CB05 - Sustainable CPC Production at the Vizag Calciner

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Abstract

Rain Carbon is a global producer of calcined petroleum coke (“CPC”) and operates its largest coke calciner at Visakhapatnam (“Vizag”) in India. The objective of this paper is to review the operation at Vizag with a focus on systems designed to minimize the impact on the environment. The paper will describe the equipment used to handle the flue gas stream from the kilns which includes a waste heat recovery boiler, steam turbine generator, SO_2 scrubber, and baghouse. The calciner achieves benchmark emission levels for SO_2 and particulate matter and demonstrates what is possible with modern pollution control equipment. The SO_2 scrubber routinely operates with an efficiency above 97 % and the byproduct is used for local brick manufacture. The power generated at the calciner helps offset the plants’ CO_2 emissions. A carbon footprint analysis is presented showing the potential impact from CPC production on climate change as well as on anode production and use in an aluminium smelter. This further enhances the sustainability of the calciner operation and its contribution to the positive aluminium life cycle story.

Keywords: Petroleum coke, CPC, calciner, anode, carbon footprint.

1. Introduction

Rain CII Carbon Vizag Limited (RCCVL) operates a 500 000 t/annum petroleum coke calcining plant at Visakhapatnam (“Vizag”) in Andhra Pradesh, India. RCCVL is part of Rain Carbon Inc., a global producer of carbon and chemical products. The company is split into two business units – Carbon Calcination (CC) and Carbon Distillation and Advanced Materials (CDAM). CDAM produces a wide range of products and is the world’s largest producer of coal tar pitch (CTP) which is combined with calcined petroleum coke (CPC) to make carbon anodes used in aluminum production. The coal tar (CT) and green petroleum coke (GPC) raw materials used by Rain Carbon are byproducts from other industries which are transformed into value-added products. This prevents them from being disposed of as waste or burned as a low-grade, high-carbon fuel.

Vizag is the company’s largest calciner and supplies CPC to aluminium smelters both domestically and outside India. The two 68 m long rotary kilns form the heart of the calcination process, but the plant features an extensive waste heat recovery and flue gas treatment system that generates electrical power from surplus heat. The system significantly reduces the impact of the calciner on the environment and enhances the sustainability of the operation. SO_2 scrubbers remove most of the SO_2 that would otherwise be emitted from the exhaust stacks and a baghouse removes particulate matter to benchmark low levels.

CPC along with CTP and alumina, are essential raw materials for aluminum production and the carbon footprint of these materials needs to be considered along with the CO_2 footprint of the electric power needed to operate the smelter. The objective of this paper is to report on the calcination process and the product carbon footprint (PCF) of CPC to show the benefits of an integrated waste heat recovery system. The lifecycle, including raw material production, will be considered to quantify the contribution of CPC on anode production and smelter operations.

2. Overview of the CPC Production Process and Vizag Flowsheet

During the calcination process, GPC is fed to one end of the kiln and discharged from the other end at a temperature of ~ (1250-1350) °C. Moisture in the GPC is driven off first followed by volatile matter (VM) which is typically in the range of (9-12) %. Most of the VM is combusted inside the kiln and provides the heat for calcination which is necessary to densify the coke structure and make it electrically conductive. A more detailed description of both GPC and CPC production can be found in [1].

GPC loses some sulfur during calcination with typical losses in the range of (8-12) % of the starting sulfur level. The high counter-current flue gas flow inside the kiln contains a significant amount of heat along with un-combusted VM, combustion products including CO_2, CO, SO_2 and H_2O, and coke fines that get entrained in the flue gas stream. A typical fines loss is ~ 10 %, but it can be higher for finer particle size GPC.

