Substitution of Platinum for Palladium in the Automotive Sector – a Case of 'WHEN', Not 'IF'

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Abstract: In 2017, palladium became more expensive than platinum for only the second time ever. Given platinum's newfound price advantage over palladium, we examine the case for its use in catalytic converters for gasoline vehicles. Gasoline and gasoline hybrid electric vehicle sales are forecast to continue growing and this should increase demand for palladium in an already tight sector. We do not think it possible for palladium supply, both from mining and recycling, to increase sufficiently to meet the growing demand for palladium over the next decade or so. Basic economic theory suggests that this will lead to demand destruction in the automotive sector and that car manufacturers will have to use less palladium per vehicle. Using platinum in catalytic converters in place of palladium appears the most realistic way for car companies to meet emissions regulations while simultaneously reducing the use of palladium. Whilst there are barriers to the use of platinum in gasoline catalytic converters, we think these can be overcome and believe that at least 25% of gross palladium demand from the autocatalyst sector could readily be replaced by platinum. Although the process of substitution of platinum for palladium in gasoline autocatalysts will no doubt be challenging, we think it will begin to take place on a commercial basis during the early 2020s.

Key words: automotive, autocatalyst; catalytic converter; emissions; gasoline; palladium; platinum; platinum group metals; substitution; three-way catalytic converter; vehicle emissions
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汽车领域用铂替代钯
———不是“要不要”，而是“什么时候”的问题

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摘　要： 2017 年，钯有史以来第二次比铂还贵。由于铂相对于钯的新价格优势，我们研究了把它用在汽油车催化转化器上的可能性。汽油车和油电混合动力汽车的销量预计将持续增长，这应该会促使该领域的钯供应愈加紧张。我们认为钯供应的增长，包括原矿开采和回收在内，不太可能满足下一个十年里不断增长的钯需求。基本的经济理论表明这将导致汽车领域的需求受抑，汽车制造商将不得不减少每辆车的钯用量。在催化转化器中使用铂替代钯看起来对汽车公司是最切合实际的途径，在符合减排规定的同时减少钯用量。虽然在汽油催化转化器中使用铂还有一些壁垒，不过我们认为这些是可以克服的并且相信汽车催化剂行业的钯总需求中至少 25%可以轻而易举地被铂替代。

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虽然用铂替代汽油车催化剂中的钯的过程势必会困难重重，不过我们认为 2020 年初有望开始商用。
关键词：汽车；汽车催化剂；催化转化器；排放；汽油；钯；铂；铂族金属；替代；三元催化转化器；车辆排放

1 Application of Platinum and Palladium in Automotive Catalytic Converters

1.1 The development of the catalytic converter

The catalytic converter was developed in the mid twentieth century to clean up the exhaust of a motor car. The technology used a relatively simple concept of placing platinum on a base metal oxide with high surface area supported on a substrate – a ceramic block. Exhaust gases flow through this and are cleaned. The technology really came into use in the 1970s when the US Clean Air Act mandated its fitment onto new vehicles. Europe and other regions followed suit in the following years by adopting increasingly stringent emissions legislation (Johnson Matthey, 1999)[1] with catalytic converters now being fitted on almost every new vehicle produced around the world (International Platinum Group Metals Association, 2018)[2].

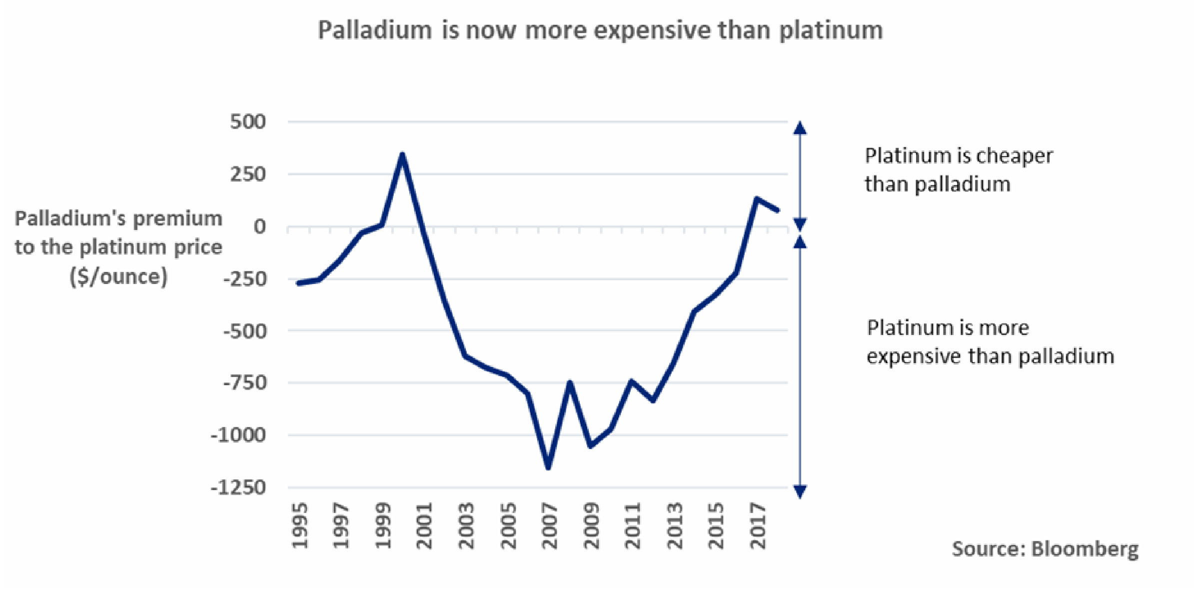
These first catalytic converters were oxidation, or two-way, catalysts, which eliminated unburnt hydrocarbons and carbon monoxide. Relatively quickly, these were replaced with so-called three-way catalysts which reacted NOx (oxides of nitrogen) with carbon monoxide and the unburnt hydrocarbons to produce carbon dioxide, nitrogen and water. These early catalysts were based on platinum as the active component as it was already a well-known catalyst for other reactions. The amount of precious metal in these early catalysts was very high as the technology had not been fully developed at that time.

Nowadays, a typical emission system for a gasoline-fuelled light vehicle contains a more modest 3–5 grams of platinum group metals (mainly palladium, with some rhodium) while a system for a diesel light vehicle contains 4-8 grams (mainly platinum, with smaller amounts of palladium and rhodium). The loading varies between different regions and is dependent on the emissions legislation in the country where the vehicle is sold, as well as the vehicle size and engine type. Higher platinum group metal loadings typically result in lower emissions and better environmental performance and therefore the general trend on a global level is for loadings to climb.

