PLATINUM ESSENTIALS

Fuel cell electric vehicles are forecast to drive material long-term demand growth for platinum

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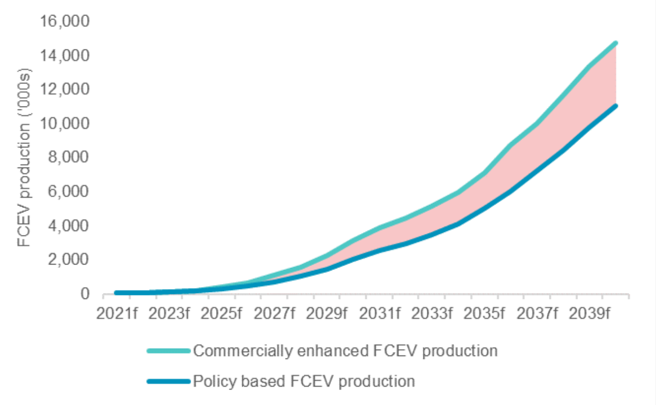
Supportive hydrogen policies could result in fuel cell electric vehicle (FCEV) demand for platinum equalling current automotive demand by 2039, but broad-based commercial adoption of FCEVs would bring this forward to 2033, adding over three million ounces to annual automotive platinum demand in eleven years.

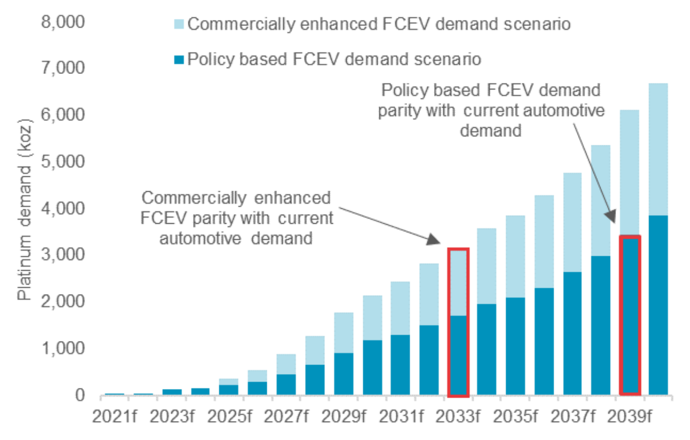
FCEVs have long been viewed as being able to offset potentially declining automotive demand for platinum in a decarbonising world. In reality, broad-based FCEV adoption has been slow to materialise due to limited vehicle and green hydrogen production volumes restricting economies of scale and hydrogen refuelling infrastructure deployment. These challenges are now being overcome, with an increasing number of FCEVs available today in all vehicle categories, supportive government policies enacted in many parts of the world, and increasing economies of scale in both hydrogen and FCEV production. Furthermore, the current Russian-driven geopolitical crisis and the need to reduce European reliance on Russian gas supplies (currently c.40% of European demand) as well as high natural gas prices should further accelerate supportive policies for green hydrogen in Europe. This report examines the potential demand for platinum from FCEVs, putting forward a policy-based scenario, and a policy plus broad-based commercial adoption scenario, both of which result in initially slow, but ultimately very significant, demand growth.

Figure 1.Global adoption of FCEVs is expected to accelerate dramatically under both policy-based and commercially-enhanced scenarios



Source: WPIC Research

Figure 2. Broad-based commercial adoption of FCEVs could see additional platinum demand reach current automotive levels by 2033



Source: WPIC Research

- ***Platinum demand growth from FCEVs may be very significant in the future***
- ***Policy driven FCEV demand could see platinum demand reach the level of 2022 automotive demand by 2039***
- ***Broad-based commercial FCEV adoption could see platinum demand reach the 2022 level by 2033***
- ***Geopolitical tensions and high energy prices accelerating development of hydrogen production in Europe are highly supportive of commercial FCEV adoption***

WPIC's ***Platinum Essentials*** is a publication which explores topics affecting platinum as an asset class. This is different to ***Platinum Perspectives***, which is a monthly publication which looks at a specific topic affecting supply demand dynamics for platinum and gives our view.

Contents

Introduction

All technologies are needed to decarbonise transport; FCEVs are complimentary to BEVs and are key to decarbonising areas unsuited to battery electrification.

Balancing the acute need to decarbonise the world with the economic reality that the early adoption of new technologies is expensive calls for a multi-pronged approach that incorporates battery electric vehicles (BEVs), fuel cell electric vehicles (FCEVs), but also more efficient internal combustion engine vehicles (ICEs) including mild-hybrid gasoline and mild-hybrid diesel powertrains. It is worth mentioning that diesel versions still emit far less CO_2 than gasoline ones. The long-promised adoption of FCEVs has been held back due to limited early production of vehicles and hydrogen restricting economies of scale as well as a lack of hydrogen refuelling infrastructure. We think these challenges are now being overcome with mature application of fuel cell technology in heavy- and light-duty vehicles, supportive hydrogen policies in key markets globally, and improving green hydrogen production economics.

In this report, we explain how a FCEV works, provide an overview of national and regional hydrogen policies, outline the geopolitical strategic benefits of green hydrogen, and put forward two scenarios for the adoption of FCEVs and the associated platinum demand growth.

We should emphasise that this report only considers road-based FCEVs and does not look at the potential deployment of and platinum demand from PEM electrolysers for the production of green hydrogen, fuel cells used in construction, rail or shipping transport, and stationary fuel cells, which could be considerable.

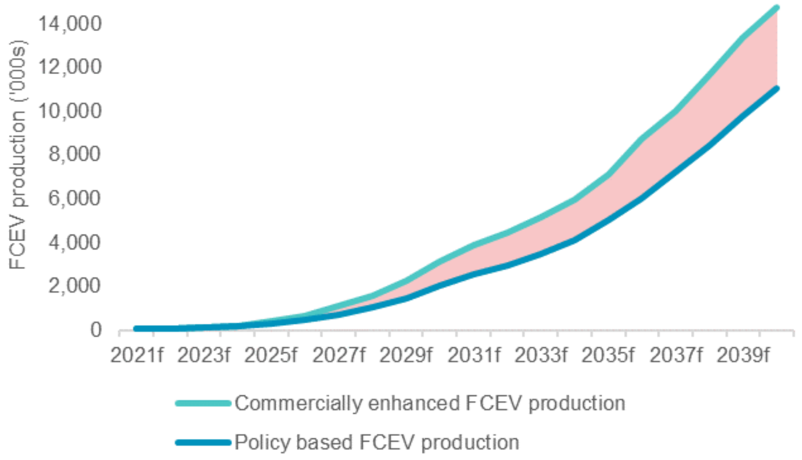
FCEV adoption from policy support alone versus policy support enhanced by broad-based commercial adoption

Two scenarios modelled: policy-driven FCEV uptake and broad-based commercial adoption.

A number of regions and countries around the world have announced hydrogen and FCEV policy support and targets, in many cases together with associated funding details and commitments. We see these as being the cornerstone of FCEV adoption. Of course, the purpose of these policies is to engender growth in the production of hydrogen and the FCEV industry until economies of scale, and/or practicable usability factors result in self-sustaining broad-based commercial adoption.

These two scenarios therefore become the bookends of our estimates with the likely outcome probably somewhere in between, but not ruling out upside in the event of step changes in any or all of hydrogen availability, technology applications, policy support and costs. We forecast annual FCEV production of 2m vehicles in 2030, rising to 11m by 2040 in the policy-based scenario, and 3m rising to 15m in the broad-based commercial adoption scenario. In terms of market penetration, the policy-based versus commercially-enhanced scenarios equate to 2-3% of global annual vehicle production by 2030, increasing to 8-11% by 2040.

Figure 3. Global adoption of FCEVs is expected to accelerate dramatically under both policy-driven and commercially-enhanced scenarios



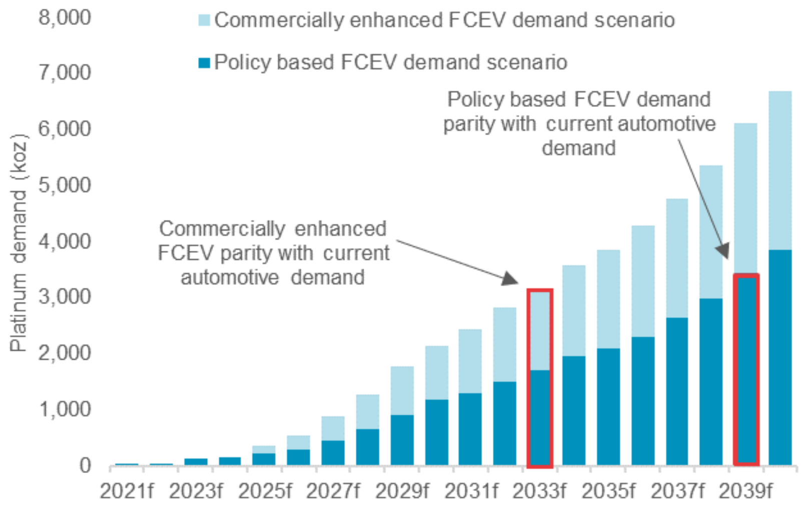
Source: WPIC Research

Policy driven production of 2m FCEVs in 2020 rising to 11m by 2040.

This accelerates to 3m and 15m with broad-based commercial FCEV adoption.

The potential platinum demand requirements are significant under both scenarios, even after assuming aggressive thrifting of platinum from automotive fuel cells from current levels, despite their relative application maturity. Under the policy-based scenario, we estimate that FCEV demand for platinum could equal 2022 forecast automotive demand by 2039. This date comes forward to 2033 in the commercially-enhanced scenario.

Figure 4. Broad based commercial adoption of FCEV could see automotive demand for platinum reach current automotive demand by the early 2030's



Source: WPIC Research

FCEV demand for platinum could match 2022 automotive platinum demand by 2039 if only policy driven, or by 2033 with broad-based commercial adoption.

