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The potential effects of powertrain developments in the auto sector on PGM demand

B. CLARKE, J.C. WATTS, and O. ATILAN
SFA (Oxford) Ltd, UK

The automobile is undergoing a period of rapid evolution as manufacturers strive to meet stringent targets to reduce global greenhouse gas emissions and average fleet fuel usage. This conference paper explores numerous drivetrain and powertrain efficiency solutions that affect or promote the sustainability of the internal combustion engine and therefore PGM loadings in automotive catalysts. This paper includes a review of increasing competition from hybrid electric, fully electric, and fuel cell powertrain offerings now and in the future.

Greenhouse gas emissions and efficiency targets transforming the automobile

In the EU, road transport is the second largest greenhouse gas (GHG) emitter after power generation, at around one-fifth of the region's CO_2 output (passenger cars represent 12%). Globally, road transport accounts for around 16% of all GHG emissions. To avoid the disastrous consequences of exceeding the carbon budget, planet Earth must move to low-carbon societies and technologies. Cars will be a significant part of this, with lowering CO_2 emissions increasingly important in vehicle design.

Legislation was passed in April 2009 for Europe to reduce the fleet average CO_2 emissions of new passenger cars to 120 g/km by 2015, with a three-year phase-in period starting at 65% in 2012. This represents a 19% reduction in CO_2 output and a 25% improvement in fuel economy on current levels. The last 10 g/km of the CO_2 target is gained from additional measures over and above new car technology such as lower rolling resistance tyres, efficiency improvements to auxiliary devices such as air-conditioning, gear shift indicators, as well as the increased use of biofuels. Europe has a long-term target of 95 g/km specified for 2020.

In May 2009, President Obama proposed new standards to regulate fuel economy and GHG emissions affecting vehicle models from 2012 to 2016. The US administration has ambitious plans to raise the average fuel efficiency of cars and light trucks to 35.5 mpg from 25 mpg by 2016. These standards equate to an estimated 160 g/km CO_2 output limit from around 200 g/km CO_2 today. Similarly, Japan has a target of 138 g/km CO_2 by 2015, although the government has adopted an integrated approach whereby 50% of the reduction will come from infrastructure (improved traffic flow). GHG legislation for transport has been rolled out to many other regions including China.

Financial penalties will apply for non-compliance, forcing manufacturers to react with more efficient technologies. In Europe, the US and Japan charges are expected to start at around €5 for each g/km CO_2 over the limit multiplied by the volume of vehicles produced. By 2020, penalties in Europe are slated at €95 for each g/km produced, but this is subject to a review in 2013.

A typical product cycle for a vehicle is around six to seven years, while the development phase of a new model is around five years from concept to production. In recent years there has been an accelerated focus on more fuel-efficient drivetrain technologies. Efficiency improvements to engines, transmissions and aerodynamics, and weight and friction reductions, as well as the electrification of the automobile, all have a part to play.

The rise of diesel power and platinum demand in Europe: stabilizing

CO_2 taxation in Europe has, since the early 2000s, boosted the share of more efficient diesel passenger cars from around 30% in 2000 to a peak of 53% in 2007. Diesel engines became an attractive option when the EU rolled out CO_2 road taxation because they are traditionally 20–30% more fuel efficient than similar sized conventional gasoline engines and so produce less CO_2. So for high mileage drivers, diesel remains the preferred option as the better fuel economics outweigh the higher purchase cost. The rising share of diesel passenger cars in Europe had a large part to play, along with more stringent emissions legislation and increasing engine sizes, in doubling platinum demand to 2.3 moz from 2000 to 2007, whereas vehicle production remained largely stable at around 16.2–16.6 million units a year. Diesel catalyst systems contain higher PGM loadings and a bias towards platinum compared to gasoline engines which feature more palladium.

However, significant advances in gasoline combustion technology as well as hybridization have started to level the efficiency playing field with diesel. Furthermore, manufacturers of small city cars are starting to favour gasoline over diesel owing to cost, short driving distances—reducing the efficiency advantage of diesel—and the addition of forced induction increasing the power per litre of displacement in newer gasoline engines. So it is unlikely that diesel will continue to grow its share of the passenger car market but rather hover around 50% with some hybridization in future. The major growth opportunity for diesel (and therefore platinum demand) is the off-road sector, starting in the US in 2011 and Europe in 2014.

