Life Cycle Inventory Assessment of Smelting Process of Platinum Group Metals at the Anglo American Platinum Ltd, South Africa

M.J. Mabiza, *Member, IAENG* and C. Mbohwa

***Abstract*— Platinum group metals are acknowledged for their contribution to the reduction of environmental damage thanks to technological innovations. A growing demand on PGM is expected to contribute to the supply of clean and renewable energy using systems such as hydrogen fuel cell technology. The credits to PGM are of no doubt, yet some environmental concerns in PGM recovery process are reported with a massive harmful SO_2 emissions into the atmosphere. Life cycle analysis of emissions from the smelter section of PGM recovery was therefore develop and equivalent carbon dioxide emissions were quantified. For one metric ton of ore milled, a total amount of equivalent carbon dioxide of about 2,084.72kgCO_2-eq was associated with the smelting process. SO_2 was revealed not to be the most important emission. In an annual initiative, smelter can process up to 36,547 million metric tons of ore milled accounting for 76,163,948,000 kg CO_2-eq. The section of the smelter showed emissions to water and emissions to soil mainly. Significant air emissions are identified as Sulphur dioxide (SO_2) efflux in the plant.**

***Index Terms*—Platinum Group Metals, Smelting process, Sulphur dioxide, life cycle inventory assessment, equivalent dioxide carbon emissions.**

I. Introduction

Platinum Group Metals (PGM) are the precious metals acknowledged for their contribution to environmental damage address through technologies. They possess a series of exceptional physical and chemical properties that find wide and diverse significant environmentally-sound related applications. In addition to their electro catalytic key role in fuel cell for clean and renewable energy production, PGM are useful in chemical processes, oil refineries for instance. PGM are also used in electronic components and they are involved in the autocatalytic converters exhaust control for auto vehicles. In medicine PGM are suitable for a variety of specialty uses and active pharmaceutical ingredients. Growing demand for PGM is expected and with it the benefit of technology development for clean energy supply and sustainability to reform the polluting automotive sector with the innovation of electric vehicles and the possibility of energy production on-site for industry and household while reducing the global carbon footprint and addressing environmental degradation attributed mainly to the use of pollutants used so far to provide sufficient energy and meet its growing demand. Whereas the credits given to PGM are of no doubt, there are however some concerns in the recovery process of PGM and one has been articulated in this paper. There is a PGM recovery process stage identified as smelting that uses high temperatures to melt ore milled. Smelting process with another process known as converting are reported with enormous greenhouse (GHG) emissions of significant SO_2 airborne release daily [1]. SO_2 is a colourless, toxic and harmful gas to both human and biodiversity which may affect the credit to green performance contribution of PGM applications. The need to understand environmental challenges due to PGM production justifies an environmental assessment.

On the other hand, mining sector is known to be one of the most polluting sectors contributing to the South African heavy carbon footprint; a sector with emissions looking as if irreducible. Although the pressure of air quality Control Act imposes penalties on increasing excessive emissions, some PGM miners still cannot face daily limits comply with the required emissions reduction. It is also observed and of direct exposure the visual impairment in plant with dust and SO_2 emissions. While the Anglo American Platinum has introduced a new technological approach with the new type of converter with the maximum conversion SO_2-SO_3 reported effective beyond 90%, other PGM miners in the country are still underperforming and not yet meeting standards in emission compliance.

II. Operational flow chart and sites of the Anglo American Platinum's activities

The South African miner Anglo Platinum Limited is the largest producer of platinum group metals in the world. It owns varied mines and operates three smelters of which Waterval (Rustenburg) where precious metals are refined and Mortimer (Limpopo) both located on the western limb of the Bushveld complex. The third smelter, Polokwane (Polokwane), is located on the eastern limb of the Bushveld complex (Fig. 2) [2]. The Bushveld Complex is the world's largest PGMs reserve that has led the global production of PGMs since 1971. Bushveld Complex abounds also in Chromium and Vanadium with the world's largest reserves [3]. Due to the Bushveld Complex location in South Africa, the country covers the largest potential economic of PGMs resources ever discovered in the world, which is estimated about 80% of the global reserves.