This is a material level of additional platinum demand, adding over three million ounces to annual automotive platinum demand in eleven years. We expect ICEs to remain a significant portion of the global drive train mix well into the 2030s; from a platinum demand perspective, with likely volume declines being fully offset by tighter emissions standards and correspondingly higher platinum loadings and platinum substitution for palladium. The corresponding need for platinum for ICE emissions control, combined with the additional FCEV platinum demand could, without increases in supply, cause platinum scarcity which would hinder FCEV growth rates, (much as battery material supply limitations could be for BEVs over the next decade). However, identified platinum reserves and resources are significant and production can be expanded with time to satisfy demand growth. While platinum scarcity will support the higher PGM basket prices necessary to incentivise mine supply growth (from c.6.1 Moz in 2022f), this growth will be greatly enhanced by the proliferation of increasingly supportive hydrogen policies and funding globally. This should also encourage a broad uptake of this important decarbonising technology.

European initiatives to ramp-up green hydrogen production to replace Russian natural gas supplies is supportive of broad-based commercial FCEV adoption.

Key takeaways and conclusions

- FCEVs are implementing a mature fuel cell technology, poised to achieve cost competitiveness with BEVs from economies of scale
- FCEVs are complimentary to rather than competitive with BEVs; better suited to uses that require off-grid operability, high range, cold tolerance, high torque, stable operating performance, high capacity utilisation/fast refuelling and minimal user input
- Fuel cell’s are best suited heavy-duty (‘HD’) vehicles, where the range, light system weight and high capacity utilisation benefits are most acute
- But fuel cell manufacturers are also expected to promote the growth of fuel cell passenger and light commercial vehicles to boost manufacturing economies of scale and thereby bring down all FCEV system costs
- Domestic green hydrogen, replacing fossil fuels more widely, including in transport, has strategic energy security benefits, more stark and likely to be acted upon during periods of geopolitical uncertainty
- FCEV growth projections are comparable to historical BEV growth achievements
- Projected FCEV demand for platinum assumes gradual thrifting of platinum from fuel cells despite their maturity
- FCEV demand for platinum could match 2022 forecast automotive demand as early as 2033 with expected policy support accelerated by successful broad-based commercial adoption

One final consideration is the potential for the impacts of the Russian invasion of Ukraine, that continued to evolve during the preparation of this report, to accelerate the roll-out of green hydrogen production in response to geopolitical tensions as well as on economic grounds at current natural gas prices. Should this occur, it would bias the outlook towards our broad-based commercial adoption scenario.

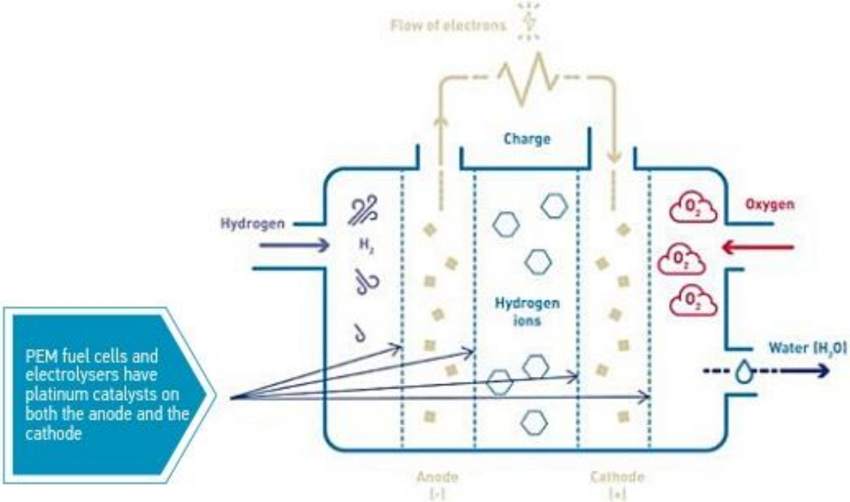
What is a fuel cell and how does it work?

A fuel cell generates electricity from the conversion of chemical energy from a fuel and an oxidising agent through an oxidation-reduction reaction. Most fuel cells currently use hydrogen gas as the fuel, and atmospheric oxygen as the oxidiser, although other fuels have been used historically, such as methanol, or are being considered for the future, such as green ammonia.

The first prototype fuel cell was developed almost 200 years ago in 1838 by Sir William Grove, and today there are several different types. However, for automotive purposes the dominant type is the platinum-based proton exchange membrane fuel cell, due to its small size, high electrical current density and ability to quickly vary its power output. A proton exchange membrane (PEM, sometimes also referred to as a polymer electrolyte membrane) is a semipermeable ionomer membrane that protons (H+) can pass through, but that acts as an electrical insulator and a reactant barrier; i.e. non-conductive of electrons and impermeable to oxygen and hydrogen. A PEM fuel cell consists of a ‘stack’ or Membrane Electrode Assembly (MEA), where each membrane is sandwiched between a cathode and an anode, both dosed with platinum, with the membrane acting as a solid electrolyte. Hydrogen gas is channelled to the anode where it reacts with the platinum catalyst causing each hydrogen atom to separate into an electron and a proton. The electrons flow to the cathode as an electrical current, and the protons flow across the membrane to combine with oxygen from air channels into the cathode, and the current of electrons to produce pure water, which is then released from the permeable catalyst surface and exits the fuel cell.

The leading fuel cell technology, proton exchange membrane or PEM, uses platinum to catalyse the splitting of hydrogen into electrons and protons, and separately to accelerate the reduction of oxygen with hydrogen. Electricity, heat and pure water are the products.

Figure 5. Fuel cell schematic



Source: Graphic from Airliquide Proton Exchange Membrane

From a kinematic perspective, the electrochemical process at the anode is rapid and requires low platinum loadings, but the process that occurs at the cathode is more sluggish, requires greater platinum loadings, and has typically offered greater opportunities for reducing platinum content (thrifting) and for the use of other materials (substitution).

Platinum’s great advantage as a catalyst at the cathode comes from its stability under the extremely corrosive environment of the oxygen reduction reaction, while still being able to activate oxygen and then release the resultant water molecule. Added to which, platinum's attributes limit the production of hydrogen peroxide, which can degrade the cathode.

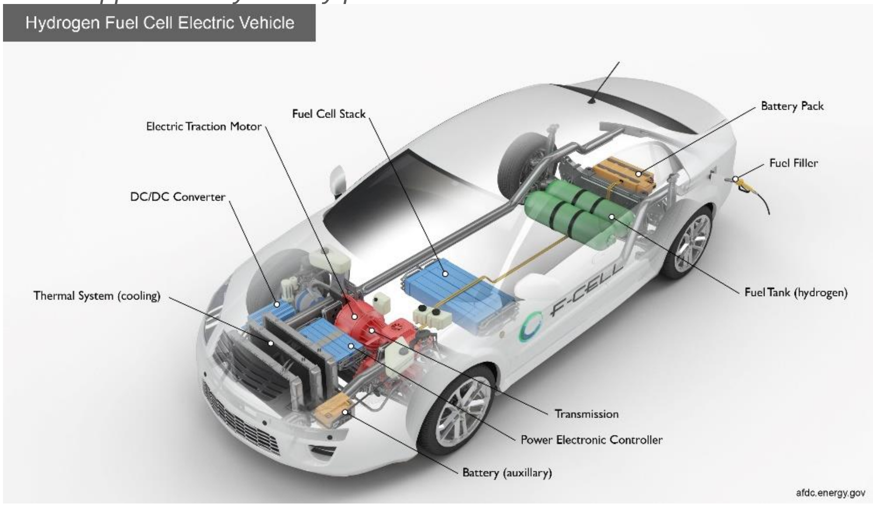
As with all catalysts, platinum is at risk of poisoning from impurities; most problematic from hydrogen are sulphur specifies and carbon monoxide. There are different possible sources of impurities, but the cleanliness of the hydrogen is key to reducing poisoning. Hydrogen produced from the electrolysis of water (green) is typically extremely pure, while grey or blue hydrogen produced from natural gas reformation needs to be cleaned before being used in a fuel cell. See the 'hydrogen rainbow' section later in this report for a digest of hydrogen fuel sources and attributes.

Fuel cells for mobility

A fuel cell electric vehicle (FCEV) has similarities with both battery electric vehicles (BEV) and mild-hybrid electric vehicles (MHEV). Like a BEV, the motive power is provided by one or more electric motors, with the energy source being a fuel cell, rather than a large heavy battery pack. In fact, FCEVs typically share ~80% of the components and systems found in a BEV. Like a MHEV, a FCEV also has a supplementary but relatively small battery to store energy from regenerative braking, also making it available to the motor during heavy acceleration, although the prime motive power is from the electric motor rather than an internal combustion engine (ICE). Importantly, FCEVs are 'off-grid' in that they do not need to be plugged in to be charged, a significant advantage in inner city locations where consumers may not have access to off-street parking and home charging points.

Typically, 80% of the components and systems in a FCEV are shared with BEVs.