This paper highlights some of the key automotive technologies being introduced in the next ten years and associated potential impacts on PGM demand.

New automotive powertrain technologies: most require PGMs

Hybridization rather than full electrification is the most likely path for vehicle technology in the medium term, keeping gasoline and diesel internal combustion engines, along with PGM-containing catalysts, in use.

Hybrid vehicles offer fuel economy benefits over similar-sized gasoline or diesel engines by combining the internal combustion engine with an electric motor. Hybrids generally have smaller engines than their conventional gasoline or diesel equivalents, so could be expected to require less PGM for the catalyst. However, the stop-start nature of the engine's operation means that running temperatures can fluctuate, thus requiring higher PGM loadings to achieve emissions standards. Furthermore, in the US, where the majority of hybrid vehicles are sold today, these vehicles are typically manufactured to meet more stringent Californian SULEV emissions standards and therefore also require higher PGM loadings.

In the coming years, assuming that vehicles are manufactured to meet the same regional emissions standards, the current view is that a switch to hybrid vehicles from conventional gasoline or diesel vehicles will have little impact on overall uptake of PGMs and will, in fact, boost requirements for palladium.

The hybrid market can be viewed as a spectrum with increasing contribution from the electric motor:

- **ICE**—conventional internal combustion engine, gasoline and diesel (uses PGMs).
- **MicroHEV**—micro hybrid electric vehicle: stop-start system including oversized starter motor (uses PGMs). See MHEV below for stop-start system description. Fuel savings are <15%.
- **MHEV**—mild hybrid electric vehicle: stop-start, regenerative braking, additional battery (uses PGMs). To improve fuel economy, the stop-start system automatically shuts off the engine when the vehicle comes to a standstill and restarts it as the accelerator is depressed. Regenerative braking converts mechanical energy lost in braking to recharge batteries and power the automatic starter. Typically, such a system has a large capacity battery of 42 v rather than the conventional 12 v. Fuel savings are typically <25%.
- **FHEV**—standard/full hybrid electric vehicle: dual-drive, ICE and electric (uses PGMs). Standard hybrids add an electric motor and rechargeable batteries to the ICE (gasoline or diesel) with an on-board computer controlling the switching between the ICE and electric drive. A hybrid car, depending on the model and driving environment, can be up to 60% more efficient than a conventional gasoline vehicle.
- **PHEV**—plug-in hybrid electric vehicle: small gasoline engine drives wheels when battery is depleted, i.e. still essentially ICE technology (uses PGMs). PHEVs differ from conventional hybrids in that they can be recharged from grid electricity and larger battery packs. Plug-in hybrids can travel in an all-electric mode for most short journeys up to around 40 miles. A plug-in hybrid car can achieve about twice the fuel economy of a conventional hybrid.
- **EREV**—extended range electric vehicle: small gasoline engine charges battery but does not provide propulsion (uses less PGMs). An EREV is a plug-in hybrid with a small ICE or other secondary source connected to a generator to resupply the batteries and allow continued driving when the batteries are drained. The EREV could be a threat to PGM loadings in the longer term when the costs of manufacture come down. Engineers can get away with a much smaller engine and therefore reduced PGM loadings. This is about as close to an electric vehicle as it is possible to get, while still retaining the practicality of a gasoline engine – i.e. it has a decent range of up to 400 miles (with the gasoline engine charging the battery), without the need to plug it in for an extended period. This avoids the 'range anxiety' that can be associated with battery electric vehicle driving.
- **EV**—fully electric vehicle (no PGMs). EVs are powered exclusively by an electric motor instead of an ICE. The electric car uses energy stored in its rechargeable batteries, which are recharged from an electricity outlet.

Automotive technology outlook: limited infiltration of electric cars

Our central case uses *Oxford Economics* and J.D. Power's forecasts for vehicle production, and our ground-up research provides estimates on the infiltration of new technologies. Non-electric combustion engines are projected to still account for 88% of global vehicle production by 2020, while mild and full hybrids are likely to increase vehicle share from 6% in 2015 to 11% by 2020.

Of course there are regional variations, with greater infiltration in western countries. In the US, for example, up to 20% of vehicles sold are projected to be hybrids, 5% plug-in hybrids and 2% EVs.

