PLATINUM ESSENTIALS

Unpacking the economics of the hydrogen economy reinforces conviction that platinum demand will benefit from a major new emerging end-market

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Platinum's largest opportunity within the hydrogen economy lies with fuel cell electric vehicles (FCEV), particularly heavy-duty. WPIC expects hydrogen end-uses to account for 11% of total annual platinum demand by 2030 (~875 koz), of which fuel cells make up over 60%. While initial FCEV adoption has been slow, the declining levelised cost of hydrogen (LCOH) from growing electrolysis capacity will reduce hydrogen costs whereby we forecast European and Chinese HD-FCEV fleets achieve total cost of ownership (TCO) parity with diesel by 2030 (Fig. 2). Greater HD-FCEV adoption results in platinum demand growth from hydrogen end markets which almost offsets declining autocatalyst demand (Fig. 1) resulting in broadly stable total platinum automotive demand within our two- to five-year market outlook.

The slower than anticipated ramp up of the hydrogen economy reflected a lack of government support by way of regulation or subsidisation. This has weighed on hydrogen-related investment appetite. However, the last 12-18 months has seen a marked increase in available subsidies and we have refreshed our analysis of the HD-FCEV market. WPIC expects three factors to support HD-FCEV markets in the coming years which will help address the core hurdle of HD-FCEV cost competitiveness relative to incumbent diesel fleets.

- OEMs plan to increase fuel cell production capacity from 24 GW to 91 GW per annum by 2030f. Rising output should support economies of scale to lower FCEV production costs and raise consumer choice,
- Subsidies are lowering the upfront capital costs of HD-FCEV, helping to mitigate currently higher H_2 fuel prices versus diesel, and
- Electrolysis technology improvements and production tax credits are forecast to lower the levelised cost of hydrogen (LCOH) by ~55% to 2030.

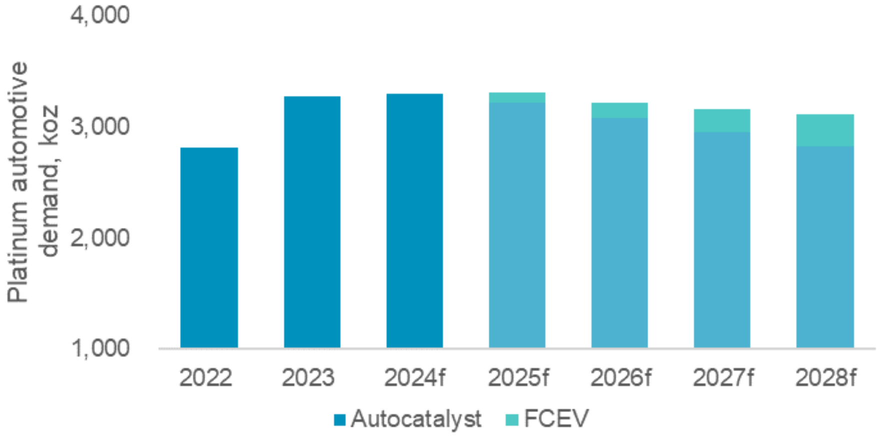
Hydrogen end markets should account for 11% of total platinum demand by 2030.

As the economic hurdles to HD-FCEV adoption recede, we forecast HD market share will reach 5% by 2030, driven by China and Europe. HD-FCEV market share gains support incremental platinum demand, bolstering the investment case for platinum where consecutive market deficits from 2023 through to at least 2028 are forecast. On average, platinum market deficits are expected to average ~430 koz between 2025 to 2028 (~5% of demand) which should reduce above ground inventories and support higher prices.

Heavy-duty fuel cell market share is forecast to increase to 5% by 2030 as the total cost of ownership converges to parity with diesel in Europe and China

Platinum markets are expected to remain in deficit through 2028f as hydrogen linked demand growth offsets declining autocatalyst demand.

Figure 1. Emerging FCEV demand offsets lower ICE autocatalyst demand



Source: Metals Focus (2022 -2024f), WPIC Research thereafter

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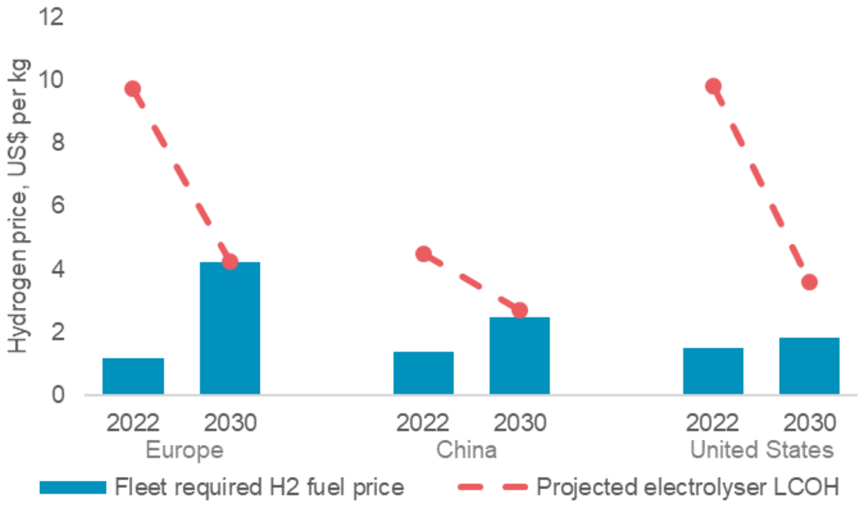
The hydrogen economy is a large new emerging market for platinum demand, estimated at ~875 koz by 2030f.

Figure 2. HD-FCEV demand growth will accelerate as the required hydrogen prices for both fleets and electrolysers converge around 2030



Source: IEA, Company data, WPIC research

Subsidies, cheaper HD-FCEVs and the falling cost of hydrogen fuel result in HD-FCEV cost competitiveness with diesel by 2030 in Europe and China, but lower diesel prices and weaker subsidies leave a gap in the US that is expected to result in weaker FCEV adoption in that geography.

Introduction

The global energy transition will require a multi-technology approach to achieve decarbonisation targets. The “hydrogen economy” offers a low to zero emission solution for hard to abate sectors such as heavy industry, power and grid balancing and commercial/industrial logistics and transport (land, sea, and air). An in-depth explanation of the hydrogen economy is discussed in WPIC's *Hydrogen 101* report (*link*). This report aims to unpack the current and projected economic competitiveness of hydrogen while presenting our outlook for hydrogen linked platinum demand to 2030.

WPIC expects hydrogen-linked annual platinum demand to increase from 40 koz in 2023 to around 875 koz in 2030 (Fig. 3) thereby constituting in 11% of total annual platinum demand. Hydrogen-related platinum demand can be broadly ascribed to upstream production via electrolysis and downstream utilisation within fuel cells for mobility or stationary power applications. Electrolysis will account for between 20% to 25% of hydrogen related platinum demand out to 2030 while fuel cell applications underpin most incremental platinum demand.

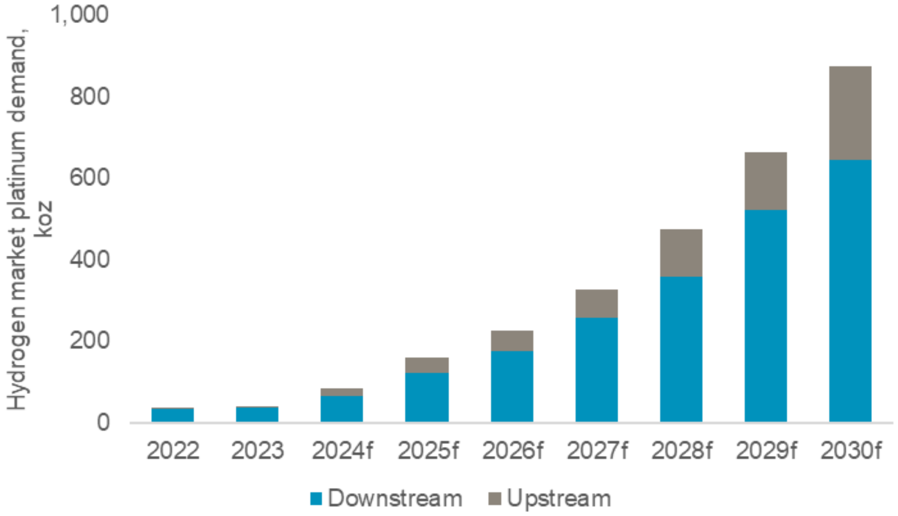
With the important role of fuel cell technology (specifically in heavy-duty vehicles), it is necessary to complement policy targets (*link*) with fundamental hydrogen market realities that have resulted in an initial slow adoption rate of FCEV.

HD-FCEV will only gain market share with more competitive costs versus incumbent diesel.

For a successful heavy-duty (HD) FCEV rollout and improved platinum demand forecast certainty, WPIC considers that the key enablers for improved HD-FCEV adoption are;

- **Rising fuel cell production capacity:** Our research undertakes a bottom-up assessment of announced OEM fuel cell manufacturing capacity with a view that increased manufacturing capabilities will underpin economies of scale with associated lower vehicle prices,
- **Total Cost of Ownership (TCO):** We evaluate the TCO of HD-FCEV against incumbent diesel fleets across Europe, China, and the United States. The altruistic decarbonisation benefits of green hydrogen cannot be expected to initiate a switch between diesel to hydrogen and this needs to be coupled with a lowering of the TCO of HD-FCEV fleets, and
- **Reconcile electrolysis levelised cost of hydrogen (LCOH):** We assess whether future electrolysis plants can supply hydrogen at a price that enables HD-FCEV fleets to achieve TCO parity with diesel while also generating a return on investment.

