Quantifying CO_2-eq Emissions of Ore-based PGM Concentration Process in South Africa and Identifying the Immediate Environmental Impacts Related

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***Abstract*— Platinum group metals (PGM) are accredited for their contribution in reducing environmental damage through technological innovations. In recent years interest in hydrogen has grown rapidly resulting to the development of the concept of hydrogen economy to address two growingly noticed challenges namely climate change impacts due to GHG emissions and the need for clean energy and sustainability supply. The credits to PGM are of no doubt, yet some environmental concerns in PGM recovery process are reported with land transformation, livestock, fauna, and flora affected by use of chemicals and other non-renewable resources. 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-based PGM Concentrate, a total amount of equivalent carbon dioxide of about 1.574,96 kgCO_2-eq was associated with this process. In an annual initiative, the concentrator can process up to 36,547 million metric tons of ore milled accounting for 57,560,063,120 kgCO_2-eq. Important emissions in this phase are waterborne and emissions to soil.**

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

I. Introduction

Energy is the lifeblood of the modern society, economy and development. Our work, spare time, and our economic, social and physical welfare all depend on the supply of a sufficient and uninterrupted energy. The challenge of the demand for energy worldwide is growing at significant rate.

In recent years interest in hydrogen has grown rapidly resulting to the development of the concept of hydrogen economy. The primary reason for this awakening is that hydrogen economy may be an answer to two challenges already faced by the world, which are growingly noticed nowadays. The first challenge is a severe series of environmental impacts resulting to climate change which is caused by greenhouse gas emissions (GGEs) formed by carbon dioxide (CO_2) and equivalent carbon dioxide (CO_2-eq) emissions. CO_2-eq emissions are pollutants such as NOx, SFx, and SOx; they result both with CO_2 emissions mainly by burning fossil fuels, coal and natural gas. The second challenge, not the least, is the need for security of energy and sustainability supply.

Hydrogen produced from water by electrolysis process is the most environmentally friendly. The process involves platinum group metals (PGM) as catalyst to increase the efficiency. Hydrogen fuel cell system as one of the most possible solutions to sustain the supply of clean and renewable energy meanwhile addressing climate change and global warming. However, conversely, the engineering process of recovering PGM noble metals suffers criticisms reported to be real concerns to the immediate environment affecting local communities and seen as future threats to the regional biodiversity.

South Africa is the largest world PGM economy accounting about 75% of the global reserves. The country's PGM's wealth has been seen as a significant competitive advantage for the global HFCT development initiatives in view of the abundant platinum metals deposits in the country in terms alternative solutions through clean and renewable energy supply, mitigation of GHG emissions, new types of business ventures, etc. [1].

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. 1) [2]. The Bushveld Complex is the world’s largest PGM reserve that has led the global production of PGM 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 PGM resources ever discovered in the world, which is estimated about 80% of the global reserves.

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A. Operational sites of the Anglo American Platinum

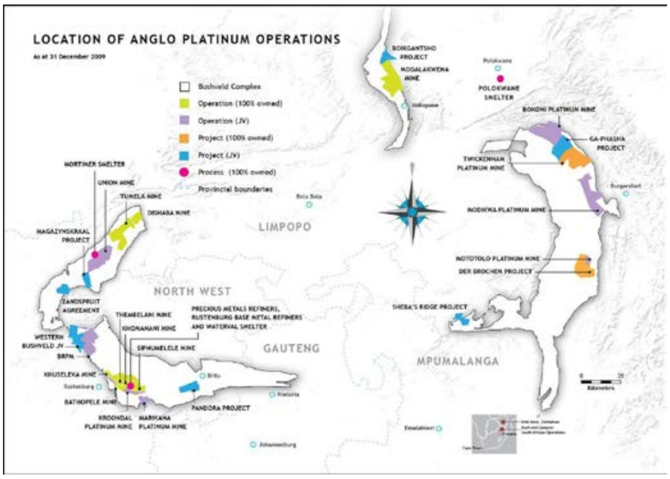


Fig 1: Location of Anglo Platinum operations in the Bushveld complex. Source: [2]

Anglo American Platinum operates in the Western limbs of the Bushveld Complex exploiting the world's largest known igneous complex that extends over 65,000km^2 and reaches a depth of about 7km [3].

An average concentration of PGM of about five grams (5g) can be found in one metric ton (1,000kg) of mined ore which can be sent directly to the Precious Metals Refinery (PMR) unit. The rest of the mined ore undergoes ore concentration operations. Precious metals are completely recovered from the mined ore [3].

II. Ore Concentration Unit

TABLE I
ANALYSIS OF THE CONCENTRATE AT THE WATERVAL ORE CONCENTRATION UNIT. SOURCE:[3]

Al_2O_3	CaO	Co	Cr_2O_3	Cu	FeO	MgO	Ni	S	SiO_2	PGM	Tot
%	%	%	%	%	%	%	%	%	%	g/t	%
3.2	4.7	.08	.80	2.1	20	15	3.6	9	34	143	92

Ore mined is received at the ore concentration unit mainly for the separation of valuable contents to rocks and sand. Ores undergo crushing, milling, and wet-screening to obtain pumpable slurry which bears the precious metals. Separation occurs in flotation cells where the reagents (chemicals) are added to aerate slugs carrying high-grade collected PGM [4](Anglo Platinum Limited, 2009). The operations of ore concentration are accountable for large amounts of waterborne emissions and emissions to soil in the PGM recovery process. An approximate composition of a metric ton received at the ore concentration unit of Waterval is given in Table I.

