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PARTIAL-PGMS: Policy Brief

Addressing environmental and Critical Raw Materials challenges

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Executive Summary

One of the major success stories in the fight against environment pollution has been the catalytic converter technology that is in use by automobiles around the world today. At the core of this technology is the catalyst itself, which is generally a precious metal such as platinum, palladium, or rhodium, the so-called Platinum Group Metals (PGMs). As successful as this technology has been, however, it is facing increasing challenges both at the technological and socio-political levels. The relentless advance of regulatory pressure on automotive emissions has introduced new requirements that current catalytic technology does not address (such as particulate matter emissions). In addition, Europe does not have its own primary production of precious metals, which has created a serious supply risk for Europe, given the provenance of these resources in politically unstable regions.

The classification of these precious metals as Critical Raw Materials for Europe, together with the need to support world-leading European environmental policy progress with the resolution of technological issues in catalytic conversion, has led to the identification of current policy gaps that could advantageously be filled with appropriate measures. More explicit linkage of the two threads of environmental and Critical Raw Material policy formulation could create the synergies needed to address both technological and socio-political challenges.

The PARTIAL-PGMs and CritCat projects, funded by the European Commission, are examining how new nanomaterials can be used to substitute effectively PGMs in current applications. As participants in the CDB services, they are seeking to contribute to European policy formulation as an important result of their work. This Policy Brief is a contribution in that sense.

1 Topic Overview

1.1 Topic

One of the first and still most fundamental initiatives in the fight against environmental pollution was the introduction of the automotive *catalytic converter* in 1975, first in the United States and subsequently in Japan and Europe by 1986. Even today, the most common type of converter found in gasoline engines is the so-called *three-way catalyst* (TWC), named for its ability to convert carbon monoxide, hydrocarbons, and nitrogen oxides. The central component of the TWC (the *catalyst*) is a precious metal, generally one of the so-called Platinum Group Metals (PGMs) – generally Platinum, Palladium, or Rhodium – or so-called Rare Earth Elements (REEs).

Today, it is estimated that the automotive industry accounts for anywhere from 65% to 80% of the demand for these precious metals in Europe. The demand for PGMs and REEs does not only come from the automotive industry; they are increasingly being adopted in emerging technologies such as fuel cells and related green energy conversion devices.

But problems have begun to emerge with this popular and effective technology. First of all, TWC converters have proven to be ineffective against *particulate matter* (PM) emissions, which will be covered in the ever-stricter European emission regulations (EURO 6c/7). These ever-tightening regulations are leading to the development of Gasoline Particulate Filters (GPFs) to address this type of emission. A particularly promising approach being pursued in Partial-PGM and CritCat is the development of an efficient *hybrid* TWC/GPF technology that combines the best of both and will be capable of meeting future EC emission standards.

Partial-PGM and CritCat are also examining how new nanomaterials can be used to substitute effectively PGMs in current applications, which leads us to the second problem: the constantly growing demand for precious metals and rare earth elements is beginning to outstrip the supply, leading them to be classified in Europe as *Critical Raw Materials*, whose availability must be monitored and ensured in Europe just like any other resource that is crucial to the well-being of Europe and its citizens.

1.2 Policy challenges

Since the mid-1970s, EU environment policy has been guided by action programmes defining priority objectives to be achieved over a period of years. The current programme, the seventh of its kind, was adopted by the European Parliament and the Council of the European Union in November 2013 and covers the period up to 2020. Through this Environment Action Programme (EAP), the EU has agreed to step up its efforts to protect our natural capital, stimulate resource-efficient, low-carbon growth and innovation, and safeguard people's health and wellbeing – while respecting the Earth's natural limits. Significant issues, affecting human health and the environment will continue to persist, even after an effective implementation of the current legislation. According to the European Environment Agency, air pollution (mainly CO, CO_2 and NO_x) has decreased the average life expectancy of Europeans by nearly a year.[1] Additionally, small suspended particles have been identified as the greatest health risk, as they penetrate into the lungs and enter the blood, causing a range of illnesses and in some cases death. The World Health Organisation recently confirmed that air pollution causes cancer.[2] Over 90% of the EU population is estimated to be exposed to health risk levels of particulate pollution, while about a third is exposed to levels above permitted.[3]

