THE ENVIRONMENTAL PROFILE OF PLATINUM GROUP METALS (PGMs)

PLATINUM GROUP METALS
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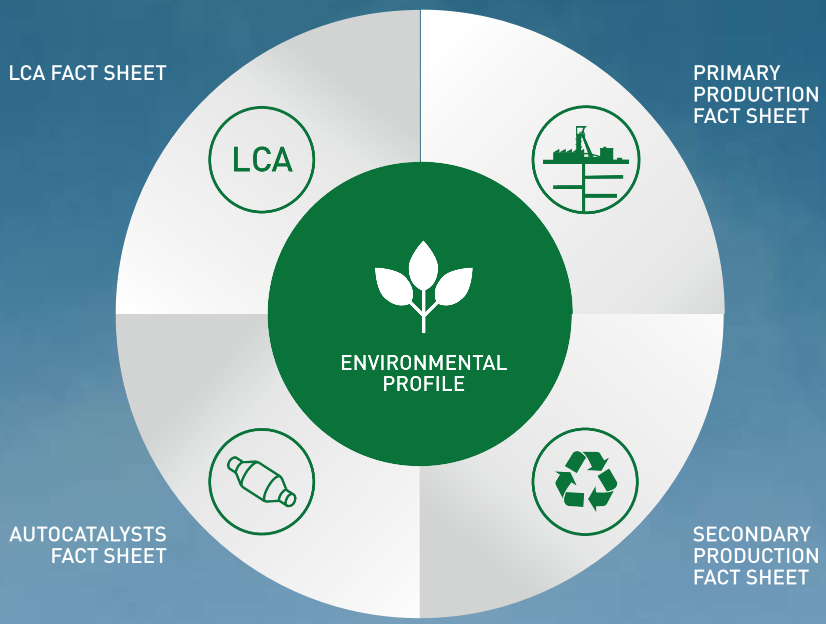
International Platinum Group Metals Association



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THE ENVIRONMENTAL PROFILE OF PLATINUM GROUP METALS (PGMs)

A cradle-to-gate life cycle assessment of the production of PGMs and the benefits of their use in a selected application

Introduction

The International Platinum Group Metals Association (IPA) conducted a Life Cycle Assessment to assess the environmental impacts of the primary and secondary production of platinum group metals (PGMs) as well as the benefits of using PGMs in catalytic converters (autocatalysts) to control vehicle exhaust pollution. Eleven out of fifteen IPA members took part in the study, representing the primary producers of PGMs (from mining to production), the secondary producers of PGMs (recycling and production) as well as the fabricators of autocatalysts.

This study is the first industry-wide assessment of the life cycle of primary and secondary PGM production, and is highly representative of the industry, covering 64% of the global PGM supply. The results represent the global average primary and secondary production of PGMs by the participating members.

The PGM industry carried out this study in order to generate a reliable, current and independent dataset of the environmental footprint of PGMs and PGM-containing products and to enable it to identify areas in the PGM life cycle where it can improve its environmental performance. The study is intended for internal use by the IPA and for communication to LCA practitioners, LCA database providers, end-users of PGMs and other selected stakeholders.

LCA Study Quick Facts

LIFE CYCLE STAGE	PRIMARY	SECONDARY	AUTOCATALYST FABRICATION
GEOGRAPHICAL COVERAGE	South Africa, USA, Canada	Belgium, UK, Japan	UK, Germany
INDUSTRY COVERAGE	70%	60%	90%
DETAILS	• Temporal coverage: 2009/2010 • Conducted by PE International according to ISO 14040 & 14044, with review by an independent technical expert		

What are PGMs?

The six platinum group metals (PGMs) platinum, palladium, rhodium, ruthenium, iridium and osmium occur together in nature alongside nickel and copper. Along with gold and silver, the PGMs are precious metals and are very rare elements in the Earth's crust. The annual production of PGMs amounts to around 400 tonnes, several orders of magnitude lower than many common metals. Due to their economic values and higher quantities, platinum and palladium are the most important metals in the PGM mix and also the main products. Rhodium, ruthenium, iridium and osmium are mined as co-products of platinum and palladium. The PGMs are highly resistant to wear, tarnish, chemical attack and high temperature, and have outstanding catalytic and electrical properties. All these unique characteristics have made them indispensable in many industrial applications.