Figure 6. FCEV schematic, showing the fuel cell, electric motor, and small supplementary battery pack



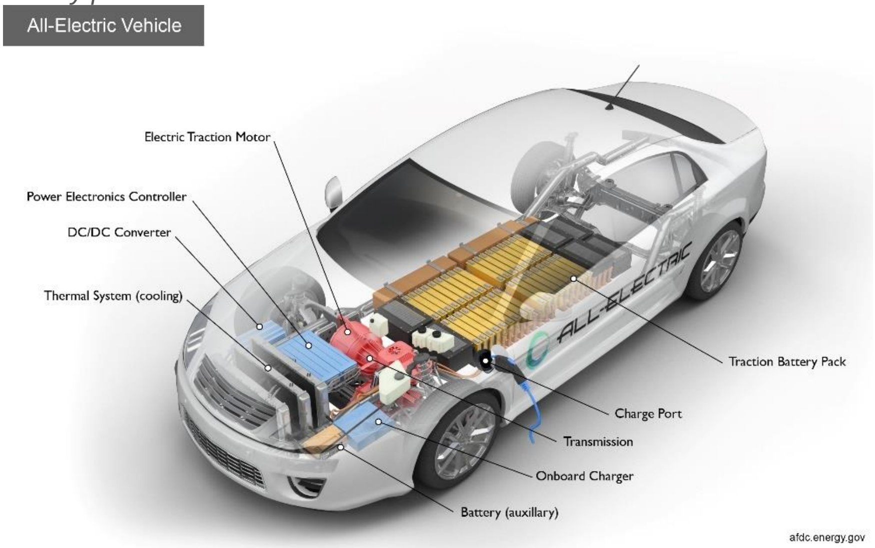
Source: How Do Fuel Cell Electric Vehicles Work Using Hydrogen? 2021. U.S. Department of Energy Alternative Fuels Data Center. Accessed February 3, 2022. afdc.energy.gov/vehicles/how-do-fuel-cell-electric-cars-work

This leads to the potential to offer a FCEV version of every BEV model in their portfolio, or even for fuel cells to be retrofitted to BEVs as range extenders to offset later life battery degradation.

FCEV advantages and disadvantages

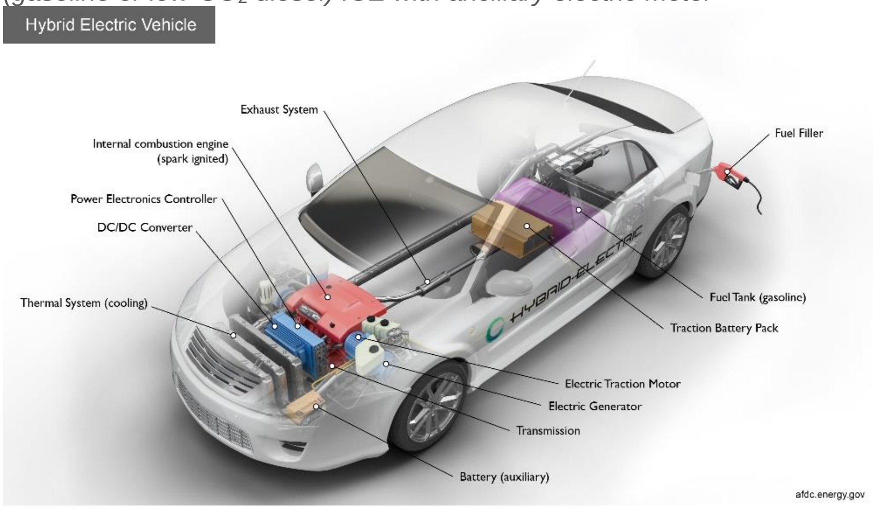
FCEVs are complimentary to BEVs in that they are better suited to consumers without access to charging infrastructure, in need of long range (without relying on battery-degrading fast charging) or high capacity utilisation for cost of capital efficiency. Additionally, FCEVs are less dependent upon consumer behaviour for day-to-day usability. The main challenges facing FCEV market penetration are limited early production of vehicles and hydrogen restricting economies of scale and a lack of hydrogen refuelling infrastructure. This is variable by region with optimal regulatory support a great enhancer of penetration.

Figure 7. BEV schematic, showing the electric motor and large, heavy battery pack



Source How Do All-Electric Cars Work? 2021. U.S. Department of Energy Alternative Fuels Data Center. Accessed February 3, 2022. afdc.energy.gov/vehicles/how-do-all-electric-cars-work

Figure 8. MHEV schematic, showing the supplementary battery back and (gasoline or low-CO_2 diesel) ICE with ancillary electric motor



Source: How Do Hybrid Electric Cars Work? 2021. U.S. Department of Energy Alternative Fuels Data Center. Accessed February 3, 2022. afdc.energy.gov/vehicles/how-do-hybrid-electric-cars-work

FCEVs suit cold environments or those with a lack of charging infrastructure, as well as users that require high-capacity utilisation or long daily ranges.

In comparison to BEVs, FCEVs' principal advantages are that they are much lighter, have greater range (although some new BEVs are beginning to come close) and are significantly quicker to refuel. The range/refuelling advantages of FCEVs puts them on a par with ICE vehicles in terms of day-to-day usability with no range anxiety and only three to four minutes to refuel. BEV manufacturers would argue that rapid charging can impart a usable range within 15-20 minutes, enough time to grab a coffee and stretch one's legs. While this is undoubtably true, rapid charging pushes lithium ion batteries out of their optimal electrochemical operating window, resulting in accelerated degradation of the expensive-to-replace battery pack. Slower charging of the battery maximises its life but takes two to four hours with high-capacity chargers, and 8-10 hours or longer on home 'trickle' charging, to deliver a comparable range. The range/battery life question is also exacerbated by ambient temperature considerations in seasonal or cold climates. Lower temperatures significantly increase internal resistance in batteries, which reduces range and operating life. PEM fuel cells on the other hand, provide consistent performance down to -30°C, which is similar to ICEs that may have to employ plug-in block warmers or small paraffin or propane heaters in colder climates (or even a little fire under the engine in more remote parts of the world!). One interesting, but as yet unexplored opportunity for fuel cells, could be as after-market retrofits to older BEVs in the form of range extenders to compensate for later life battery degradation, or even just range/recharge freedom in exchange for sacrificing some internal storage space.

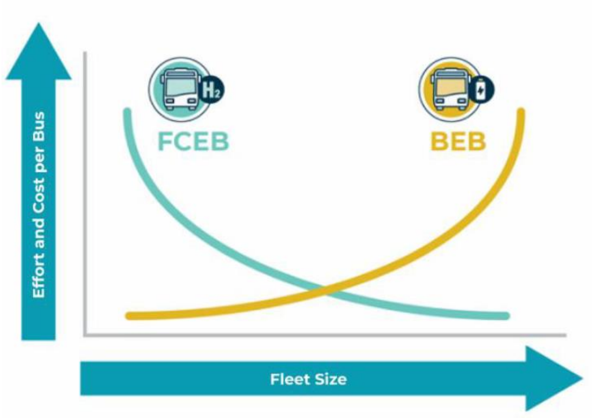
One advantage BEVs have over FCEVs when both are using renewable power for charging or their hydrogen source, is that BEVs are typically ~62% efficient from a well-to-wheel perspective, whereas FCEVs are ~40% efficient (figures from ANL GREET model [FCEV] and U.S. EPA [BEV]). However, this equation changes quickly when capacity utilisation rates and the cost of capital are considered. In an environment calling for high capacity utilisation rates, such as city buses, long-distance truck driving, plant or farm equipment, or warehouse forklifts, FCEV capacity utilisation might be >90% whereas it could be <50% for a BEV being operated on a battery sensitive charge cycle; a huge difference when applying a cost of capital overlay.

BEVs are more efficient users of electricity than FCEVs running on green hydrogen.

Furthermore, while charging LVs from is unlikely to overly tax the primary electrical power grid now, it will require significant grid upgrades at certain adoption thresholds. This is particularly true for HD vehicles operating from depot environments where charging multiple vehicles overnight or on an opportunity basis can require significant grid upgrades, especially as the fleet grows larger. On the other hand, the per vehicle cost of installing hydrogen refuelling infrastructure falls at larger fleet sizes as the quicker refuelling times mean that it can service a greater number of vehicles, as illustrated in the following schematic for bus operators.

FCEVs have a lower impact on grid demand for electricity, which can be a significant consideration with larger fleets of heavy-duty vehicles.

Figure 9. Per vehicle refuelling costs for FCEV fall with increasing fleet size, whereas the additional grid upgrade costs for BEVs continue to grow with the fleet