Addressing these problems, EU has imposed a gradual reduction of toxic and pollutant emissions from cars, along with the so-called EURO standards for car emissions. European policy is a notable example of worldwide excellence in addressing environmental issues. A particular highlight of this policy is its ever-stricter set of "EURO" emission regulations on vehicle emissions, which keep technologies like catalytic conversion at the leading edge. Thus, in addition to particulate matter mass (PM), with the introduction of EURO 6, the new European legislation will also introduce a particulate matter number (PN) requirement for all spark ignition vehicles (Appendix I). Measurements, on state-of-the-art gasoline engine powered vehicles, show that conventional MPFI engines are already below the future proposed limits, while gasoline engines with ***direct injection*** are above these limits and will require additional R&I efforts in order to comply with these new limits.

The European Union, maintaining its focus on achieving the Greenhouse Gas (GHG) emission reductions, has undertaken certain actions to achieve, by 2020, a reduction of 20% GHG, compared to the base year 1990, fulfilling that way the commitments for the second period of the Kyoto protocol (2013 - 2020). To address this target, EU has developed a new test, called the Worldwide Harmonised Light Vehicle Test Procedure (WLTP), to replace the New European Driving Cycle (NEDC), which was designed in the 1980s. While the old NEDC test determined test values based on a theoretical driving profile, the WLTP cycle was developed using real-driving data, gathered from around the world. The aim was to be used as a global test cycle protocol across different world regions, so pollutant and CO_2 emissions (Appendix II) as well as fuel consumption values would be comparable worldwide. However, while the WLTP has a common global 'core', the European Union and other regions will apply the test in different ways depending on their road traffic laws and needs. Additionally, although the new test is closer to the real driving conditions, it fails to represents everyday driving profiles. Furthermore, the current EU legislation do not address the emissions of nitrous oxide (N_2O) from road transportation (Appendix III), a gas that have a huge global warming potential (GWP), as its weighting factor is 298 times more compared with that of CO_2.

As the global economy continues to grow, there is an ever-increasing pressure on the Earth's resources. Among other turbulences in economic life, the availability and prices of certain important raw materials have been subject to increasing uncertainty. The issues around these so-called critical raw materials (CRMs) include strong and growing demand from the industry, as well as limited and volatile supply. Uncertainty surrounding the supply of raw materials may put constrains on economic growth, as rising prices make key industrial sectors less profitable. In the worst cases, severe shortages of CRMs may also result in temporary production halts. In the longer term, the risk remains that the expertise, concerning the use of existing advanced materials or further development of new ones will be lost. The EU is highly dependent on imports of raw materials that are crucial for a strong European industrial base, an essential building block of the EU's growth and competitiveness.

To address this challenge, the European Commission has created a list of critical raw materials (CRMs) for the EU, which is subject to a regular review and update. After the first approach in 2011, the CRM list has been updated in 2014 (second list) and in 2017 (third list). Furthermore, the EU has published the "Report on CRMs and the circular economy" (2018), highlighting the potential for a more circular usage of CRMs in our economy. Reviewing important sectors for CRMs, it describes relevant EU policies, refers to key initiatives, presents and gives sources of data, identifies good practices and indicates possible further actions. Noble metals (PGMs) and Rare Earth Elements (REEs) are classified as "at risk" on the European Union list of critical materials, mainly because of their geographically concentrated supply, in regions outside the EU (South Africa and Russia). Additionally, recycling from consumer products is in its infancy. This transforms the technological problem into a challenge at European level, where social-economic policy must support the search for potential solutions. Huge research and development efforts in academic and industrial research have been directed towards the development of innovative material solutions that can reduce the use of PGMs and REEs, in high-tech applications, to address the problem of CRMs limited supply. Currently, only the EU Reduction and Recycling strategies cannot mitigate the risks resulting from the fact that primary production occurs mainly outside the EU. On the other hand, the potential of PGMs and REEs reductions via their substitution is considered as extremely crucial for the European Industry. Thus, finding sustainable solutions for the replacement of PGMs has become not only a technological challenge, but also a policy-related challenge. There is currently a linkage gap between the process of policy formulation to address the issue of Critical Raw Materials and the issue of R&D to discover and develop effective substitutes for the PGMs that are currently vital to the implementation of European environmental and industrial policy.