Figure 3. Hydrogen-linked platinum demand approaches 875 koz per annum by the end of the decade



Source: IEA, Company data, WPIC research

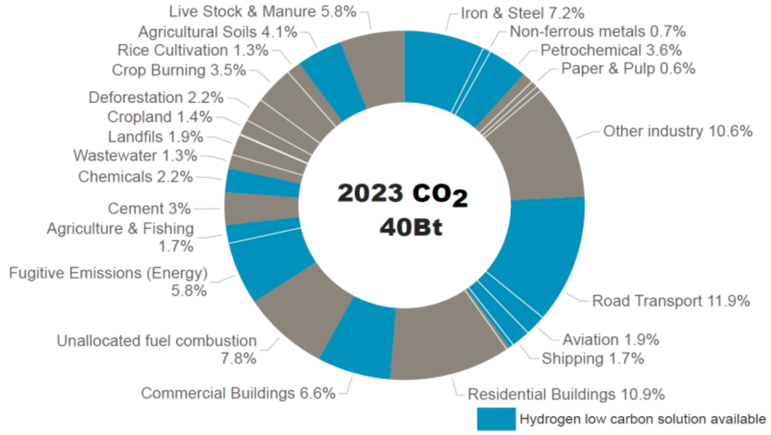
Blue and green hydrogen will help decarbonise hard-to-abate sectors.

Fuel cells do the heavy lifting

The energy transition is a dynamic process, where no single technological pathway is sufficient to achieve decarbonisation goals. Green technologies such as renewable energy, batteries, biomass, or green hydrogen should not be seen as competing with one another, but rather as complementing one another for a common goal of reducing emissions. The hydrogen council expects the hydrogen economy to enable decarbonisation within industries that account for 20% (Fig. 4) of global carbon dioxide (CO_2) emissions. But what is the hydrogen economy?

The hydrogen economy can be segmented into upstream, midstream, and downstream. Upstream comprises hydrogen production, which today is a carbon intensive process typically utilising steam methane reformation (SMR). SMR produces grey hydrogen, however, momentum is building towards low carbon intensity blue and green hydrogen respectively. Blue hydrogen production uses carbon capture and storage (CCUS) technology alongside SMR to reduce CO_2 emissions by around 60% to 99% versus grey hydrogen.

Figure 4. Hydrogen could decarbonise industries which accounted for 20% of total global CO_2 emissions in 2023

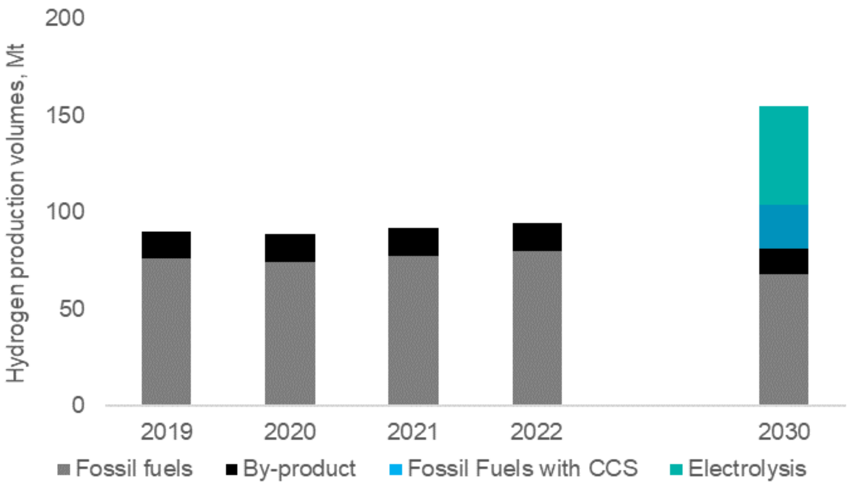


Source: Our World in Data, WPIC research

Green hydrogen is a zero-emission production route, produced via electrolysis of water (i.e. splitting water into hydrogen and oxygen) utilising renewable energy. Two established electrolysis technologies have been commercialised, Alkaline and Proton Exchange Membrane (PEM).

Total hydrogen production is forecast to increase by 6% CAGR between 2022 to 2030. However, all incremental hydrogen production growth will come from low carbon technologies thereby requiring the establishment of large new markets for blue and green hydrogen (Fig. 5).

Figure 5. Existing hydrogen production is reliant upon fossil fuel use such as coal gasification and steam methane reforming (SMR). Low carbon hydrogen via electrolysis and CCS should increase to ~50% market share by 2030.



Source: IEA, WPIC research

A large existing hydrogen market offers a ready-made offtake opportunity for low-carbon hydrogen producers.

PEM electrolysis is forecast to have a 38% market share of the electrolyser market.

Electrolysers

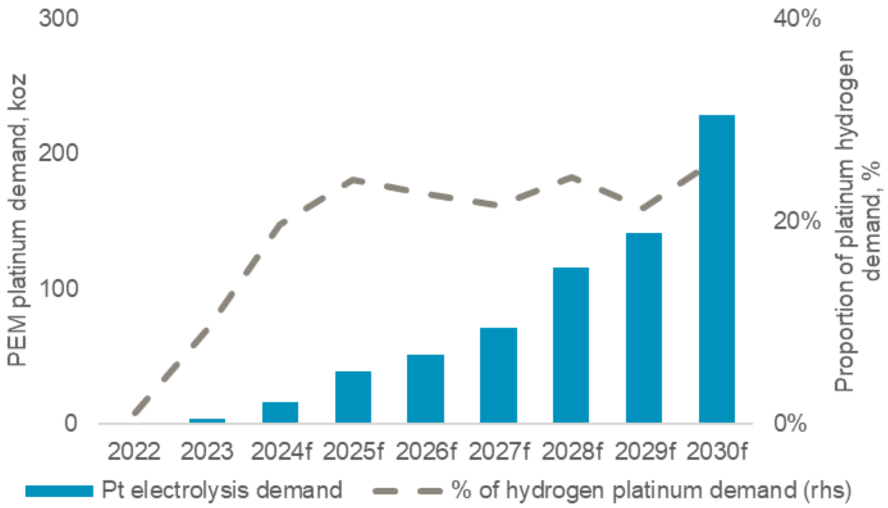
PGMs (platinum and iridium) are used within a PEM electrolyser's catalyst coated membrane. Like most existing industrial applications, platinum demand is reflected as net of recycling and is largely a function of net new plant commissioning's. WPIC utilises a blend of data from the IEA, The Orange Group and internal research to forecast electrolyser capacity growth to 2030f. Electrolyser capacity is expected to reach a cumulative 212 GW by 2030 from 6 GW in 2023, representing growth of 66% CAGR.

Electrolyser linked platinum demand will initially be volatile as initial green hydrogen projects are commissioned.

PEM is forecast to have a 38% share of the electrolyser market in 2030. Whilst some alkaline electrolyser designs are starting to use platinum catalysts, how widespread this practice is, is not clear and thus not modelled by us at this time. The potential for platinum catalysts to be used at scale in alkaline electrolysers presents upside to our base case projections.

The timing of PEM capacity additions will underpin annual platinum demand which is forecast to increase from 4 koz to 229 koz between 2023 to 2030f (Fig. 6). The near-term commissioning of PEM projects will result in electrolysis rapidly increasing its share of hydrogen related platinum demand over the next two years, eventually settling between 20% to 25% from 2025f. However, electrolysis is unlikely to become as large a proportion of hydrogen related platinum demand as the downstream applications within the hydrogen economy particularly once fuel cell electric vehicle deployment begins scaling.

Figure 6. PEM electrolysis underpins a meaningful minority contributor to hydrogen related platinum demand, accounting for around 20% to 25% of platinum demand linked to hydrogen



Source: IEA, The Orange Group, WPIC research

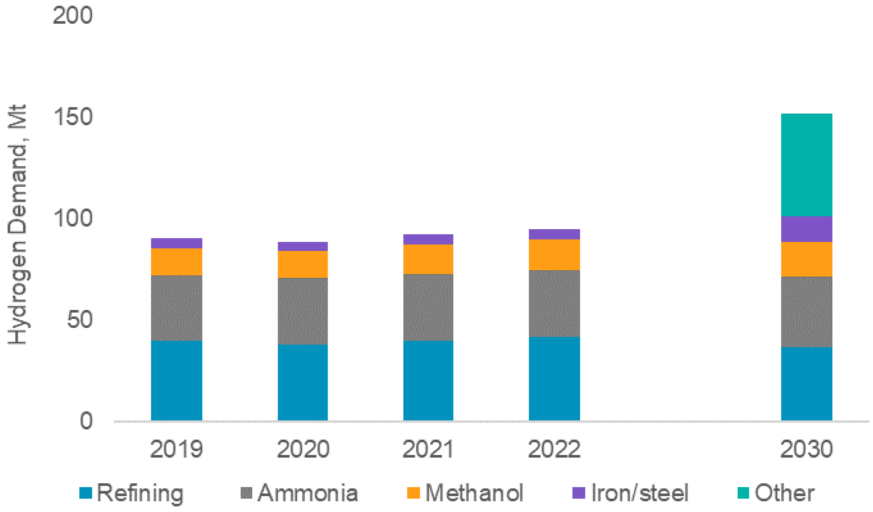
Fuel Cells

Fuel cell end markets will include mobility (land, sea and air) and stationary power applications.

The downstream component of the hydrogen economy relates to consumption. Today, grey and black hydrogen is primarily used in industrial processes, particularly within the petroleum industry, as a feedstock for fertiliser, and for other chemical production. These sectors will require decarbonisation by transitioning to blue and green hydrogen, but more importantly new end-markets are expected to develop with the emergence of low-carbon hydrogen supply. Today's ~95 Mtpa hydrogen consumption is forecast to increase to 150 Mtpa by 2030 (6% CAGR), underpinned by new end markets utilising clean hydrogen to achieve their decarbonisation goals (Fig. 7). Amongst these markets platinum demand will mainly be linked to PEM fuel cells over the longer-term.