The flue gas from the kiln cannot be exhausted to atmosphere due to the presence of un-combusted VM and particulate material and these must be combusted in a large refractory lined chamber called a pyroscrubber. Many calciners exhaust the hot gas from the pyroscrubber directly to the atmosphere via a tall "hot" stack. Combustion of coke fines in the pyroscrubber produces additional CO_2 and SO_2 and these add to the total emissions of the calciner. CO produced in the kiln is converted to CO_2 in the pyroscrubber.

The Vizag calciner employs a complex system for handling the pyroscrubber exhaust. The hot gasses (~ 1200 °C) are passed through a waste heat recovery boiler (WHB) which generates high pressure steam (6.37 MPa at 485 °C) as the gas is cooled. The steam is routed to a steam turbine and generator which produces electrical power (50 MW turbine). The cooled flue gas from the WHB (180 °C) passes through an SO_2 scrubber and finally goes to a baghouse to remove any remaining ash and particulate matter before the exhaust gasses are discharged to atmosphere. The Vizag calciner layout showing key process equipment is shown in Figure 1. Photos of equipment in the flue gas stream are shown in Figures 2-3.

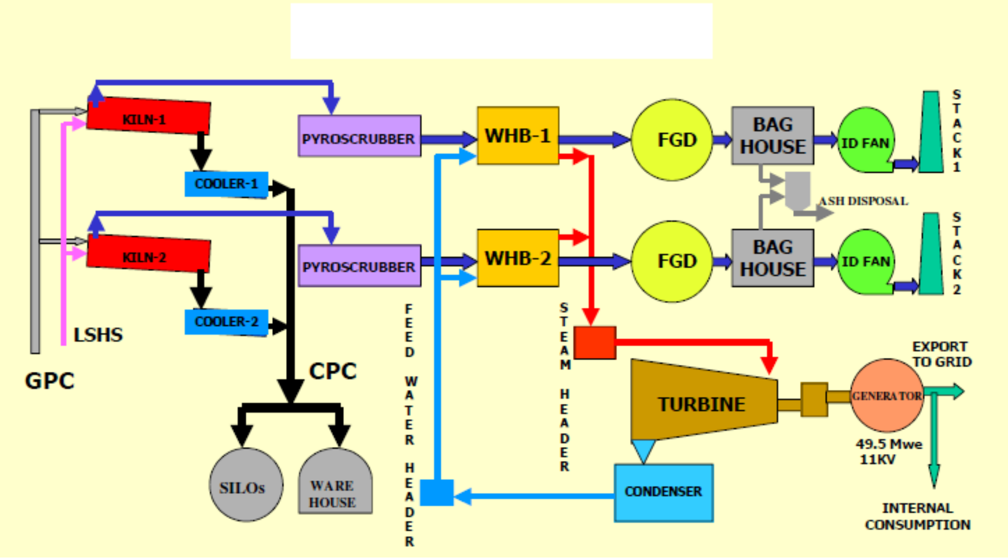

Figure 1. Schematic of Vizag Flowsheet.

Figure 2. Pyroscrubber and Waste Heat Recovery Boiler.

Figure 3. SO_2 Scrubber and Baghouse.

2.1 SO_2 Scrubbing and Byproduct Lime Use

The plant uses dry scrubbing technology and requires continuous injection of hydrated lime [$Ca(OH)_2$] into the scrubber reactor. The cooled flue gas enters at the bottom of the scrubber and water is injected along with lime to maintain an exit flue gas temperature of around 85 °C which is necessary for efficient removal of SO_2 via reaction to form $CaSO_3/CaSO_4$. After the scrubber, the flue gas passes through a set of cyclones to remove part of the lime. The lime is recycled back to the scrubber for further reaction and to reduce overall lime consumption. The Vizag calciner has done extensive work over the last 10 years to improve the efficiency of the scrubber and consistently achieves an SO_2 removal efficiency > 97 %.