There are very wide-ranging views on the rate of growth and ultimate size of the electric vehicle fleet, as expected for such an immature market with immense technological problems still to solve:

- There are no standards or sharing of data on Li-ion vehicle batteries.
- Much viability and safety testing remains to be done.
- The ageing process of lithium-ion (Li-ion) batteries in real-life driving situations is still poorly understood. Manufacturers are not yet sufficiently confident to provide warranties since the scale of their potential liability is unclear.
- Li-ion is extremely temperature-sensitive, requiring expensive thermal management systems.
- Costs, while coming down, are still prohibitive and need to fall by around 70%.
- Manufacturers will make a loss on electric vehicles for many years to come.
- Combustion and hybrid technology will continue to dominate for the next 20 years.
- Most consumers are not yet switched on; electric vehicles will remain a niche market with limited uptake expected, mainly as city cars.
- Electric vehicles, as with combustion engine technology historically, will follow a path of evolution rather than revolution.

Nonetheless, the well-to-wheel efficiency argument for EV is quite compeling. According to Siemens AG, average power stations emit around 600g of CO_2/kWh, which is equivelent to 90 g/km CO_2 output for an EV. Most vehicles powered by combustion engine technology achieve on average 140 to 200 g/km now, although effiency models are available that easily achieve 120 g/km. Advancing hybridization and efficiency improvements by manufacturers are continuing to improve CO_2 emissions, so 90 g/km should be mass market in the not to distant future.

The most confident manufacturers predict that electric vehicles could take 10% or more of the global market in the next ten years, while those who doubt that electric vehicles will ever be more than a tiny niche product see the global market as no more than a few hundred thousand vehicles.

Market share forecasts for the main types of hybrid to electric cars in 2015 are summarized in the points below for the US and Europe, the main regions of deployment:

- Micro hybrid electric vehicle: 7% US, 32% EU
- Mild hybrid electric vehicle: 6% US, 8% EU
- Full hybrid electric vehicle: 6% US, 7% EU
- Plug-in hybrid electric vehicle: <2% US and EU
- Fully electric vehicle: <1% US and EU

Figure 1 highlights just how limited the infiltration of electric vehicles is projected to be in the next six years, at <500 000 units out of a population of vehicles produced that could rise from around 65 million units in 2010 to over 90 million units.

Fuel cell electric vehicles (FCEVs): the obvious long-term choice

FCEVs combine hydrogen gas and oxygen in a chemical reaction using layers of plastic film coated with platinum between metal plates (FC stack) to power an electric motor with water as the only waste product. Platinum loadings per vehicle are currently around 30 grams, so mass production would tighten the market considerably. However, high manufacturing costs are forcing companies to trim platinum loadings with each new generation of FCEV.

Almost all car manufacturers have a fuel cell programme. Offerings at the most advanced stages come from Mercedes-Benz, Honda, Toyota, General Motors and Hyundai.

Mercedes-Benz announced in late 2009 that it has started production of the B-Class F-CELL, building 200 models for lease to customers in Europe and the US from spring 2010. Honda plans mass production for the FCX Clarity in 2018, which was launched in 2008. All current offerings are cost prohibitive to mass commercialization, so are leased out. Vehicle costs are estimated at >$100 000 per unit, which is nonetheless down from >$1 000 000 a few years ago.

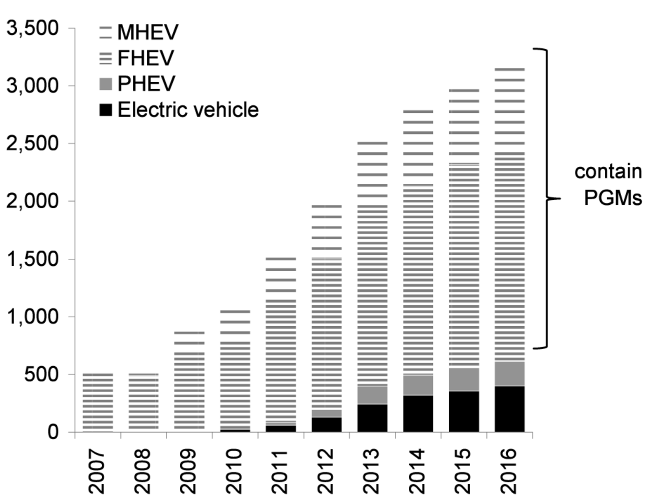

Figure 1. New technologies: global production, '000 units. Source: J.D. Power and Associates

Toyota appears to be advancing to a realistic goal to commercialize its FCEV with a sales target price of $50 000 per unit by 2015. In a recent announcement the company said it had cut the costs of manufacturing its FCEV by 90% in the last five years and hopes to shave off a further 50% in the next few years. Toyota has lowered platinum loadings to 10 grams, while reductions from electrolyte membrane in the cell and carbon fibre have also been achieved. Mass production will reduce costs further.