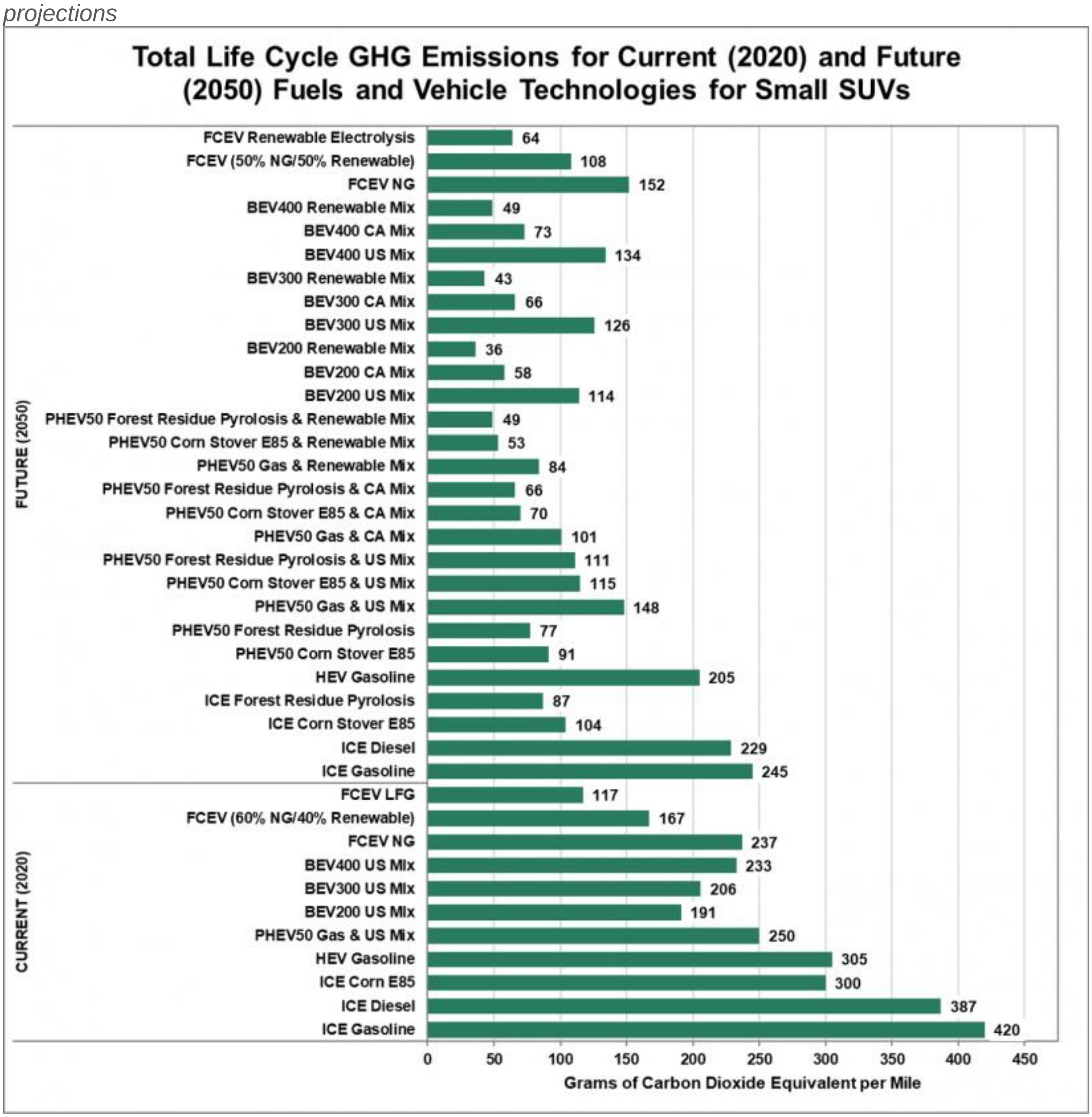


Source: Center for Transportation and the Environment (CTE), IDTechEx

Additionally, green hydrogen is an excellent energy storage medium for excess renewable energy during periods of low grid demand, presenting an alternative to feathering wind turbines for example, and significantly improving effective FCEV well-to-wheel efficiency. There of course other energy storage solutions, including pumped storage, batteries and compressed air, but hydrogen has the advantage of also being mobile rather than only captive to the grid.

Green hydrogen can be a storage medium for excess renewable energy during periods of low grid demand, and it is transportable, unlike grid scale batteries.

Figure 10. FCEVs fare well on comparative total life cycle greenhouse gas emissions, both today and on future projections



Source: U.S. Department of Energy, Office of Vehicle Technologies, Hydrogen and Fuel Cell Technologies & Bioenergy Technologies, Note: FCEV = fuel cell electric vehicle. HEV = hybrid-electric vehicle. BEV = battery-electric vehicle. PHEV50 = plug-in hybrid electric vehicle with 50-mile electric range. ICE = internal combustion engine. NG = natural gas. E85 = 85% ethanol and 15% gasoline. LFG = landfill gas

One final point of comparison is the relative green credentials ‘point scoring’ competition between BEVs and FCEVs. Both are only as green as the source of the energy used to either charge the batteries, or to produce the hydrogen (in the case of electrolysis), with other hydrogen options such as blue and grey hydrogen also adding the potential for CO_2 emissions for FCEV. That said, fuel cells contain more environmentally benign materials than the cocktail of metals that go into batteries and are significantly easier to recycle (although the economics of recycling will be dependent upon the platinum price and FCEV platinum loadings at the time a vehicle is scrapped).

Fuel cells have greater recyclability characteristics than batteries, at present.

Reaching a definitive conclusion on the green credentials discussion is a) difficult, and b) highly dependent upon the geography in which a vehicle is operated. As shown in Fig 10, the US DOE estimates that FCEVs running on green hydrogen compare favourably to all other drivetrains in the US in terms of total life cycle greenhouse gas emissions, only being edged out of top spot by BEVs charged with 100% renewable energy on the already discussed efficiencies (but before considering capacity utilisation rates).

The hydrogen rainbow

Hydrogen as a fuel comes from a number of possible sources with varying levels of green credibility and impurity challenges. To quickly distinguish between different sources of hydrogen, the varieties have allocated colours:

Green hydrogen: Intuitively carbon-free, green hydrogen is produced through the electrolysis of water using renewable energy for a minimal CO_2 footprint as well as being low in impurities.

Green hydrogen is produced using renewable energy.

Yellow hydrogen: Produced by the electrolysis of water using mixed-origin grid energy, or renewables when available and grid when not, to maximise capacity utilisation. Medium CO_2 footprint but also low in impurities.

Pink hydrogen: Produced through the electrolysis of water using nuclear power for a minimal CO_2 footprint and low impurities.

Turquoise hydrogen: Produced from the pyrolysis of natural gas or methane, produces solid carbon as a by-product. Minimal CO_2 footprint and low in impurities.

Blue and grey hydrogen are off the table in Europe given the push to reduce the continent’s reliance on Russian natural gas.

Blue hydrogen: Produced by steam reformation of natural gas or coal with CO_2 capture and sequestration. Low to medium CO_2 footprint with entrained impurities.

Grey hydrogen: Produced by steam reformation of natural gas without CO_2 abatement. Medium to high CO_2 footprint with entrained impurities.

Brown and black hydrogen: Produced by the gasification of brown or black coal without CO_2 abatement. High CO_2 footprint with entrained impurities

White hydrogen: Historically referred to naturally occurring hydrogen but now refers to hydrogen produced as a by-product of industrial processes.

National hydrogen policies

As already suggested, the biggest early adoption challenges facing FCEVs are infrastructure- and policy-linked. In a rather chicken and egg scenario, the hydrogen refuelling stations (HRS) are needed to make FCEVs a viable consumer option, but the automakers are reluctant to invest too heavily in FCEV development until the HRS networks are in place, and governments are reluctant to support HRS rollout until they know that FCEVs are available for consumers.

Nonetheless, things are moving with the development of HRS networks within a number of countries and regions announcing hydrogen and FCEV strategies, although targets can be set on electrolysis capacity, HRS network scale, or FCEV sales, making comparisons difficult (see Fig. 10). Countries and regions to highlight include China, targeting 1,000 HRS by 2030, South Korea, which is targeting 80,000 FCEVs on the road and 310 HRS by 2022, and Germany, which is planning 400 HRS by 2023. Longer term, South Korea is targeting the production of 6.2m FCEVs p.a. by 2040 of which 3.2m will be for export. Vehicle emissions policies that already target fleet CO_2 levels, long standing in North America and new to Europe in 2021, already provide automakers with an incentive for a FCEV to reduce fleet emissions.

Figure 11. Select green hydrogen and FCEV policies and funding

Country	2030 depoyment targets	Public investment committed
Australia	N/A	A$1.3B (US$0.9B)
Canada		C$25M by 2026 (US$19M)
California	200 HRS by 2025	US$20M p.a. Grants of US$4,500 to US$9,500 per FCEV
China	1,000,000 FCEVs 1,000 HRS by 2030 2,000 HRS by 2035	No coordinated central funding or subsidies as yet
EU	40GW electrolysis	€3.8B by 2030 (US$4.3B)
France	6.5GW electrolysis 20,000-50,000 LV 800-2,000 HD 400-1,000 HRS	€7.2B by 2030 (US$8.2B)
Germany	5GW electrolysis	€9B by 2030 (US$10.3B)
Japan	800,000 FCEV 1,200 FC bauses 10,000 FC forklifts 900 HRS	¥699.6B by 2030 (US$6.5B)
South Korea	Annual production of 6.2M FCEV 1,200 HRS 80,000 FC taxis 40,000 FC buses 30,000 FC trucks 15GW stationary FC produced	₩2.6T by 2030 (US$2.2B)
Netherlands	30,000 FCEV 3,000 FC HV	€70Mpa (US$80Mpa)
Spain	4GW electrolysis 5,000-7,500 FCEV (LV+HV) 100-200 FC buses 100-150 HRS	€1.6B (US$1.8B)

Source: IEA, DOE, ICCT, WPIC Research

National policies have been enacted around the world to support the development of hydrogen production and hydrogen refuelling station networks for FCEVs.

As an aside, it is worth noting that green hydrogen (and blue, produced from natural gas with CO_2 carbon capture and storage, CCS) are increasingly seen as critical for decarbonising industry and home heating, as well as an energy storage medium for excess renewable power.

Strategic energy independence supports accelerated hydrogen production

Green hydrogen can be a solution to national energy independence.

Furthermore, domestic green (or pink) hydrogen production can be a significant asset in times of geopolitical tension when international energy supplies can be used for political leverage, and this may shape domestic energy policies. This has come into sharp focus during the preparation of this report with Russia’s invasion of Ukraine; an action that is leading to broad international isolation of and sanctions against Russia. The problem for Europe is that it is dependent upon Russia for ~40% of its natural gas needs, and as energy prices rise in a time of crisis Europe is effectively helping to finance Russia’s military costs. The problem for Europe is that there are limited options to source gas from alternative sources in the scale that is needed.

One solution (already announced during the preparation of this report) would be to accelerate the production of green-hydrogen; and with no changes to its natural gas infrastructure (pipes, valves, domestic heating etc), Europe could halve its reliance on Russia by blending 20% hydrogen into its natural gas network. This is a longer-term possible solution, but as Russia’s leadership have proven continued disregard for the rule of international law over more than two decades, we think the invasion of Ukraine has started a sustained need to minimise all economic relationships with Russia that provide it with material foreign currency income and/or political leverage.

One other side effect of the invasion and higher energy prices is that green hydrogen is economically competitive at current natural gas prices, which are admittedly inflated by the current situation.

