PGM MARKET ANALYSIS

Platinum demand from fuel cell cars – dream or reality?

For decades the platinum industry has been expecting fuel cell electric vehicles (FCEVs) to become a significant source of demand for PGMs, yet it has been continually disappointed. However, recent developments, including companies in the supply chain sharing investment risk and expertise, a growing hydrogen fuelling infrastructure, and technical advances which improve fuel cell stack costs and durability, indicate that **the outlook could now be different**.

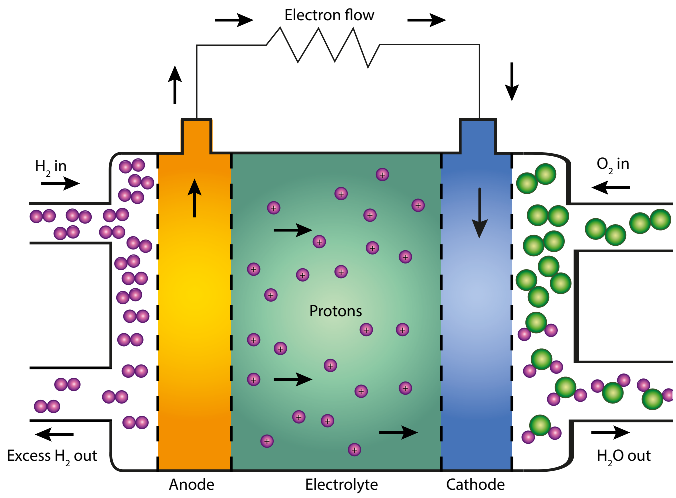
In the long term, demand for PGMs will only become really significant if FCEVs win a sizeable share of light-duty vehicle production. At present, production of fuel cell-powered electric cars is only ~3,000 per year, but is predicted to grow by several orders of magnitude over the next two decades. This means that PGM demand upside, both in vehicles *and* in electrolysers to produce hydrogen as fuel, exists – but is several years away from becoming significant.

A constant in the recent history of fuel cells is the need for PGMs as catalysts in several of the most rapidly-growing technologies. Here we explore the potential market for one of the most exciting uses for fuel cells – in passenger vehicles – and its implications for demand for the PGMs, mainly **platinum** and, to a smaller extent, **ruthenium and iridium**.

Fuel cell technologies have been through numerous phases of research, development and, increasingly, commercialisation. Several very different fuel cell technologies exist, each of which has advantages and disadvantages related to the materials required and each is suited to different end-uses and scales of operation.

The type of fuel cell of principal interest to the PGM markets is the proton-exchange membrane fuel cell (PEMFC). It functions at relatively low temperatures (40-90°C) and reacts quickly to demand for power, making it particularly suitable for both transport and stationary applications (with efficiencies of 60% and 35% respectively). PEMFCs contain platinum and platinum-ruthenium catalysts in their electrodes, and they operate on pure hydrogen and ambient oxygen.

PEMFC Flow Diagram



Source: SFA (Oxford)

Platinum and ruthenium are used in fuel cells for the same fundamental reasons as they are in the automotive and chemical industries – they are excellent catalysts that make chemical reactions take place at higher speed, at lower temperature and at higher rates of conversion than would otherwise be the case, and they are robust under a fuel cell's harsh operating conditions.

The general principle of a PEM fuel cell: at the anode catalyst, hydrogen H2 splits into a positive part, the proton

(H+) and a negative part, the electron (e-). The membrane of a fuel cell is designed to be permeable for protons, but not for electrons. The electrons thus flow through the external circuit – generating electricity as we know and use it – and return to the cathode side of the fuel cell. At the cathode, oxygen gas (from air) reacts with electrons and protons to form water, which is the only emission from the process. This basic unit (Membrane Electrode Assembly = MEA) is highly scalable to increase the power of a fuel cell; many separate MEAs can be combined to form a fuel cell stack.

