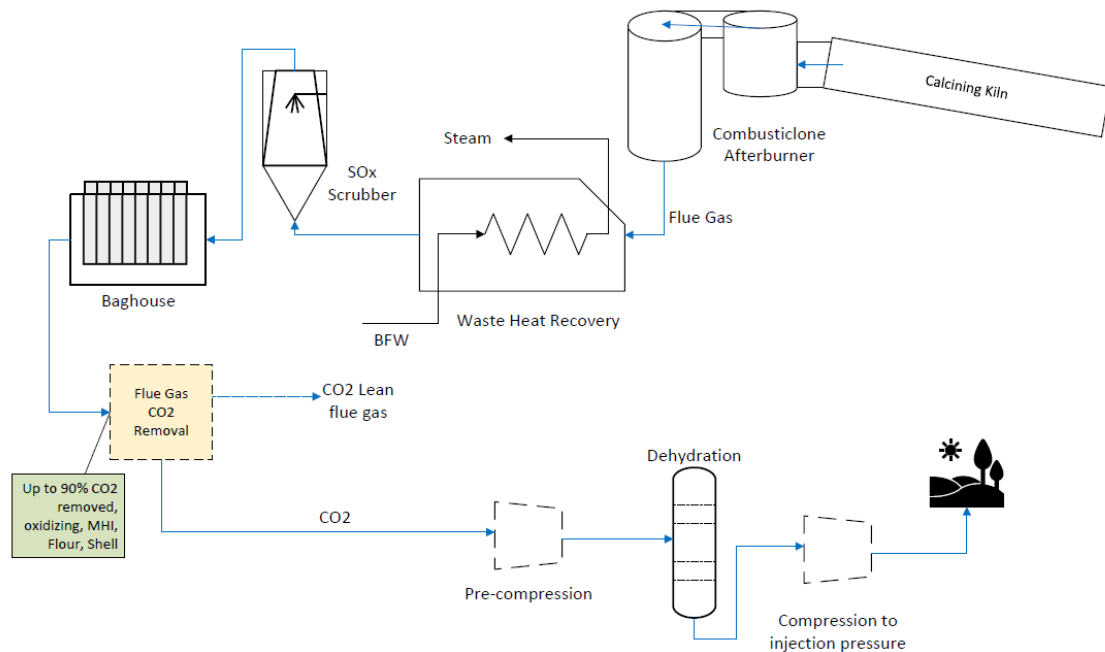


Figure 5. Location of carbon capture plant in Lake Charles calciner flowsheet.