Hydrogen fuel cells are a technology which utilise an electro-chemical process that combines hydrogen fuel with atmospheric oxygen to generate electricity, with water vapour being the only emission. WPIC expects annual fuel cell platinum demand to increase from 36 koz in 2023 to 645 koz in 2030f (51% CAGR), accounting for around 75% of hydrogen related platinum demand in that year.

Figure 7. Hydrogen demand is forecast to increase by 6% CAGR between 2022 to 2030, driven by new hydrogen economy demand ("other").



Source: IEA, WPIC research

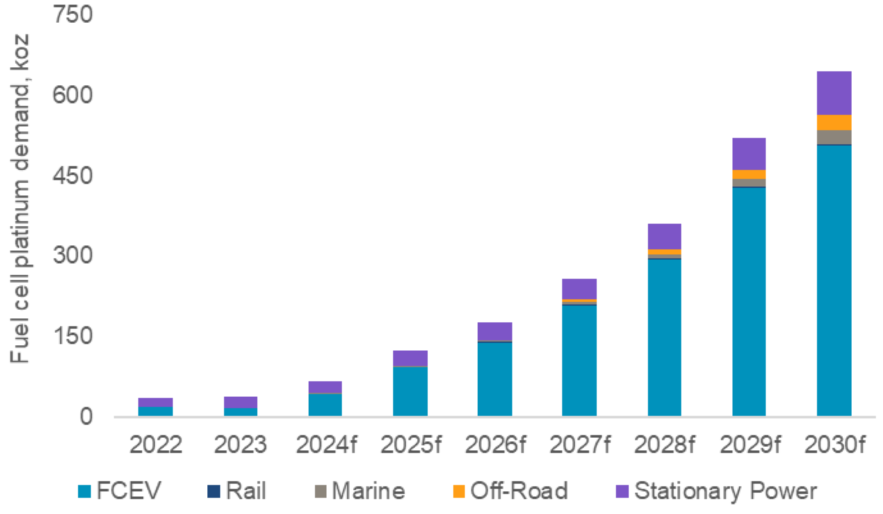
Fuel cell electric vehicles share characteristics with both internal combustion engine vehicles and battery electric vehicles, thereby supporting use across transport roles. Fuel cell production can be simplistically described as modular. This allows fuel cell manufacturers to sell fuel cell units to multiple end markets without requiring significant changes to the manufacturing process. In practice this would see a passenger vehicle using one fuel cell unit, while a heavy-duty vehicle might use two of the same fuel cell units because of its higher power requirements. Equally, fuel cells can also be used in stationary applications, such as for off-grid or back-up power generation.

Fuel cell platinum demand is forecast to exceed 600 koz by 2030.

The ability to service multiple end markets should allow fuel cell manufacturing capacity to achieve economically sustainable production utilisation rates whilst demand remains nascent. Fuel cells have the potential to support the decarbonisation of several mobility applications from road transport to rail, and marine applications. Towards the end of the decade, it is possible that fuel cell powered aeroplanes could also be in light commercial operations. At this point in time, the first flights are only just being completed in pre-production prototypes. Elsewhere, fuel cells may displace diesel generators in certain stationary power and micro-grid applications.

As some of these markets are only at a very nascent stage of development, our modelling is focused on the automotive industry and FCEVs. WPIC expects fuel cell electric vehicles (FCEV) will account for a large majority of total fuel cell platinum demand, around 80%, by 2030 (Fig. 8).

Figure 8. Fuel cell platinum demand is likely to be underpinned by road transport given the stage of development and underlying market size



Source: WPIC research

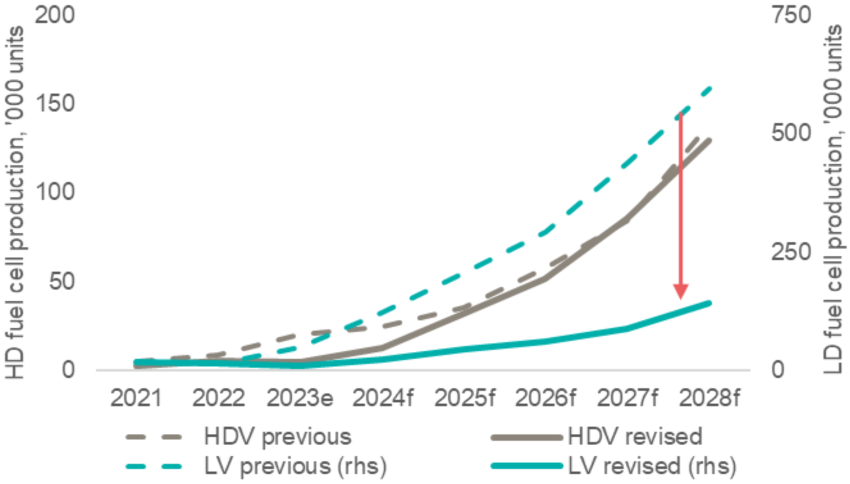
Battery technology and fuel cell technology are both required to decarbonise transport.

Beyond policy, what's the bottom line for FCEV?

WPIC has previously examined the potential demand for platinum from FCEVs utilising policy-based scenarios underpinned by national hydrogen policies (*link*). However, FCEV adoption has not met national targets primarily due to a general failure of legislative support for the roll out of hydrogen infrastructure. Elsewhere there is reluctance of some automakers to prioritise hydrogen vehicles amidst the rapid market share gains of battery electric vehicle (BEV) technology after COVID. Slower than expected FCEV adoption has led us to lower our outlook for light-duty FCEV adoption within the latest two- to five-year outlook (*link*).

Where BEV technology is suitable for LDV, it is less suitable for heavy-duty transport where cargo capacity is undermined by large and heavy batteries and utilisation rates are reduced by longer charging times versus refuelling. Compared to BEV, fuel cells are seen as an attractive technology to decarbonise heavy-duty transport and our medium-term HD-FCEV demand targets are largely unchanged (Fig. 9). WPIC expects HD-FCEV market share to increase off a low-base of <0.1% in 2023 to around 5% in 2030.

Figure 9. The evolution of market dynamics makes it less likely for light-duty FCEV production to scale of the next five years



Source: Bloomberg, Company data, WPIC research

Authorities have, to date, struggled to provide the necessary incentives to accelerate FCEV adoption.

WPIC expects HD-FCEV to account for most of the hydrogen related demand for platinum by 2030. Since early policy targeting FCEVs has thus far proved inadequate to drive uptake, WPIC will unpack the economics of hydrogen transport, and assess whether they are compelling relative to incumbent diesel.

The successful decarbonisation of heavy-duty transport requires enabling conditions being in place that support the adoption of HD-FCEVs by fleet operators. For fuel cells, these include both push- and pull-factors.

Push-factors

Push-factors involve automakers, regulators and governments "pushing" a product/technology towards consumers and include;

- Cost competitive fuel cell vehicles versus the diesel and BEV alternatives. This requires:
  - Economies of scale in fuel cell manufacturing capacity, and
  - Comparable operating costs.

- Suitable FCEV model variety to meet various consumer needs,

- Hydrogen infrastructure:
  - Widely accessible hydrogen refuelling stations (HRS),
  - Supporting hydrogen infrastructure to transport H_2 fuel, and
  - Cost competitive H_2 fuel.

The development of the HD-FCEV market could be analogous to light-duty BEV in the recent years. BEV gained market share as the number of models and availability of public charging infrastructure increased. Furthermore, it is worth noting that whilst automakers are beginning to explore vertical integration into battery production to mitigate supply chain risks, most batteries in BEVs remain supplied by third-party OEMs such as CATL, LG Energy Solutions and Panasonic. Thus, a scaled and well-functioning third-party fuel cell supply chain is likely critical to increasing acceptance of the technology by automakers.

Global OEMs are progressing investments to increase fuel cell manufacturing capacity by almost fourfold between 2022 to 2030.

To this end, WPIC has undertaken a bottom-up analysis of planned fuel cell production capacity, taking the view that these third-party fuel cells will be used by automakers to provide a greater number of FCEV model options that meet the needs of various market participants.

Utilising announced projects, our analysis highlights that fuel cell manufacturing capacity is forecast to increase from 24 GW in 2022 to around 91 GW by 2030 (Fig. 10). Asia is expected to lead fuel cell production by 2030 with China and South Korea attaining market shares by capacity of 28% and 26% respectively.

Figure 10. Fuel cell OEM manufacturing capacity plans indicate significant expansion ambitions.

Region	**Plant capacity (GW)**		**Fuel cell stack power**	**Theoretical production**
OEM	**2022**	**2030**	**(kw/unit)**	**('000)**
Rest of World	9.4	23		244
Hyundai		*23*	*95*	*244*
China	12.8	26		223
*Domestic brands**		*14*	*136*	*101*
Hyundai		*1*	*95*	*6*
Bosch		*10*	*100*	*97*
Ballard (weichi)		*2*	*100*	*19*
North America	0.5	7		67
Ballard		*2*	*100*	*19*
Bosch		*5*	*100*	*48*
Japan	0.5	19		160
Toyota		*13*	*128*	*100*
Honda		*6*	*100*	*60*
Europe	0.5	16		278
Bosch		*5*	*100*	*48*
Plug Power		*1*	*60*	*30*
Symbio LCV		*9*	*45*	*192*
Symbio HD		*2*	*225*	*8*
Global FC capacity (GW pa.)	**24**	**91**		**972**

*Source: IEA (2022), Company Announcements, WPIC research (2030), *China domestic OEMs Foton, SAIC, SinoHytec and others*

Fuel cell vehicle production is forecast to increase by 56% CAGR to 2030.