1.2 Palladium has not always been the dominant platinum group metal in catalytic converters for gasoline vehicles

As we mention above, the first catalytic converters were based on platinum technology which was active, well understood and robust. However, in the late 1990s, social and legislative pressure meant that fuel quality improved. Lead, which can poison catalysts had generally already been removed and, now, refiners started removing more Sulphur from the gasoline and diesel fuel they sold. Sulphur typically poisons palladium catalysts in particular and the removal of this element meant that scientists were able to research introducing palladium into these three-way (gasoline) catalysts. The lower price of palladium at the time meant that it was economically attractive to introduce this metal, alongside or in place of platinum and the first palladium-based gasoline catalytic converters were born. For technical reasons, platinum remained, and still remains, the dominant metal in diesel exhaust aftertreatment.

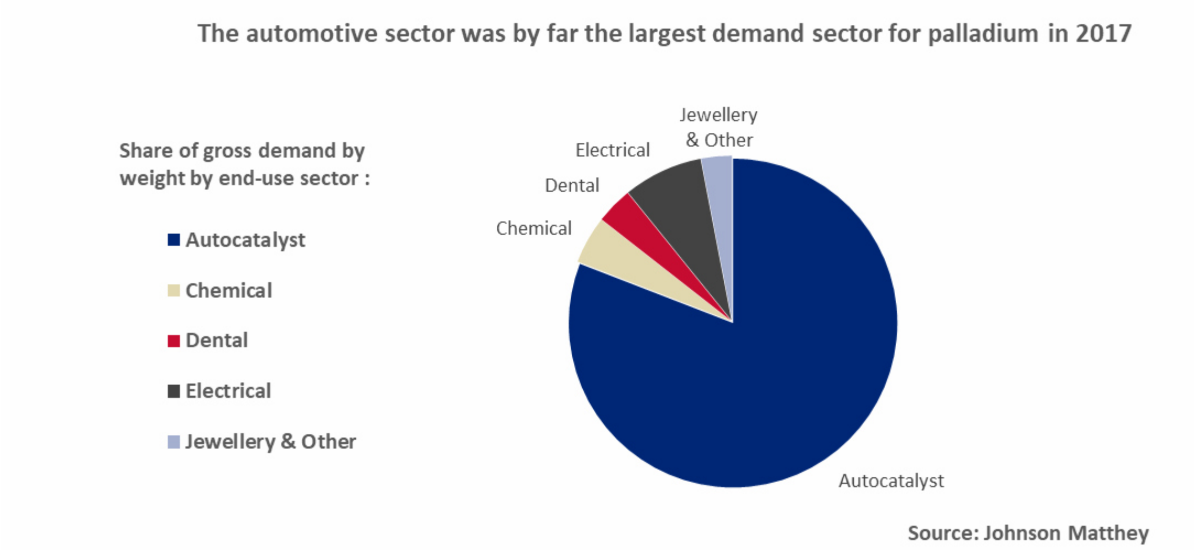
Continued work on the use of palladium in gasoline catalytic converters meant that its use continued to grow, largely at the expense of platinum, throughout the late 1990s. The combination of rapidly growing demand and disruption to supplies of the metal from Russia drove the palladium price to all-time highs in 2000 and 2001. The car companies were sensitive to this price strength and concerns over the metal’s availability at that time, and switched many of their catalysts from using palladium and rhodium to using platinum and rhodium over the next two years to control their costs. The palladium price fell back and car companies and catalyst designers then progressively reintroduced palladium in the following years to take economic advantage.



With palladium demand continuing to increase over recent years, driven by ever higher global vehicle sales and tighter emissions regulations for gasoline vehicles, and with finite mine availability, the palladium price has continued to strengthen relative to platinum. Last year, the palladium price rose above the price of platinum for only the second time ever. Will this provide the carmakers and catalyst producers with sufficient motivation to alter their catalyst formulations, reintroducing platinum in place of palladium as they did in the early 2000s?

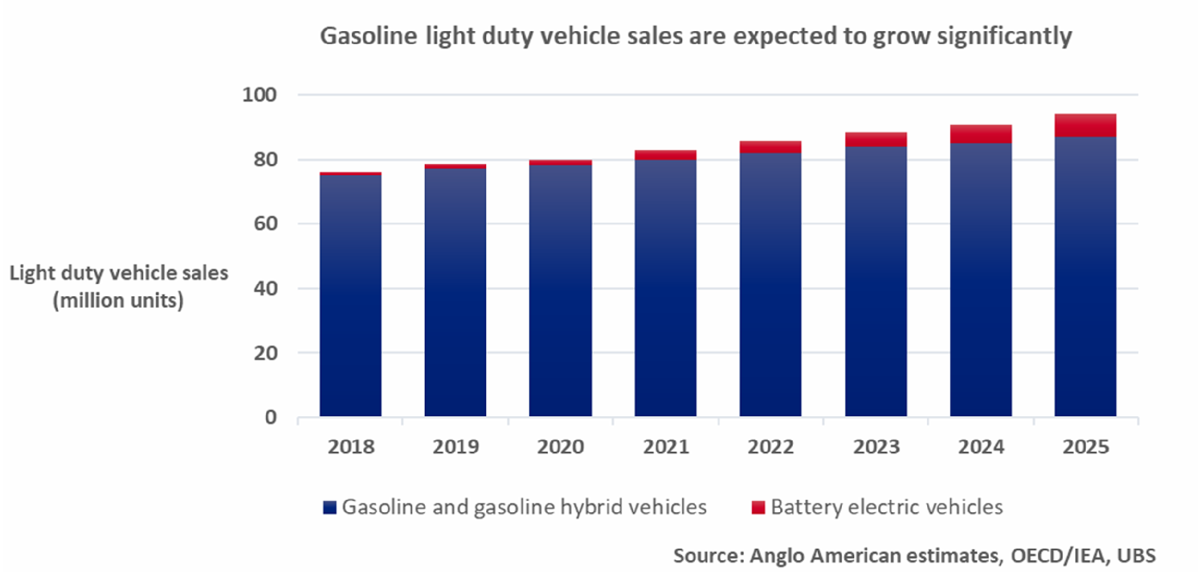
1.3 Palladium demand is forecast to continue growing

Palladium is used in a wide range of applications, from the dental sector to the manufacture of fertilizers but by far the most important application is its use in the automotive sector as the active component in a catalytic converter. This accounted for some 85% of total gross demand in 2017, or roughly 8.6 million ounces of palladium (Johnson Matthey, 2018)[4]. The vast majority of this metal is used to clean up the exhaust of gasoline vehicles.