After exiting the cyclones, the remaining lime is carried over and removed in the baghouse. The cleaned flue gas stream is exhausted through the cold stack with less than 70 mg/Nm^3 of suspended particulate matter (SPM). The sulfated lime byproduct collected in the baghouse is sent to a local domestic brick manufacturer where it is mixed with other raw materials to produce bricks used in construction, Figure 4. This avoids landfilling the lime byproduct and the bricks meet all local engineering standards for strength, stability, uniformity, etc.

Figure 4. Bricks Produced Locally in Vizag with Lime Byproduct.

3. Vizag Calciner Operating Data – 2019

Table 1 shows some of the key operating data for the Vizag calciner in 2019. The cold stack has a continuous emissions monitoring system (CEMS) for measuring SO_2 and SPM emissions in real time for environmental reporting purposes. The Vizag plant does not have a CO_2 monitor in the stack but the CO_2 emissions can be calculated based on the carbon content of the GPC feed, the tons of GPC fed to the kiln, the CPC production rate, and the carbon content of the CPC product.

Table 1. Vizag 2019 Plant Data.

Inputs	**Units**	**Value**
GPC Feed Tons (Wet Tons)	t	679 282
Hydrated Lime Use	t	20 010
Dedusting Oil	t	1039
Power Use by Plant	MWh	50 897
Thermal energy from fuel combustion	MWh	5995
Third party water	m^3	498 772
Outputs	**Units**	**Value**
CPC Production	t	504 660
Power generation	MWh	309 422
CO_2 Emissions	t	365 061
SO_2 Emissions from Cold Stack	t	146
SO_2 Emissions from Kiln to Pyroscrubber	t	9766
Sulfated Lime Byproduct	t	31 895
Average Stack SO_2 Concentration	mg/Nm^3	55
Average Stack SPM Concentration	mg/Nm^5	60
Average Stack Flow Rate	Nm^3/h	180 000

The CO_2 emissions generated by the calciner are due to a combination of VM and fines combustion. The average VM content of GPC used at Vizag in 2019 was ~ 11 % and the approximate composition of VM is CH_3 making it hydrogen rich relative to pure carbon. GPC loses most of its hydrogen during calcination and VM combustion generates less CO_2 than carbon combustion. The coke fines carried into the pyroscrubber are predominantly carbon (with some sulfur, nitrogen and oxygen) and will combust to give a higher mass of CO_2 relative to VM.

All coke calciners have an economic incentive to maximize the yield of CPC produced per ton of GPC. Maximizing the yield also reduces CO_2 emissions. The Vizag calciner has focused significant effort on improving the kiln yield and one of the technology changes implemented has been direct oxygen injection into the kiln. This eliminates the need to combust heavy fuel oil in a burner to provide supplemental heat for calcination. Fuel oil combustion requires the addition of large volumes of combustion air which increases the flue gas volume/velocity and increases fines carryover. The plant now generates its own oxygen in a dedicated plant using power from the WHB. This has eliminated heavy fuel use during normal operation other than plant startups.

4. Product Carbon Footprint Analysis

A Product Carbon Footprint (PCF) is the sum of Greenhouse Gas Emissions (GHG) and GHG removals in a product system, expressed as CO_2 equivalents and based on a Life Cycle Assessment (LCA) using the single impact category of climate change [2]. In accordance with ISO 14067 [2], PCF comprises four stages: (1) goal and scope definition, (2) lifecycle inventory analysis, (3) lifecycle impact assessment and (4) interpretation of results.

The goal and scope definition are the most crucial, requiring description of the product application and system including assumptions, allocations, and system boundaries. The life cycle inventory (LCI) comprises quantified input and output data (mass and energy data) along the life cycle of the product system, starting with raw materials, production, product application, and the end-of-life phase. During the assessment, the potential impact to climate change is calculated based on the LCI data related to a functional unit (FU). The definition of a FU allows the relation of the potential impact of a product on its function rather than its physical properties. The PCF study concludes with the interpretation and discussion of the calculated results on the overall impact of the product system. The present study and results were still under critical external review while the paper was being written but the review is expected to confirm compliance with the ISO 14067 standard.