Facts about PGMs

PGMs are very rare elements and most PGM-bearing ores are extremely low-grade, with mined ore grades ranging from 2 to 6 grams per tonne.[1] PGM mining is a capital, energy and labour intensive process; extraction, concentration and refining of the metals require quite complex processes that may take up to six months.

Most of the largest primary producers of PGMs are located in South Africa which hosts 95% of the known world reserves.[2]

PGMs have outstanding catalytic qualities which make them the premier choice for a number of industrial applications, such as petroleum refining, nitric acid manufacturing, and autocatalysts. There are two main properties that explain the widespread use of PGMs in cleaning car and other vehicle exhaust since the early 1970s: their resistance to poisoning (e.g. from fuel impurities); and their high thermal stability which means they retain their catalytic activity for longer than other materials in the harsh conditions of vehicle exhaust.

PGMs are used rather than consumed. The high recyclability of PGMs means they can be re-used many times, thus ensuring that their impact on the environment is kept as low as possible.

95%

The PGM industry routinely recycles PGMs from their applications. Using state-of-the art recycling technology, up to 95% of the PGM content of spent automotive catalysts (and other PGM-containing applications) can be recovered. However, the high technical recyclability of PGMs is sometimes jeopardized by insufficient collection and inappropriate pretreatment of PGM-bearing materials.

1 Johnson Matthey, http://platinum.matthey.com/about-pgm/production/south-africa.
2 U.S. Geological Survey, Mineral Commodity Summaries, January 2013.

How are PGMs produced?

Primary Production

PGM-bearing ore is typically mined underground or, less usually, from open pits. The ore is blasted before being transported to surface. Crude ore is crushed, milled and concentrated into a form suitable for smelting, which takes place at temperatures that may be over 1500°C (2732°F). Unwanted minerals such as iron and sulphur are removed leaving a matte containing the valuable metals which are separated in a series of refining processes. Nickel, copper, cobalt, gold and silver may be extracted in the refining process as co-products.

Electricity consumption is high, not only for ore haulage but also to drive compressed air to the miners' hand-held pneumatic drills and, because the hard rock in platinum mines has a high thermal gradient, to refrigerate the working areas. The power grid in South Africa, where the bulk of production considered in this study takes place, relies heavily on burning hard coal, leading to relatively high CO_2 emissions: more than 90% of electricity is generated that way. To a great extent, the local electricity grid mix is beyond the control of South African PGM producers. However, every effort is made to reduce primary energy demand.

Secondary Production (Recycling)

PGMs can be recycled from a variety of end-of-life products (such as spent autocatalysts) and even from residues created during primary production. Secondary production processes can vary widely depending on the specific material or combination of materials treated. Some secondary producers of PGMs use a dissolving process to create a PGM-rich solution for refining, while others may use a smelting process to create a matte. In both cases, the final PGM products are identical in quality and purity to those refined from mined material.