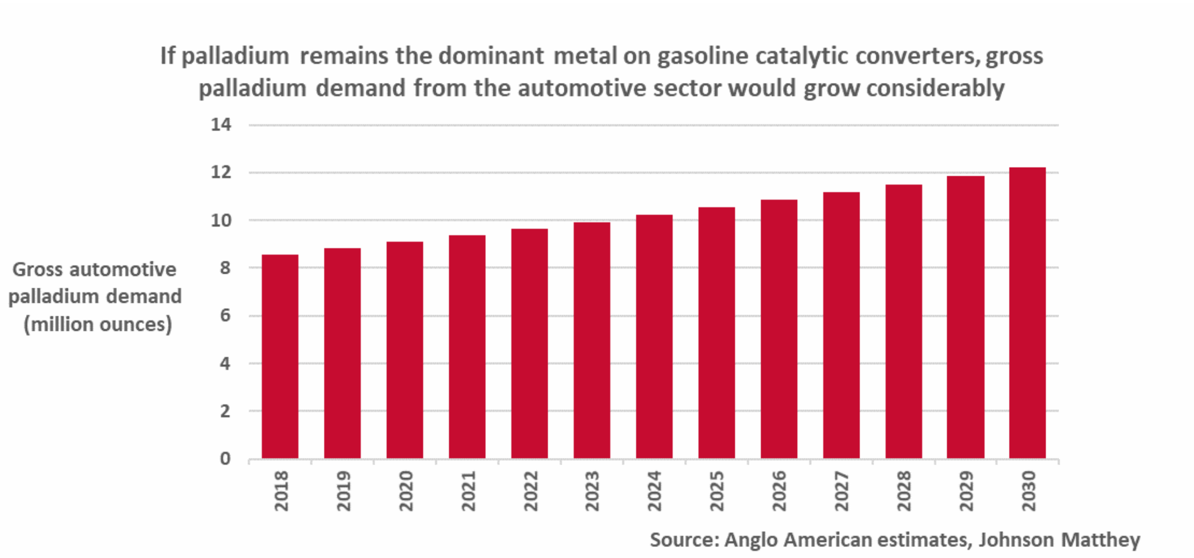
Demand from the automotive sector has grown rapidly and continues to grow. In China in particular, total vehicle sales have expanded strongly over the past few years, driven by growth in all sectors of the light vehicle market. Elsewhere in the world, there has been meaningful albeit less marked growth in total vehicle sales. Nevertheless, demand for palladium from the autocatalyst sector has increased in most countries. A growing consumer preference for larger vehicles such as SUVs and pick-up trucks is increasing demand for palladium as there is a positive correlation between vehicle size, or more particularly engine size, and catalytic converter size and hence platinum group metal demand. Furthermore, tighter emissions legislation requires higher loadings of platinum group metals on autocatalysts, as using higher volumes of platinum group metals leads to lower emissions from the vehicle.

Going forwards, gasoline and gasoline hybrid electric vehicle sales are forecast to grow significantly. We expect sales of pure gasoline vehicles to climb from 72 million units a year in 2018 to 74 million units in 2025. On top of this, we expect sales of electrified vehicles to climb from 5 million units a year in 2018 to 22 million units in 2025. For instance, the International Energy Agency's main scenarios forecast global electric vehicle deployment of between 40 and 70 million by 2025. Of these electrified vehicles, the vast majority will be gasoline hybrid vehicles. It is worth noting that these hybrid vehicles have the same platinum group metal loadings, and the same mix of metals, as standard (internal combustion engine) gasoline vehicles. Therefore, the growth potential for palladium demand from the automotive sector is substantial.



Even if the vehicle mix differs from our base case forecast, it is difficult to see a scenario in which there is not significant growth in gasoline light vehicle sales over at least the next decade. For instance, Bloomberg New Energy Finance forecasts sales of electrified vehicles (including hybrid vehicles) sales to climb to just 11% of total light vehicle sales per year by 2025 (Bloomberg New Energy Finance, 2018)[5]. The diesel engine's share of total internal combustion engine vehicles is declining and the number of gasoline vehicles produced annually seems likely to rise over this period at least.

Continued growth in vehicle sales and a move to ever-tighter emissions rules means that palladium demand - from the automotive sector and overall too - will continue to grow quite rapidly, if nothing else changes. If we assume that gasoline car sales grow at 3% per year between now and 2030 and that palladium remains the dominant metal on gasoline catalytic converters, this suggests that gross palladium demand from the automotive sector would climb from approximately 8.6 million ounces in 2018 to 12.2 million ounces in 2030. So, if nothing else changes, will palladium supply be able to keep pace?



2 Supply and Demand Analysis of Palladium

2.1 The outlook for palladium supply

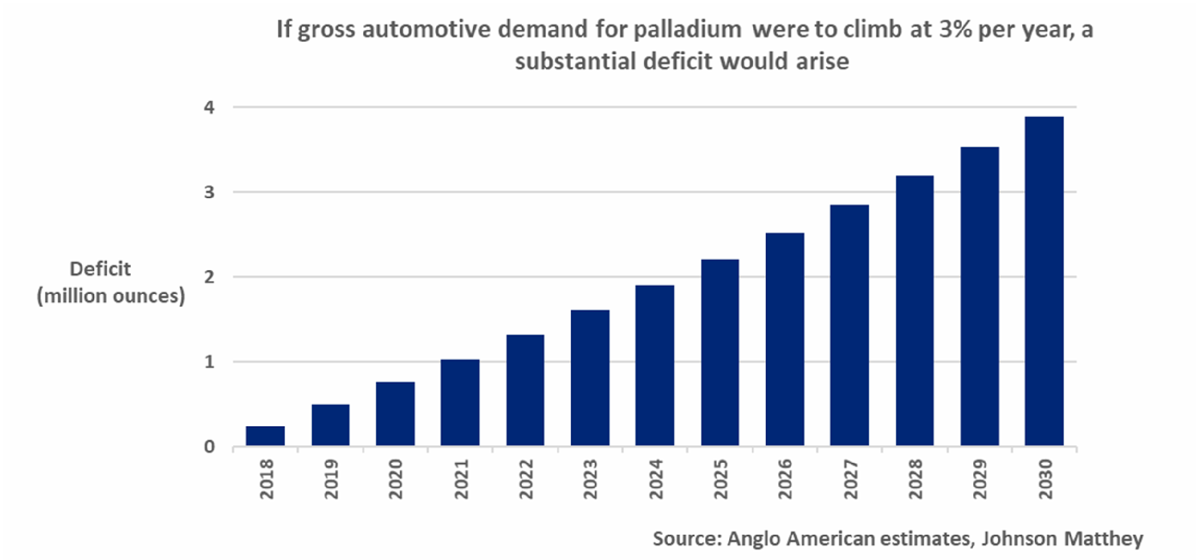
In our view, it is not possible for overall supply to expand at the same pace as unconstrained demand growth over the next decade. Palladium is mined primarily in Russia and in South Africa. Although there are some reported outline plans to increase output from Russia's Norilsk region, the timescale required to construct a new mine and the associated infrastructure means that Russian output is likely to remain relatively flat over the next decade or so.