4.1 Goal and Scope Definition

CPC from Vizag used in anode production for aluminium electrolysis was investigated relative to its potential impact on climate change, taking the whole product lifecycle into account (cradle to grave). The potential contribution of the product to climate change and global warming is measured as a product's "Global Warming Potential" (GWP, time frame 100 years = GWP100) related to the FU. The current PCF study of CPC from Vizag was divided into three scenarios, considering the different lifecycle stages as shown in Figure 5.

The GWP was calculated for all 3 scenarios using IPCC 2013 [3] related to the FU of CPC for production of 1 t aluminium.

Scenario 1: Calcination of CPC at Vizag

First, the different process steps in calcination at Vizag and all upstream activities were investigated for their impact, including production of GPC in the refinery process, energy generation, calcination of GPC with waste heat recovery, addition of dedusting oil in processing of CPC to the final product and treatment of waste gases.

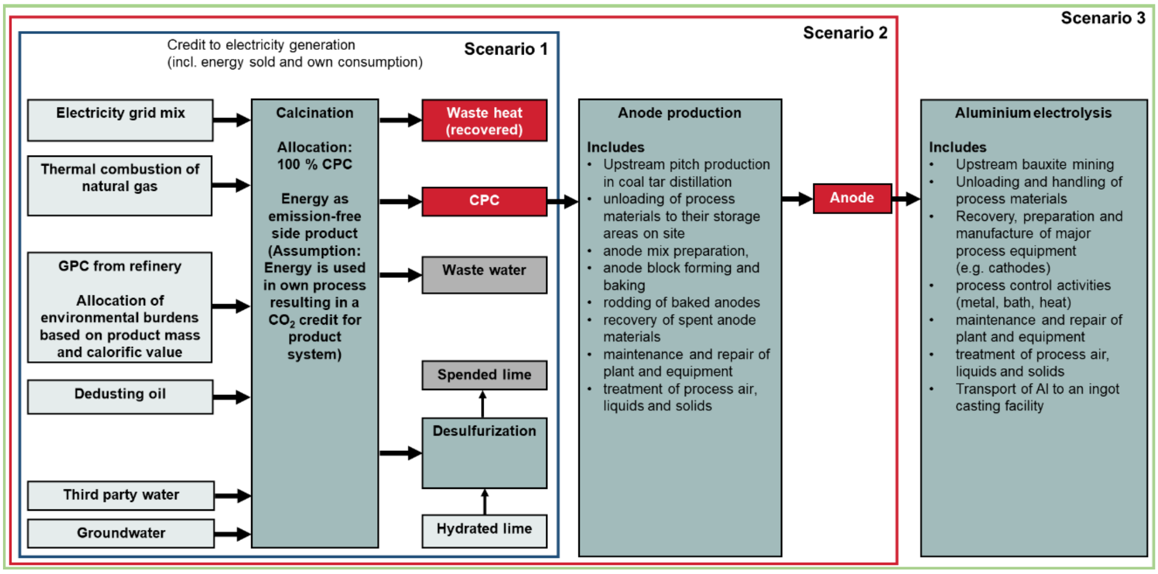

Figure 5. Process Map, Lifecycle Modelling of Vizag CPC.

The electrical power produced from the waste heat recovery system was classified as an emission-free byproduct and the amount generated is well in excess of the power required to operate the calciner. In the lifecycle model, it was assumed that the power is used for the calcination process and the surplus is exported to the local grid which generates a CO_2 credit for the product system. An emissions rate of 0.82 t CO_2 per 1 MWh of power for India is assumed in accordance with the literature [4, 5]. To analyse the potential technological benefit, the PCF of Vizag CPC was compared to CPC production without waste heat recovery as a reference.