FCEVs offer greater distances and faster refuelling than battery equivalents. Hydrogen fuel is currently almost double the cost of gasoline, but FCEVs can achieve at least 30% extra range over gasoline equivalents.

Fuel cells (containing PGMs) offer the most compelling long-term solution to reducing emissions and replacing the combustion engine, but competition is fierce from technology advances in gasoline, diesel, hybrid and electric vehicles. Several hurdles remain including unit costs, full government support, mass commercialisation and, most significantly, refuelling infrastructure. California, Japan, Germany and South Korea support a fuel cell vision but there is still a long way to go, so production is likely to reach only a few thousand vehicles in the next five years. If sustainable and abundant energy becomes available from renewable or nuclear sources, hydrogen then becomes more realistic as a store of energy.

Combustion engine (and PGM demand): future secure

Automotive technology has come a long way since the internal combustion engine was invented in 1906, particularly in the last 20 years as the rising costs of fuel and emissions legislation have motivated significant efficiency improvements for the gasoline engine and associated drivetrain, not to mention the advance of sophisticated exhaust aftertreatment catalyst systems.

The primary advantage of the gasoline engine over other technologies has always been the lower cost to the consumer, particularly over diesel and hybrid offerings. However, as diesel and hybrid vehicles have promoted significant improvements in efficiency, i.e. more miles per gallon and therefore reduced CO_2 emissions per mile travelled, so diesel has gained acceptance in Europe and hybrids continue to make a case as an alternative for consumers in most western auto markets.

Nonetheless, gasoline technology has not remained static. Major efficiency improvements have been made to gasoline technologies by borrowing technology from more sophisticated (and expensive) diesel and hybrid vehicles. New efficiency features such as high pressure direct injection (from diesel), the rebirth and improved reliability of forced induction—turbos and superchargers—(diesel), stop-start using a regenerative starter motor (hybrid), regenerative braking (hybrid), and electronics and accessories powered by an electric motor (hybrid) all contribute towards ensuring the gasoline engine (and diesel increasingly using hybrid technology) remains competitive going forward.

A holistic approach to improving the efficiency of the automobile enhances the gasoline combustion engine's chances of survival well into the future. Engineers are examining the entire automotive package to make efficiency improvements wherever possible. Of the energy lost from combustion to drive, 62.4% is from the engine bay, 5.6% from the drivetrain, 2.2% from accessories, 17.2% from idling, 2.6% from aerodynamic drag, 4.2% from rolling resistance and 5.8% from braking (source: www.fueleconomy.gov).

The following technological advancements are significantly improving combustion engine efficiencies and reducing CO_2 output, while ensuring longevity for PGMs in automotive catalyst applications:

Direct injection (DI, also known as stratified injection)

DI allows increased performance and lower fuel consumption by improving the efficiency of fuel intake and the use of higher compression ratios. Efficiency improvements are estimated at 12–15%. These engines are still developing rapidly but the loadings of PGMs on catalyst for DI engines are similar to those for conventional engines. Direct injection systems require additional NOx aftertreatment over conventional systems. Emissions legislation has been tightened for gasoline engines to take DI into account from Euro 3 onwards.

Mechanical friction reduction

Ever since the late 1990s engine development has resulted in a >30% reduction in mechanical friction; this translates to a >10% boost in efficiency.

Continously variable transmission (CVT) and automated manual transmission (AMT)

A conventional system uses a fixed number of metal gears but CVT allows an infinite number of engine/wheel speed ratios. A rise in fuel efficiency of >5% is estimated. AMT drives similarly to a manual transmission, but is lighter, hydraulic or electric, and does not require a clutch pedal. AMT is >5% more energy efficient than manual systems.