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A. *Schematic Recovery Process of the Platinum Group Metals at Anglo American*

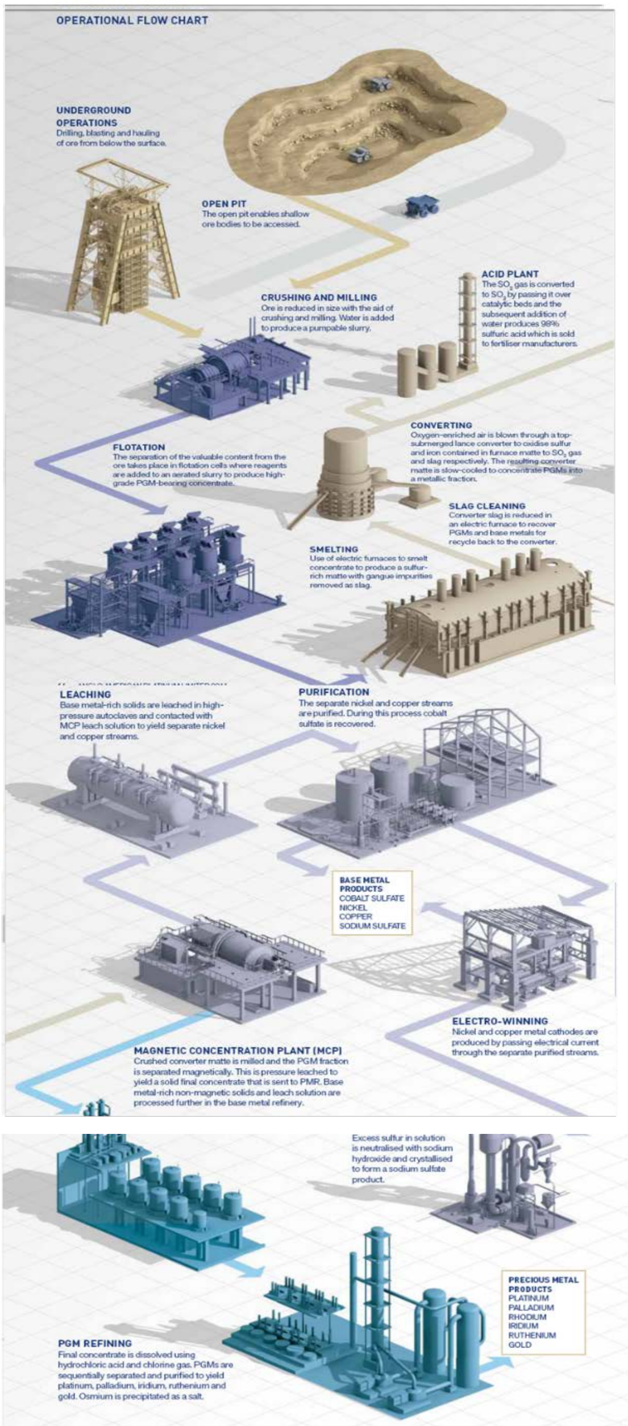

Fig 1: Operational flow chart of the Anglo American Platinum. [7]

B. *Operational sites of the Anglo American Platinum*

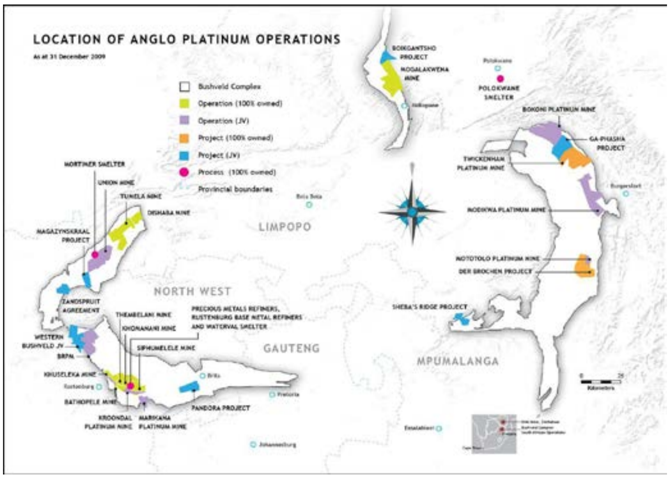

Fig 2: Location of Anglo Platinum operations in the Bushveld complex. Source: [2]