Scenario 2: Anode production including CPC

Calcination and production of anode blocks was evaluated with all related upstream activities for required input materials (e.g. CTP, CPC, steel, refractory materials, etc.) in Scenario 2. In this life cycle phase, CPC is mixed with recycled anode butts and CTP binder to form green anode blocks. This process requires electrical energy for crushing, grinding, mixing, forming, etc. and fuel for process heating of the CTP and anode paste. The green anode blocks are sent to a baking furnace which requires the addition of natural gas or heavy fuel oil to achieve final anode baking temperatures of ~ 1120 °C. The last step in the process is rodding of the anode blocks using cast iron to make an electrical connection between the carbon block and steel pins or stubs.

Scenario 3: Anode use in aluminium electrolysis

Scenario 3 considers the whole lifecycle of CPC including the use of rodded anodes in aluminum electrolysis. The electrolysis process has the additional environmental burden of the indirect GHG emissions associated with electrical power generation. The power generation source has a major impact on GHG emissions and varies significantly across the globe [6]. The most widely used energy sources for aluminium production (coal and hydro) are compared in this evaluation using representative datasets from China and Canada.

The lifecycle model across all three scenarios shown in Figure 5 is based on Vizag operating data from 2019 (Table 1). Secondary data for all upstream and downstream activities and for the reference process were taken from the GaBi Professional database (Software version: GaBi ts 9.5.1.46) [7] and literature. The data sets for anode production and aluminium electrolysis in the GaBi Professional database are based on previous work from World Aluminium and take regional differences into account [6].

However, some assumptions were made for upstream processes. The production of aluminum fluoride from hydrogen fluoride and aluminum hydroxide [8] is based on stoichiometric calculations. The production of the carbon cathode includes the production of the raw materials (coal tar pitch and petroleum coke) and assumes a similar baking process as for the anode [9]. Due to missing data, other raw materials (anthracite and graphite) and further processing by graphitization weren't considered. The model does not include downstream transports of CPC nor the construction of production facilities, such as the rotary kilns for calcination.

5. Impact Assessment

5.1 Vizag CPC Calcination

Figure 6 shows the Product Carbon Footprint for CPC from the Vizag calciner. The left bar shows the global warming potential of a standard calcination process as it is contained within the GaBi Professional database [7]. The right bar shows the global warming potential of CPC from Vizag considering the specific site emissions and the credit for energy production. Without considering the credit, the CO_2 emissions for CPC from Vizag are ~14 % lower than those in the GaBi CPC reference process. This is due to the strong focus on operating with a high kiln yield including use of oxygen injection and elimination of heavy fuel oil use for routine operations.

The largest contributors to the CO_2 footprint of CPC are the calciner process emissions (~57%) followed closely by emissions generated during GPC production (~40 %). All other emission contributors are ≤ 3 %. The generation of excess power at the Vizag site creates a CO_2 credit, reducing the total emissions by ~ 45 % with an assumed emission rate of 0.82 t/MWh $CO_2$for the Indian power grid [4, 5]. This is a large reduction and shows the significant benefit of the waste heat recovery system. For regions utilizing a higher percentage of renewable power, the CO_2 emission factor and the credit would be lower.