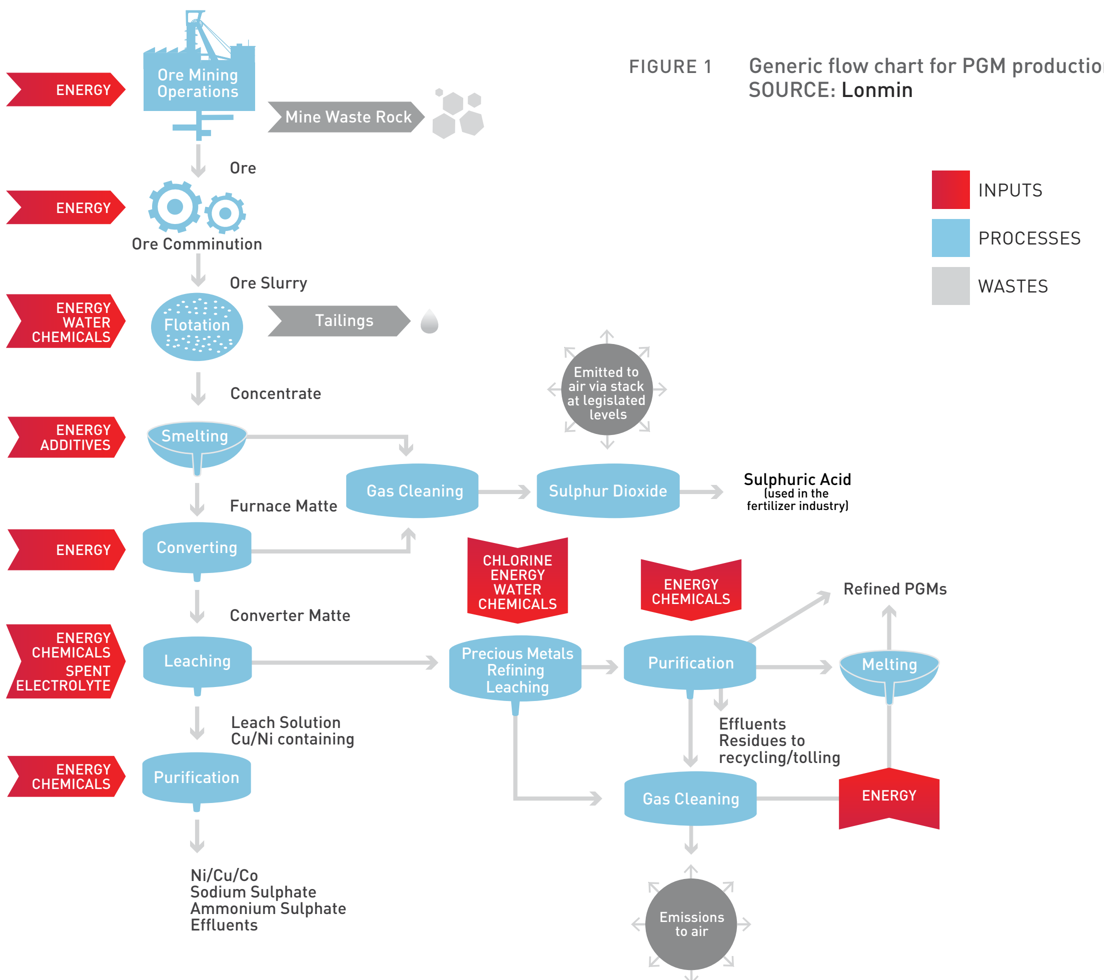


FIGURE 1 Generic flow chart for PGM production in South Africa
SOURCE: **Lonmin**

What are the main applications?

Platinum group metals play a vital role at the heart of modern societies. They are found in numerous products, from hard disks to aircraft turbines, from anti-cancer drugs to mobile phones, from industrial catalysts to ceramic glazes. PGMs have played a role in the manufacture of many goods we use on a daily basis. Numerous applications in which PGMs are involved benefit the environment and our quality of life, such as water purification, N_2O abatement and surgical implants, to name a few.

The infographic below shows the main usages of PGMs:

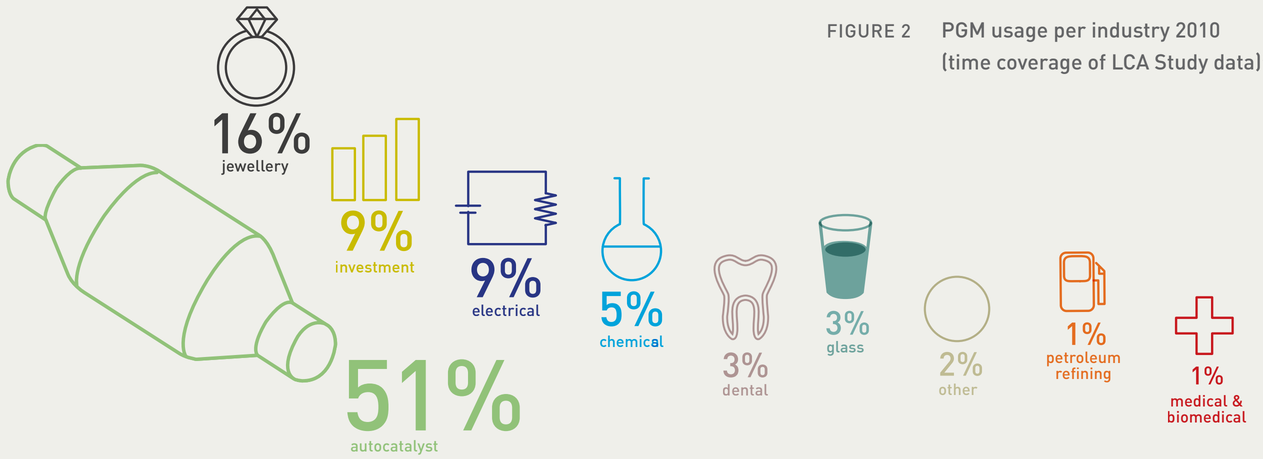


FIGURE 2 PGM usage per industry 2010 (time coverage of LCA Study data)[3]