III. Recovery of PGMs, Gas Emission, and Use of Energy by the Smelter Process of Ore

Smelting is a part of the PGM recovery process intended to recuperate precious metals from the concentrates ore milled by use of furnaces. A simplified smelter process flow schematic at the Waterval is given in Fig. 3 below.

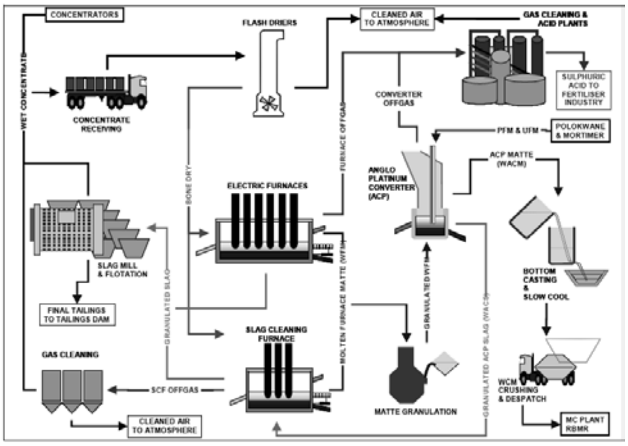

Fig. 3: Simplified Smelter Process Flow Schematic at Waterval. Source: [5]

A. *Use of Energy*

The primary smelter at Waterval is made of two six-in-line electric furnaces of Hatch design, equipped with a primary electric transformer of capacity of 39MVA. The parallel piped furnaces are designed with internal dimensions of 25.8m long and 8.0m wide with an endowed refractory shell of a nominal design power flux of about 146kW/m^2. The voltage supplied to the primary transformer is 88kV which is de-escalated to 6.6 kV by use of five secondary transformers of 20MVA. The electrical voltage is further de-escalated by six 6.5MVA transformers to the final voltage of 100-200V when they are connected in star coupling and to 170-350V in delta on each furnace. The secondary smelter, less in capacity and power, is designed for the recovery of possible precious metals still contained in the furnace slag that is to be discarded. To reduce the energy requisite for smelting and minimize blowbacks or explosions from the furnaces, the wet concentrates which contains about 17% by mass of moisture is firstly dewatered by four electrical presses to less than 12% of moisture. The concentrates may then be dried in-depth by means of a drying process with a series of instantaneous flash dryers of different drying capacity from 3,875 to 12,000kg/h with different feed-rate varying from 35 to 58t/h. Moisture is finally reduced to less than 0.5% by using the combustion of coal to provide hot gas in a fluidised bed [4].

At an average temperature near to 1500°C, depending on the composition of the concentrate sulphide gangue mineral, a composition of silicate slag and oxide is separated from the inorganic sulphide matte and discarded. Matte then includes base and noble metals. According to [5], the analysis of the composition of furnace matte is as shown in Table I, in which the iron (Fe) 41% and S 27%, (not needed), are still prevailing. In general this is the composition of the matte at this stage of the PGMs recovery, in which 95% of the total of the slag is discarded. Smelters have a feed rate ranging from 25 to 54T / h.