2 Recommendations

Here are the recommendations for policy and regulatory changes:

2.1 Link European environmental policy to PGM and REE reduction

Current forecasts indicate that, as PGMs are increasingly adopted not only in automotive catalytic applications but also other emerging technologies, future needs will greatly exceed annual production, as well as global reserves. For example, detailed studies have indicated that presently known platinum reserves may last only for 15 years with the current increasing consumption trends. European environment policy, especially the EURO set of automotive emissions regulations, could be linked to policy goals of reducing the use of precious metals. For example, the Partial-PGM / CritCat projects have recommended goals of reduction of platinum group metals by at least 35%, and decrease of rare earth elements by no less than 20%. This policy linkage will spur a redirection of industrial attention to the issue of Critical Raw Materials.

2.2 Identify and strengthen R&I initiatives for PGM substitutions

Certainly, EU R&I policy should support continuous research to improve catalyst performance and functionality, but it should also specifically address the reduction in amount of PGMs used in catalyst technology. For example, Partial-PGM and CritCat are not only examining the use of different metals, but also researching innovative processes for the actual *design and construction* of new nanomaterials that can substitute the PGMs, utilizing leading edge technologies such as machine learning to create a systematic, rational synthesis process that is more promising in the long term than a mere search for substitutes. R&I Programme policymakers should ensure that such promising avenues of process innovation for PGM substitution are identified (e.g. through expert consultation committees) and funded, thus aligning European R&I policy and environmental policy on a solid path to long-term success.

2.3 Better automotive after-treatment systems with improved performance, using smaller amounts of CRMs

The current trends in automotive catalysis are focused on the development of more efficient systems with optimal use of CRMs, capable to meet future requirements. Rational design through multi-scale modelling is a methodology that can provide fundamental knowledge on phenomena occurring in nanoscale can lead to the development of more active catalysts. Furthermore, the synthesis of the catalysts can be optimised. The current systems are typically prepared by washcoating of alumina slurry containing Pd, Pt, Rh, and promoters (CeO_2 particles) on the surfaces of honeycomb monoliths. The main drawback of the wash-coating method is that most of the noble metals are buried inside the alumina matrix, and thus large amounts of PGMs are needed to obtain systems with approved efficiency and durability. The direct anchoring of the noble metals on the supports (mainly cordierite), offers a novel approach to maximize the catalytic surfaces, also yielding effective use of precious metals. Moreover, the use of Additive Manufacturing tools can contribute to the effective immobilization of the active phase, without the use of wash-coating. The 3D-Printed supports can provide also significant advantages on flow and heat properties as well as optimal use of CRMs. Finally, in order to address the development in engine technology, more efficient Gasoline Particulate Filters (GPFs) should be developed, improving the: (i) Size of the filter, (ii) Backpressure (ii) Ash storage and (iv) high soot filtration to deal with light off temperatures, thermal durability and cost issues.

2.4 Partial or complete substitution of PGMs by Transition metals in automotive catalysts.

The choice of PGMs as the active catalytic phase in after-treatment systems is justified by three main factors: (a) only the precious metals had the required activity needed for the removal of the pollutants in the very short residence times dictated by the large volumetric flows of the exhaust in relation to the catalyst size which could be accommodated in the available space; (b) the precious metals were the only catalytic materials with the requisite resistance to poisoning by residual amounts of sulfur oxides in the exhaust; (c) the precious metals were less prone to deactivation by high-temperature interaction with the support. Based on both economical – increased price- and political reasons – overexploitation, trade and governmental restrictions- the research efforts have been focused on the replacement (partial or complete) of platinum group metals (PGMs) with eco-friendly transition metals. Although this task is very challenging only few studies have been reported up to now. The research efforts within PARTIAL-PGMs have revealed that this objective is achievable through the synthesis of novel nanoporous materials and perovskites using transition metals and their functionalization in large-scale by nanotechnology approaches. These techniques can lead to excellent dispersion of metallic nanoparticles (Cooper) over the catalytic substrates offering high catalytic efficiency, low cost and environmental compatibility.