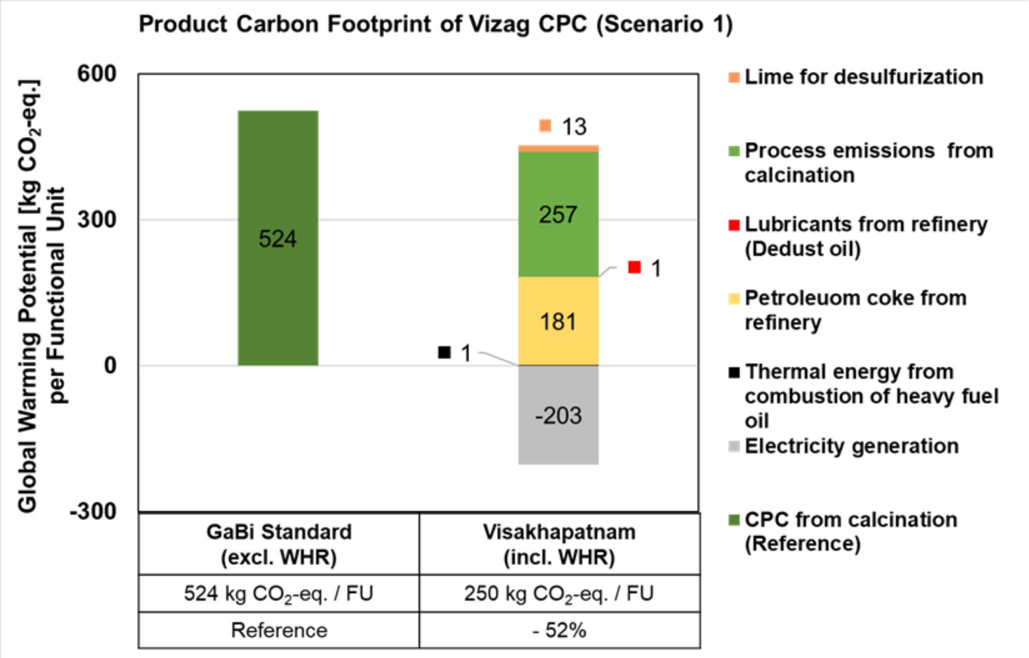

Figure 6. PCF for CPC from Vizag Calciner (FU = Functional Unit).

5.2 Anode Production from CPC

Figure 7 shows the total CO_2 emissions from anode production when CPC from a plant without energy recovery is used in comparison to CPC produced at the Vizag calciner. The waste heat recovery system at Vizag reduces the anode PCF by ~ 31 %.

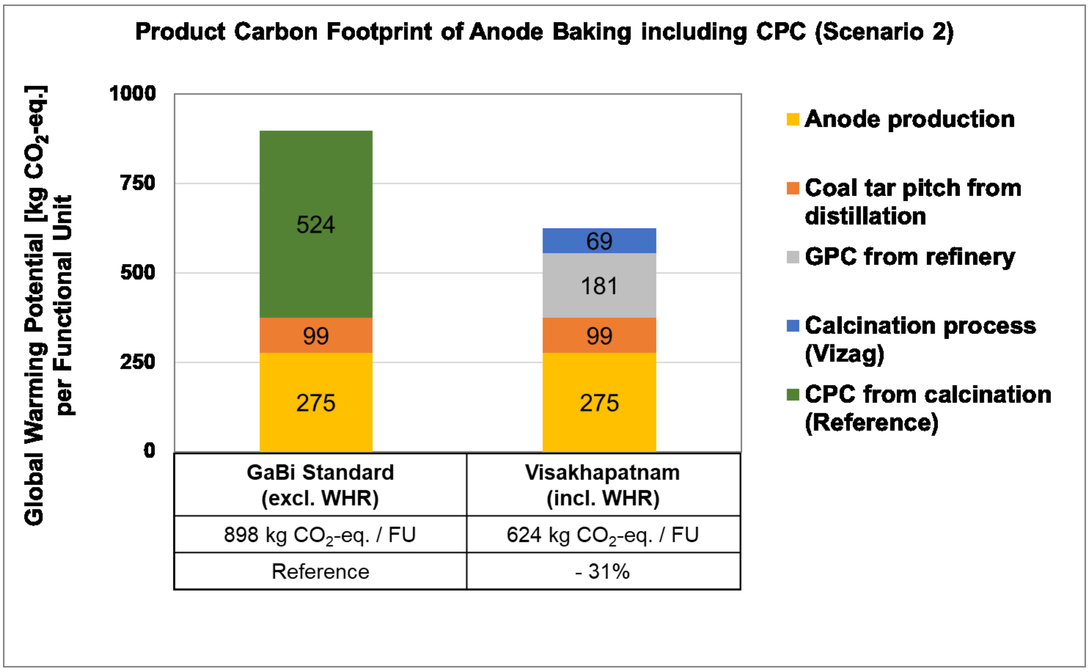

Figure 7. Contribution of CPC in Anode Production (FU = Functional Unit).