In South Africa, palladium is mined as a by-product of platinum. Low prevailing platinum prices have had a negative impact on the profitability of the platinum mining sector in that country over recent years. This has resulted in limited capital expenditure by the mining industry and indeed in the rationalisation and closure of some mine production. Again, as in Russia, it takes a number of years to develop a new mine and we believe that it is much more likely that South African palladium production will decline over the next five to ten years than that it will increase. Overall, it is hard to see any expansion in global primary or mined production over this time period.

Of course, a reasonable volume of palladium is also recovered from scrapped vehicles, having been used in catalytic converters fitted fifteen or twenty years earlier in many cases. This accounted for some 35% of total palladium supply by volume in 2017 (Johnson Matthey, 2018)[4]. We confidently expect the weight of metal recovered to grow over the next decade and for recycling's importance as a source of metal to grow. Nonetheless, we do not see scope for meaningful growth in overall palladium supply – both of mined and recycled metal – to meet the scenario of unconstrained demand growth mentioned above, driven by the automotive sector.

2.2 What happens if demand outpaces supply?

It is possible for demand to exceed supply for a limited period of time. When this occurs, it typically results in rising prices, based on simple economics. In the same simple economic model, this either stimulates new production or destroys a portion of demand.



We expect palladium supply to remain largely unchanged from today's level over the next few years. Based on this assumption, we can model the supply-demand balance for palladium. If primary supply and non-automotive demand for palladium were to remain unchanged at 2018 levels, and automotive palladium demand were to climb at 3% per year (in line with the growth rate for gasoline/gasoline hybrid vehicles suggested earlier), this would mean that demand would significantly exceed supply. We do not believe this is feasible for more than a couple of years because there are only limited levels of above ground stocks following several years of deficits of palladium.

As we explained earlier, the reality of mine construction suggests that there is, at best, very limited scope for new mine production to be brought onstream over the next five years at least. This strongly suggests that palladium prices should rise and that price sensitivity will be seen in some demand segments as a result. Given the importance of the automotive sector to palladium demand, we expect much of this price sensitivity to occur in this end use segment.

2.3 What does demand destruction mean for palladium in the automotive sector?

If the automotive sector is to use less palladium, there are a limited number of possibilities. Logically, either the number of gasoline cars manufactured should fall or the weight of palladium contained in an average car must decline. As explained above, even with strong growth in the sale of battery electric vehicles, this is from a low baseline level and therefore we expect the number of internal combustion engine vehicles manufactured and sold to increase year-on-year until at least the mid-2020s.

There are, though, various routes to reducing the amount of palladium used per vehicle. We do not believe that it is politically feasible for legislators to relax emissions rules. Therefore, vehicle manufacturers will have to maintain environmental performance whilst trying to remove palladium. This can be done by, for instance, electrically heating catalysts so that they become more active at lower temperatures; or by lightweighting the catalyst by making it from different materials; or by retuning the engine; or even by lightweighting the car. All of these options require considerable engineering effort and additional cost and are therefore relatively unattractive.

Looking just at the catalyst, it may be possible to replace some of the palladium used with one or both of its sister metals, rhodium or platinum. Today, the rhodium price is more than twice that of palladium and this change does not make much economic sense despite rhodium's greater activity. In contrast, replacing palladium with the cheaper platinum holds out the potential promise of cutting palladium demand while making financial savings.

However, car companies are currently only in the initial stages of researching the idea of substituting a share of the palladium used in catalytic converters with platinum. Approximately 90% of palladium used in the automotive sector is for catalytic converters fitted to gasoline light duty vehicles, with very little used in other segments. The very small share of demand from light duty diesel vehicles means that potential cost savings from substitution within this segment would be very limited and substitution is therefore unlikely to occur.

But is there sufficient motivation for carmakers and catalyst producers to alter their gasoline catalyst formulations, reintroducing platinum in place of palladium as they did in the early 2000s? Is anything different this time?

3 Substitution of Platinum for Palladium

3.1 Why is it more difficult to replace palladium now than in the early 2000s?

The simple answer is that little research and development effort has been spent on platinum-based catalytic converters in recent years. From 2002 to 2016, palladium was cheaper than platinum and the use of palladium was economically sensible. More work was carried out on palladium as a result and palladium catalyst technology advanced more rapidly than platinum did, on gasoline vehicles at least. This makes palladium more effective and harder to replace than was the case at the start of the millennium.

It is a simple trap to fall into the assumption that simply because platinum is cheaper than palladium, it should be reintroduced into the gasoline catalytic converter. From a physical perspective, one atom of palladium weighs roughly 55% of the weight of a single atom of platinum, so it would be surprising if the same amount of each metal was required to make a catalyst work to a given level.

Added to this, a three-way catalyst is actually rather complex. It must react hydrocarbons and carbon monoxide with oxides of nitrogen (NOx). But, of course, there are a number of different hydrocarbons in a given car's exhaust stream and each will react slightly differently. As a result, palladium might be better suited to some vehicle models and engines. Nonetheless, research (Johnson Matthey, 2013)[3] shows that similar weights of each metal can be used to achieve roughly similar environmental benefits.

It is clear therefore that the current prices of both metals provide a potential opportunity for a vehicle manufacturer to make financial savings by substituting palladium with platinum in at least some catalyst formulations. However, is this the case in reality, and will carmakers make this move?

3.2 Barriers to substitution

A barrier to research and development work is the lack of engineering resources and budget to work on such a project at present. Many engineers working in the autocatalyst segment are currently turning their attentions to the development of hybrid engine technology or qualifying engines under real world testing rules instead.

Another factor is the capital cost of testing and qualifying new catalyst formulations. To recoup this money, vehicle manufacturers need to change a sufficient number of catalysts and be confident that prices will remain in their favour to justify this. Currently, we believe it is unlikely that a car company researching new catalysts would save enough money to cover the capital costs of the substitution work required. A typical gasoline light duty vehicle contains about 4g of palladium. As of 13th August, if 4g of palladium was swapped for an equal weight of platinum, it would represent a saving of approximately $12 per vehicle.

There are also some purely technical limitations to the use of platinum in place of palladium. For instance, palladium is particularly effective at low temperature performance. This is especially important for the share of hybrid vehicles which stop/start more frequently (as the engine swaps between battery power and the internal combustion engine) and to meet real world urban driving emissions requirements. Furthermore, palladium is also currently more effective than platinum at reducing NOx emissions at high vehicle speeds. In the near-term, these technical constraints may mean that a slightly higher platinum loading might be required to achieve the same performance as a given palladium loading. However, over the longer term we believe that platinum is, in principle, as effective a catalyst as palladium. In the longer term, we continue to think that substitution of palladium with platinum in a gasoline catalytic converter will be possible.