FCEV production has typically been below industry nameplate capacity. This could be attributable to capacity scaling ahead of aggressive policy targets for light-duty FCEV set in 2019. At the same time, light-duty BEV was achieving market inflection, thereby de-prioritising light-duty FCEV. Elsewhere, production challenges and the lack of policy clarity have further weighed on FCEV utilisation rates. More recently, policy certainty in the form of financial support has improved, leading to optimism that FCEV capacity will raise utilisation rates.

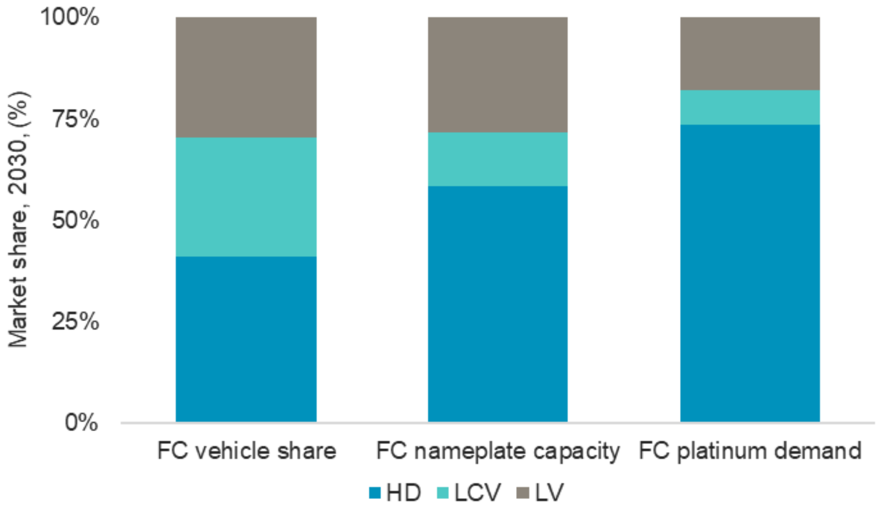
The heavy-duty vehicle segment will drive around three quarters of total fuel cell vehicle platinum demand.

The ongoing investment commitment to grow production by established OEMs is a positive step in the right direction and validates the use case for hydrogen in the automotive sector. WPIC forecasts annual FCEV production of 725,000 vehicles in 2030 (+56% CAGR). This represents a 75% utilisation rate against the global theoretical production capacity of around 972,000 units in 2030. Our 2030 FCEV forecast comprises;

- HD-FCEV demand of 300,000 p.a. units, and
- LCV and LV demand of 215,000 units each respectively.

The importance of fuel cells to heavy-duty could be overlooked. HD-FCEV demand represents a 41% of total FCEV units in 2030. However, the average HD-FCEV has a higher power requirement than the average LCV and LV which translates into HD-FCEV utilising 58% of fuel cell capacity by rated power (47 GW). HD-FCEVs also operate under more demanding conditions than LCV and LV and when coupled with their higher power requirements this results in higher platinum loadings per kw power for HD-FCEV. Therefore, WPIC forecasts the HD-market will account for 372 koz or 74% of total FCEV platinum demand in 2030 (Fig. 11).

Figure 11. Heavy-duty FCEV's will underpin the majority of platinum demand from FCEV due to the requirements for higher power and more challenging operating conditions



Source: WPIC research

FCEV market share gains can be accelerated by achieving a competitive total cost of ownership comparison with incumbent diesel fleets.

With most hydrogen FCEV linked demand for platinum expected to be from heavy-duty, light-duty applications account for a minority of platinum demand. We expect fuel cells to fill niche applications in the light-duty market. We highlight the emergence of fuel cell range extenders in LCV markets where a 40kw fuel cell is attached to a larger battery. Stellantis owned Symbio is targeting 200,000-unit sales pa. of these LCV hybrids by 2030f, which is significant in volume, but marginal in platinum demand at 45 koz annually. This reiterates the importance of HD-FCEV for platinum demand, leading to the question of, "What can incentivise HD-FCEV demand"? These are our industry pull-factors and summarise, why a consumer would choose fuel cell over competing technologies.

Pull-factors

Without regulatory compulsion, consumers are only likely to switch to an FCEV on the grounds of economics, potentially with an altruistic factor also incorporated in the consideration process.

This therefore means that the total cost of ownership (TCO) versus the comparable diesel alternative (in the HD segment) is the pull-factor for a fleet manager. TCO will be influenced by the up-front cost of the vehicles and the cost of running them. Factors involved with running a vehicle include fuel, tolls and service costs, including carbon pricing schemes. The upfront cost will be influenced by the availability of government funded purchase or tax schemes. Regional approaches to FCEV support are likely to vary, however, the successful adoption of HD-FCEV relies on delivering a comparable or better total cost of ownership (TCO) as incumbent diesel offerings.

Assuming servicing costs are comparable for a heavy-duty FCEV and diesel, we have calculated the TCO using the following abridged equation:

$$Capex\ (FCEV) + Opex\ (H_2) - Subsidy\ (H_2)$$

$$=<$$

$$Capex\ (diesel) + Opex\ (diesel) + Carbon\ cost\ (diesel)$$

Turning this equation around and comparing FCEV to incumbent diesel, one can calculate an implied cost of hydrogen to achieve a competitive TCO for HD-FCEV. This is done by flexing the capital costs of HD-FCEV's and diesel fuel prices to determine a range of hydrogen prices.

European TCO

In Europe, we have applied a capital cost premium of up to 300% for HD-FCEV over a diesel equivalent truck, and diesel price range of between US$1.00 and US$2.00 per litre. The fixed assumptions are as follows:

- Diesel class-5 LH truck: US$168,000 (ex. VAT),
- Cost of capital: 6.00%,
- Annual milage: 200,000 km,
- Fuel efficiency: 33.3 l/km (diesel), 8.3 kg/km (FCEV), and
- Operating life: 9 years.

European HD-FCEV fleets achieve parity with diesel at a H_2 fuel price of around US$4.00 per kg considering subsidies, economies of scale and carbon pricing.

The resulting scenario analysis in Europe (Fig. 12) implies that hydrogen fuel prices must be below the range of US$0.00 to US$4.96 per kg to achieve or better parity with diesel (capex and diesel price variability dependent). The scenario analysis intuitively shows that higher capital costs for FCEVs and/or lower diesel prices are negative for the uptake of FCEVs because lower priced H_2 fuel is required to be competitive.

Figure 12. The implied cost of hydrogen fuel is the maximum price hydrogen can cost (under the given HD-FCEV capex and diesel price assumption) whilst still achieving TCO parity with diesel

European implied hydrogen fuel price (US$ per kg) to achieve TCO parity with diesel

		HD-FCEV purchase price premium to diesel, %						
		0%	**25%**	**50%**	**100%**	**175%**	**250%**	**300%**
Diesel price, US$ per litre	**1.00**	2.48	2.22	1.97	1.46	0.69	-0.07	-0.58
	1.20	2.97	2.72	2.46	1.96	1.19	0.43	-0.08
	1.40	3.47	3.22	2.96	2.45	1.69	0.92	0.41
	1.50	3.72	3.46	3.21	2.70	1.93	1.17	0.66
	1.60	3.97	3.71	3.46	2.95	2.18	1.42	0.91
	1.80	4.46	4.21	3.95	3.44	2.68	1.91	1.40
	2.00	4.96	4.70	4.45	3.94	3.17	2.41	1.90

Source: Company data/presentations, WPIC research

Today, European HD-FCEVs sell at a ~250% premium to diesel trucks, which implies H_2 fuel costs of around US$1.17 per kg (Fig. 12: Orange cell) are required to compete with US$1.50 per litre diesel. German hydrogen prices are currently quoted as being between US$16 to US$24 per kg, which highlights the economic obstacles facing the industry. The challenge being that scaling the industry to bring costs down requires early consumers to buy uncompetitive vehicles. However, WPIC believes HD-FCEVs can become competitive with diesel around 2030 at hydrogen prices of ~US$4.00 per kg (Fig. 12: Purple cells) given the following;

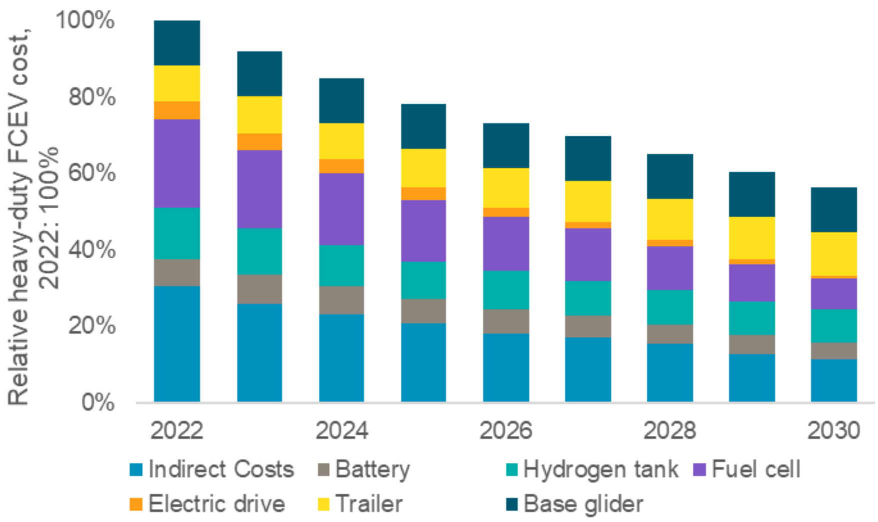
- **Declining capital costs:** With economies of scale and gains on the learning curve, like-for-like HD-FCEV are forecast to decrease by 45% between 2022 to 2030 (Fig. 13). The ICCT expects the HD-FCEV price premiums to decline to ~20% over the nearest diesel equivalent. We previously highlighted that fuel cell production capacity is slated to increase to 91 GW by 2030 (Fig. 10). This should support decarbonisation driven demand growth where Europe has provisionally agreed with the heavy-duty automotive industry for a 45% reduction in CO_2 emission by 2030.