Variable valve timing (VVT)

Valves control the flow of air and fuel into the cylinders and exhaust gases out of them. The timing of valves opening and closing, as well as the distance travelled by the valves, affects efficiencies. Traditional valves use fixed timings and lift settings, whereas with VVT the valves are usually opened sooner at higher speed than at lower speed. This can optimise the flow of air into the cylinder, boosting power and economy. Efficiency improvements are estimated at around 5%. Fiat, in 2009, launched its MultiAir system that further enhances the efficiency of VVT by reducing mechanical efficiency losses while increasing low down torque and power output. Fiat has suggested that its MultiAir system could allow the removal of platinum-containing diesel particulate filters—a major feature of Euro 5 legislation. This is most likely to occur on small cars, such as the Fiat 500.

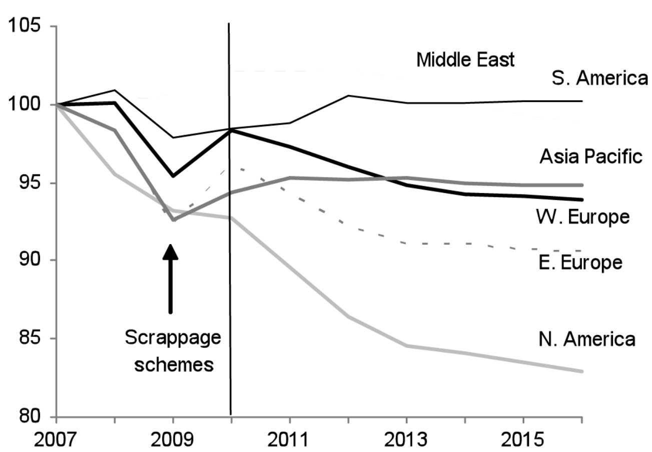

Figure 2. Average engine size: passenger cars, indexed at 100=2007. Source: J.D. Power & Associates

Forced induction: turbo and supercharging

Forced induction uses fans to force compressed air into an engine's cylinders thereby allowing extra power to be gleaned from each explosion. The boost to power allows manufacturers to use smaller engines without sacrificing performance. Potential efficiency improvements are estimated at 7–8%.

Increasingly sophisticated engine control units (ECUs)

An ECU ensures the optimal quantity of fuel, ignition timing and other parameters to keep the engine running smoothly and efficiently. ECUs regulate the time in an engine cycle at which valves open in VVT (or actuation) and control the waste gate on turbochargers.

Engine downsizing

An accumulation of the above technological improvements results in more power per cubic centimetre of displacement. Therefore, combustion engines can and have been contracting in size without meaningful losses in performance, leading to lower emissions.

Downsized engines (such as turbocharged and supercharged), particularly when combined with direct injection, enable similar or improved performance at reduced engine size and hence the potential for greater fuel economy. Scrappage schemes, boosting sales of small cars with gasoline engines, temporarily distorted average engine sizes in Europe and Asia in 2009, while North America has apparently embraced downsizing with an expected drop in average engine sizes from 2.9 to 2.6 litres by 2016. A reduction in US engine sizes, if emissions legislation were to stay at today's stringency, could lead to an annual demand reduction of 25 koz of palladium and 9 koz of platinum. However, growth in China and other emerging economies more than offsets this drop. Downsized engines should mean slightly lower loadings, but less stable engine operating temperatures in hybrids, as well as forced induction and direct injection, require slightly higher loadings.

Low rolling resistance tyres and inflation diagnostics

Low rolling resistance tyres (using silica) minimize heat loss as tyres roll down a road, while still maintaining wet grip performance (which has been the challenge in the past). Around 4% of fuel used in a car is wasted by rolling resistance.

Longer gear ratios and higher number of gears (7-speed manuals, 8-speed autos)

The improvements made to low down torque in both gasoline and diesel engines through the use of forced induction and VVT have allowed manufacturers to adjust gear ratios and introduce taller gears to ensure lower RPMs at cruising speeds. This leads to significantly more miles per gallon, especially on highways.

Electric power steering

Conventional hydraulic systems are being replaced with lightweight electric motors which use energy only when the steering wheel is actively turned. On straight roads the motor is inactive, thereby saving energy and fuel.

Stop-start and regenerative braking (see hybrid section above for full description)

Bosch claims the system cuts fuel consumption by up to 5% in the European Driving Cycle, which equates to an 8% reduction in CO_2 emissions.

Efficient on-board electronics

Minor efficiency gains in the electrical elements also contribute and all manufacturers have made improvements to the speakers, rear window defrosters and lighting.