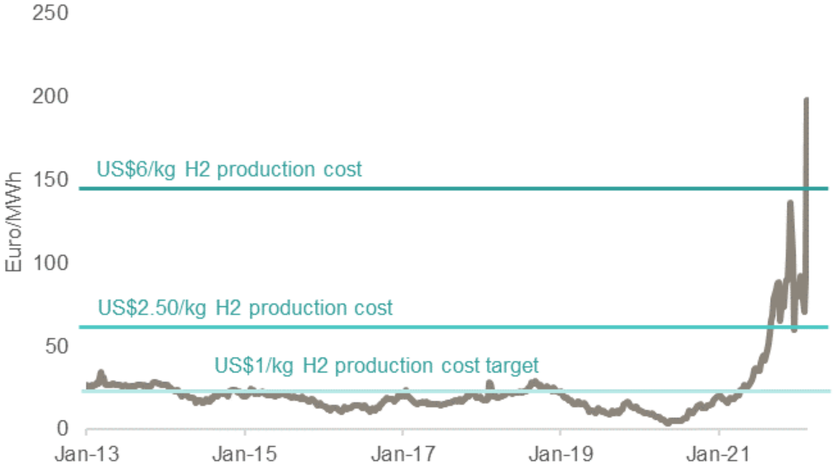
To put hydrogen's competitiveness into perspective:

- Producing green hydrogen from renewable electricity currently costs between US$3/kg and US$6/kg
- The target for the hydrogen industry has been to bring this down to US$1/kg through technological improvements and economies of scale
- US$1/kg equates to a competitive cost level with historical gas prices
- World gas prices have rallied since mid-2021 and accelerated since Russia's invasion of Ukraine
- Current European gas prices equate to a hydrogen cost of ~US$6/kg

Green hydrogen production costs are expected to fall with increasing economies of scale, but are competitive with hydrocarbons at current, albeit elevated, prices.

This cost analysis does not include the added strategic benefit of reducing reliance on Russian energy supplies. While gas prices are elevated for (hopefully) temporary reasons, it seems unlikely they will revert to historical levels. For European policy makers the path to improving energy security should be obvious and balance sheet light; they should offer a floor price of US$4-5/kg H2 and let private money fund the profitable build out of hydrogen infrastructure.

Figure 12. Chart of weekly average European day-ahead gas prices (Pegas); Note that spot prices of >€140/MWh equate to >US$6/kg H2



Source: Bloomberg, WPIC Research

Automotive demand for green hydrogen is somewhat incidental to the amount of hydrogen needed to replace natural gas; on our policy driven scenario, European FCEV demand for hydrogen is <200kt in 2030 versus European plans to replace Russian gas with up to 20mt of green hydrogen by 2030.

While the above discussion centres on the security of natural gas supplies, we have a view that increased hydrogen production would also accelerate the rolling out of hydrogen refuelling stations and the broad-based commercial adoption of FCEVs. After all, Europe also imports ~25% of its oil from Russia, although a rebalancing of global oil trade is easier than for natural gas from an infrastructure perspective. If this manifests it would likely push the pace of FCEV adoption and the associated platinum demand towards the upper boundary of our estimates.

Existing and proposed FCEVs

The early adoption of FCEVs has been led by bus and forklift truck operators. The depot-based nature of bus fleet operations makes them ideally suited for FCEVs as the operator can have dedicated hydrogen refuelling stations. Similarly, forklift trucks are working in a captive warehouse environment and benefit greatly from full performance rather than batteries where it declines towards the end of a shift.

The leaders of the light vehicle (LV) consumer market are currently Hyundai (NEXO) and Toyota (Mirai), which have both offered FCEV for a number of years. Automakers that expect to launch LV FCEVs in the near future include BMW (iX5, 2022), Honda (relaunching the Clarity, 2023), Hyundai (Staria, 2023), Kia/Hyundai (FK), Land Rover (Defender), and Ineos Grenadier amongst others.

Hyundai, Toyota and BMW are the greatest proponents of FCEVs, but many other automakers are also planning models.

Figure 13. Toyota Mirai FCEV, available to buy or lease now

Source: Toyota Motor Corporation

The emerging options appear to be broader in the light commercial vehicle (LCV) category, albeit less developed, with Ford, Renault, Stellantis, and Tevva all expecting to start LCV FCEV sales within two years.

Figure 14. Zerro FCEV Ambulance

Source: Zerro Ambulance

The benefits of FCEV over alternative low carbon drive train options are probably at their strongest in the heavy-duty (HD) size due to the capacity utilisation considerations, the load capacity losses sacrificed to the weight of the battery, and for the largest vehicles the practical considerations of road and tyre wear and even the maximum weight allowances for infrastructure such as bridges. Indeed, this segment has the greatest number of manufacturers involved, but it is less developed than the LV segment with most of the offerings somewhere between development and advanced trials. In no particular order, companies involved in the development of HD fuel cell trucks include Hyzon, Cummins, Ballard, Volvo and Daimler, Bosch, Hyundai, MAN, Toyota, and Nikola. The HD segment also includes buses, which as mentioned are already on the road in many cities around the world, particularly in China and Europe.

Heavy-duty vehicles benefit most from FCEV range, refueling times, capacity utilisation and light system weight compared to batteries.

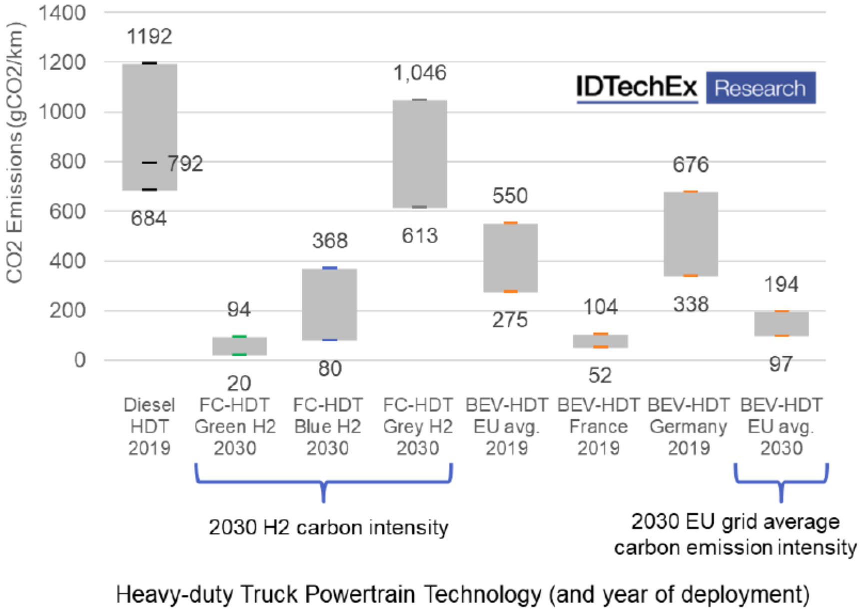
Figure 15. Hyundai Xcient fuel cell truck implemented in Switzerland for fast moving consumer goods transport

Source: Hyundai Motor Company

According to the ICCT, the HD segment accounts for only 10% of the global vehicle fleet and yet is responsible for emitting 43% of its greenhouse gas emissions. IDTechEx estimates that significant CO_2 savings could be made switching to FCEVs in the HD sector if fuelled with green hydrogen.

The heavy-duty segment is only 10% of the current global fleet but accounts for 43% of its emissions.

Figure 16. IDTechEx estimates that the HD segment could deliver significant emission reductions switching to FCEVs using green hydrogen



Source: Hyundai Motor Company

According to the European Environmental Bureau, the construction sector, which includes mining, accounted for 36% of global final energy use and 39% of energy related CO_2 emissions in 2017. To put this into perspective, mine trucks can weigh 220 tonnes and burn 134 litres of diesel an hour. Fuel cells are perfectly suited operationally for decarbonising industrial and agricultural applications such as mine trucks, excavators and agricultural tractors when the ability to generate fuel onsite from renewable power, and the high-capacity utilisation rates are necessary advantages. Indeed, WPIC member, Anglo American Platinum is currently trialling a fuel cell mine truck at its Mogalakwena platinum mine in South Africa. Anglo American has a target of transitioning its 400 strong fleet of mine trucks to FCEV by 2034, including those operated by Anglo American Platinum.

Although not included in this report, fuel cell applications extend to the construction and rail sectors.

Furthermore, operators in a number of countries around the world are trialling fuel cell powered trains on lines that currently operate diesel locomotives, and which would be commercially unviable to electrify, principally remote and branch lines.

Figure 17. Anglo American Platinum mine truck

Source: Anglo American

Figure 18. FCEV bus falls into the HD category

Source: Ballard

One final, albeit small sector suited to FCEV's range and refuelling benefits is automotive racing. For example, with the aim of promoting hydrogen fuel cells Le Mans is launching a hydrogen fuel cell category in the 2024 edition of the 24 hour endurance race, with a prototype in advanced development.

FCEV production estimates

Forecasting the pace of FCEV penetration is a tricky business, as already highlighted there is substantial and growing support for the hydrogen economy, but matching up near-term ambition with real-world action is difficult. Furthermore, while the light commercial vehicle (LCV) and HD segments are best suited to the advantages offered by fuel cells, the LV segment is currently the most developed with regard to currently available vehicles.