By far the largest use of PGMs today is for automobile catalytic converters (autocatalysts), a pollution control device fitted to cars, trucks, motorcycles, and non-road mobile machinery. In catalytic converters, PGMs are coated onto a substrate housed in the exhaust system where they act as catalysts to reduce harmful emissions to legislated levels. Autocatalysts convert over 90% of hydrocarbons (HC), carbon monoxide (CO) and oxides of nitrogen (NO_x) from gasoline engines into less harmful carbon dioxide, nitrogen and water vapour. In diesel cars, oxidation catalysts are used to convert HC and CO to water and carbon dioxide, and catalysed soot filters trap and oxidise particulate matter (PM).

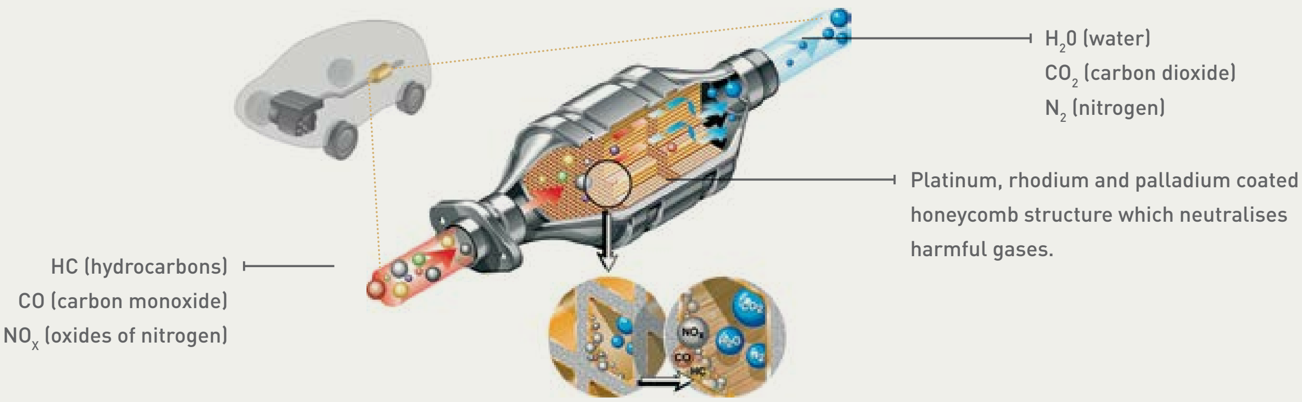


FIGURE 3 The structure and function of an autocatalyst
IMAGE CREDIT: **UMICORE**

3 Data from Johnson Matthey Platinum 2013 Interim Review.

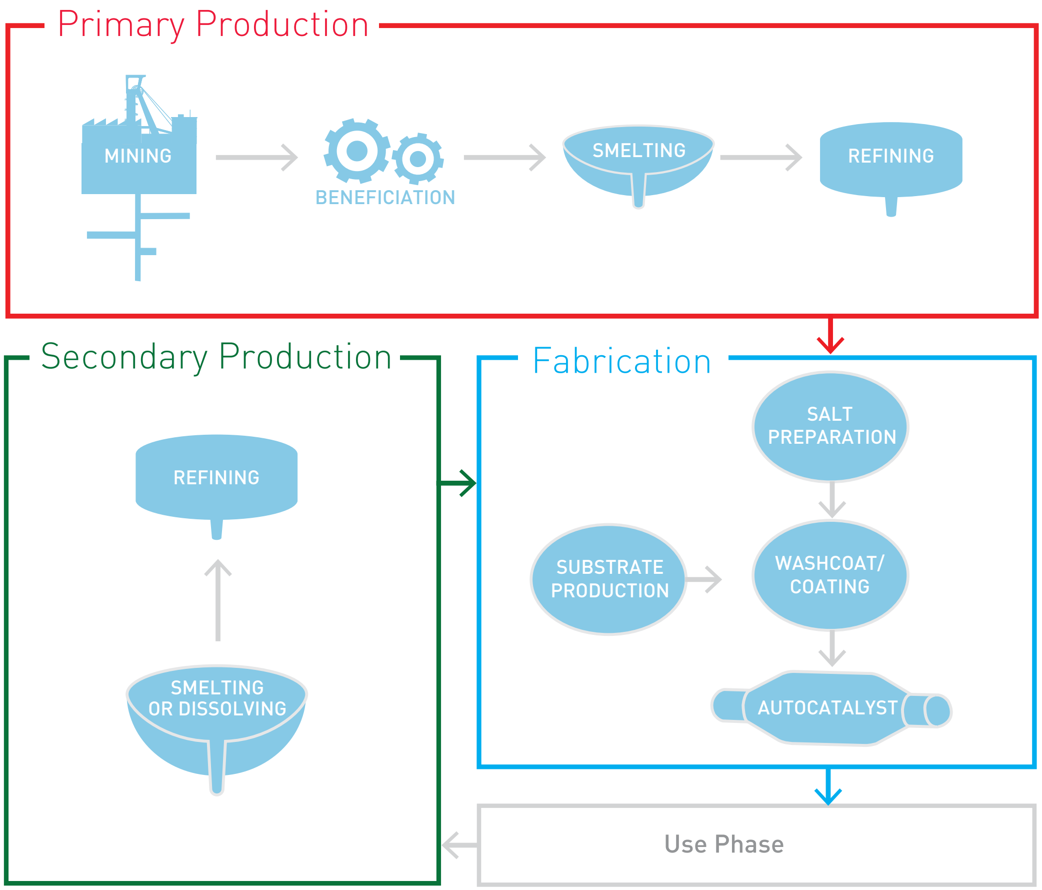
Goal and scope of the PGM LCA Study

The LCA conducted to collect the data presented in this Environmental Profile follows the "cradle-to-gate" approach which covers the processes from the extraction of the raw materials to the finished product. For PGMs it includes all aspects of ore extraction, the production of other raw materials, energy supply and the production of the PGMs themselves. The cradle-to-gate Life Cycle Inventory (LCI) also includes the production of fuel and ancillary materials, and represents all resource use and emissions caused by primary and secondary PGM production as well as the use of PGMs in a catalytic converter application.

The study focuses on the autocatalyst application as this is the largest use of PGMs today. A typical catalyst is made up of a mix of PGMs sourced from both primary and secondary production. The PGM mix in the study is assumed to be approximately 72% primary PGMs and 28% recycled PGMs, based on the gross weight of PGMs used in autocatalysts and the gross weight of PGMs recycled from end-of-life autocatalysts in 2010.

The manufacture of downstream co-products, the canning process and the collection of spent autocatalysts are not included in this study.

The system boundaries and unit processes considered in this study are shown in the diagram below:



The functional units for the study were:

- 1kg of platinum, 1kg of palladium and 1kg of rhodium (production phase)[4];
- 1 Three Way Catalyst (TWC) in a EURO 5 1.6l gasoline engine vehicle over 160,000km life-time (use phase);
- 1 Diesel Oxidation Catalyst (DOC) and 1 catalysed soot filter (CSF) in a EURO 5 2.0l diesel engine vehicle over 160,000km lifetime (use phase).

4 IPA Study mix representing the global average primary and secondary production of PGMs by the participating members.

Key findings based on LCI and LCA results

The study illustrates that the impacts of PGM production are significantly mitigated by the in-use benefits

- Power consumption during mining and ore beneficiation has been identified as the major impact (72%) of the production of PGMs on the environment; these two energy-intensive processes precede the final separation of metals during refining, thereby producing not only platinum, palladium and rhodium but also several other base metal products such as nickel, copper and cobalt, and other precious metal products such as iridium, osmium, ruthenium, gold and silver, which are not considered in this study.
- A further 27% of the impact comes from smelting and refining.
- Only 1% of impacts are attributed to recycling[5]: the low footprint of recycling compensates for the higher footprint of primary production. This is expected for various reasons, including the vast difference in the concentration of PGMs between primary and secondary sources.
- Over 1.3 tonnes of toxic and harmful pollutants including CO, HC, NO_x and PM are avoided by the use of catalytic converter systems in one EURO 5 gasoline plus one EURO 5 diesel vehicle in use over 160,000km each; this is equivalent to a reduction in these emissions of up to 97%.
- Emissions of CO_2 are increased by between 2% and 6% through the use of autocatalysts; this is due to the conversion of CO and HCs into CO_2 during vehicle use; however, this increase is small when compared to CO_2 emissions from the combustion of the fuel used to drive the vehicle.

The environmental impacts of PGM production[6] have been quantified for a variety of categories; the two most requested categories, Global Warming Potential (GWP)[7] and Primary Energy Demand (PED)[8], are presented on the right.