- **Subsidies:** Several EU member states are subsidising the purchase of HD-FCEV vehicles. In Germany, a FCEV purchase scheme will subsidise up to the lesser of 80% of the cost differential between a FCEV and diesel HD-vehicle or EUR500,000. Using our example of a US$168,000 diesel purchase price and 250% FCEV premium, a purchase subsidy of US$336,000 could be claimed thereby significantly reducing the upfront premium of FCEVs.

- **Carbon pricing:** Europe's Emissions Trading System (ETS) is a "cap and trade" system aimed at reducing emissions via a carbon market. The ETS does not cover commercial road fleets. A new scheme, ETS2, will be introduced from 2027 and incorporates road transport. The ETS2 cap will be set to bring emission down by 42% by 2030. European carbon prices have traded within a range of EUR50 to EUR100 per CO_2 tonne over the past two years. A carbon tax on diesel CO_2 effectively raises operating costs. WPIC estimates a US$80 per CO_2 tonne carbon price on 42% of a diesel trucks emissions, effectively raises diesel prices by US$0.10 per litre assuming emissions of ~800 grams per kilometre.

Fuel cell vehicle prices should decrease as manufacturing scales.

Figure 13. Fuel cell vehicle costs are expected to decline by 45% between 2022 to 2030



Source: ICCT, WPIC research

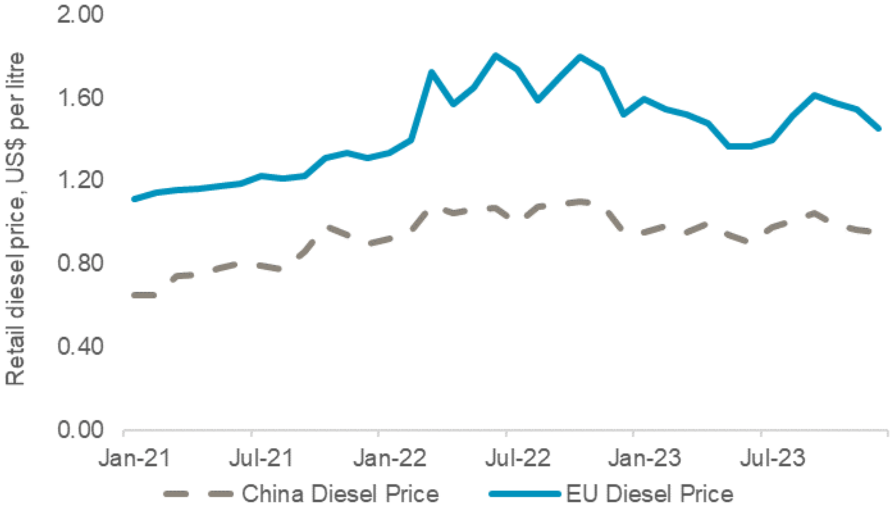
China is forecast to become the largest single FCEV market globally by 2030.

WPIC notes that higher hydrogen prices could be absorbed if green fleet operators are able to charge a premium versus diesel fleets. Charging extra for carbon free logistics would support increased cost recovery (i.e. help absorb higher hydrogen prices), however, this is not factored into our base case analysis.

Chinese TCO

China is likely to have the largest global FCEV market based on government targets and announced production capacity. We conducted a regional TCO scenario analysis for China, as above for Europe. Using assumptions applicable to Chinese market conditions, China's FCEV economics are, at face value, more challenging than Europe's since diesel fuel prices are on average US$0.50 per litre cheaper than Europe (Fig. 14).

Figure 14. Diesel prices vary by region, which shift the economics of a TCO calculation.



Source: Bloomberg, European Commission Oil Bulletin. WPIC research

China's fuel cell policy support combines direct purchase subsidies, purchase tax reductions, H_2 fuel purchase subsidies and regional road toll exemptions.

China's diesel trucks are also cheaper than European vehicles at around RMB450,000 per vehicle (~US$63,000). Lower diesel capex is similarly offset by cheaper HD-FCEV costs with quotes of around RMB1,450,000 (US$203,000). Given regional factors, WPIC's scenario analysis implies that Chinese hydrogen prices need to be less than the range of US$0.52 to US$2.97 per kg to achieve TCO parity with diesel (Fig. 15). Although a lower H_2 fuel price is required in China than in Europe, domestic factors could support greater Chinese HD-FCEV uptake.

- **Subsidies (purchase price):** China offers a range of HD-FCEV purchase subsidies at both national and local levels. A RMB504,000 (US$70,000) national subsidy is applicable on heavy-duty trucks above 31-tons. In some regions national subsidies are matched in what is termed a land subsidy. Combined, the ~RMB1,000,000 of subsidies all but eliminates the higher purchase price of HD-FCEV compared to diesel (Fig. 14 - shift from orange to purple cells).

- **Subsidies (operating costs):** China offers several subsidies to lower HD-FCEV operating costs. Purchase price subsidies for H_2 fuel of between RMB10-20 per kg (US$1.50 to US$2.80 per kg) are available across several Chinese provinces. While in Shandong province, HD-FCEV have been temporarily exempted from highway tolls charges of RMB2.14 per km. The Orange Research Institute estimates toll exemptions could reduce life cycle opex by RMB1,710,000. WPIC does not include the exemption of tolls in its analysis given how regionally specific the subsidy is. However, WPIC estimates the implied H_2 fuel cost to achieve diesel parity could increase by US$1.60 per kg to above US$4.00 per kg should this toll exemption be rolled out nationally.

- **Chinese hydrogen prices:** Selling prices for domestic hydrogen vary widely across China. Green hydrogen has been quoted at less than US$2.00 per kg in Henan and Xinjiang, but up to US$9.00 per kg in Shanghai. In China, emissions of below 4.90 CO_2 kg / H_2 kg are deemed clean hydrogen versus emissions of below 3.38 and 4.00 CO_2 kg / H_2 kg in the EU and US respectively. The additional emissions headroom likely supports cheaper clean hydrogen production costs and therefore lower H_2 fuel selling prices.

Figure 15. The implied cost of hydrogen fuel is the maximum price hydrogen can cost (under the given HD-FCEV capex and diesel price assumption) whilst still achieving TOC parity with diesel

Chinese implied hydrogen fuel price (US$ per kg) to achieve TCO parity with diesel

Diesel price, US$ per litre	HD-FCEV purchase price premium to diesel, %: 0%	33%	67%	100%	150%	200%	250%
0.60	1.49	1.36	1.23	1.10	0.91	0.72	0.52
0.70	1.74	1.61	1.48	1.35	1.16	0.96	0.77
0.80	1.98	1.85	1.73	1.60	1.41	1.21	1.02
0.90	2.23	2.10	1.97	1.85	1.65	1.46	1.27
1.00	2.48	2.35	2.22	2.09	1.90	1.71	1.52
1.10	2.73	2.60	2.47	2.34	2.15	1.96	1.76
1.20	2.97	2.85	2.72	2.59	2.40	2.20	2.01

Source: Company data/presentations, WPIC research

China appears well placed to meet its 50,000 FCEV target by 2025. With the inclusion of purchase subsidies, an HD-FCEV could achieve TCO parity with diesel at a H_2 fuel price of between US$2.00 to US$2.50 per kg. These are prices already being quoted today within certain regional pockets of China.

The Inflation Reduction Act appears to emphasise clean hydrogen production ahead of FCEV.

United States TCO

The introduction of the Inflation Reduction Act (IRA) could stimulate the hydrogen economy across the United States. However, direct purchasing support for HD-FCEV is lower than that available in Europe and China. The IRA legislation caps purchase credits up to US$40,000 per commercial vehicle until 2032. In addition to limited purchase support, diesel prices across the States average around US$1.10 per litre which supports a competitive TCO for incumbent diesel vehicles. Using the same methodology as in Europe and China, WPIC estimates that H_2 fuel prices would need to be US$1.51 per kg without a purchase subsidy or US$1.82 per kg with a purchase subsidy for HD-FCEV to achieve TCO parity with diesel by 2030f (Fig. 16).

Figure 16. The implied cost of hydrogen fuel is the maximum price hydrogen can cost (under the given HD-FCEV capex and diesel price assumption) whilst still achieving TOC parity with diesel

United States implied hydrogen fuel price (US$ per kg) to achieve TCO parity with diesel

Diesel price, US$ per litre	HD-FCEV purchase price premium to diesel, %: 0%	33%	67%	100%	133%	167%	200%
0.90	2.23	1.93	1.62	1.32	1.02	0.71	0.41
1.00	2.48	2.18	1.87	1.57	1.27	0.96	0.66
1.10	2.73	2.42	2.12	1.82	1.51	1.21	0.91
1.20	2.97	2.67	2.37	2.06	1.76	1.46	1.15
1.30	3.22	2.92	2.62	2.31	2.01	1.71	1.40
1.40	3.47	3.17	2.86	2.56	2.26	1.95	1.65
1.50	3.72	3.41	3.11	2.81	2.50	2.20	1.90

Source: Company data/presentations, WPIC research

Clean hydrogen production costs need to be decreased in order for H_2 fuel prices to decline and allow for FCEV parity with diesel on a total cost of ownership basis.

Our analysis suggests the United States requires the lowest implied H_2 fuel price to achieve TCO parity with diesel. However, where US legislative support for HD-FCEV adoption is less comprehensive than in Europe and China, the IRA appears to place more emphasis on subsidising clean hydrogen production. We discuss this further on page 18, and whether this could indirectly support the economics of HD-FCEV.