TABLE I
FURNACE MATTE ANALYSIS AT THE WATERVAL ANGLOPLAT SMELTER. SOURCE: [3]

	Co %	Cr %	Cu %	Fe %	Ni %	S%	PGM g/t	Total%
Anglo Platinum Waterval	*0.5*	*0.5*	*9*	*41*	*17*	*27*	*640*	*95*

Subsequently, at elevated temperatures the concentrates melt further and splits into two liquids phases; a lighter molten matte and slag rich in iron, having a density of about 2.7 to 3.3, is separated under the gravity from the molten matte, being denser, with a density of about 4.8 to 5.3 and rich in nickel and copper sulphides and in precious and base metals [3]. The lighter molten matte is discarded and undergoes milling and cleaning of slag for possible recovery of PGMs, and the molten matte is finally conveyed and discarded to the tailings dam (Fig. 3).

TABLE II
PGMS RATIO IN THE FURNACE MATTE COMPOSITION OF THE SMELTERS IN SOUTH AFRICA SOURCE: [3]

	Anglo Platinum Waterval	Anglo Platinum Union	Implats	Lonmin Merensky	Lonmin UG2	Northam
PGM g/t	*640*	*830*	*1050*	*1000*	*2500*	*724*

IV. SKETCH OF AN INPUT/OUTPUT SINGLE STAGE OR UNIT OPERATION OR UNIT PROCESS IN A FLOW CHART

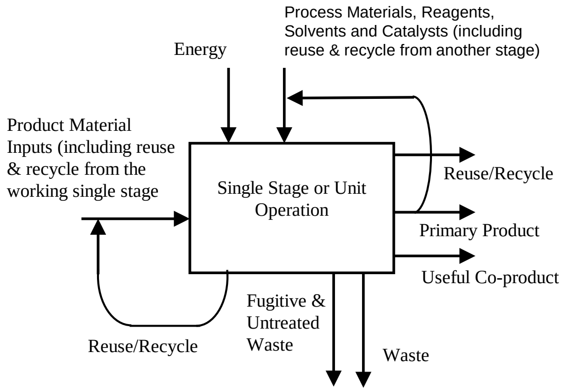

Fig. 2: Input/output of a single stage or unit operation or unit process in a flow chart. Source: Adapted from [6] Bras & Roman

V. THE LIFE CYCLE INVENTORY OF FLOW-MATERIAL

A. *Flow-material in the smelting phase at Waterval smelter. PGMs recovery: 640g/t of matte*

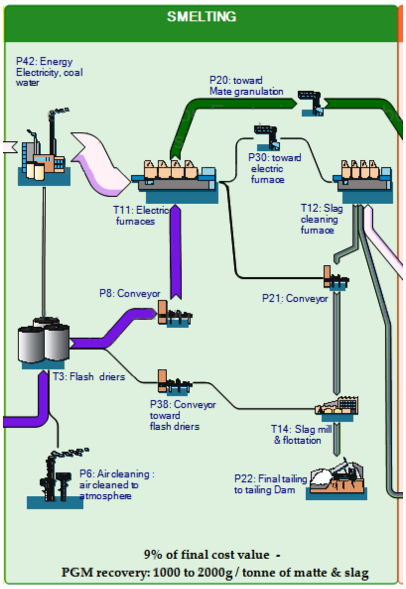

Fig. 4: Flow-material in the smelting phase at Waterval smelter. PGMs recovery: 640g/t of matte.

B. *Equivalent Carbon Dioxide (CO_2-eq)*

The most important CO_2-eq emissions in the smelting process were from polysulphides, cast iron, blown air used at the flash dryers, gas flow, sulphuric acid, water treatment used at granulation, flux of limestone (rocks) added to reduce the viscosity and liquidus temperature of the slag and an iron silicate slag known as the Fayalite (Fe_2SiO_4). Most emissions in this phase are discarded in a tailings dam. These are waterborne emissions and emissions to soil. Airborne emissions in this process count SO_2.

The following Table III presents a typical composition of one tonne (1t) of ore in the smelter. A total amount of equivalent carbon dioxide of about 2084.72kgCO_2-eq is associated with the process. The masses displayed in the column “product” together with the designated constituents, are apparent weights which are in relation to the molecular masses of these constituents. They are the total masses of the constituents in the entire life cycle analysis (mining-off-gas. The column "share", however depicts, by a length, the amount of CO_2-eq emissions emitted by each constituent in the phase (Table III).

