Palladium Fundamentals

Dominates Catalytic Converters – Confirming Positive Outlook

September 2012

Demand for palladium is intensifying worldwide as a result of 1) price-driven substitution of palladium for platinum in gasoline and diesel catalytic converter applications, 2) expanding automotive production and 3) ever more stringent governmental emission regulations. These primary demand drivers are buttressed by compelling, but often misunderstood, palladium fundamentals which include:

1. **Simple, Price-Driven Substitution to Palladium** – From their first introduction in 1974 to 1989 catalytic converters were exclusively a platinum-based technology. Driven by the cost of platinum, catalytic converter technology using palladium was developed by Ford for first use in its 1989 model cars. Palladium historically had traded, with notable exceptions, between 20% and 25% of the price of platinum. In late 2010, palladium moved up to trade between 40% and 45% where it is today and where it continues to have a price advantage over platinum.

2. **Platinum to Palladium Interchangeability** – A gasoline catalytic converter using today's technology takes ***just*** one gram palladium to replace one gram platinum. This "one-for-one" technology first emerged in 2002 after the price of palladium had surged to peak at $1,094/oz. in early 2001, far exceeding the $640/oz. platinum price at the time. Prior to this palladium price bubble, a gasoline catalytic converter had typically required about two grams of palladium to replace one gram of platinum, using technology developed by Ford and others. The "two-for-one" palladium technology had been developed to provide a more cost-effective alternative to the "platinum-only" technology employed in catalytic converters from 1974 to 1989. As the price of palladium traditionally traded around 20% and 25% of the price of platinum, the economics for switching to palladium were compelling despite the initial "two-for-one" substitution ratio.

3. **2002 Reverse Substitution Misconception** – In 2001, when the price of palladium surged to $1,094/oz. while platinum languished at $640/oz., and when the then-existing technology required two ounces palladium to replace one ounce platinum in catalytic converters, a notable change in worldwide PGM consumption occurred in which 1) the total volume of platinum used in catalytic converters swelled while 2) the total volume of palladium used fell. Market analysts at the time concluded the auto companies had simply returned to using platinum for catalytic converters in response to the higher price of palladium. The truth of the matter is peculiar and more complex. In actuality, the introduction of diesel catalytic converter technology in Europe in 2002 and 2003, made solely with platinum, drove increased platinum usage for several years. At the same time, a cost-driven shift from "two-for-one" technology to newer "one-for-one" technology underway in gasoline catalytic converters drove palladium usage down. In reality, it does not appear that there was any appreciable shift back to platinum in gasoline catalytic converters during this period. And the "one-for-one" technological shift solidified the catalytic converter market for palladium for gasoline emissions, and likely triggered the research notion of using palladium for diesel emissions.

4. **Automotive Production: Surging** – Consensus estimates currently show global light-duty automotive production will reach a record 81 million vehicles worldwide in 2012, top 95 million in 2015 and grow at a cumulative annual growth rate (CAGR) of 4% through 2025, reaching 140 million vehicles per year. Looking specifically at growth in emerging markets, China's automotive production in 2012 is at 18.5 million vehicles, and will expand at a CAGR of 5% over the next decade to 30 million vehicles.

5. **Automotive Powertrain: Gasoline Dominates** – Today's global powertrain mix is comprised of 77% gasoline, 19% diesel, 3% hybrid, 1% other (battery and natural gas).
    - Gasoline engines (77%) are expected to continue to dominate the market through at least 2025.
    - Diesel engines (19%) emerged as the technology of choice in Europe where the price of diesel fuel is artificially held below the price of gasoline.
    - Hybrids (3%) are expected to gain further market share and include a conventional gasoline engine with a catalytic converter.
    - Battery technology (among the 1%) will be used for some applications, but based on current battery technology, hybrids with gasoline engines remain the only viable battery alternative.
    - Natural gas (among the 1%) powered vehicles will fit some applications well, but the need for frequent refueling or the need for extreme compression of the fuel inherently will limit their market potential to limited-range bus and truck fleets. (The heavy catalysis required to control unburned methane emissions from natural gas is a palladium technology.)

6. **Palladium in Diesel Applications** – Originally, diesel catalytic converters used exclusively platinum, although palladium has made significant inroads during the past several years. A "one-for-one" substitution ratio has evolved for those parts of the diesel catalytic converter where palladium can be used. In the laboratory, research has demonstrated the ability to accommodate up to a 50% total palladium loading in light diesel applications, although the actual palladium loading in diesel catalytic converters being used today is around 30%. There are reasons platinum is more efficient as a catalyst in diesel emissions, including the following:
    - Diesel emissions are lower temperature than gasoline emissions. However, platinum's primary advantage in diesel applications relates more to the fact that the diesel exhaust stream is a highly oxidizing environment in which palladium is readily oxidized to a less catalytically active palladium oxide, whereas platinum resists oxidation and remains active in its metallic form.
    - Platinum is more resistant to sulfur poisoning than palladium. In a gasoline exhaust stream, the high temperatures mean that the catalyst automatically de-sulfates. In the lower temperature diesel environment, de-sulfation occurs less readily.

    So, platinum's advantage in diesel applications stems from a complex mix of factors, but the bottom line is that platinum is more effective in the lower temperature, highly oxidizing diesel exhaust environment.

    Incidentally, a small amount of palladium in a platinum catalyst adds thermal stability to the platinum. This characteristic drove the initial introduction of palladium into diesel catalytic converters when carbon soot filters first were introduced, because in flaring off the accumulated carbon soot the high temperature exothermic reaction would tend to sinter the platinum-only catalyst filter.

