Connections Series
Autos: Fuel Cell Electric Vehicles

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Fuelling the future of cargo mobility

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Executive summary

Though the supporting infra & technology is still at a nascent stage, hydrogen-powered FCEVs are considered a promising technology

FCEV likely to enjoy structural growth: 50% CAGR in 2022-30

The global FCEV sales volume jumped ~80% YoY to 17.5k units in 2021 and was dominated by the Korea market with a 49% global market share. In detail, Korean FCEV sales volume was 8.6k units in 2021, followed by the US (3.4k units), Japan (2.5k units), China (1.6k units) and Europe (1.0k units). Looking ahead, we expect FCEV sales volume to increase from 22k in 2022 to 567k in 2030, implying a CAGR of 50%. Key growth drivers are: (1) falling FCEV cost with a core component—fuel cell system cost down from US$1,000 per kW in 2022 to US$350 per kW in 2030, (2) falling hydrogen fuel price—from US$10 per kg in 2022 to US$4 per kg in 2030, (3) expanding infrastructure—hydrogen refuelling station (HRS) network, from ~1k stations in 2022 to ~9.1k stations in 2030 or 33% CAGR, and (4) favourable regulation tailwinds with generous cash subsidies which account for 20-50% FCEV vehicle price. We expect Europe to top Korea as the largest FCEV market globally in 2030, followed by China and Japan, driven by European countries' aggressive HRS expansion plan and FCEV purchase subsidies.

FCEV's key application to stay in CVs, while PVs mainly go for electrification

Although PVs currently dominate FCEV sales, FCEV penetration amid total PVs will stay minimal in 2030 (<0.3%) as pure electric vehicle (EV) is a better technology solution for PV in terms of cost and performance. However, electric vehicles face great challenges in decarbonizing the commercial vehicles, as batteries are too heavy to meet the requirements of both long distance and heavy loading. Thus hydrogen-powered FCEV could be a mid- to long-term solution for commercial vehicle in certain scenarios like cold winter regions, and long-distance and heavy-loading transportation owing to its much higher energy density—1.5 times higher than petrol and diesel, and ~200 times higher than lithium batteries. Development of FCEV technologies focussed on commercial truck makers is escalating, which has been seen from the partnerships amongst various OEMs. Thus we forecast global FCEV sales volume penetration amid commercial vehicles to increase from 0.1% in 2022 to 9.1% in 2030 and 50% in 2040.

Fuel cell HDT to reach cost parity with diesel engine HDT by 2029 on falling hydrogen fuel price

The primary consideration of commercial vehicle fleet owners is the total cost of ownership (TCO) on a 'payload carried per km' basis, ~55% of which comes from fuel cost currently. We expect the hydrogen pump price to decline from ~US$10 per kg in 2022 to US$4 per kg in 2030 (~11% CAGR) with key drivers as: (1) lower production cost on increasing share of cheap green hydrogen supply—from US$4/kg to US$2/kg; (2) lower refuelling cost on HRS' installation cost reduction and rising utilization—from US$5/kg to US$1.6/kg; and (3) lower transportation cost on maturing liquid hydrogen storage technology—from US$1/kg to US$0.4/kg. As a result, we expect the TCO of a 40t fuel cell HDT to reduce from ~US$247 per 100km in 2022 to US$91 per 100km in 2029 combined with the falling cost of fuel cell systems, when it will reach cost parity with a similar weight (size) diesel powered heavy truck.