The CO_2 emissions generated during anode production will vary depending on the anode production technology used and the efficiency of the operation. One of the major contributors during anode production are the baking furnace CO_2 emissions. This is due to the combined combustion of CTP VM and natural gas or heavy fuel oil used to achieve target baking temperatures. Fuel consumption can vary significantly, and benchmark smelters operate furnaces with a gas consumption as low as 1.8 GJ/t. At the other end of the scale, some older furnaces with poor sealing and poor fire control have gas consumptions closer to 3 GJ/t. The figures presented here are average/indicative values and a smelter wanting to undertake a detailed emissions study would need to look at their own emissions more thoroughly.

5.3 Anode Use in Aluminium Electrolysis

The PCF of aluminium electrolysis is shown in Figure 8 and includes emissions generated from the production of nearly all raw materials and related upstream processes. This includes bauxite mining, alumina and aluminium fluoride production, baking of anodes and cathodes, production of refractory materials, etc. as well as direct process emissions from the smelting cells and indirect emissions from power generated to operate the smelter.

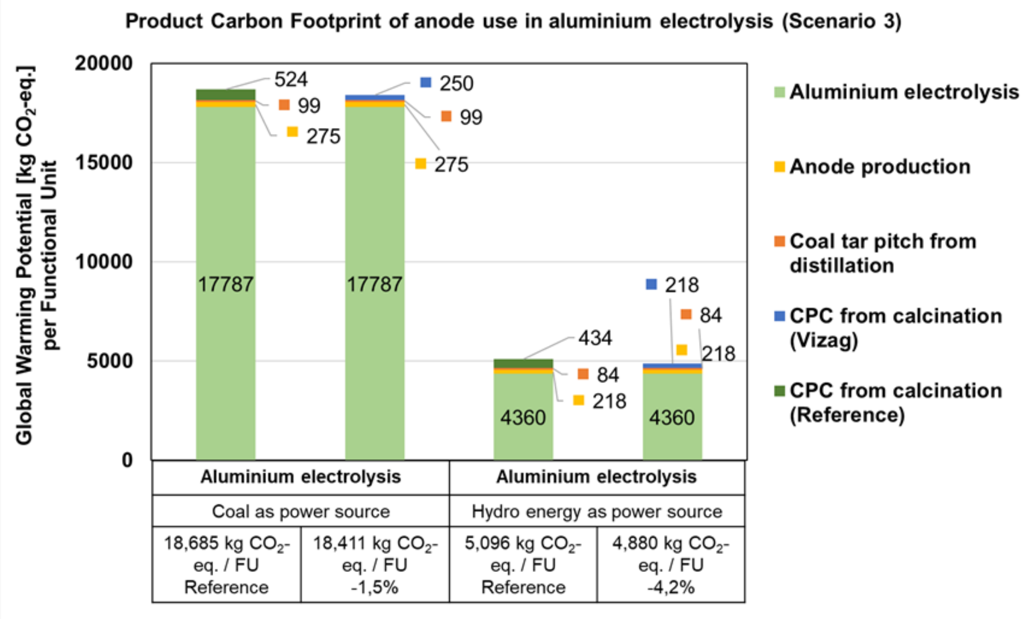

Figure 8. Contributions of CPC to Smelter Operations (FU = Functional Unit).

The contribution that CPC and anode production makes varies significantly as a function of the power source for the smelter and regional differences in process technology as a default in the secondary data. For a hydro powered smelter, the anode (including emissions from CPC, CTP and anode production) contributes (10-14) % of the total smelter CO_2 emissions but this drops to ≤ 4 % for smelters operating with coal fired power. This does not include CO_2 emissions from anode consumption during electrolysis which is significantly higher. For a smelter operating with a net carbon consumption of 0.42 (kg C)/(ton aluminum) for example, anode process emissions contribute ~ 1.5 ton CO_2 /ton aluminum [10].