7. **Ever-Tightening Emission Regulations** – The next steps forward in light-duty vehicle emission standards will require increased PGM loadings in Europe (From Euro 5 to Euro 6 in 2014) and in China (From Euro 4 to Euro 5 in 2015). Car manufacturers make specification decisions based principally on a desire to achieve "cost-effective" compliance. Consequently, their strategy in recent years has generally been to maximize the use of lower-cost palladium in the PGM catalysis mix.

    In the primarily light-diesel vehicle European market, the cost difference in metal prices led companies to reduce their platinum consumption in light-duty diesel converters and introduce a greater proportion of palladium. As Euro 6 standards are implemented, the light-duty diesel market is projected to move to a platinum to palladium ratio of about 2:1 in traditional diesel emission systems.

8. **Technological Thrifting: Lowers PGM Usage** – As catalytic converter technology advances, there is continual fine tuning of the technology to steadily thrift down the PGMs required to meet a given emission standard. For example, during the last few years the average PGM content in a U.S. built light-duty gasoline vehicle was 4½ grams; today the average is about 4 grams, an 11% reduction. This "thrifting down" happens gradually, continues with every new catalytic converter platform and was a driving factor around 2002 when technological developments allowed the palladium loadings required in catalytic converters to be cut in half to a "one-for-one" substitution with platinum. The earlier technology was likely driven by a cautious approach to the first-time use of palladium, which at the time was an untried material in catalytic converters. With time and experience, technological confidence grew to where the amount of palladium used could be reduced to equal that of platinum.

9. **PGM Content and Cost per Vehicle** – The PGM content in a catalytic converter varies by car size, engine type and relevant emission standards. The average content of a catalytic converter in the three big car producing areas of the world is roughly as follows: 4 grams in North America; 6 grams in Europe, where over 55% of the cars produced are diesel; and 2 grams in China, where regulatory requirements are not yet as tight and cars on average are smaller. At present, the 4 gram average in North America is made up of about 3½ grams palladium (substantially up recently from 3 grams), no platinum (down recently from ½ gram) and ½ gram rhodium; the 6 gram average in Europe is split 50/50 between platinum and palladium with ½ gram of rhodium somehow in the mix (a modest recent change from 3 grams platinum, 2½ grams palladium and ½ gram rhodium); and the 2 gram average in China is mostly palladium. On average worldwide, a useful rule of thumb is that for every one million cars produced, about 100,000 ounces of PGMs are required. As to PGM cost per car in the United States, today with 3½ grams of palladium amounting to approximately 11.3% of an ounce, the palladium in a U.S. catalytic converter is worth about $70. Adding ½ gram of rhodium at $18, the total PGM cost in a catalytic converter is about $88 at current prices.

10. **Indisputable Technological Success –** Catalytic converter effectiveness exceeds 90% in eliminating harmful emissions – air quality being fundamentally restored.

11. **A Palladium Based Technology** – The price-driven technological shift from "two-for-one" to a "one-for-one" substitution of palladium for platinum cemented the market going forward for palladium in gasoline converters. Gasoline catalytic converter technology worldwide is now almost exclusively palladium based, augmented with small amounts of platinum and rhodium where necessary.

12. **Emerging New Technology Considerations** – New catalytic converter technology is driven first by reliability, second by durability, and third by economics – in that order. Platinum is usually given preference in new technology developments because of some superior natural catalytic advantages. Palladium follows as its dependability and durability are demonstrated by research and application over time. Thus, while platinum applications usually have the initial technological advantage, palladium has won its dominant long-term market position due to continuing research, driven by basic cost economics. Outside of platinum, palladium and rhodium, no other primary catalyst materials have been demonstrated to meet the three criteria noted above for catalytic converter applications.

13. **Rate of Change to New Technology** – Car companies focus early in their design process on the specific technology to be applied in future product lines and, once established, they rarely change the technology imbedded in existing product lines. In practice, emerging technological changes usually take a long time to implement despite their potential cost savings. As a matter of history, this is why there was little reverse substitution back to platinum resulting from the palladium price bubble. This general principle certainly applies to catalytic converter technology.

14. **Available Palladium Supply** – In 2011, about 67% of the palladium supplied to the market was used for catalytic converters – with the supply including about 775,000 ounces from the Russian state palladium inventory. If sales from the Russian inventory are excluded, then approximately 73% of the worldwide primary palladium supply went to catalytic converters. Failing to recognize the effect of the Russian inventory sales in the palladium supply is misleading, particularly in view of the current depleted state of this formerly vast Russian stockpile. Palladium is facing a substantial supply deficit going forward that will likely be met by a combination of price-driven demand destruction and shifting back to platinum or using rhodium.

15. **Palladium to Platinum Price Ratio: Currently at + 40%** – PGM market pundits now debate whether the existing palladium to platinum price ratio of +40% is imbedded in today's market dynamics, or whether it will increase in the future. As previously observed, palladium increased from about 25% of the price of platinum pre-2010 to range between 40% and 45% post-2010. Analysts have the ratio moving to 60% in the future and some ask about pricing parity with platinum. The "Palladium/Platinum" price ratio is much more valuable, and more visceral, than oft quoted metal price ratios – Gold/Silver (XAU/XAG) and Gold/Platinum (XAU/XPT) have little relevance except to measure relative gains or losses of investors against portfolios. The Palladium/Platinum ratio, on the other hand, is directly related to the competition for identical markets between these two metals – in catalysis, in catalytic converters and even in jewelry.