2.5 Development of novel Low- or No-PGMs catalysts for other industrial applications.

In terms of size, automotive catalysis accounts for more than 90% of the total demand of PGMs in catalysis. However, large amounts of noble metals are currently used in the abatement of VOCs from industrial processes as well as in processes involving the utilisation of other feedstocks (e.g. CH_4) for chemical synthesis and energy production. Thus the design and synthesis of catalysts with low CRMs content is of primary importance for European Industry. PARTIAL-PGMs demonstrated, in low TRL (4-5), the catalytic conversion of VOCs by No-PGMs catalysts. The synthesis of CRM free catalysts will secure the undisturbed supply of the European industry with critical resources and address challenging environmental issues including the decrease of fossil fuels by means of alternative low-carbon energy sources and the reduction of toxic emissions from mobile and stationary sources. Reaching these targets will contribute to the Sustainable Development goals set by the EU for combating climate change and the environmental pollution and will support the transition to a circular economy, offering significant benefits to the European industry and society

2.6 Advanced characterisation techniques of nanomaterials – Real time monitoring of industrial lines

The comprehensive characterisation of the nanomaterials involves the refinement of a full set of both nano-scale specific and bulk-related physico-chemical properties. As a result, the use of several complementary techniques is required to get a comprehensive depiction of the nanomaterials. In general, several characterisation techniques can be applied to investigate a given physico-chemical property. However, this flexibility has to be further qualified, depending on the class of nanomaterials and the operating conditions. Thus there is a strong need for the development of advanced characterization tools that will enable researchers to observe and characterize events at the nanoscale. The new tools will shorten the development time required for moving upmarket, while fully complying with legitimate health and environmental expectations of the European citizens. Furthermore, the introduction of advanced characterisation tools in certain industrial production lines, developing an on line process approach, would allow a real-time control of process, and thus, lead to a substantial saving of time, resources and energy. Moreover, the proposed advanced characterization methodology will assist the development of a pan-European standard for the characterization of nanostructured materials in general and catalysts in particular, increasing the scientific acceptance of EU research centers and universities worldwide. Both innovative materials and processes will contribute to the improvement of the quality of life, especially in relation to environmental issues.

2.7 Recyclability of PGMs

The sustainable availability of PGMs in the EU can be accomplished not only by substituting the noble metals with other abundant metals, but also by improving the circular efficiency of the entire value chain e.g. through the implementation of closed-loop approaches. The potential for recycling precious metal-containing waste (e.g. spent auto-catalysts) can be considered of as an “urban mine”.

Currently the PMGs recycling input rate for PGMs is quite low (~11%) due to sorting and recycling technologies. Effective recycling requires a well-tuned recycling chain, consisting of different specialised stakeholders, starting with the collection of old products, followed by sorting/ dismantling and preprocessing of relevant fractions, and finally recovery of the metals. On the other hand, recycling technology has made significant progress. However, further improvements are needed to increase the yields from the recycling process, as well as to extend the range of metals that can be recycled.

3 Project Group

PARTIAL-PGMs

PARTIAL-PGMs proposes an integrated approach for the coherent development of smart and innovative nanostructured automotive post-treatment systems by integrating TWCs on GPF, capable to meet future regulations, with reduced PGMs and REEs, leading to development of 2nd generation GPFs.

www.partial-pgms.eu

CritCat

Exploring the properties of ultra-small transition metal ™ nanoparticles in order to achieve optimal catalytic performance with earth-abundant materials and substituting critical metals, especially rare platinum group metals (PGMs), used in heterogeneous and electrochemical catalysis.