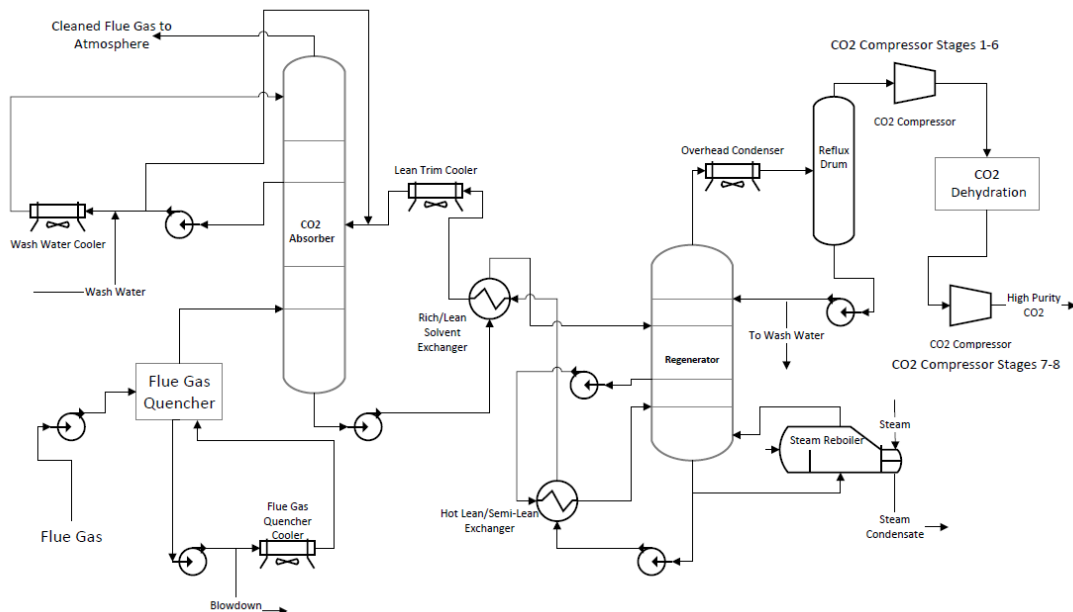


Figure 6. Carbon capture plant flow sheet.

The process equipment required is very large. The CO<sub>2</sub> absorption tower is 42 m tall with an internal diameter of 9.1 m and the footprint of the plant is 130 m × 40 m. It needs to be near the

calciner to reduce the length of the duct from the exhaust stack. The basic operation of a carbon capture plant using an amine-based solvent and supplying a pipeline for underground CO<sub>2</sub> sequestration has been described previously [18].

To meet the CO<sub>2</sub> pipeline requirement for pressure and water content, a dehydration system is integrated within the CO<sub>2</sub> multi-stage compression unit. The final water content needs to be below 200 ppm to reduce downstream equipment corrosion and potential condensation in the CO<sub>2</sub> pipeline.

## 5.2 Capital and Operating Cost Estimates

Given the size and complexity of the equipment required, carbon capture systems have a high capital cost. The most recent estimate for a Lake Charles calciner installation including the pipeline is 235 MUSD (~200 MUSD for the carbon capture plant and 35 MUSD for the pipeline and connections). The operating energy requirements are also high and the plant needs ~10.5 MW of power and a low temperature steam supply to regenerate the solvent: 52 t/h at 150 °C and 300 kPa. The total operating cost of the plant including energy, solvent, labour, maintenance, and cooling water is estimated at 18 MUSD per year.

The Lake Charles calciner produces up to 36 MW of power (but more typically 30–32 MW) from its WHR system via a steam turbine using high pressure steam at 500 °C and 6.2 MPa. The plant consumes around 5 MW of this power during normal operation and exports the rest to the local Entergy power grid.

To operate the CO<sub>2</sub> capture plant, RC could derate a portion of the high-pressure steam to meet the low-pressure steam requirement for the solvent regeneration system. Based on energy balance calculations, the WHR system should be capable of providing 100 % of the energy needed to operate the carbon capture plant. This represents an elegant solution for producing close to emissions free CPC. The energy from the WHR system is emissions free and the CO<sub>2</sub> from the calcining process would be captured and sequestered.

Since all the energy would be provided from the WHR system, the energy cost would be equivalent to the lost revenue from the renewable energy sales. This represents a substantial cost but an 85 USD/t tax credit to sequester the CO<sub>2</sub> should cover the operating cost. The BIL requires that construction on CCS projects needs to start before 2032 to qualify for the 45Q credits and the credit is available for a period of 12 years.

That leaves payback on the capital investment as the biggest economic hurdle to executing a project like this. The only way a project could provide an ROI (return on investment) is through a significant sales premium for a low CO<sub>2</sub>, CPC product. RC believes the project is technically feasible but the question is whether the aluminum industry would be willing to pay the sort of premium for a substantially lower CO<sub>2</sub> product.

It would not eliminate the scope 3 emissions for producing CPC however with the GPC production making up the majority of this. Using the example of the Alouette smelter study referenced previously [6], it means the scope 1-3 CO<sub>2</sub> footprint for CPC provided to Alouette could be reduced from 616 kg CO<sub>2</sub>/t Al (with no offset for WHR energy production) to 337 kg CO<sub>2</sub>/t Al representing a 45 % reduction.