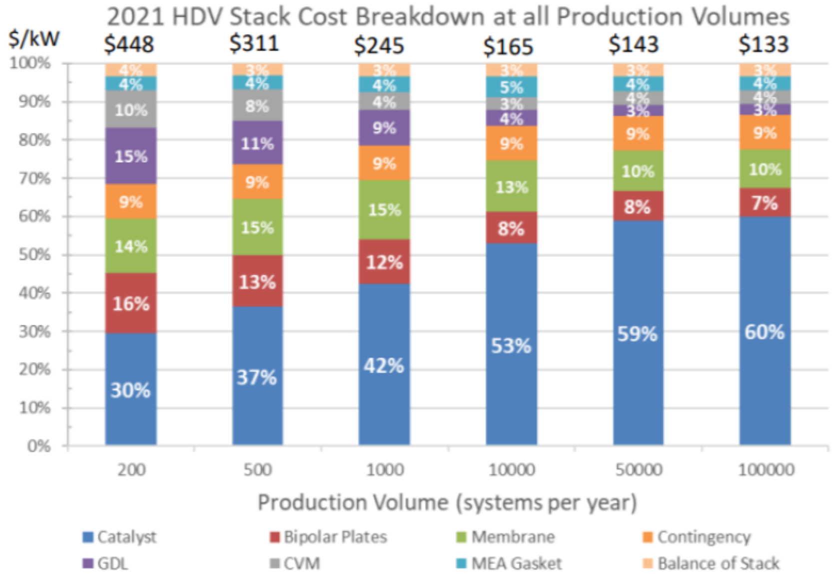
What we do have is good visibility on LV FCEV production numbers to date, as well as planned fuel cell production capacity plans for some of the major players, although whether those fuel cells are destined for on-road, off-road or static purposes is not always clear.

Hyundai, for example, currently has fuel cell manufacturing capacity of 23,000 units per annum and is planning to commission two further 50,000 unit factories by the end of 2023, taking its total capacity to 123,000 units per annum, which it is aiming to increase to 700,000 by 2030 (500,000 for FCEVs But if we assume that all are using the power and estimated loadings of the fuel cell used in the Nexo, 123,000 fuel cells a year equates to platinum demand of 175 koz p.a, while 700,000 units equates to a million ounces, although we would expect the loadings per kW to be thrifted between now and then.

Hyundai has some of the most ambitious plans for FCEV manufacturing, planning to reach output of 700,000 fuel cells stack per annum by 2030.

It is worth noting that production volumes are the key driver to achieve economies of scale and bring down the system cost of FCEVs towards parity with ICE. This is illustrated in the following chart produced by the US DOE, which shows that costs almost halve going from producing 1,000 to 100,000 fuel cells per year.

Figure 19. Increasing economies of scale are key to bringing down fuel cell system costs



Source: US Department of Energy/Strategic Analysis Inc, IDTechEX

Production volumes are key to delivering economies of scale and reducing fuel cell costs.

Consequently, we have examined two scenarios. Firstly, a policy-driven scenario, where FCEV adoption is driven by government and regional subsidies, incentives, and legislated targets. And secondly, a commercially-enhanced adoption scenario, where government and regional policies have engendered infrastructure critical mass and FCEV and hydrogen production economies of scale sufficient to promote widespread adoption on the grounds of costs and practicable usability.

Forecast FCEV production

The first thing to emphasise is that our regional FCEV estimates are based around production rather than sales. This has a particularly big impact in North America where, in California, LV FCEV sales have been amongst the highest in the world, albeit dominated by vehicles made in Asia. In contrast, while the US could be an important producer of HD FCEVs, there is a lack of a coherent federal hydrogen policy, which has prompted us to take a cautious approach to US production estimates in the policy driven scenario.

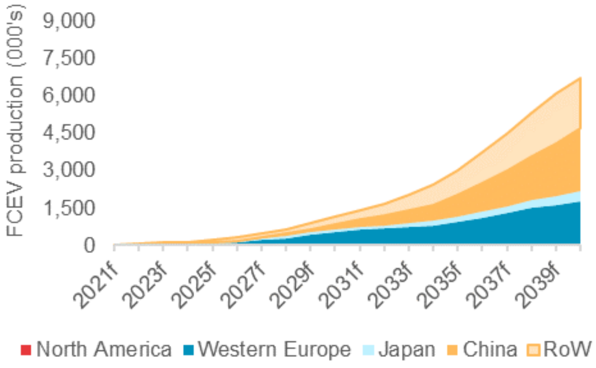
Regional estimates are based upon production not sales.

LV FCEV production scenarios

In the policy-driven scenario, we anticipate that LV production will be led by China, followed by South Korea, with more than 50% of its output planned for export, then Europe. Annual production could exceed 200,000 units in 2024 and two million units in 2030. We have taken a view that the greater current commercial availability of LV FCEVs means that adoption in this sector could run ahead of LCVs and HDs. Thus, while there is upside baked into the commercially-enhanced adoption scenario, it is relatively muted.

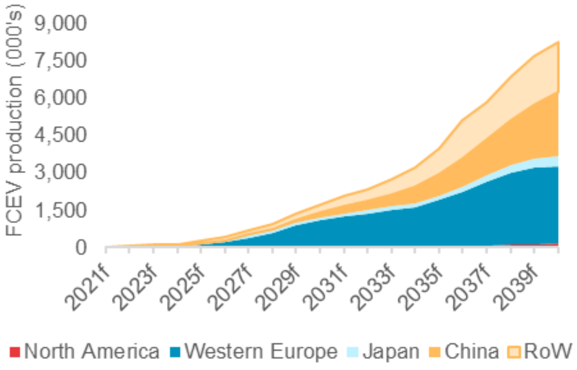
Although heavy-duty FCEVs have a stronger rationale, light vehicle adoption is important to provide economies of scale for regional hydrogen refueling infrastructure.

Figure 20. Policy-based LV FCEV production by region dominated by RoW (South Korea), Europe and China



Source: WPIC Research

Figure 21. Commercially-enhanced LV production assumes greater output from Europe and North America



Source: WPIC Research

LCV FCEV production scenarios

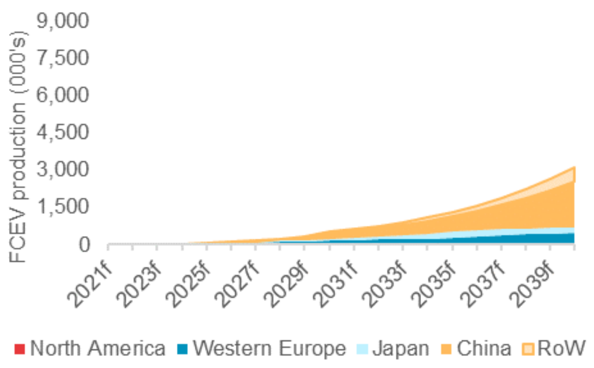
LCV production numbers in the policy driven scenario (fig 20) are expected to be led China and South Korea with a little more upside built into all of the regions under the commercially-enhanced scenario. Given that the fuel cell powertrains are likely to be highly interchangeable between LCV and LV models there could be substantial variability in the outlook for LCV if relative demand causes automakers to prioritise one or the other.

China and South Korea are the key markets driving FCEV growth.

This last point could be true even for HD if the fuel cells are designed to be used as multiple units; for example, Toyota has been trialling Hino trucks with two Toyota Mirai fuel cells providing the motive power.

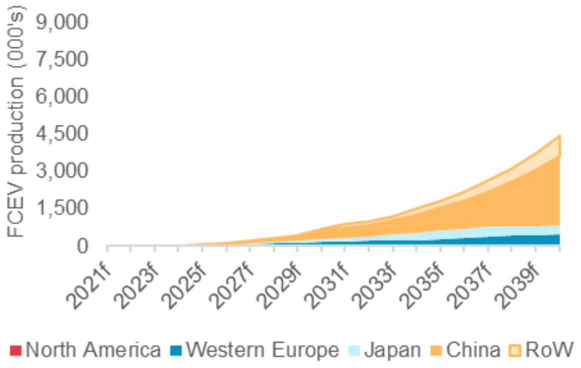
Looking further out, it is also possible that an accelerated uptake of HD FCEVs could begin to cannibalise demand from the LV market, in particular, which would reduce demand from that sector and increase HD demand.

Figure 22. Policy-based LCV FCEV production is dominated by China, with other regions broadly balanced (excluding North America)



Source: WPIC Research

Figure 23. China still dominates in the commercially-enhanced LCV production scenario, but increased output assumed for other regions



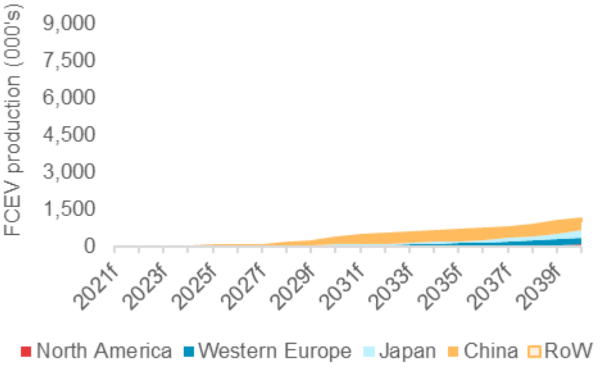
Source: WPIC Research

HD FCEV production scenarios

It is all about China, China and China in the policy-driven scenario, with a particular focus on buses, which can be supported by dedicated refuelling facilities. Furthermore, China has the most ambitious HRS plans, and although a large country, an extensive refuelling network is supportive of HD transportation and distribution networks along specific transport corridors. Other regions have potential, but we only see significant early production come through in the commercially-enhanced scenario, noticeably in North America.

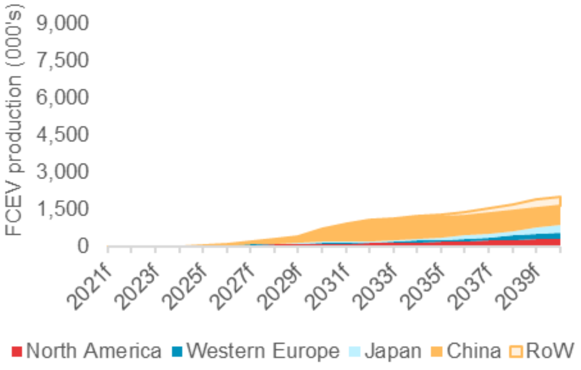
Lacking a cohesive national policy framework leads to the US not featuring strongly in terms of FCEV production, but California is expected to be a major market for FCEV imports.