Reaching four-dollar hydrogen

Our above TCO analysis forecasts that Western European operated HD-FCEV would achieve parity with diesel at hydrogen prices roughly US$4.00 per kg by 2030. This is well below the cost of green hydrogen currently.

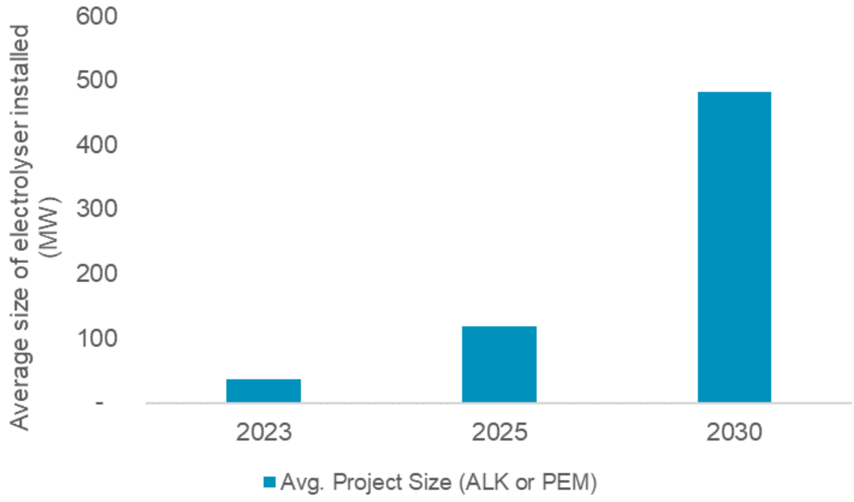
Thus, our analysis moving forward will focus on what future levelised cost of hydrogen (LCOH) is achievable from electrolysis and whether the future LCOH be low enough to economically deliver hydrogen for HD-FCEV transport?

Green hydrogen producing electrolysis capacity is forecast to increase from 6 GW in 2023 to 290 GW by 2030.

Before one considers the future LCOH, it is important to recognise the current state of hydrogen as a tradeable commodity. The retail price of hydrogen varies widely by region, ranging from US$2.00 per kg in China to US$16.00 per kg in Germany. These variances reflect the niche status of the green hydrogen market at present. Green hydrogen accounts for 1% of the global hydrogen market, reflecting a nascent industry not yet benefitting from economies of scale or established midstream infrastructure. However, the electrolysis market is developing to meet future green hydrogen demand. Global electrolysis capacity is expected to increase from 6 GW in 2023 to 290 GW in 2030. Amongst this growing electrolysis market, the average installation size is estimated to increase ten-fold from 50 MW currently to 500 MW between 2028 to 2030 (Fig. 17).

Scaling electrolyser plants improves capital intensity per MW of installed capacity. Furthermore, as more capacity is commissioned, technology maturation, manufacturing rollout and project execution will combine to further support lower capital intensities.

Figure 17. Average electrolyser capacity increasing with introduction of GW scale projects.



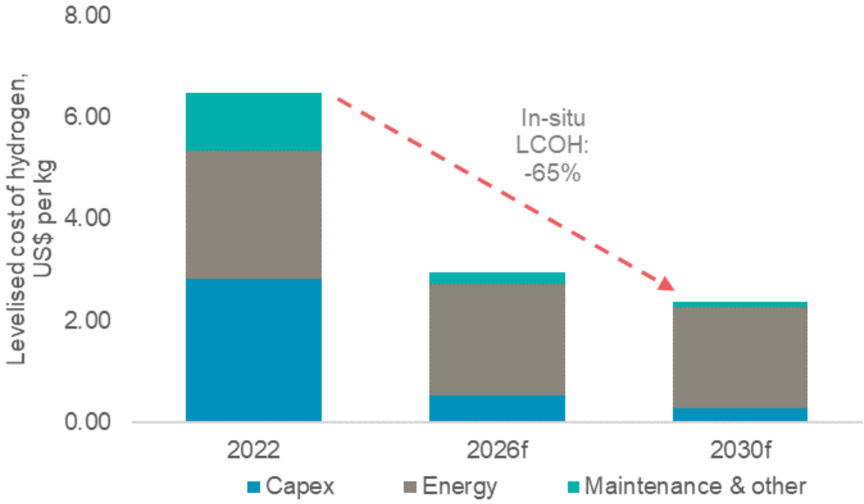
Source: IEA 2023, WPIC research

Regional green hydrogen costs will vary widely due to the cost of renewable energy, and this will underpin the development of "hydrogen hubs" capitalising on favourable economics.

European LCOH

Using data from a range of sources, WPIC estimates that electrolyser capital intensities will decrease from US$2,000 per kw in 2022 to US$300 by 2030. However, the biggest factor behind project economics and the in-situ LCOH remains the cost of electricity (Fig. 18). WPIC estimates that in-situ LCOH could decline by around 65% to around US$2.40 per kg between 2022 to 2030.

Figure 18. Energy is the largest component of in-situ levelised hydrogen costs as electrolyser capital intensities, technology efficiencies and stack durability improves

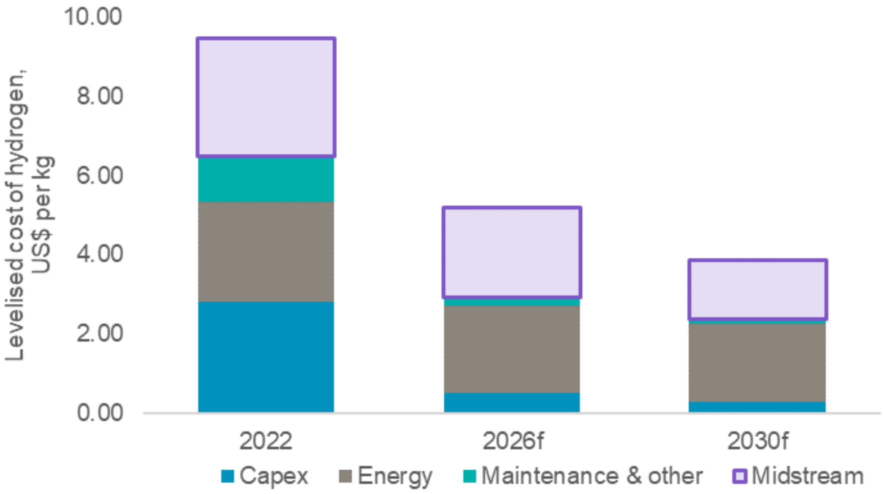


*Source: IEA 2023, *in-situ LCOH calculated using US$46 per MWh, WPIC research*

Advancing along the technology curve suggests European green hydrogen costs could decrease to around US$4.00 per kg by 2030 which would improve the input cost economics of downstream markets.

It is worth noting that the in-situ LCOH metric it is not without limitations since it is an "at gate" hydrogen cost. This ignores midstream costs (compression, liquification and transport) and return on investment requirements for the providers of capital. Midstream costs can vary widely depending on how hydrogen is transported (e.g. compressed liquified versus piped) and how far it is transported (regional versus international). WPIC estimates regional midstream costs (i.e. within the US or EU) averaged around US$3.00 per kg in 2022 and could half by 2030 with greater infrastructure rollout (Fig. 19). For an economically successful electrolyser, the required hydrogen selling price must therefore be higher than the in-situ LCOH plus midstream costs.

Figure 19. Midstream hydrogen infrastructure is immature and these costs must be considered when determining an electrolyser's levelised hydrogen cost



Source: IEA 2023, WPIC research

WPIC adopts a net present value (NPV) methodology which determines a pre-tax internal rate of return (IRR) for proposed electrolysis investments. This NPV model is the basis for a scenario analysis which estimates IRR based on a range of hydrogen selling prices and energy input costs (Fig. 19). Today's electrolyser economics for EU projects indicate hydrogen selling prices need to exceed US$10.00 per kg. Looking forward to 2030, with renewable energy costs of around US$46/MWh (equivalent to Spain), the required selling price for hydrogen could decrease to around US$4.00 per kg whilst supporting an

IRR of greater than 8% (Fig. 20: Purple cells). In higher cost renewable energy locations in the EU (US$60/MWh), hydrogen prices of US$4.50 per kg are needed for profitability.

Figure 20. Electrolyser returns are most sensitive to energy prices and the selling price for hydrogen

Western electrolyser IRR scenario analysis, 2030

Energy price (US$ per MWh)	Hydrogen selling price (US$ per kg)						
	3.50	**4.00**	**4.50**	**5.00**	**5.50**	**6.00**	**6.50**
80	#	#	#	#	12.3%	25%	35%
70	#	#	#	10.2%	23.1%	33%	43%
60	#	#	8.0%	21.5%	32.1%	41%	50%
50	#	5.5%	19.9%	30.7%	40%	49%	56%
40	2.6%	18.2%	29%	39%	47%	55%	63%
30	16.4%	27.8%	38%	46%	54%	62%	69%

Source: IRENA 2022, WPIC research, Assumptions include US$46 MWh energy, US$300/MW capital intensity, 46% electrolyser utilisation rate

Our LCOH scenario analysis indicates that electrolysis projects could deliver an 8% IRR at hydrogen prices of US$4.00 per kg. This hydrogen price is comparable to the approximate US$4.00 per kg H_2 fuel price required for HD-FCEV to achieve parity with diesel (Fig. 12). We can therefore conclude that European heavy-duty FCEV adoption is likely to increase as the LCOH converges to US$4.00 per kg. In the meantime, subsidies will assist industry first movers. The EU Hydrogen Bank hosted its first auction in Q1 2024. The bank allotted EUR800m to subsidise hydrogen producers with a revenue premium ("top-up") of up to EUR4.50 per kg. The auction was oversubscribed. Bids up to the price will be ranked in reverse order, from lowest to highest and will be awarded support in that order, until the auction budget is exhausted. Including any of the EUR4.50 per kg revenue top-up, the implied LCOH would accordingly decrease speeding up convergence with the implied hydrogen price required by HD-FCEV fleets to achieve parity with diesel. The European Hydrogen Bank's funding is derived from the EUR40 billion Innovation fund, providing optimism that subsidies will continue to flow and act as a revenue bridge mechanism for several years whilst the industry scales.