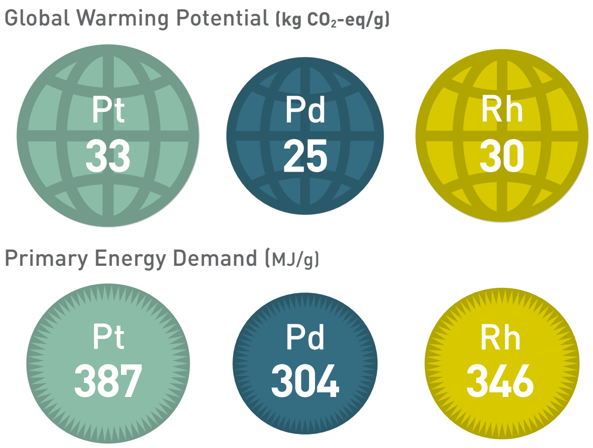


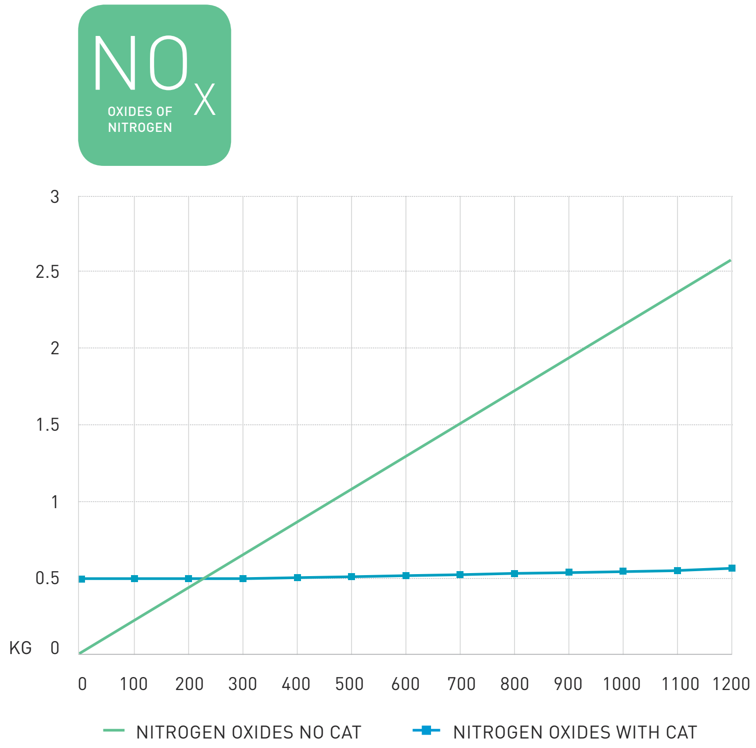
FIGURE 4 Summary result of the Life Cycle Impact Assessment for the average production of 1 gram of PGMs*
Source: IPA LCA Study 2013[9]

*Data in round figures

- The reduction in emissions of HC, CO, NO_x and PM as a result of the use of a catalytic converter outweigh the emissions generated during the production of the catalyst including PGMs and other related materials used to support the functionality of the catalyst.
- For all investigated EURO 5 systems the break-even point for emissions of CO, HC, NO_x and PM is reached after at most 40,000km and in some cases (e.g. CO and HC in a Three Way Catalyst) after only a few kilometres of driving. The "break-even" point is the driving distance of the vehicle in which the additional environmental burden of producing the catalytic converter is counteracted by the role of the catalytic converter in reducing vehicle emissions. For example, in a vehicle equipped with a DOC + CSF catalytic system, the break-even point for CO is reached after 100km, hence at that distance the CO emissions from producing the catalyst (including the PGM loading) have been cancelled out by the reduction of CO emissions from the vehicle.[10]