Figure 24. Policy-based HD FCEV production is dominated by China, followed by Europe and Japan



Source: WPIC Research

Figure 25. China still dominates in the commercially-enhanced HD scenario but output from RoW kicks up considerably as does production in North America



Source: WPIC Research

FCEV penetration rates remain conservatively low

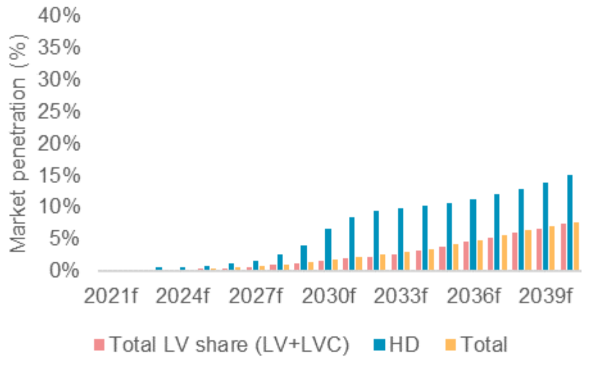
Demonstrating how a little shake of the dog can wag the tail a long way, growth rates are very similar under both scenarios, with CAGRs of a little over 50% between now and 2030, albeit off a very low base, before falling below 20% thereafter. FCEV market penetration remains relatively low at only 2% for LV + LCV in 2030, rising to 8% later in the decade, and 3% rising to 11% under the commercially-enhanced adoption scenario. While these growth rates appear high, we note that they are broadly similar to those seen in the BEV uptake over the past ten years.

Projected FCEV CAGRs are similar to those delivered by BEVs over the past ten years.

Looking at the FCEV segments in more detail, while smaller in numbers, the penetration rates are much higher for HD vehicles, reaching 8% by 2030 and heading past 15% later in the decade under the policy driven scenario, but almost 40% by 2040 under the commercially-enhanced scenario. We have assumed that individual markets are likely to have FCEV saturation points relative to other drivetrain technologies, which creates a stepped production profile depending upon the starting dates of significant FCEV vehicle adoption and HRS roll-out in different regions.

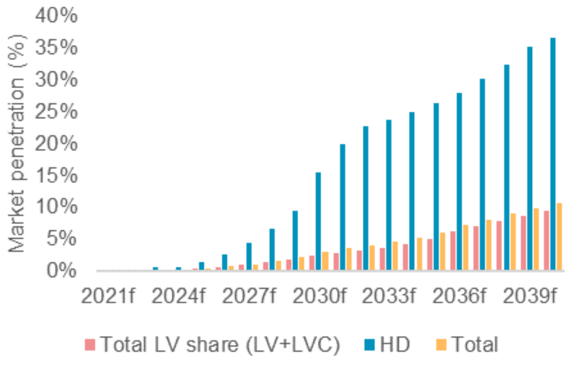
Penetration rates are expected to remain relatively low in the light and light commercial vehicle segments but could be as much as 40% in heavy-duty.

Figure 26. HD FCEV market penetration reaches around 15% under the policy-driven scenario…



Source: WPIC Research

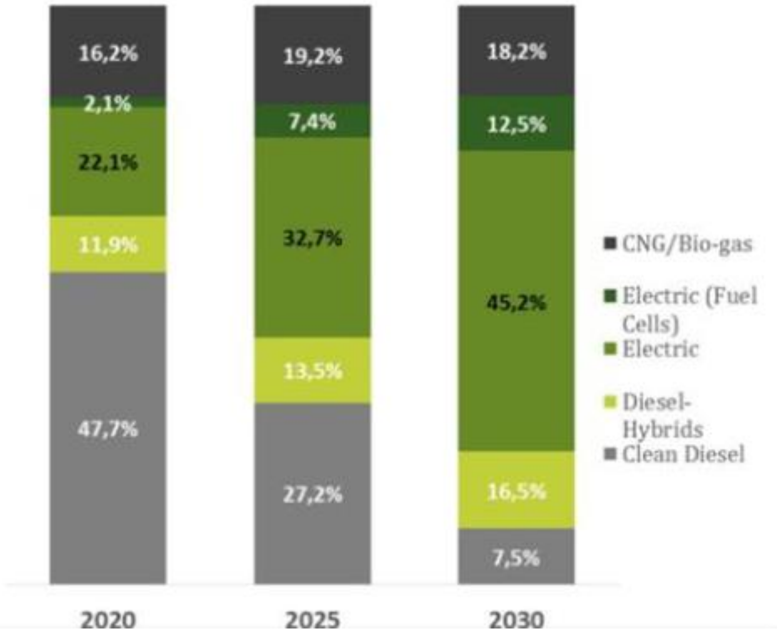
Figure 27. …but reaches almost 40% under the commercially-enhanced scenario, in contrast to more muted upside in LV and LCV FCEVs



Source: WPIC Research

To provide some context to our estimated penetration rates, Solaris, one of Europe’s largest bus manufacturers expects FCEV buses to make up 12.5% of the European city bus fleet by 2030.

Figure 28. Solaris Bus and Coach expects FCEVs to make up 12.5% of the European bus fleet by 2030



Source: Solaris Bus and Coach, IDTechEX

Building the FCEV demand outlook

Power and platinum loadings

After vehicle production numbers, fuel cell power output and platinum loadings are the most important factors in determining FCEV demand for platinum. In general, platinum loadings are greater for HD over LV and LCV, due to higher capacity utilisation needs resulting in increased potential for catalytic poisoning by impurities in the fuel and from other sources. We estimate that current loadings are typically around 0.53g/kW for HD vehicles, and between 0.18g/kW and 0.13g/kW for LCV and LV.

We expect platinum loadings in fuel cells to be thrifted as confidence grows in the deliverable lifetime mileages, and the cleanliness of the hydrogen as impurities can poison the platinum catalyst.

As with catalytic converters there are ongoing efforts to reduce the platinum loadings of PEM fuel cells, with the DOE having a target of 0.10g/kW by 2030, which appears achievable. Our estimates assume that average LV loadings decline to 0.10g/kW by 2030 and further reduce to 0.08g/kW later in the decade. Similarly, HD loadings are expected to decline to 0.25g/kW over the same time period.

Trade-off with battery capacity

As mentioned earlier in the report, a FCEV incorporates an auxiliary battery as well as the fuel cell. This means that the power supplied by the fuel cell is often significantly below the power of a comparable ICE vehicle today as the electric motor can draw on the fuel cell and the battery during peak load, with the fuel cell powering the motor and recharging the battery when load requirements are lower.

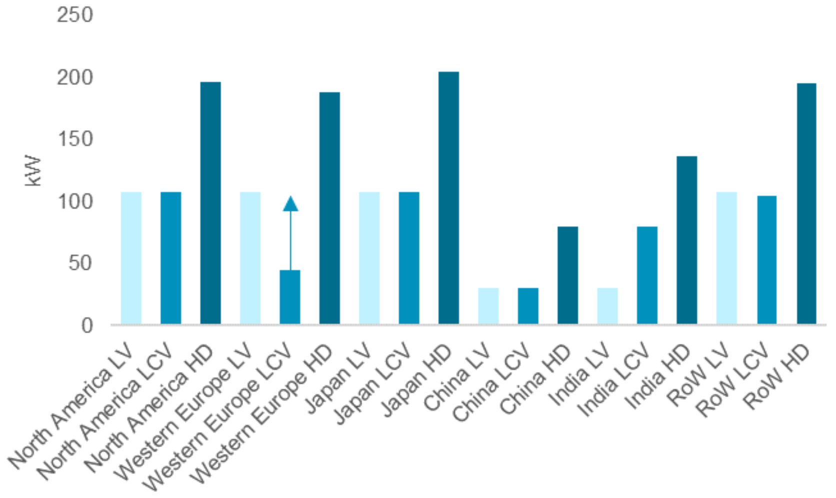
This means that there is a trade off in the size of the fuel cell with the size of the battery. At one end of the spectrum, constant load applications, the fuel cell will be sized to provide almost all of the power requirements of the electric motor and the ancillary battery will be relatively small. At the other end the vehicle could almost be considered a BEV with a smaller fuel cell acting as a range extender. Examples of the latter include buses in China with 30kW fuel cells and a large battery pack in contrast to the typical 70-100kW fuel cell and 30-45 kWh battery of a single decker bus in Europe. To provide some context to these numbers, a typical single decker diesel bus in Europe would rate at 220-260kW with the difference reflecting the instant torque of electric motors.

We expect fuel cell power capacities to grow with time in the light commercial and heavy-duty segments in particular.

We think these preferences will be somewhat regional in nature, and generally accentuate existing differences in internal combustion engine capacities in different parts of the world (e.g. smaller engine capacities in China than in comparable vehicles in the US). And we are also forecasting fuel cell sizes to increase in some geographies, with initially smaller fuel cells and larger batteries gradually being switched to larger fuel cells and smaller batteries. In some geographies like Europe, this reflects the current packages offered by automakers. For example Stellantis are using Symbio fuel cells in their light commercial vehicle, which are currently offered at 45kW, but with Symbio planning larger fuel cells in the near future when there is scope to gain carrying capacity by changing the balance of the system. With relatively few HRS currently available, there is also an initial advantage in being able to charge the vehicle and use the fuel cell as a range extender by stopping to fuel up opportunistically when passing HRS, but as availability of HRS improves this equation begins to switch.

There are regional variations in the balance between fuel cell power output and battery capacities.