There are also some non-technical barriers to substitution, such as pricing considerations. For instance, car companies often purchase fixed volumes of platinum group metals up to five years in advance. The purchases are frequently made either on a forward basis or by purchasing the material and holding it as physical inventory. Hence, many car manufacturers are quite insulated from short term price fluctuations and tend to consider their procurement decisions over a longer time horizon. As a result, there may be a significant lag in response between price movements and changes in procurement strategy by automotive companies. Although the palladium price climbing above the platinum price in 2017 for the first time since 2001, platinum group metal loadings for vehicles being sold today were typically designed at a time when palladium was at a discount to platinum of $400 per ounce or greater. There may also be concerns by car companies that the price differential between platinum and palladium will not be maintained over a long enough timeframe to make substitution worthwhile. By historical standards, the palladium price has only been at a premium to the platinum price for a very short period of time.

Furthermore, a common hedging strategy adopted by many car companies is to purchase material on a forward basis rather than on the spot market (buying metal on a forward, rather than spot basis mitigates the risk of platinum group metal prices changing in the future). This is an important distinction as platinum is in contango and palladium in backwardation. This means that buying platinum for immediate delivery is cheaper than buying for delivery in one year's time and that the reverse is true for palladium. As of 13th August this year, palladium's premium over platinum was narrower on a one-year forward basis, at just $45 per ounce, than it was on the spot market, at $83 per ounce. By focusing on the forward price of platinum group metals, car companies may be more reluctant to substitute metals than if they were buying metals at today's spot prices.

There are also some strategic decisions to be made. Following on from the 'Dieselgate' scandal in Europe, where several automakers, including VW, were accused of manipulating emissions data and environmental performance, companies are being more risk averse. The companies are not willing to risk any more issues with vehicle emissions being higher than expected or not meeting required standards. The reputational risk to the company from not taking all possible action to meet emissions regulations is perceived as significant.

There is also perceived to be a first mover disadvantage. If a large car company were to replace a significant share of its palladium demand with platinum, that this could depress the palladium price. The company might then not benefit itself from having transitioned away from using palladium. However, by doing nothing, the company exposes itself to the risk of higher prices if all other market participants also adopt the same strategy of doing nothing.

We believe that at least some vehicle manufacturers are likely to replace palladium with platinum in some of their catalyst formations to mitigate their exposure to a higher palladium price. We see this as the most feasible way for automotive manufacturers to meet the growing demand for gasoline cars without reducing the overall amount of platinum group metal loading per vehicle, which is likely to be a more expensive process than switching palladium for platinum. Although thrifting of palladium on the catalyst is possible, there is both limited scope for reducing the volume of platinum group metals used and also limited resource availability for carrying out the work.

4 How Soon Is Substitution Likely to Occur?

As explained above, we expect that a share of palladium demand from the light duty gasoline sector will be replaced by platinum demand. However, the process of substitution will not be quick and is unlikely to occur on a commercial basis before the early 2020s. We think it will take at least 18 months between starting research and development work on a new catalyst and the catalyst becoming commercially available. This encompasses the time taken to develop and test the new formulation, before submitting it to the appropriate regulator for approval. However, for a larger number of catalysts, it would take a longer period of time and resource availability will be a constraint.

Therefore, in the longer term, we believe that substitution poses a significant upside opportunity for autocatalyst platinum demand. We believe that at least 25% of gross palladium demand from the autocatalyst sector could readily be replaced by platinum. This could boost platinum demand by about 2.5 million ounces per year by 2030 and reduce palladium demand by about the same amount. This is somewhere in the region of the volume of gross palladium demand from the autocatalyst sector that would need to be replaced by platinum to make palladium supply and demand balance, and we have little doubt that this will take place.

In conclusion, while the process of substitution of platinum for palladium in gasoline autocatalysts will no doubt be challenging, we think it will begin to take place on a commercial basis during the next five years. It is the most feasible way for car companies to meet emissions requirements from the gasoline vehicle sector, and ultimately, the most cost effective solution for vehicle producers if the palladium price continues to increase. The extent to which the price differential between the two metals grows will be the main influence on when and to what extent substitution occurs as this will determine the profitability of the switch for car manufacturers.

【中译稿】

1　铂钯在汽车催化转化器中的应用

1.1　催化转化器的发展历程

催化转化器是在二十世纪中叶发明的，用来净化汽车的尾气。这项技术采用了一个相对比较简单的概念，把铂化合在具有高比表面积的贱金属氧化物上，再一起涂敷并烧结在一种多孔的陶瓷载体上。汽车尾气通过这个装置得到净化。这项技术到 20 世纪 70 年代才真正投入使用，当时美国的《清洁空气法案》规定新车必须加装催化转化器。在接下来几年，欧洲和其他地区也效仿美国的做法，通过了越来越严格的排放法规 (庄信万丰，1999)[1]，现在全世界生产的每辆新车几乎都加装了催化转化器 (国际铂族金属协会，2018)[2]。

这些第一代催化转化器是氧化型或二元催化剂，能够净化未充分燃烧的碳氢化合物和一氧化碳。但是很快就被所谓的三元催化剂取而代之，三元催化剂能促使氮氧化物、一氧化碳和未充分燃烧的碳氢化合物进行一定的氧化还原反应，生成二氧化碳、氮气和水。这些早期的催化剂以铂为活性组分，因为它已经是人们所熟知的其他反应的催化剂。这些早期催化剂中的贵金属含量非常高，因为当时先进的催化技术还没有完全被开发出来。

如今，一辆轻型汽油车上的典型排气系统约含 3~5g 的铂族金属 (主要是钯，也含少量的铑)，而轻型柴油车的系统约含 4~8g (主要是铂，也含少量的钯和铑)。铂族金属的涂敷量因地区而异，主要取决于各国汽车尾气的排放法规，以及车辆大小和发动机类型。铂族金属的涂敷量越高，通常尾气排放就越少，环保性能就越好，因此全球的总体趋势是涂敷量在逐步提高。

1.2　钯并非一直是汽油车催化转化器中采用的主要铂族金属

如上所述，第一代催化转化器基于活跃、熟悉、成熟的铂技术。但是，到了 20 世纪 90 年代末，社会和立法压力迫使燃料质量提高。使催化剂有毒的铅已经普遍被取缔，现在炼油厂开始去除他们所销售的汽油和柴油燃料中更多的硫。硫尤其会使含钯催化剂中毒，降低硫含量意味着科学家们可以尝试把钯应用到这些汽油车三元催化剂上。当时比较低的钯价格意味着引入这种金属在经济上具有吸引力，与铂并用或者替代铂，于是诞生了第一代基于钯的汽油车催化转化器。由于技术上的原因，铂过