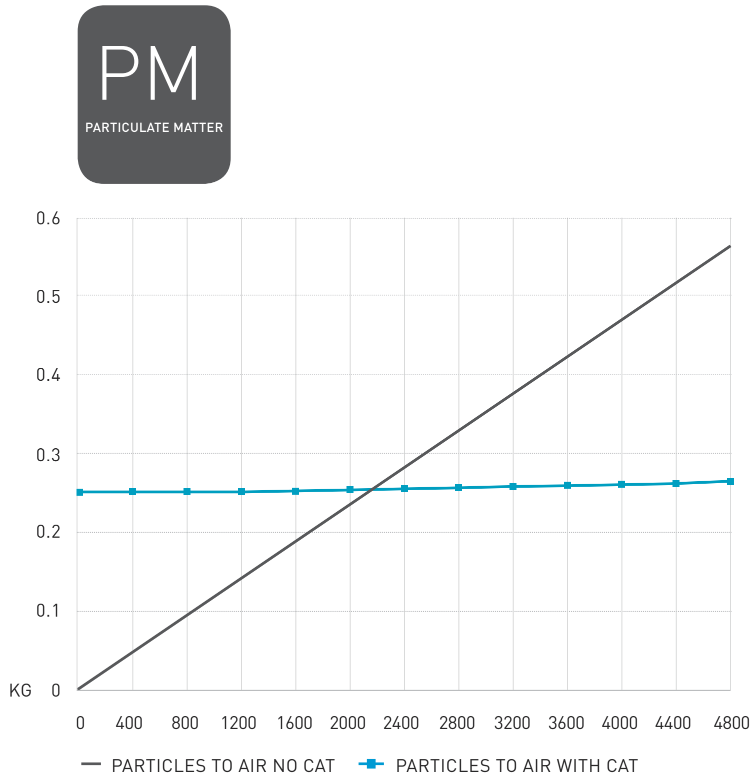
5 Based on the production volumes considered in this study (representing 60% of global PGM recycling from all secondary sources).
6 The results for GWP and PED are representative of the global average primary and secondary production of PGMs by the participating members.
7 The Global Warming Potential is calculated in carbon dioxide equivalents (CO_2-Eq). This means that the greenhouse potential of an emission is given in relation to CO_2.
8 The Primary Energy Demand is the quantity of energy directly withdrawn from the hydrosphere, atmosphere or geosphere or energy source without any anthropogenic change.
9 IPA Study mix representing the global average primary and secondary production of PGMs by the participating members.
10 The fuel consumption of the vehicle is not considered here.

Examples for use phase benefits



The production of a TWC emits 0.60kg NO_x; the benefit during the use phase, however, is that the catalyst in the vehicle reduces emissions by 332kg over the vehicle's lifetime. The break-even point for NO_x emissions is reached after a driving distance of approximately 250km.

FIGURE 5 Reduction in NO_x emissions from a vehicle by the application of PGMs in a Three Way Catalyst (TWC) (EURO 5) system; **SOURCE: IPA LCA Study 2013**



During the cradle-to-gate production of the catalyst system used in a diesel engine, 0.25kg of particulate matter (PM) is emitted; however, the use of these catalysts reduces the vehicle engine PM emissions by 18kg over the vehicle's lifetime. The break-even point for PM is achieved after a driving distance of approximately 2,200km.

FIGURE 6 Reduction of particulate matter (PM) in a DOC + CSF (EURO 5) system; **SOURCE: IPA LCA Study 2013**

Take-away messages

Mineable deposits of PGMs are very rare in the Earth's crust; the extraction and refining of PGMs is a capital, energy and labour intensive process.

The PGM industry acknowledges its footprint and is committed to reduce adverse environmental effects.

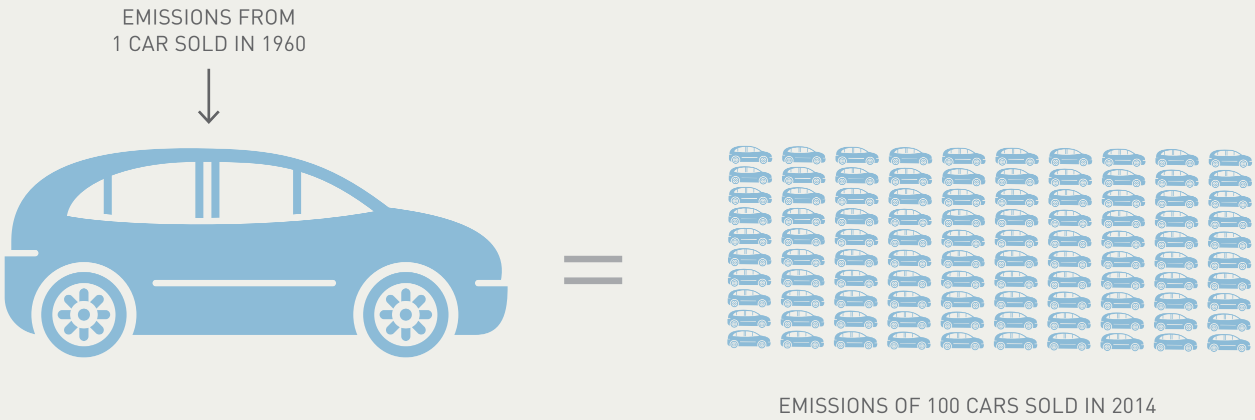
PGMs are produced in low volumes, several orders of magnitude lower than many common metals[11]; they are used in very tiny quantities.[12]

The high and repeatable recyclability of PGMs reduces the environmental impact of PGM production with each recycling round.