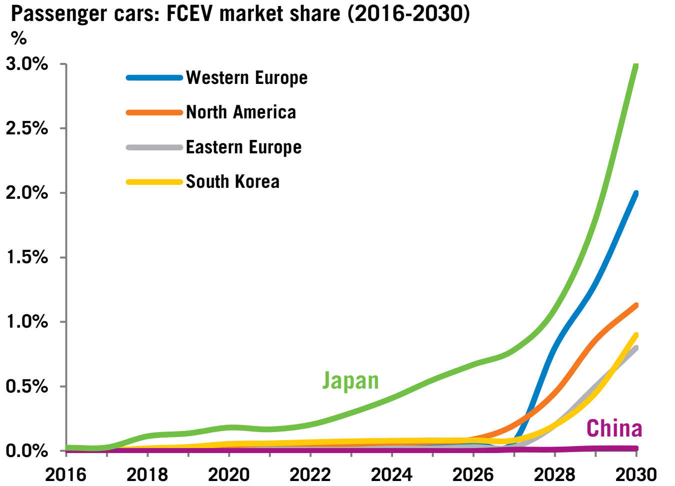
An electric vehicle powered by a fuel cell is, just like a battery-powered car, pollution-free at the point of use (tank-to-wheel basis). If hydrogen is obtained, not from burning coal or gas, but from renewable sources, fuel cell vehicles can become fully zero-emission on a well-to-wheel basis. Hydrogen can be produced through electrolysis – using electricity to split water into hydrogen and oxygen in an electrolyser, effectively a fuel cell operating in reverse. **And, like a fuel cell, the electrolyser can use platinum-and iridium-based electrodes to decompose water efficiently.** When the electricity to drive an electrolyser is derived from green sources (wind, hydro or solar), there is no carbon footprint. This approach is even more attractive when renewable energy is surplus to immediate requirements, as hydrogen can be used very effectively to store energy produced intermittently from renewables until fuel cells convert this hydrogen back into electrical power on demand.

The PEMFC has been adopted for fuel cell-powered passenger cars and forklift trucks and is also being used or considered as an alternative electric powertrain for buses, delivery trucks, trains and marine vessels. Fuel cells are proving to be very suitable for fleets of vehicles which operate on limited routes out of central depots, as this makes refuelling with hydrogen easier. Fuel cells are a good alternative to diesel power in cities where air pollution is a public health concern: zero emissions at the point of use and a low carbon footprint when hydrogen has been generated from renewable energy are strong selling points for city authorities, public transport operators, freight companies and consumers. Consequently, large orders are being placed for heavy-duty fuel cell vehicles by city transport operators (London, Beijing) and haulage contractors (for Budweiser) on the strength of their environmental credentials.

However, in the long term, demand for PGMs will only become really significant if FCEVs win a sizeable share of light-duty vehicle production. At present, production of fuel cell-powered electric cars is only ~3,000 per year, but is predicted to grow by several orders of magnitude over the next two decades. This means that PGM demand upside, both in vehicles *and* in electrolysers to produce hydrogen fuel, exists – but is several years away from becoming significant.

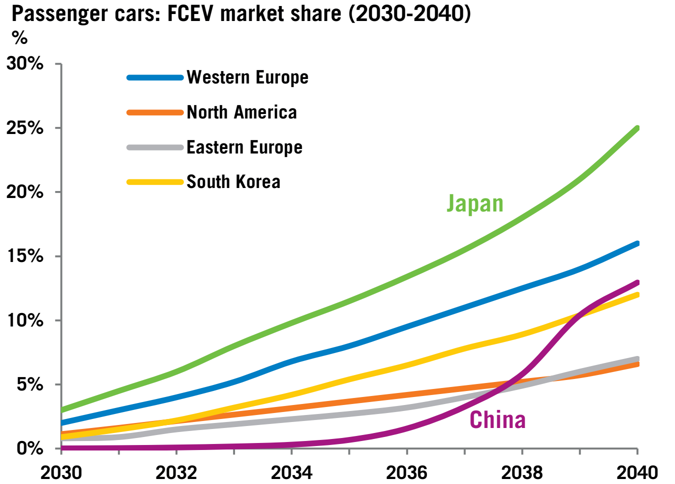
The importance of FCEVs in national and regional vehicle fleets will vary widely. Japan, the technical pioneer, has the highest national FCEV market share. Market pioneers Toyota and Honda, coupled with a national priority to make green and safe energy available within a relatively prosperous, small and self-contained country, have put Japan at the forefront of the FCEV wave. Despite this strong government and commercial support, the lead times to develop the fueling infrastructure and vehicle technology should not be underestimated; FCEVs are only expected to break through 1% of light vehicle production in Japan by 2028.