The composition of the above concentrate (Table I), are required, precious metals (PGM plus gold) and metals (nickel (Ni), copper (Cu) and cobalt sulphate ($CoSO_4$)) [5].

In general ore concentration results in land transformation, livestock, fauna, and flora affected by use of chemicals and other non-renewable resources. Important and varied wastes are generated which interact with local communities. Airborne emissions affect and put under stress local communities and the immediate environment such as underground water, livestock, fauna, and flora. In return, mining companies put in place appropriate management systems tailored to ISO 14001:2004 standards to track legal compliance in an effort to prevent pollution (Anglo Platinum Limited, 2009)[4].

III. Sketch of an Input/Output Single Stage or Unit Operation or Unit Process in a Flow Chart

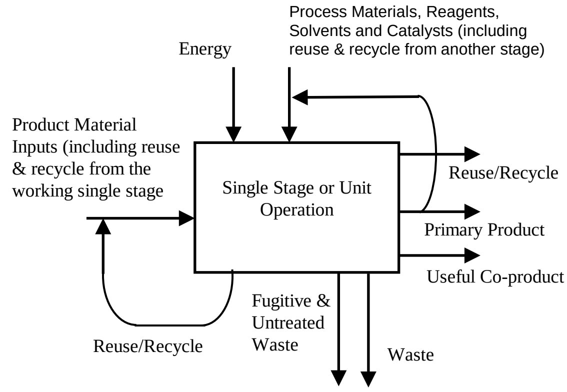


Fig. 2: Input/output of a single stage or unit operation or unit process in a flow chart. Source: Adapted from [6]

IV. Inventory Assessment of Flow-Material in the Ore Concentration Phase

A. The Life Cycle Inventory of Flow-Material: 400g/t of Concentrate

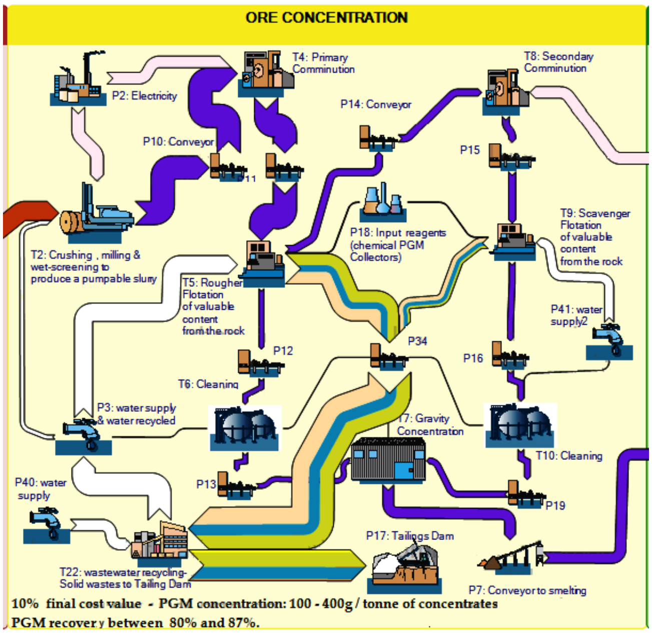


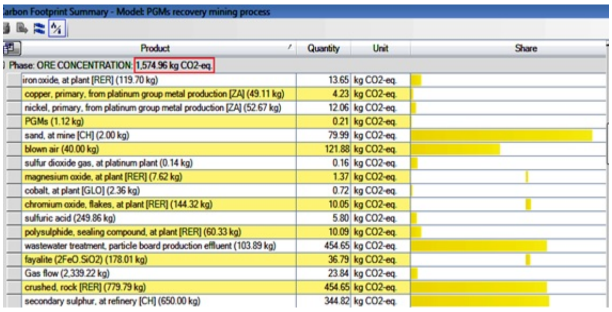
Fig. 3: Flow-material in the concentration phase. PGM recovery up to 400g/t of concentrates.

The concentration phase of PGM recovery accounts for significant solid and liquid emissions ending at tailings dams. Acid mine drainage that affects the groundwater sources is one of the most important issues. This phase uses large quantities of water and this calls for on-site recycling wastewater, which in turn causes direct and indirect emissions due to the use of a certain amount of energy from emitting resources in CO2 and the use of chemicals.