## 6. Discussion and Conclusions

The objective of this paper was to provide a detailed overview of the contributors to CO<sub>2</sub> emissions from a petroleum coke calcining plant. In the absence of online CO<sub>2</sub> analysers, the

easiest way to estimate CO<sub>2</sub> emissions is through a mass balance approach but this requires accurate data for the following:

- Total tonnes of GPC fed to the calciner over time period of interest.
- Moisture content of the GPC feed.
- Carbon content of the GPC feed.
- Total tonnes of CPC product produced.
- Carbon content of the CPC product.
- Volume/mass of fuel consumed and associated CO<sub>2</sub> emissions.

Some of these measurements are difficult as outlined previously. The moisture level and carbon content vary continuously and this needs to be considered. Any physical losses of GPC or CPC in the form of dust emissions or spillages will result in an over-estimation of the CO<sub>2</sub> emissions. Any un-combusted coke fines in the pyroscrubber will also contribute to errors.

The paper documents the benefits of using online CO<sub>2</sub> analysers to provide an accurate measurement of CO<sub>2</sub> emissions. The analysers and flow meters must be well maintained with frequent calibration checks. The analysers can be used to provide real-time measurement of kiln yields which is valuable since kiln yields have a significant impact on the economics of the calciner operation.

Data is presented in the paper to show just how much changes in green coke quality such as particle size distribution can drive calciner CO<sub>2</sub> emissions. RC's Norco calciner operates with a low VM, coarse particle size GPC and had the lowest CO<sub>2</sub> emissions in RC's global calciner network in 2023. Table 5 shows the specific CO<sub>2</sub> emissions at five of eight RC plants for 2022 and 2023. Differences are driven by GPC differences, operating differences and design differences with GPC differences having the most significant impact. Data for three of the five plants were measured from online CO<sub>2</sub> analysers. For the two plants without online CO<sub>2</sub> analysers, total emissions were calculated using the mass balance approach described earlier.

**Table 5. Specific CO<sub>2</sub> emissions of RC calciners.**

MT CO <sub>2</sub> /MT CPC	Calciner Process Emissions		Total Product Carbon Footprint (PCF)	
	2023 data	2022 data	2022 data	
Calciner	Measurement	From PCF	Without CO <sub>2</sub> offset for WHR	With CO <sub>2</sub> offset for WHR
Plant A – Norco	0.575	0.563	1.221	0.668
Plant B	0.600	0.576	1.255	1.144
Plant C	0.734	0.756	1.364	1.364
Plant D	0.758	0.704	1.371	1.144
Plant E	0.802	0.739	1.452	0.983

Table 5 also includes 2022 data for total product carbon footprints for the five calciners. The estimates were made by RC's Life Cycle Assessment modelling group and include all scope 1-3 emissions. For the four plants with WHR systems, estimates are made with and without CO<sub>2</sub> offsets for energy generation. The Norco plant has the largest offset/reduction due to the significantly higher efficiency of generating steam vs electricity.

RC's shaft calciner is not included in Table 5 but long term, it is expected to have the lowest specific emissions in RC's portfolio after it is ramped up to full design capacity (expected early 2025). When the shafts are operated below their design feed rate, supplemental gas is sometimes

required to achieve target real densities. This will be eliminated once rates exceed ~85 % of the design level.

Calciners that operate with a higher yield of CPC per tonne of GPC have lower CO<sub>2</sub> emissions and changes that reduce GPC fines carryover have a positive benefit on reducing CO<sub>2</sub> and SO<sub>2</sub> emissions. WHR in combination with SO<sub>2</sub> scrubbing has a significant benefit for society in reducing SO<sub>2</sub> emissions and net CO<sub>2</sub> emissions. Calciners that operate with these systems offer a more sustainable solution for production of CPC.

Carbon capture technology offers the potential to substantially eliminate calciner CO<sub>2</sub> emissions and is both proven and available today. The paper presents a case study for a carbon capture option at the Lake Charles calciner which could be fully powered by the WHR system. The technology comes with a high capital and operating cost however and would not be feasible without a significant price premium for a low CO<sub>2</sub> CPC product.

The other long-term option which would eliminate CPC emissions and all smelter related anode emissions is inert anode technology. It is not clear if this will ever be successfully developed and implemented however, and the broader industry must continue to work on all options to reduce supply chain emissions.

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