Passenger cars: FCEV market share (2016-2030)



Source: SFA (Oxford), LMC Automotive. Note: Eastern Europe includes Russia and Turkey.

Passenger cars: FCEV market share (2030-2040)



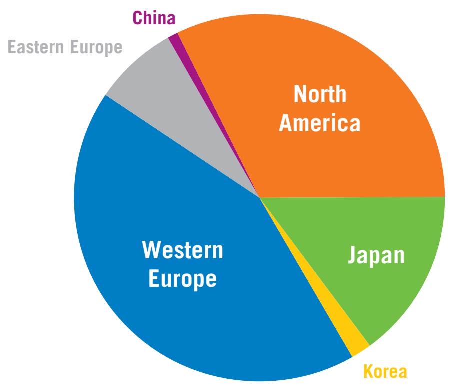
Source: SFA (Oxford), LMC Automotive. Note: Eastern Europe includes Russia and Turkey.

Western Europe, with legislated needs to cut all forms of emissions from transport, follows closely, with strengths in the development of fueling infrastructure and in building collaborations throughout the technology chain. South Korea, with strength in vehicle technologies, is next.

In terms of absolute FCEV demand, China will emerge post-2035 to dominate by 2040. Though a relative laggard in the rate of adoption of fuel cell and hydrogen technology, the sheer size of China's passenger vehicle market means that by 2040, China will produce almost twice the number of cars as Western Europe, more than three times as many as North America and five times the output of first mover Japan.

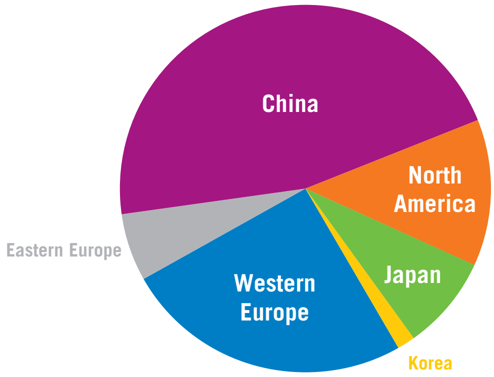
North America and Western Europe are expected to take up FCEVs rapidly in the late 2020s to satisfy the ongoing need for long distance personal mobility under stringent emissions legislative control. These two regions are expected to make up three-quarters of production in 2030, but by 2040, China is forecast to make up almost half of the global market.

Fuel cell car production by region (2030)



Source: SFA (Oxford), LMC Automotive. Note: Eastern Europe includes Russia and Turkey.

Fuel cell car production by region (2040)

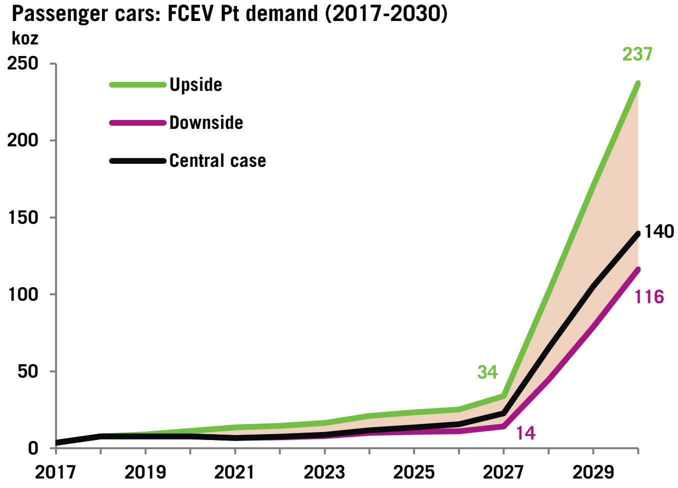


Source: SFA (Oxford), LMC Automotive. Note: Eastern Europe includes Russia and Turkey.