6. Discussion and Conclusions

The data presented in this paper shows that it is possible to significantly reduce the emissions from a coke calcining plant either directly or indirectly through the addition of waste heat energy recovery systems and modern pollution control equipment. At the Vizag calciner, CO_2 emissions are reduced indirectly by ~ 45 % through waste heat power generation and direct SO_2 emissions are reduced by more than 97 % with SO_2 scrubbing.

Today, there is a strong push from aluminum producers to promote low-carbon aluminum. Several smelting companies operating hydro-powered smelters now market low carbon metal under a variety of different product trade names such as REDUXA® (Hydro Aluminium), ECOLUM™ (Alcoa), RenewAl™ (RioTinto), ALLOW (Rusal), and Natur-Al™ (Century Aluminum). A recent publication [11] argues the case for low carbon aluminum labeling when it can be demonstrated that the primary aluminum footprint is < 4 (t CO_2 eq.)/(t aluminum). The Aluminium Stewardship Initiative (ASI) now offers certification programs for companies in the aluminum supply chain to quantify their CO_2 footprint and sustainability performance [12].

The product lifecycle of aluminium is dominated by the impact of the smelter power source. The contribution from the anode (excluding consumption) to total smelter CO_2 emissions is (10-14) % for a smelter with a hydro based power source but ≤ 4 % for a smelter with a coal-based power source. These values are similar in magnitude to those reported in previous studies [10, 13, 14]. Reducing the carbon footprint of an anode therefore has limited impact on the CO_2 footprint of a smelter operating with coal fired power, but a more significant impact on a smelter operating with hydro-electric power.

Several aluminum producers are pursuing inert anode (IA) technology (Rusal and Alcoa/RioTinto via Elysis) and if successful, this would remove all emissions associated with anode production and consumption at the smelter. IA technology has been under development for more than 50 years, however the pathway to successful commercial implementation remains challenging. A recent publication [15] highlights the negative impact of IA's on the reversible cell voltage and energy requirement of smelting cells. They are projected to be at least 20 % higher with an IA cell relative to today's lowest energy cells. For a hydro-powered smelter, it could be argued that the higher energy consumption would not matter in terms of GHG emissions. For coal-powered smelters however, the increase in energy consumption with inert anodes would increase total GHG emissions.

Today, roughly 30 % of the world's primary aluminum is produced in smelters using low GHG power sources (predominantly hydro and nuclear) [16]. The rest comes from coal-fired power (60 %) and natural gas (10 %). China has dominated global smelting capacity growth since 2000 and most of this has come from coal-fired power. China has been adding some hydro-powered capacity in Yunnan province recently, but the world has a long way to go in reducing its dependence on coal fired power for primary aluminum production.

Rain Carbon remains strongly committed to improving the sustainability of its operations and minimizing the impact on the environment through continuous process improvements and technology changes. The company now has two major projects underway to support this effort. The first is construction of a vertical shaft calciner near Vizag which will offer a lower CO_2 footprint than the existing rotary kiln calciner due to a significantly higher kiln yield. It will also feature an advanced waste heat recovery/power generation system and a high-efficiency ammonia scrubber that will produce a value added, fertilizer byproduct.

The second project involves construction of an innovative new plant and process to produce anhydrous carbon pellets (ACP). Plants are being built in the US and in India at the new shaft calciner site. The technology has been described previously [17] and a key feature is the potential for a significant reduction in fines carryover. The fines are removed and agglomerated to form pellets which densify during calcination rather than being carried over and combusted in the pyroscrubber. This will further reduce CO_2 and SO_2 emissions in the calcining process.

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