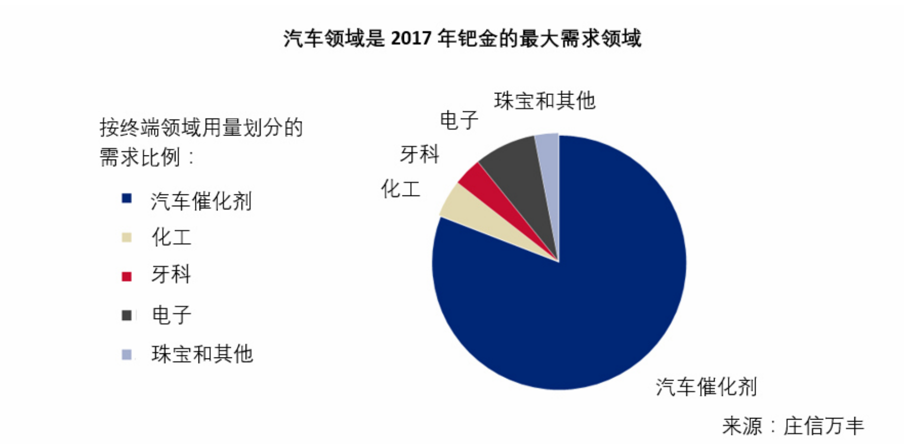
去一直是并且现在依然是柴油尾气后处理装置中的主要贵金属。

随着对研究钯应用在汽油催化剂上的不断深入，20 世纪 90 年代末钯的用量持续增长，大幅度地替代了铂。钯需求的快速增长加上来自俄罗斯的钯的供应中断使得钯价格在 2000 年和 2001 年创下新高。当时汽车公司对钯价格走强很敏感并且担心买不到，于是为了控制成本他们在接下来两年里把许多催化剂中的钯铑技术改成铂铑技术。随着钯价格回落，汽车公司和催化剂设计师才在接下来几年逐步重新启用钯，以利用其成本优势。

近几年不断增长的全球汽车销量，和针对汽油车日趋严格的排放限制，推动了钯需求的持续增长，再加上有限的矿山产量，使得钯的价格相对于铂不断走强。去年，钯的价格史上第二次超过铂价。这会给汽车制造商和催化剂生产商带来足够强烈的动机去改变他们的催化剂配方，跟 2000 年初那样用铂替代钯吗?

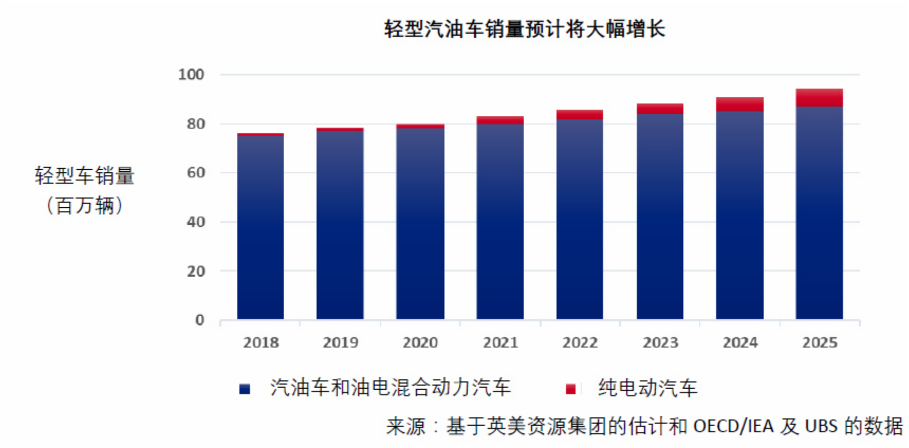
1.3 钯需求预计将继续增长

钯应用广泛，从牙科到化肥制造，不过目前为止最重要的应用是在汽车领域用作催化转化器中的活性组分。这占 2017 年总需求的 85%左右，或者将近 860 万盎司钯 (庄信万丰，2018)[4]。绝大部分钯被用作汽油车的尾气处理。



汽车领域的需求增长迅猛，并且将继续增长。尤其在中国，受轻型车领域的全面增长推动，过去几年汽车总销量激增。在世界其他地方，汽车总销量的增长虽然没有那么显著不过也表现不俗。不管怎样，在大部分国家汽车催化剂行业对钯的需求都有所增长。消费者越来越偏好更大型的车辆，如 SUV 和皮卡，刺激了对钯的需求，因为车辆大小，或者更具体点来说是发动机大小，与催化转化器的大小，以及铂族金属的需求量呈正相关性。而且，更严格的尾气排放法规要求提高汽车催化剂中的铂族金属涂敷量，因为铂族金属的用量增加将减少汽车尾气排放。

未来，汽油车和油电混合动力汽车的销量预计将大幅增长。我们预测纯汽油车的销量到 2025 年将从 2018 年的 7200 万辆增长到 7400 万辆。除此之外，我们预测电动车的销量到 2025 年将从 2018 年的 500 万辆增长到 2200 万辆。比如，国际能源署的主要情景预测显示全球电动车保有量到 2025 年将在 4000 万辆到 7000 万辆之间。在这些电动车中，绝大部分将是油电混合动力汽车。值得一提的是这些混合动力车具有与标准(内燃机)汽油车一样的铂族金属涂敷量和贵金属配比，因此，在汽车领域钯需求的增长潜力是巨大的。



来源：基于英美资源集团的估计和 OECD/IEA 及 UBS 的数据

即使车型构成与我们的基本情景预测不同，也很难看出会有一种情形至少下一个十年里轻型汽油车的销量不会大幅增长。比如，据彭博新能源财经预测，电动车(含混合动力车)的销量到 2025 年将每年增加到只占轻型车辆总销量的 11% (彭博新能源财经，2018)[5]。柴油发动机占内燃机车辆总数的比重在下降，汽油车的年产量看起来至少在这段期间有可能增加。

假设其他条件不变的前提下，汽车销量持续增长以及日趋严格的尾气排放法规意味着来自汽车领域以及总体的钯需求将持续快速增长。如果我们假设从现在到 2030 年之间，汽油车销量以每年 3%的速度增长，并且钯依然是汽油催化转化器中的主要金属，这表示汽车领域的钯总需求将从 2018 年的 860 万盎司左右增长到 2030 年的 1220 万盎司。那么，如果其他条件保持不变，钯供给能否够跟上呢?