Potential PGM demand: Projections of platinum demand rely on assumptions about platinum loadings per vehicle. Fuel cell cars on the market today from Hyundai, Honda and Toyota have fuel cell stack power outputs ranging from 100 kW to 114 kW. The Toyota Mirai is reported to contain around 30 g of platinum, or 0.26 g per kW. The United States Department of Energy (DOE) sponsors research into meeting long-term targets for fuel cell stack performance: its 2020 target for platinum loading is 0.125 g per kW for an 80 kW stack, a loading of 10 grams per car.

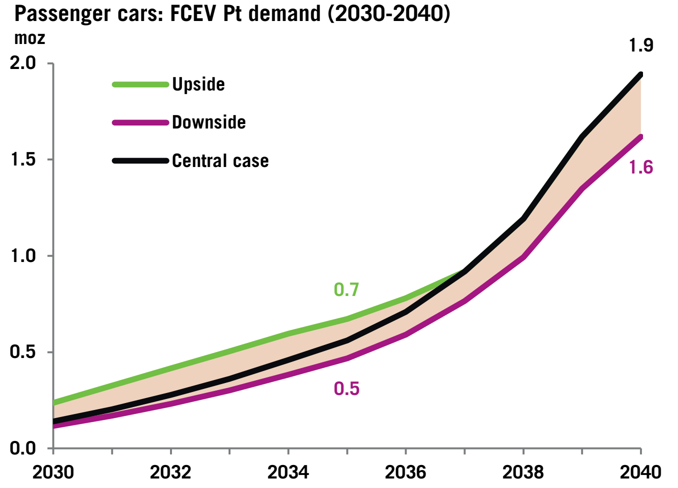
Our current central case assumes 30 g in 2017 reducing to 12 g by 2021 and to 6 g by 2030, with the latter number broadly equivalent to the platinum loadings on today's diesel passenger cars. On this basis, **demand for platinum would grow to 140,000 ounces in 2030 and reach 1.9 million ounces by 2040**.

Passenger cars: FCEV Pt demand (2017-2030)



Source: SFA (Oxford)

Passenger cars: FCEV Pt demand (2030-2040)



Source: SFA (Oxford)

There would be supplementary demand for ruthenium, which is used to protect platinum catalysts from poisoning by trace carbon monoxide in the hydrogen fuel, **and for iridium**, used in combination with platinum in electrolysers.

But is this an old story? For decades the platinum industry has been expecting fuel cell vehicles to become a significant source of demand for PGMs, yet it has been continually disappointed. Demand for platinum in fuel cells has certainly increased, but in 2017 it was about 50,000 ounces for all fuel cell applications, and transport (cars, trucks and buses) accounted for less than half of the total. However – and although several challenges to FCEV commercial success have still to be overcome – there are reasons to expect that it will be different this time.

More companies in the fuel cell supply chain are sharing investment risk and expertise. Toyota is one of the best known brands in the FCEV industry; its success stems not just from attractive vehicles (>3,000 Mirai on the road to date in California) but from the extensive fuelling partnerships in which it has invested to develop target markets, to ensure that consumers can fill their vehicles. Toyota realised early on that partnerships and collaboration are the only way to make a viable fuel cell and hydrogen industry. Audi and Hyundai announced in June 2018 an agreement to cooperate on developing fuel cell vehicles. Audi and VW Group brands will have access to parts based on Hyundai's know-how accumulated from the development of the ix35 Fuel Cell SUV and its successor, the Nexo, under a multi-year patent cross-licensing agreement, covering a broad range of fuel cell electric vehicle components and technologies. Hyundai expects that tighter EU CO_2 emissions limits in 2025 will drive demand for more hydrogen cars.

Importantly, a hydrogen fuelling infrastructure is developing. The fuel infrastructure at present is inadequate to support a large fuel cell vehicle fleet (unless centrally-fuelled, like buses) but it is expanding – 64 new public refuelling stations were opened worldwide in 2017. At the end of 2017, Japan had the most public stations (91), followed by Germany with 45 stations and the USA with 40. Many initiatives are taking place:

- **Japan H2 Mobility (JHyM) company was formed by ~17 companies** (auto, energy, refuelling, finance) in March 2018 to develop a hydrogen station network for FCEVs;
- **South Korea is to invest $2.3 billion in a hydrogen fuel cell vehicle industrial ecosystem over the next 5 years**, with a target to install 310 hydrogen stations by 2022, to supply 16,000 fuel cell vehicles;
- **ITM Power in UK is rolling out a network of stations on key routes.** The hydrogen is generated on-site using an ITM PEM electrolyser, eliminating the need for fuel deliveries;
- **In Germany, Shell will dispense hydrogen** at its fuel filling stations, through a joint venture including industrial gas manufacturers Air Liquide and Linde, car manufacturer Daimler and energy companies Total and OMV, aiming to roll this out at 400 locations by the early 2020s;
- **Toyota & Air Liquide are developing an initial network of 12 fueling stations in the northeast US corridor.**
- **The Hydrogen Council was launched by 13 leading energy, transport and industry companies** in January 2017 to foster a role for hydrogen in the world's future energy systems. It has since expanded to 53 members.

Source: H2stations.org by Ludwig-Bölkow-Systemtechnik GmbH (LBST)

Efficiency gains in renewable energy generation fit very well into the fuel cell industry. Coupling locally generated renewable energy (wind, solar) with electrolyser technology allows hydrogen to be produced and stored, taking advantage of excess renewable energy that would otherwise be wasted if the grid cannot take it. Producing a practical fuel with minimal carbon content meets environmental legislation and avoids the cost and risks of trucking or piping fuel (like oil derivatives) from centralised production facilities to customers.

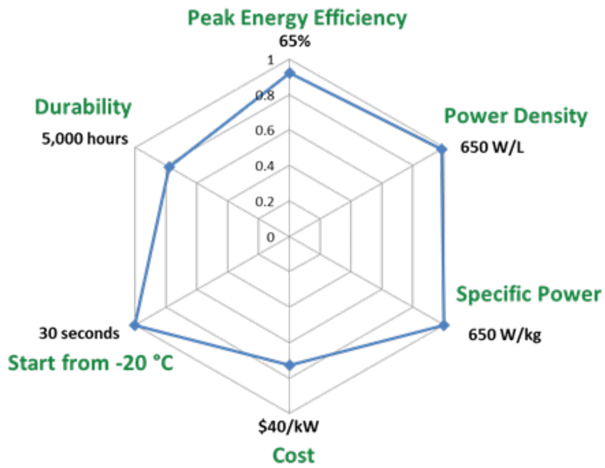
The same core fuel cell technology can be supplied to road (cars, buses, freight), rail and marine. Markets are opening up rapidly, so there is potential for economies of scale. The need for alternatives to internal combustion engines (diesel, gasoline) is driven by air quality legislation and the shortcomings of alternatives – for example, electrification of railway lines is very costly; LNG has minimal CO_2 improvement in marine applications.

Technical advances continue to reduce fuel cell stack costs and improve durability. Durability and cost are the primary challenges to fuel cell commercialisation, and there is still a competitive deficit for FCEVs here. It will not be enough for FCEVs to demonstrate environmental and performance advantages over ICEs and batteries if they cannot compete at the level of the sticker price. The US DOE 2020 target for stack cost per kW is $40, believed to be a competitive level for FCEVs against incumbent and future technologies.

Longer term, the DOE targets reduction to $30/kW to maintain competitiveness against alternative powertrains including advanced gasoline systems. Cost reduction is a function partly of reducing the platinum loading, but this also includes improving catalyst activity and optimising the catalyst support structure as well as streamlining other elements in the fuel cell system as a whole. DOE reported an improvement in estimated cost from $53/kW in 2015 to $45/kW in 2016.

The durability target is 5,000 hours, equivalent to 150,000 miles of driving, with less than a 10% loss of performance, and by 2015 the projected durability had reached 3,900 hours.

Public demand for clean air and government proposals to eliminate internal combustion engines (ICEs) are creating an enabling environment for electric vehicles. Several countries with large vehicle populations have announced their intention to ban new sales of ICEs, notably India (from 2030), China, France and the UK (all from 2040). In these circumstances, consumers seeking an alternative to diesel cars which offers the same range, economy and ease of refuelling will consider an FCEV.



Source: US DOE. Note: Fuel cell power system 2020 targets versus 2015 status (blue) for light-duty vehicle applications. (The status is indicated as a fraction of the targets.) Cost status is for a modelled system when manufactured at a volume of 500,000 units/year.

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