TABLE III
EQUIVALENT CARBON DIOXIDE TO THE SMELTING PROCESS

Carbon Footprint Summary - Model: PGMs recovery mining process

Product	Quantity	Unit	Share
Phase: SMELTING: 2,084.72 kg CO2-eq.			
iron oxide, at plant [RER] (119.70 kg)	164.89	kg CO2-eq.	
copper, primary, from platinum group metal production [ZA] (49.11 kg)	51.07	kg CO2-eq.	
nickel, primary, from platinum group metal production [ZA] (52.67 kg)	145.65	kg CO2-eq.	
PGMs (1.12 kg)	2.57	kg CO2-eq.	
sand, at mine [CH] (2.00 kg)	4.39	kg CO2-eq.	
blown air (40.00 kg)	115.49	kg CO2-eq.	
sulfur dioxide gas, at platinum plant (0.14 kg)	1.92	kg CO2-eq.	
magnesium oxide, at plant [RER] (7.62 kg)	16.50	kg CO2-eq.	
cobalt, at plant [GLO] (2.36 kg)	8.70	kg CO2-eq.	
chromium oxide, flakes, at plant [RER] (144.32 kg)	121.41	kg CO2-eq.	
sulfuric acid (249.86 kg)	70.09	kg CO2-eq.	
polysulphide, sealing compound, at plant [RER] (60.33 kg)	144.94	kg CO2-eq.	
wastewater treatment, particle board production effluent (103.89 kg)	177.36	kg CO2-eq.	
fayalite (2FeO.SiO2) (178.01 kg)	467.46	kg CO2-eq.	
0ffGas flow (2,339.22 kg)	287.95	kg CO2-eq.	
Limestone, rock [RER] (779.79 kg)	177.36	kg CO2-eq.	
secondary sulphur, at refinery [CH] (650.00 kg)	126.96	kg CO2-eq.	

The Life Cycle Assessment in PGM recovery process in the smelter section showed waterborne emissions and emissions to soil mainly. Notable airborne emissions are identified as Sulphur dioxide (SO_2) efflux in plant.

VI. Results

PGM smelting process unit appears to be the operational process the highest contributing to the overall equivalent carbon dioxide emissions of the whole PGM recovery process from the ore mining process to the PGM refinery process. The smelter is powered with electric energy from Eskom (the sole South African power supplier) produced using coal as primary resource. Coal burning power generation contributes up to 88 percent of the energy delivered to the national electric grid; 12 percent being generated from energy mix. Coal burning power generation plants accounts for enormous CO_2 emissions and, to date, South Africa has the highest African carbon footprint due to the use of these types of plants to meet the energy in demand of the local heavy transforming industry.

VII. Conclusion

It is evaluated that the smelter accounts for about 2084.72kgCO_2-eq in the treatment of a metric ton of ore milled. In an annual period of activity the smelter can treat up to 36,547,000 metric tons of ore milled. With this the smelting process can account for 76,163,948,000 kgCO_2-eq yearly and this is understood as an enormous polluting accountability. To address such a challenge, especially in the context of the local industry, a progressively endeavor to shifting to a set of non-polluting sources of power supply should be undertaken aggressively. It is reported that over 91% of greenhouse gas emissions are indirectly identified from electricity purchased from Eskom [7]. As previously indicated, Eskom is the sole supplier of electricity in the country of which 88% is produced from coal-fired power generation [1].

Measures can be put in place to proceed further reducing other greenhouse emissions on activity within the plant with strong emphasise on process improvement, recycling, reuse, landfill reduce, waterborne and airborne pollution reduce.

Platinum group metals should indeed be found as a metal contributing to the relief of the current strain observed into environment and the echo-system. There are ways to rethink and reduce emissions of the upstream of PGM production process to least possible and to more and more insignificant as to development of renewable power systems such as the hydrogen fuel cell.

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