Figure 29. FCEV – Estimated regional average power per vehicle by category



Source: WPIC Research

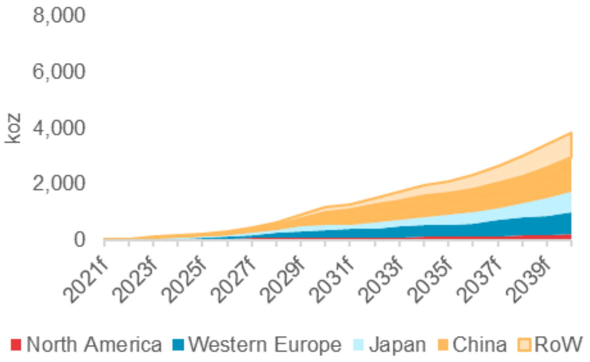
There are regional variations in the balance between fuel cell power output and battery capacities.

Estimated FCEV demand for platinum

Pulling together the FCEV production estimates, fuel cell power outputs and platinum loadings results in the following platinum demand forecasts. Under both scenarios, FCEV demand is initially very modest with the first real step up in demand coming with the commissioning of larger fuel cell production facilities in South Korea in 2024. Over time, however, the demand begins to become more meaningful, in the policy-driven scenario reaching 1 Moz p.a. by 2030, continuing to grow to almost 4 Moz by 2040. The initial trajectory is similar in the commercially enhanced adoption scenario, before accelerating to 1.3 Moz p.a. by 2028, moving on to almost 6.7 Moz by 2040.

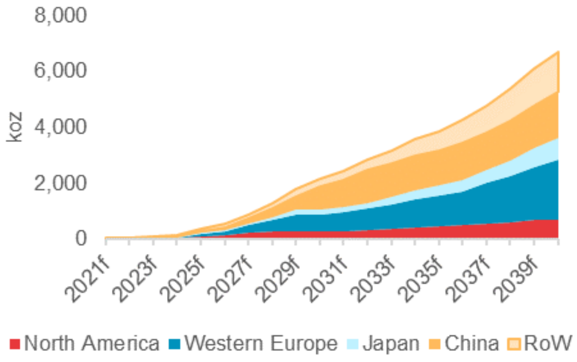
FCEV demand for platinum could equal 1 Moz by 2030 on policy driven adoption alone. For reference, current platinum mine supply totals ~6.1 Moz.

Figure 30. FCEV demand for platinum reaches more than 1Moz by 2030 in the policy driven scenario, and almost 4Moz by 2040



Source: WPIC Research

Figure 31. The relatively greater market penetration of HD FCEVs in the commercially enhanced scenario boosts platinum demand due to higher HD loadings



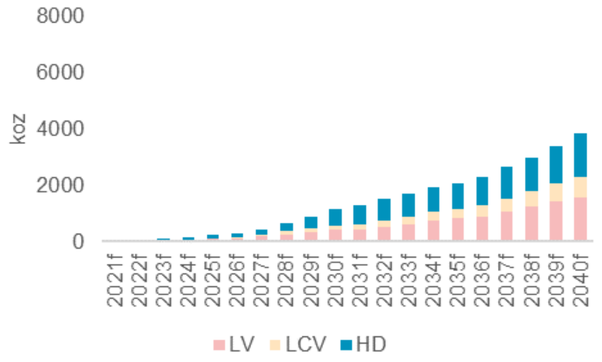
Source: WPIC Research

In terms of the split of demand by vehicle category, it is expected to be relatively evenly split between LV+LCV and HD under the policy driven scenario. Under the commercially enhanced adoption scenario, the relatively higher market penetration of HD FCEVs, with their associated higher platinum loadings, results in HD demand for platinum significantly exceeding LV and LCV demand.

As already mentioned, however, the flexibility of fuel cells between different platforms and vehicle segments means the balances between the three segments could vary, although we have a good degree of confidence in the total production outlook for fuel cells and the corresponding demand for platinum.

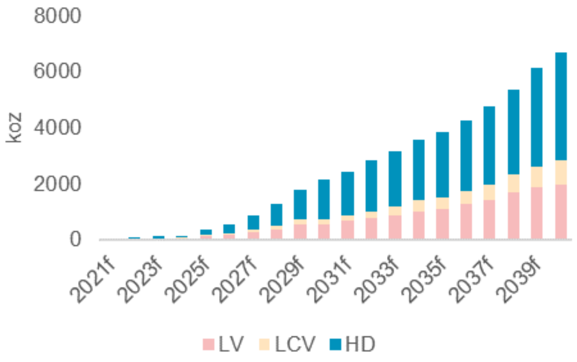
The balance in demand between vehicle segments could vary but the outlook for fuel cell production has a relatively high degree of confidence.

Figure 32. FCEV demand for platinum reaches is more than 1Moz by 2030 in the policy driven scenario, and almost 4Moz by 2040



Source: WPIC Research

Figure 33. The relatively greater market penetration of HD FCEVs in the commercially enhanced scenario boosts platinum demand due to higher HD loadings



Source: WPIC Research

FCEV outlook compared to ICE

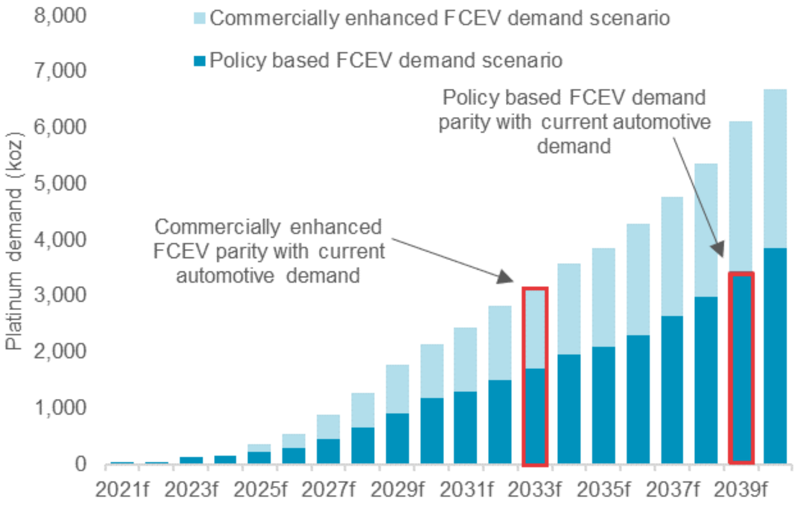
For comparative purposes, automotive demand for platinum in 2022f is expected to total 3,129 koz (for catalytic converters).

Exceeding this level of annual demand from FCEVs is achieved in 2039 under the policy-led scenario. Despite many commentators predicting the end of the internal combustion engine, we are of the view that this is impractical on grid and economic grounds and that continuingly stringent emissions regulations should allow for internal combustion engines to continue to be an important part of the drivetrain mix for a long time to come. Nonetheless even the policy-based scenario shows that FCEV demand for platinum could exceed the current demand from internal combustion engine vehicles and add to the future demand from the remaining ICE fleet. (We intend to quantify these effects in a future *Platinum Essentials*)

FCEV demand for platinum could equal current automotive demand as soon as 2033.

In the commercially-enhanced demand scenario, FCEV demand for platinum reaches 2022f automotive demand by 2032. This is a significant increase in the demand for platinum, which will most likely result in total demand being close to supply growth possibilities. Mining companies will need careful planning, always difficult when they need to be making investment decisions now, to satisfy demand 10 years in the future. There may be a need for some cannibalisation of demand from jewellery or industrial consumers, and possibly thrifting in fuel cell catalyst loadings beyond our assumptions. At this point, it is also worth reiterating that this analysis considers only FCEV demand growth and does not look at the potential deployment of and platinum demand from PEM electrolysers for the production of green hydrogen, fuel cells used in rail or shipping transport and stationary fuel cells, which could be considerable.

Figure 34. FCEV demand for platinum



Source: WPIC Research

Conclusion

BEVs and FCEVs each have a role to play in decarbonising transportation.

The reality is that this is not a case of BEV versus FCEV; decarbonising the world is such a herculean task that no single low-carbon technology is going to win out; we're going to need to use all of them. As a result, the future will in some regards look not totally unfamiliar, with some consumers having a preference for BEV or FCEV in the same way that people have favoured petrol or diesel, with preferences dictated by lifestyle or capacity utilisation needs.

Platinum demand from FCEVs could exceed that from catalytic converters today, adding over three million ounces to annual automotive platinum demand in eleven years.

The platinum demand potential from FCEV alone is relatively small to begin with under both scenarios, but becomes material from the late 2020's and accelerates to significant levels quickly thereafter. It is worth mentioning again that this platinum demand growth excludes PEM electrolysers for the production of green hydrogen, fuel cells used in construction, rail or shipping transport, and stationary fuel cells, which could be considerable. While fuel cell vehicle numbers grow from low levels, the projected penetration rates and volumes are very similar to those seen in the penetration of BEVs since 2012 and those currently projected to 2030, making the FCEV projections entirely reasonable. What we have not examined here is the interplay between the growth in platinum demand from FCEV and the outlook for ICE demand for platinum. Our view is that ICEs will remain a significant portion of the global drive train mix well into the 2030s; from a platinum demand perspective, with likely volume declines being fully offset by tighter emissions standards and correspondingly higher platinum loadings and platinum substitution for palladium. The corresponding need for platinum for ICE emissions control, combined with the additional three million ounces of FCEV platinum demand could, without increases in supply, cause platinum scarcity which would hinder FCEV growth rates, (much as battery material supply limitations could be for BEVs over the next decade). However, identified platinum reserves and resources are significant and production can be expanded with time to satisfy demand growth. While platinum scarcity will support the higher PGM basket prices necessary for mine supply growth (from c.6.1 Moz in 2022f), this growth will be greatly enhanced by the proliferation of increasingly supportive hydrogen policies and funding globally. This should also encourage the broad uptake of this important decarbonising technology.

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