China LCOH

China's lower cost manufacturing and low diesel prices were shown to shift hydrogen's economics. In China, hydrogen must be produced at a lower cost of around US$2.25 per kg to compete with diesel ICE (Fig. 15). Our China LCOH model considers;

- Domestic alkaline electrolyser capital intensity of US$420 per kw in 2022 declining to US$125 per kw in 2030f,
- Electrolyser operating rates of 75%, and
- Electricity costs of US$33 per MWh (kept constant over the forecast period) based on the average electricity cost from China's three prevalent renewable technologies (wind, solar and hydropower).

The IRA's production tax credits subsidise up to US$3.00 per kg of the cleanest rated hydrogen production.

WPIC estimates that by 2030, at hydrogen prices of around US$2.70 per kg, Chinese electrolysers would achieve an >8% IRR, incentivising development (Fig. 20 - purple cell). This is higher than our previously calculated implied H_2 fuel price range of between US$2.00 to US$2.50 per kg to reach TCO parity with diesel fleet (Fig. 15).

We highlight that the differential between our LCOH and TCO calculations is marginal and likely within an acceptable margin of error. Moreover, we previously noted that the Henan and Xinjiang regions where H_2 fuel prices are already being quoted at US$2.00 per kg which is low enough for HD-FCEV fleets to comparable TCO with diesel.

Figure 21. Chinese electrolysers could a LCOH which converges with the required hydrogen price for HD-FCEV to breakeven with diesel by 2027

Chinese electrolyser IRR scenario analysis, 2030

Energy price (US$ per MWh)	Hydrogen selling price (US$ per kg)						
	2.40	**2.50**	**2.60**	**2.70**	**2.80**	**2.90**	**3.00**
40	#	#	#	#	#	#	3%
36	#	#	#	#	1%	14%	22%
32	#	#	#	13%	22%	29%	36%
28	-2%	12%	21%	29%	36%	42%	48%
24	20%	28%	35%	42%	48%	53%	58%
20	35%	41%	47%	53%	58%	63%	68%

Source: IRENA 2022, DOE, Company reports, WPIC research. Assumptions include US$33 MWh energy, US$125/MW capital intensity, 46% electrolyser utilisation rate

The IRA is set to expire from 2033 which incentivises bringing forward investments to capitalise on subsidies.

North America LCOH

US Congress passed the IRA in 2022, with the bill intended to accelerate the deployment of clean energy technologies. The IRA has provisions for clean hydrogen production (section 45V), with subsidies scaling based on production emissions. The cleanest hydrogen (i.e. with the least associated CO_2 emissions) is eligible for a US$3.00 per kg production tax credit through to 2032 (Fig. 22). In addition to the hydrogen production tax credit, producers are also eligible to a renewable energy tax credit of 2.6 US cents per kWh if their electrolyser is powered by renewable energy. This renewable energy credit is increased five-fold for domestic sourced supply agreements and labour quotients. WPIC estimates a maximum credit could reach US$3.72 per kg of hydrogen produced in the cleanest CO_2 emission profile range.

Figure 22. The IRA clean hydrogen production tax credit increases as CO_2 emissions decline

CO_2 emission profile	Credit value (US$/$H_2$ kg)
4.0 - 2.5 kg	0.60
2.5 - 1.5 kg	0.75
1.5 - 0.4 kg	1.00
0.4 - 0.0 kg	3.00

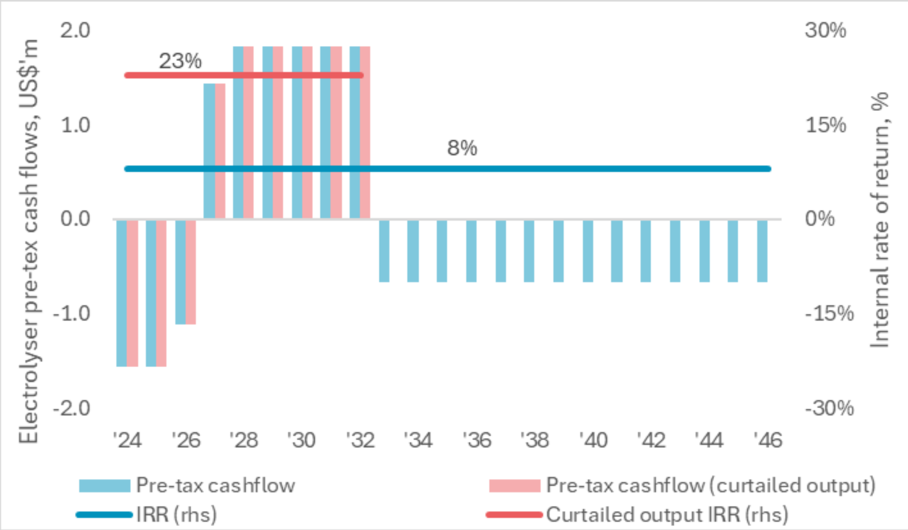
Source: DOE, ICCT, WPIC research.

The IRA is a strong piece of legislation; however, it has drawbacks. The legislation has additionality, geographical and hourly correlation requirements which could constrain the growth potential of domestic green hydrogen. In effect means that renewable energy must be sourced from a facility which is,

- No older than three years old,
- On the same regional grid as the electrolyser, and
- Supplying energy which is used by the electrolyser within the hour it was produced by the renewable energy plant (from 2028).

In addition to several onerous requirements, when a NPV model is utilised to calculate an IRR for an US-based electrolyser (as per above examples in Europe and China), the output scenario appears implausible due to the abrupt 2032 cutoff of the IRA. In effect, all the value is created whilst IRA production tax credits are applicable, and the project could still achieve its respective hurdle rate whilst generating negative cashflows after credits are withdrawn from 2033 (Fig. 23 - blue). Unless operational efficiencies can reduce costs or hydrogen selling prices rise, the likely result of such cash flow polarity (i.e. negative from 2033) would be the rationalisation of the plant after subsidies unwind thereby increasing the project's IRR (Fig. 23 - red).

Figure 23. The IRA production tax credits cutoff from 2032, which materially impacts project cashflows and would incentivise early termination to increase project returns



*Source: DOE, ICCT, WPIC research.*Electrolyser capital intensity US$250/kWh at a fixed renewable energy price of US$52/MWh*

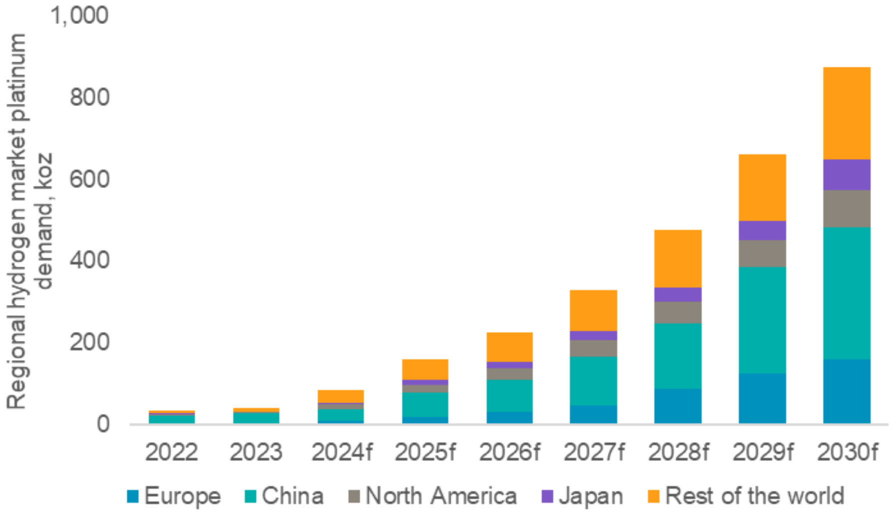
Overlooking the improbable cashflow profile, WPIC estimates that a US electrolyser investment could generate an 8% IRR at a hydrogen selling price of around US$3.58 per kg in 2030 given;

- Electrolyser capital intensity: US$300 per kw,
- Three-year project construction followed by two-year ramp-up once commissioned from 2030,
- Energy prices: stable US$52 per MWh (US average),
- Operating rates: 4,000 hrs per year or 46%, and
- IRA subsidy: US$3 per H_2 kg produced to 2032.

Our estimated LCOH in the US of around US$3.58 per kg is higher than the implied US H_2 fuel price required by US fleet operators to achieve parity with diesel (~US$1.82 per kg, Fig. 15). Accordingly, the economic case for HD-FCEV in the US appears less compelling than that of the EU and in China due varying subsidy structures across different geographies. However, WPIC does not rule out all growth in hydrogen within the US because there are attractive regions for hydrogen production where low-cost energy could help reduce the LCOH (WPIC uses national average energy prices, not regional). The investments as part of the IRA across seven regional hydrogen hubs are indicative of efforts to develop a hydrogen economy. However, for modelling purposes, WPIC forecasts hydrogen linked platinum demand will be proportionally larger in China and Europe (Fig. 24) because domestic electrolysis capacity has a LCOH which is in-line with the implied H_2 fuel price which would be required to achieve HD-FCEV TCO parity with incumbent diesel fleets. The US's relatively small contribution to hydrogen demand for platinum also reduces the political risks associated with Trump winning the upcoming election and revoking the Inflation Reduction Act (which he has threatened to do).