Recycling could not occur if there had not been a primary ounce of PGMs produced beforehand. Ensuring the steady supply of PGMs to meet society's current and future needs requires both increased levels of recycling and ongoing investments in primary production.

Vehicle regulations around the world have been progressively tightened so that it would take just 1 car sold in the 1960s to equal the harmful exhaust emissions from 100 of today's automobiles with catalytic converters. PGMs enable car manufacturers to comply with emissions standards and help regulators to implement tightening emissions regulations.

Catalytic converters reduce outdoor air pollution in both cities and rural areas which was estimated by the WHO to cause 3.7 million premature deaths worldwide in 2012.[13]



11 The global production of PGMs in 2011 was 430 tonnes (platinum: 202 tonnes; palladium: 205 tonnes; rhodium: 24 tonnes); source: Johnson Matthey Platinum 2013 Interim Review; data excludes Russian State palladium sales and recycling.
12 The average PGM loading for a EURO 5 European Light Duty Diesel (LDD) catalyst system is 7-8 grams, for a EURO 5 European Light Duty Gasoline (LDG) catalyst it is 2-3 grams (average PGM content as used in the IPA LCA Study for Europe).
13 WHO Fact Sheet on Ambient (outdoor) air quality and health, March 2014.

What is LCA?

Life Cycle Assessment provides information to decision makers by giving insights into the potential environmental impact of materials and products, whether from raw material extraction, manufacture, end of life disposal or a combination of any of these. An LCA shows where the greatest environmental impacts occur and where improvements would deliver the most benefits.

A typical LCA study consists of four phases:

1. Goal and Scope: The goal and scope outline the rationale of the study, the anticipated use of the results of the study, the boundary conditions, and the assumptions used to analyse the product system under consideration.
2. Life Cycle Inventory (LCI): The life cycle inventory stage quantifies the material and energy use and environmental releases for the product system being studied. These results can be used in isolation to understand emissions, waste or resource use. Additionally, the results can provide insights which may lead to product design improvements.
3. Life Cycle Impact Assessment (LCIA): The evaluation of the environmental relevance of the inputs and outputs of the system.
4. Interpretation: Interpretation of the results of the study, including recommendations and limitations of the study as well as an analysis of the validity of the results based on those limitations.

Why the LCA was conducted

In 2008, the IPA began to formulate an environmental strategy as a result of increased environmental awareness within the organisation and in response to market, customer and regulator expectations. In 2009, the membership developed the PGM industry's Sustainability Principles which include improving its understanding of the environmental, social and economic impacts and benefits of its materials across their life cycle.

In committing itself to a life cycle approach, the industry determined that it will:

- Collaborate with suppliers, customers and other stakeholders to understand the life cycle of its products and materials;
- Contribute to a global database of life cycle information and share best practices in order to reduce the overall footprint of PGM products.

To support the industry's commitment to understand and improve the sustainability performance of PGMs, the IPA commissioned the consultancy and software firm PE International to carry out an LCA study with the aims to:

- Generate current life cycle data on PGMs and their application in autocatalysts;
- Provide data to determine the benefits of PGMs (e.g. in applications and through recycling);
- Identify areas (in the PGM life cycle) where the industry can improve its performance;
- Support benchmarking within the industry.

About the IPA

The IPA is a non-profit organisation representing 80% of the mining, production and fabrication companies in the global platinum group metals (PGM) industry, comprising platinum, palladium, iridium, rhodium, osmium and ruthenium.

Companies participating in the LCA study

Anglo Platinum · Implats (Distinctly Platinum) · Lonmin · Royal Bafokeng Platinum · Stillwater Mining Company · Vale · Johnson Matthey · BASF The Chemical Company · umicore · Heraeus · Tanaka Kikinzoku Group

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CONTACT INFORMATION

International Platinum Group Metals Association
Schiess-Staett-Str. 30, 80339 Munich – Germany
Phone +49-89-5199-6770, Fax +49-89-5199-6719
info@ipa-news.com, www.ipa-news.com