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

TABLE III

EQUIVALENT CARBON DIOXIDE TO THE SMELTING PROCESS



Carbon Footprint Summary - Model: PGMs recovery mining process

Product	Quantity	Unit	Share
Phase: ORE CONCENTRATION: 1,574.96 kg CO2-eq.			
iron oxide, at plant [RER] (119.70 kg)	13.65	kg CO2-eq.	
copper, primary, from platinum group metal production [ZA] (49.11 kg)	4.23	kg CO2-eq.	
nickel, primary, from platinum group metal production [ZA] (52.67 kg)	12.06	kg CO2-eq.	
PGMs (1.12 kg)	0.21	kg CO2-eq.	
sand, at mine [CH] (2.00 kg)	79.99	kg CO2-eq.	
blown air (40.00 kg)	121.88	kg CO2-eq.	
sulfur dioxide gas, at platinum plant (0.14 kg)	0.16	kg CO2-eq.	
magnesium oxide, at plant [RER] (7.62 kg)	1.37	kg CO2-eq.	
cobalt, at plant [GLO] (2.36 kg)	0.72	kg CO2-eq.	
chromium oxide, flakes, at plant [RER] (144.32 kg)	10.05	kg CO2-eq.	
sulfuric acid (249.86 kg)	5.80	kg CO2-eq.	
polysulphide, sealing compound, at plant [RER] (60.33 kg)	10.09	kg CO2-eq.	
wastewater treatment, particle board production effluent (103.89 kg)	454.65	kg CO2-eq.	
fayalite (2FeO.SiO2) (178.01 kg)	36.79	kg CO2-eq.	
Gas flow (2,339.22 kg)	23.84	kg CO2-eq.	
crushed, rock [RER] (779.79 kg)	454.65	kg CO2-eq.	
secondary sulphur, at refinery [CH] (650.00 kg)	344.82	kg CO2-eq.	

Table III shows a total amount of carbon equivalent of 1,574.96kg CO_2-eq to process one metric ton of ore by concentration. 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).

V. RESULTS

The most significant CO_2-eq emissions in the table III are attributed to wastewater treatment (454.65kg CO_2-eq), crushed rocks (454.65kg CO_2-eq), Sulphur (344.82kg CO_2-eq), blown air (121.88kg CO_2-eq) and the sand (121.88kg CO_2-eq). Blown air represents indirect CO_2-eq due to the energy used to pump slurry from milling to comminution. Comminution consists of grinding the slurry ore to powder (Fig. 3). It is also important to observe that wastewater treatment can likely transfer reagents (PGM collectors) to the tailings dam, with the unfortunate occurrence acid mine drainage.

VI. CONCLUSION

Mining companies have put in place appropriate management systems tailored to ISO 14001 standards. These also track legal compliance and prevent pollution [4]. Yet factual damage impacts caused in the surroundings of processing plants are held responsible of real environmental challenges namely, air pollution with volatile organic compounds and dust emission, acid mine drainage containing chemicals, noise pollution that interact with local communities, affecting human health, underground water, livestock, fauna, flora and forced relocation.

VII. THE OUTLINE OF THE CARBON EQUIVALENT EMISSIONS IN PROCESSING A METRIC TON OF ORE FOR THE RECOVERY OF PGMS

TABLE IV

RECAPITULATION OF CO_2-EQ EMISSIONS IN PROCESSING A METRIC TON OF ORE FROM MINING TO OFF-GAS HANDLING PHASE

Product	**Relative mass (kg)**	**kg CO2-eq**					
		Mining	Ore concentration	Smelting	Converting	Off-gas handling	Total
Blown air	40,00	42,65	121,88	115,49	34,38	1,43E-15	*314,40*
Chromium oxide, Flakes	144,32	3,52	10,05	121,41	75,33	-5,16E-15	*210,31*
Cobalt	2,36	0,25	0,72	8,70	90,60	6,33E-16	*100,27*
Copper	49,11	1,48	4,23	51,07	314,37	1,74E-14	*371,15*
Crushed rocks	779,79	138,29	454,65				*592,94*
Dust	0,20	1,26					*1,26*
Fayalite	178,01	12,87	36,79	467,46	355,30	-1,02E-13	*872,42*
Gas flow/ particles	2339,22	8,34	23,84	287,95	94,38	401,01	*815,52*
Iron oxide	119,70	4,78	13,65	164,89	118,18	6,43E-14	*301,50*
Limestone				177,36			*177,36*
Magnesium oxide, flakes	7,62	0,48	1,37	16,50	44,59	-4,36E-15	*62,94*
Nickel	52,67	4,22	12,06	145,65	355,22	3,58E-14	*517,15*
PGM	1,12	0,07	0,21	2,57	83,34	1,90E-16	*86,19*
Polysulphide, sealing compound	60,33	3,53	10,09	144,94	60,81		*219,37*
Sand	2,00	17,43	79,99	4,39			*101,81*
Secondary sulphur	650,00	102,35	344,82	126,96			*574,13*
Sulphuric acid	249,86	2,03	5,80	70,09	23,03	107,80	*208,75*
Sulphur dioxide	0,14	0,06	0,16	1,92	0,63	2,71	*5,48*
Wastewater treatment, particle board production effluent	103,89	138,29	454,65	177,36			*770,30*
Total Equivalent Carbon Dioxide (KgCO₂eq)		*481,90*	*1574,96*	*2084,71*	*1650,16*	*511,52*	**6303,25**

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