China, Europe and South Korea are set to be the three largest end markets for hydrogen linked platinum demand.

Figure 24. China and Europe will lead platinum demand linked to the hydrogen economy since the required H_2 fuel price needed to achieve TCO parity with diesel falls towards the LCOH range of domestic electrolysis capacity



Source: IEA, Company data/presentations, WPIC research

HD-FCEV markets will underpin a significant portion of the incremental 875 koz of platinum demand from the hydrogen economy by 2030.

Conclusion

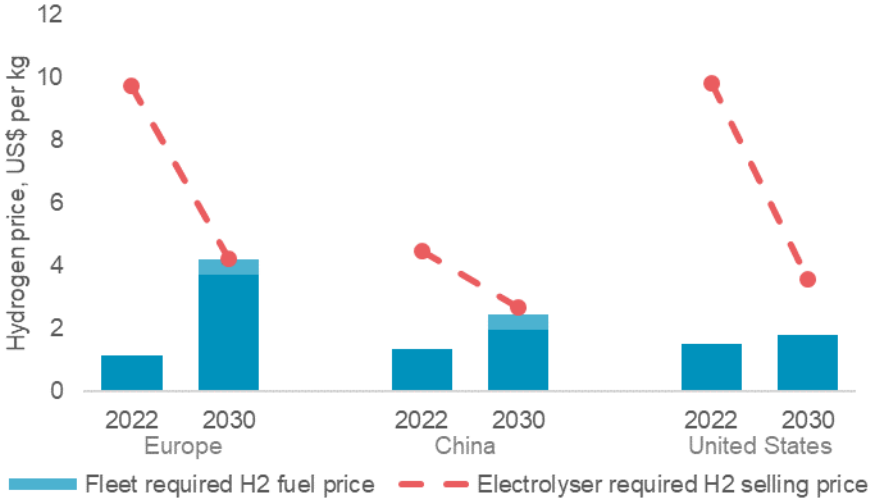
PEM electrolysis is a meaningful medium-term platinum demand segment. However, most future hydrogen-linked platinum demand will be underpinned by fuel cell vehicles, particularly in the heavy-duty segment. The ramp up in FCEV adoption has been slower than initially targeted by national hydrogen strategies. Hence, our analysis now explores both push- and pull-factors which are required to achieve greater HD-FCEV adoption. Most prominently, it was found that HD-FCEV adoption would scale on the back of:

- **Rising fuel cell production capacity:** A bottom-up analysis of OEM growth plans shows fuel cell capacity is expected to increase from 24 GW to 91 GW by 2030. The increase in fuel cell supply will improve economies of scale, likely leading to declining FCEV costs (-45% by 2030, Fig. 12) and greater consumer choice,

- **Subsidies are helping HD-FCEV to compete with diesel on a TCO basis with a higher cost H_2 fuel:** We determine that subsidies allow the implied H_2 fuel price to be between 20% to 240% higher than would otherwise be necessary to compete with diesel fleets on a TCO basis. These subsidies could support early HD-FCEV adoption whilst H_2 fuel prices remain high. Notably, the Henan and Xinjiang regions in China already sell H_2 fuel at prices which allows HD-FCEV to be competitive with diesel, and

- **Electrolysis technology improvements and production tax credits will lower the LCOH by an average of 55% to 2030:** We expect increased supply and declining green hydrogen production costs to support lower hydrogen selling prices. WPIC expects electrolysis LCOH to converge to the implied H_2 fuel price for European and Chinese fleets to achieve TCO parity with diesel by 2030 (Fig. 25).

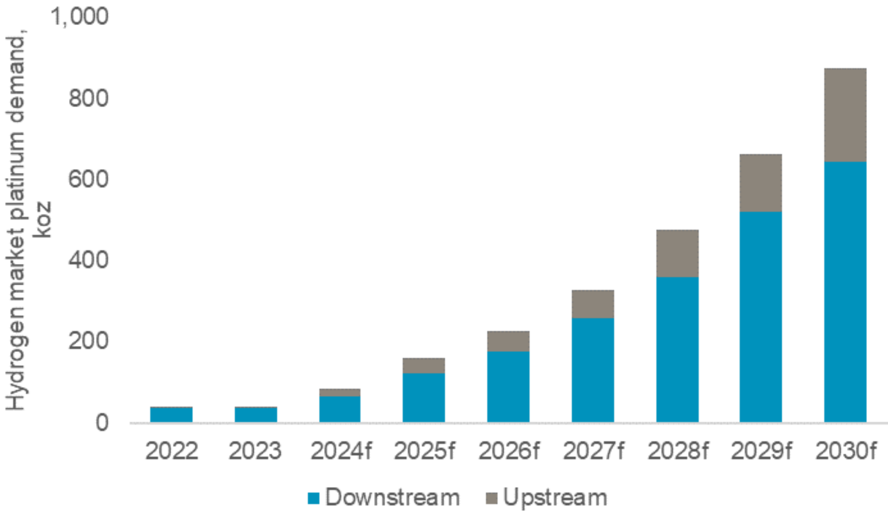
Figure 25. HD-FCEV demand growth will accelerate as the required hydrogen prices for both fleets and electrolysers converge around 2030



Source: IEA, Company data, WPIC research

Heavy-duty transport has been slow to decarbonise with diesel's market share remaining >90%. WPIC analysis shows that the LCOH will decline and converge to a H_2 fuel price which makes HD-FCEV competitive with diesel. We expect this convergence will accelerate HD-FCEV adoption resulting in a 5% market share by 2030. We estimate that HD-FCEV will account for the majority of total hydrogen related platinum demand, which we forecast to reach 11% of total annual platinum demand by 2030 (~875 koz).

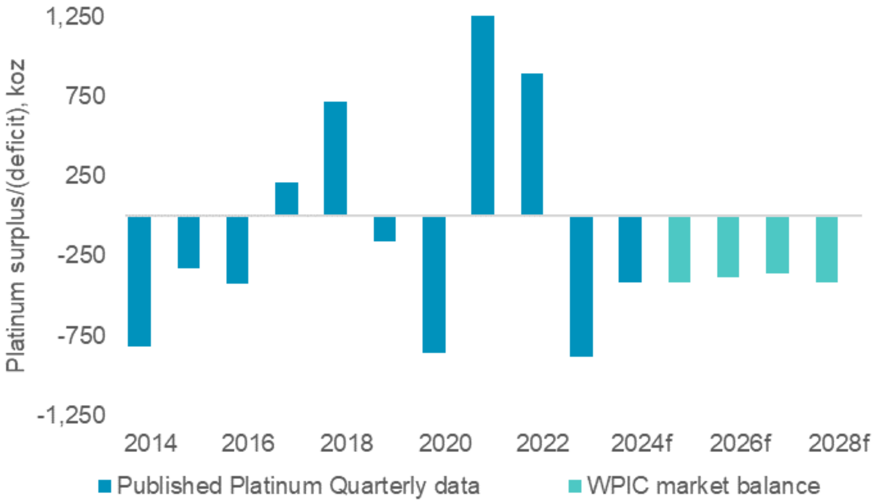
Figure 26. Hydrogen linked platinum demand approaches 875 koz per annum by the end of the decade



Source: IEA, Company data, WPIC research

WPIC expects platinum demand from hydrogen end markets to broadly offset declining autocatalyst demand from lower internal combustion engine market share. This results in stable total platinum demand within our two- to five-year market outlook. WPIC thus expects platinum markets to record consecutive market deficits from 2023 through to at least 2028f (Fig. 27). On average, platinum market deficits are expected to be 430 koz between 2025f to 2028f (~5% of demand). Above ground stocks will be required to supplement supply shortfalls, with deficits expected to reduce by three quarters to 1.1 Moz by 2028f.

Figure 27. Platinum market deficits are expected to persist between 2023 to at least 2028



Source: SFA (Oxford) 2013 – 2018, Metals Focus 2019 – 2024, WPIC research thereafter

Glossary

Battery Electric Vehicle (BEV) - A plug-in vehicle with a large battery that is plugged in to an electric power source to charge.

Fuel Cell Electric Vehicle (FCEV) - An electric vehicle that uses a fuel cell to produce electricity (by passing hydrogen and oxygen over a platinum catalyst). Thus, they drive an electric motor/s consuming hydrogen fuel.

Hybrid Electric Vehicle (HEV) – A vehicle with a small battery combined with small combustion engine. The vehicle has negligible electric only range as the engine cuts in and out routinely. The battery is charge by the engine.

Levelised Cost of Energy (LCOE) – Methodology to assess and compare the costs of alternative methods of energy production.

Levelised Cost of Hydrogen (LCOH) – Standardised methodology which accounts for operating and capital costs to produce hydrogen allowing comparability across production pathways.

Net Present Value (NVP) – The sum of the present value of future cashflows. The calculation allows future cash flows to be reflected in today's real value terms thereby allowing comparable of different investment opportunities.

Platinum Group Metals (PGMs) - A group of metals commonly present with platinum in platinum bearing ore. Can refer to some or all of platinum, palladium, rhodium, iridium, ruthenium, and osmium.

Plug-in Hybrid Electric Vehicle (PHEV) - A vehicle that combines an internal combustion engine with a mid-sized battery that can be plugged in to charge to run as a BEV for a limited distance as well as run on petrol or diesel alone.

Proton Exchange Membrane Water Electrolysis (PEM) - An electrolyser splits water molecules (H_2O) into its constituent oxygen and hydrogen elements by breaking the bonds. PEM technology uses a gas-tight solid polymer-based membrane as an electrolyte. PEM employs platinum and iridium as coated catalysts as part of the membrane.

Total Cost of Ownership (TCO) – Calculation of an assets life cycle costs which incorporates both the purchase price and operating costs. Used to compare returns forecasts of different assets.

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