来源：英美资源集团的估计和庄信万丰的数据

2　钯的供需分析

2.1　钯供给展望

我们认为，下一个十年钯总供应量不可能会以无限的需求增长一样的速度扩张。钯的开采主要在俄罗斯和南非。虽然据多家报道俄罗斯的诺里尔斯克地区有一些增产计划，但是建设新矿以及配套基础设施所需的时间意味着俄罗斯的产量在未来十年左右可能会基本持平。

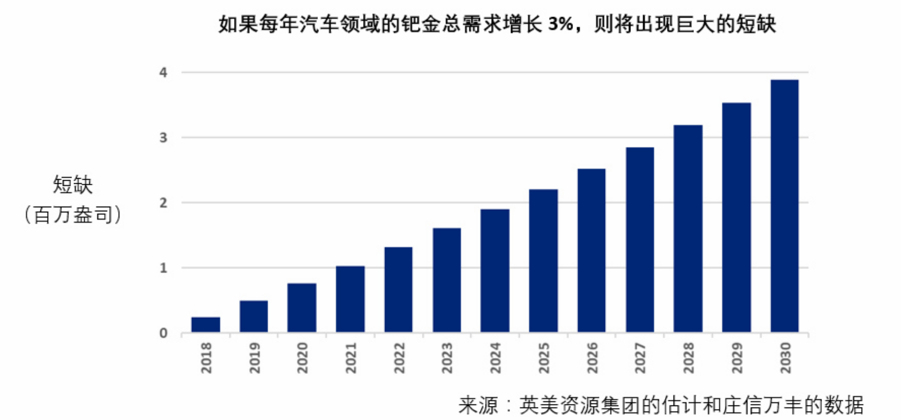
在南非，钯是作为铂的副产品开采的。铂的价格普遍偏低对近几年南非铂开采业的盈利能力产生了负面影响。由此导致采矿业的资本支出有限，实际上有些矿被整顿和关停。而且，跟俄罗斯一样，开发一座新矿需要好几年时间，我们认为更大的概率是南非钯产量在未来五到十年将不增反降。总的来说，很难看出同期全球原矿开采或精炼产能有任何扩张的潜在可能性。

当然了，有相当一部分的钯可以从报废车辆中回收，这些车辆在许多情况下已经被使用了十五年或二十多年。这占了 2017 年钯总供应数量的 35% 左右 (庄信万丰，2018)[4]。我们很有信心地预测回收金属的数量在下一个十年将增长，并且报废催化剂的回收作为金属来源的重要性也将提高。不过，我们预计钯总供应–包括开采和回收的金属–不太可能大幅增长以满足上文提到的由汽车领域推动钯的需求无限增长的情形。

2.2 如果供不应求会怎样?

在一段时间内可能出现供不应求的情况。当这种情况发生时，根据简单的经济学原理，通常会导致价格上涨。在同样简单的经济模型中，这或者刺激新的生产，或者丧失一部分需求。

我们预计未来几年钯供应将基本上维持在当前的水平。基于这一假设，我们可以建立钯的供需平衡模型。如果原矿供应和非汽车领域的钯需求量都保持在 2018 年的水平不变，以及每年汽车领域钯的需求增长为 3% (与前面提到的汽油和油电混合动力汽车的增速一致)，那么需求将大大超过供应。我们不认为这种情况只会持续几年，因为经过几年的钯短缺后，地面上的库存已经十分有限。



正如我们前面解释过，即使在最好的情况下矿山建设的实际情况也意味着至少未来五年投产的新矿山是非常有限的。这充分证明钯价格应该会上涨，因此在部分细分领域会出现价格敏感性。鉴于汽车领域对钯需求的重要性，我们预计这种价格敏感性将主要出现在这个终端领域。

2.3 汽车领域需求受抑对钯意味着什么?

如果汽车领域减少钯用量，只有有限的几种可能性。从逻辑上，制造的汽油车数量应该会减少，或者平均每辆车所含的钯用量必须减少。如上所述，即使电动车的销量大幅增长，但由于基数较小，我们预计内燃机车辆的产销数量至少到 2025 左右将保持同比增长。

不过，仍然有多种技术路径减少每辆车的钯用量。但是，我们认为让立法者放松排放法规在政治上是行不通的。因此，汽车制造商将不得不在符合环保要求的同时，尽量减少钯的用量。譬如，这可以通过通电加热催化剂来实现，这样使催化剂可以获得更好的低温活性；或者采用不同原料使催化剂实现轻量化；或者重新标定发动机；或者甚至使汽车实现轻量化。所有这些可选方案都需要大量的工程投入和额外的成本，因此相对来说不具有吸引力。

如果只看催化剂，或许可能使用钯的一种或两种姐妹金属即铑或铂，来替代部分的钯用量。目前，铑的价格是钯的两倍多，尽管铑的活性更强，但是这个变化在经济上是不可取的。相反，用更便宜的铂替代钯可以在节省采购成本的同时，又规避了钯供应短缺的风险。

然而，目前汽车公司对于用铂替代催化剂中部分钯的研究还处于初期阶段。汽车领域消耗的 90% 左右的钯是用在轻型汽油车的催化转化器上，而在其他汽车细分领域的用量非常少。由于轻型柴油车

对钯的需求量非常小，所以就意味着在这个细分领域替代钯能获得的潜在成本节约将非常有限，因此这种替代不太可能发生。

但是，汽车制造商和催化剂生产商这次是否已有足够强烈的动机去改变他们的汽油催化剂配方，跟 2000 年初那样用铂替代钯吗？那么这次的情况会有何不同呢?

3　铂替代钯

3.1　为什么现在要替代钯比 2000 年初还困难?

一个简单的答案是近几年对基于铂的催化转化器的研发投入少之又少。从 2002 年到 2016 年，钯一直比铂便宜，所以使用钯更经济。对钯所做的研发工作越多，钯催化剂技术进步相比铂的就越快，至少在汽油车上是如此。这使得选用钯就更有效，比 21 世纪初更难被替代。

只是因为铂比钯便宜，就应该把它重新用在汽油催化转化器上，这样的假设纯粹是一个陷阱。从物理的角度看，一个钯原子的重量大约只有一个铂原子的 55%，所以如果让催化剂达到一定性能水平所需的两种金属的数量是相同的就太奇怪了。

除此之外，三元催化剂其实更复杂。它必须促使碳氢化合物、一氧化碳和氮氧化物反应进行一定的氧化还原反应。当然，每辆汽车的尾气中含有不同燃烧程度的碳氢化合物，每种的碳氢化合物的反应会略有不同。因此，钯可能更适合某些车型和发动机。不过，研究结果 (庄信万丰，2013)[3]显示，类似质量的这两种金属可以达到近似的环保效果。

因此，显然这两种金属当前的价格水平为汽车制造商创造了一个机会，至少可以在部分催化剂配方中用铂替代钯，来达到节约成本的目的。可是，现实是这样的吗，汽车制造商会这么做吗？