www critcat eu

Appendix I – Evolution of European Emission Regulations

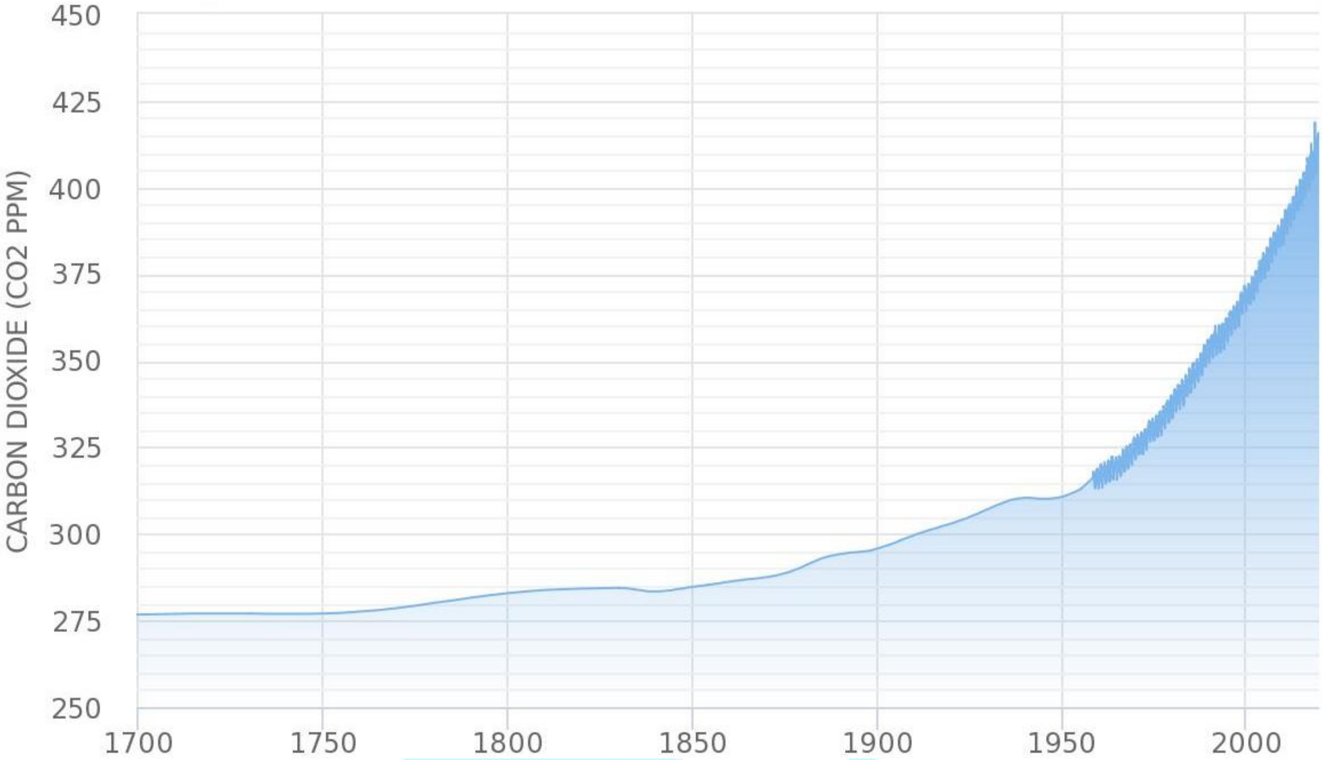
Table 1. Evolution of the European regulations of the most important atmospheric pollutants for light gasoline commercial vehicles e.g. ≤1305 kg (Category N1-I)

Regulations	Euro 1	Euro 2	Euro 3	Euro 4	Euro 5	Euro 6
NO_x (mg/km)			150	80	60	60
CO(mg/km)	2720	220	2200	1000	1000	1000
THC (mg/km)			200	100	100	100
$HC+NO_x$ (mg/km)					68	68
Particulates (mg/km)					5*	4.5*
Particulates (PN) (#/km)						$6x10^{11}$**

* For gasoline vehicles with direct injection engine running under lean conditions (stratified combustion)
** After 2017

Appendix II – Global CO_2 Levels

Figure 1: Global levels of CO_2 the period 1700- up to now



Appendix III – Global Nitrous Oxide concentration

Figure 2: Global levels of Nitrous Oxide the period 1700- up to now

References

1. Reuters, Oct. 10th 2007
2. IARC 2013, Air pollution and cancer
3. European Environment Agency, 2013, Air Quality in Europe — 2013 Report