Active aerodynamics to reduce drag

A vehicle's aerodynamic efficiency has a major impact on fuel efficiency. BMW's 'Efficient Dynamics' range of vehicles showcase active air flaps that regulate air flow to the engine. If the ECU determines that engine cooling is not needed, the flaps close to reduce drag and improve efficiency. Active air flow control on large vehicles could lift efficiencies by >8%.

Evolutions in variable valve timing

Mechanical camshafts will eventually be replaced by hydraulic or electric valve opening to optimize every operating condition. Fiat's MultiAir system is the first production step here.

Lightweighting

Safety and comfort have increased the weight and size of vehicles considerably since the late 1980s. However, that trend could start to reverse as fuel efficiency and CO_2 emissions take centre stage. New models could increasingly rely on smaller platforms, lightweight body panels and lower capacity forced induction engines.

Thermoelectric generators (TEGs)

These generators convert heat to power, in the vehicle's case from an internal combustion engine's exhaust to potentially power electrical auxiliaries such as climate control. BMW estimates a 5% improvement in efficiency, and TEGs could be on the road by 2014. Honda and VW are also working on TEGs.

Solar panels

Prototypes using solar panels on the roofs have achieved 200W of output, enough to improve fuel efficiency by ~1%. It is early days for the technology, so this figure could rise.

Automotive PGM demand outlook: positive

Platinum was under siege in 2009 from scrappage schemes promoting small palladium-rich gasoline cars, palladium substitution in diesel and the collapse of the commercial sector. Looking ahead, automotive demand is projected to rebound, reaching 4.75 moz by 2014 from 3 moz in 2010. Emissions legislation will accelerate demand in passenger cars in Europe as production recovers with higher loadings per vehicle (+375 koz in the next two years—Euro 5, 2009–11).

A strong automotive recovery is already underway in Japan and the US and sales continue to climb in China, although this largely favours palladium in gasoline passenger cars. Palladium automotive demand growth will therefore outperform that of platinum by making a full recovery one year earlier in 2011, rather than 2012.

However, platinum consumption will also increase in the heavy duty sector (+60 koz) and there is new demand from off-road vehicles in the US from 2011, while further upside exists in off-road legislation in Europe in 2014. In the long term, the roll-out of Euro 6 to China and the rest of the world for HDVs requiring diesel particulate filters could further spur platinum demand. This will offset the impact from smaller engine capacities and palladium substitution.

In the longer-term the impact of auto electrification on the combustion engine, and hence PGM autocatalyst demand, is likely to be slight as electric vehicles are forecast to comprise only 1% of the global fleet by 2020.

Conclusion

Evolving drivetrain technology poses little threat to the combustion engine and hence to PGMs. Reducing CO_2 emissions is increasingly important in vehicle design and, as yet, there is no clear winner to take the place of the gasoline- or diesel-powered combustion engine. Downsized engines (such as turbocharged and supercharged), particularly when combined with direct injection, enable similar or improved performance at reduced engine size and hence the potential for greater fuel economy. Although the catalyst in a downsized engine may be smaller, PGM loadings tend to higher.

Electrification of vehicle drivetrains is best viewed as a spectrum, with fuel-saving hybrids becoming increasingly mainstream while full electric vehicles remain niche. Hybrids generally have smaller engines than their conventional gasoline or diesel equivalents, but the lower average engine operating temperature can require slightly higher PGM loadings in their autocatalysts.

Huge cost and practical hurdles (range) remain so infiltration of full electric vehicles (EVs) in the mass market will take tens of years, leaving PGM autocatalysts securely in most vehicles. In the foreseeable future, batteries will remain one of the most expensive components in electric cars. SFA forecasts limited infiltration of EVs of 0.4% and 1% by 2015 and 2020 respectively, while the US government estimates plug-ins will comprise 4% of the global fleet by 2030. Fuel cell vehicles (containing PGMs) require full government support and infrastructure roll-out in order to gain traction. Vehicle manufacturing costs continue to fall and in five to ten years fuel cell economics will be compelling.

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Beresford Clarke

Head of Research, SFA Oxford Ltd

Beresford Clarke, a Senior Analyst for SFA, works on all aspects of precious and base metal supply and demand, and specifically the provision of data and technical writing related to present and future PGM supply, including the evaluation and analysis of PGM mines and future potential projects worldwide. Beresford has a background as a precious metals commodity analyst, with an MSc in Mineral Economics from the Royal School of Mines in London and an honours degree in Geology. Beresford has also spent a number of years working in exploration in West Africa.