3.2　替代壁垒

研发方面的一个壁垒是目前缺乏工程资源和预算来从事这种项目。目前从事汽车催化剂领域的许多工程师都把注意力放在开发混合动力发动机技术或者让按真实的国际测试标准来重新标定发动机的工作上。

另一个因素是新的催化剂配方测试和验证的资金成本。为了回收这部分成本，汽车制造商将需要足够的催化剂批次产量，和保持金属价格会一直有利于自己的信心来支撑这一替代项目决定。目前，我们认为研究新催化剂的汽车公司不太可能节省足够多的钱，以支付这种替代工作所需的资金成本。由于一辆典型的轻型汽油车大约含 4 g 钯，截至 8 月 13 日，如果 4 g 钯被同等数量的铂替代，每辆车可节省 12 美元左右。

用铂替代钯还存在一些纯技术上的局限性。比如，钯的低温性能特别好。这对发动/熄火更频繁的混合动力汽车尤其重要(因为发动机动力会在电池和内燃机之间进行切换)，可以满足现实世界中的城市工况排放要求。另外，在高速工况下钯在降低氮氧化物排放性能上也比铂有效。短期来看，这些技术上的局限意味着在给定的钯涂敷量的情况下，要达到同样的性能需要的铂用量可能会略高一些。不过，长期来看，我们认为铂在原则上是跟钯一样有效的催化剂。长远来看，我们依然认为用铂替代汽油催化转化器中的钯是可能的。

在替代上还有一些非技术壁垒，比如定价策略因素。例如，汽车公司经常会提前采购 1~5 年的铂族金属用量，他们频繁以现货远期定价方式采购贵金属，或者直接采购现货作为库存。因此，许多汽车制造商不在乎短期价格波动，倾向于从更长远的角度来考虑他们的采购决策。所以，在价格波动与汽车公司的采购策略变化之间可能存在严重的反应滞后。尽管在 2017 年内钯的价格自 2001 年以来第一次超过铂价，但是目前在售车辆上的铂族金属涂层配方，通常还是在钯价比铂价低 400 美元/盎司或以上的时候设计的。汽车公司还可能会担心铂和钯的价差未必能够持久，从而使得这种替代是值得考虑的。历史上，只有很短一段时间内出现钯价格高于铂的价格。

而且，许多汽车公司采取的一个常用价格风险对冲策略是采用远期定价而不是现货点价的方式(采用现货远期交易，而不是用现货点价交易，来降低铂族金属价格未来的波动风险)。这是一个重要的区分指标，因为铂是期货溢价，而钯是期货贴水或现货溢价。这表示采购立即交货的铂比采购一年后交货的铂更加便宜，而钯的情况正好相反。截至今年 8 月 13 日，钯相对铂的一年期远期价格的溢价值已降至 45 美元/盎司，而实时现货点价之间的溢价值为 83 美元/盎司。因此，相比有些采用现货点价购买铂族金属的汽车公司，那些专注于远期价格采购的汽车公司就可能更不情愿去考虑替代金属了。

还有一些战略性决策需要做。鉴于欧洲的“柴油门”丑闻中，包括大众在内的多家汽车制造商被指控操纵排放数据和影响排放性能，因此现在的汽车公

司更加担心承担风险。他们不愿意再冒车辆排放高于预期或者不达标的风险。一旦没有采取一切可能的措施来达到排放规定，就会给公司带来巨大的信誉风险。

而且还存在先发劣势的认知。假如一家大型汽车公司用铂替代它的很大一部分钯需求，这可能会打压钯的价格。那么这家公司替代钯的做法并没有给自己带来收益。然而，如果和所有其他汽车公司一样也采取同样不作为策略的话，这家公司也一起将面临价格上涨的风险。

我们相信至少一部分汽车制造商可能会在他们的某些催化剂配方中用铂替代钯，来减少钯价格上涨的风险。我们认为这是汽车制造商在不减少每辆车的铂族金属总涂敷量的前提下满足日益增长的汽油车需求最可行的途径，因为减少总涂敷量的方法可能比替代方法的代价更大。虽然在催化剂中降低钯用量是可能的，但是减少铂族金属用量的幅度是有限的，而且可选的具有催化效果的活性组分的资源也是有限的。

4 多久可能发生替代?

如上所述，我们预计轻型汽油车的一部分钯需求将被铂替代。不过，替代的过程不会很快，而且在 2020 年初以前不大可能开始批量化生产。我们认为从开始新催化剂的研发工作到新催化剂投入商用至少需要 18 个月的时间。这包括提交给有关部门审批之前研制和测试新配方所需的时间。然而，对于更多催化剂的替代工作需要更长的时间，而且可利用资源将是一个制约因素。

因此，从长远来看，我们认为这种替代将为汽车催化剂领域的铂需求制造一个巨大的上行机会。我们相信汽车催化剂行业中至少 25%的钯需求量可以随时被铂替代。在 2030 年底前可能每年使铂的需求量增加约 250 万盎司，而钯的需求量会减少同等的数量。这差不多是铂替代钯之后钯会达到供需平衡的预计范围，而且我们毫不怀疑这种替代将在汽车催化剂行业发生。

总而言之，虽然汽油车催化剂中铂替代钯的过程势必会困难重重，但是我们认为在接下来五年内会开始批量化生产。这是汽车公司满足汽油车行业排放要求的最可行途径。如果钯价格持续上涨，最终对汽车制造商来说这也将是最具成本效益的解决方案。这两种金属的价差扩大程度将是影响替代何时发生、替代范围大小的主要因素，因为这将决定汽车制造商替代之后的盈利能力。

References:

[1] MARTYN TWIGG. Twenty Five Years of Autocatalysts (汽车催化剂的二十五年) [R/OL]. Johnson Matthey: 1999. https://www.technology.matthey.com/article/43/4/168-171.

[2] International Platinum Group Metals Association (国际铂族金属协会). Autocatalyst Factsheet (汽车催化剂资料) [EB/OL]. 2018. https://ipa-news.com/assets/sustainability/Autocatalyst%20Fact%20Sheet_LR.pdf?PHPSESSID=2320345af28d94c3f24934dd0a49f0bb.

[3] COOPER J., BEECHAM J. A Study of Platinum Group Metals in Three-Way Autocatalysts (汽车三元催化剂领域消费的铂族金属研究)[J]. Platinum Metals Review, 2013, 57(4): 281-288. https://www.technology.matthey.com/article/57/4/281-288.

[4] Johnson Matthey May 2018 report (庄信万丰 2018 年 5 月报告) [EB/OL]. http://www.platinum.matthey.com/documents/new-item/pgm%20market%20reports/pgm_market_report_may_2018.pdf.

[5] Bloomberg New Energy Finance 2018 report (彭博新能源财经 2018 年报告) [R/OL]. https://bnef.turtl.co/story/evo2018?teaser=true.