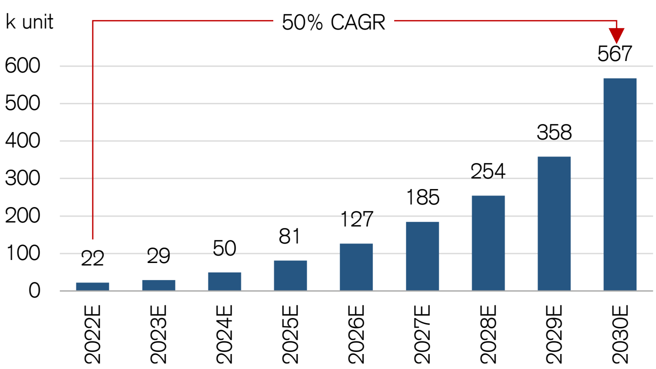
"What will drive FCEV's structural growth ahead? Cheaper vehicles, cheaper hydrogen, more infrastructure, and policy tailwinds.

FCEV likely to enjoy structural growth: 50% CAGR in 2022-30

Fuel cell electric vehicles (FCEV) likely to enjoy structural growth globally—50% CAGR in 2022-30. Key growth drivers : (1) falling FCEV cost with a core component; (2) falling hydrogen fuel price; (3) expanding hydrogen refueling infrastructure; and (4) favourable regulation tailwinds with generous cash subsidy

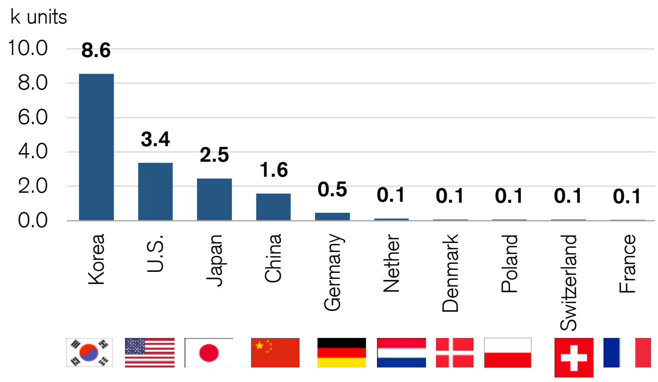
Global FCEV sales volume jumped by ~80% YoY to 17.5k units in 2021, which was dominated by the Korea market with 49% global market share. In detail, Korean FCEV sales volume was 8.6k units in 2021, followed by the US (3.4k units), Japan (2.5k units), China (1.6k units) and Europe (1.0k units). Looking ahead, we expect FCEV sales volume to increase from 22k in 2022 to 567k in 2030, implying a CAGR of 50%. Key growth drivers are: (1) falling FCEV cost with core component—fuel cell system cost down from US$1,000 per kW in 2022 to US$350 per kW in 2030; (2) falling hydrogen fuel price—from US$10 per kg in 2022 to US$4 per kg in 2030; (3) expanding infrastructure—hydrogen refuelling station (HRS) network, from ~1k stations in 2022 to ~9.1k stations in 2030; and (4) favourable regulation tailwinds with generous cash subsidies that account for 20-50% of an FCEV vehicle price. We expect Europe to top Korea as the largest FCEV market globally in 2030 followed by China and Japan, driven by European countries' aggressive HRS expansion plan and FCEV purchase subsidies.

Figure 1: Global fuel cell electric vehicle (FCEV) sales outlook



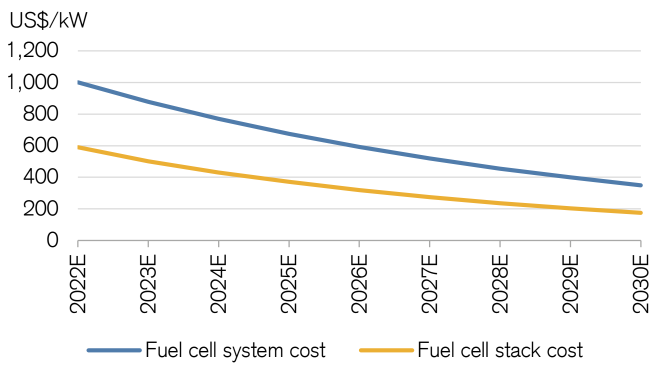
Source: Credit Suisse

Figure 2: Global top 10 FCEV markets (2021)



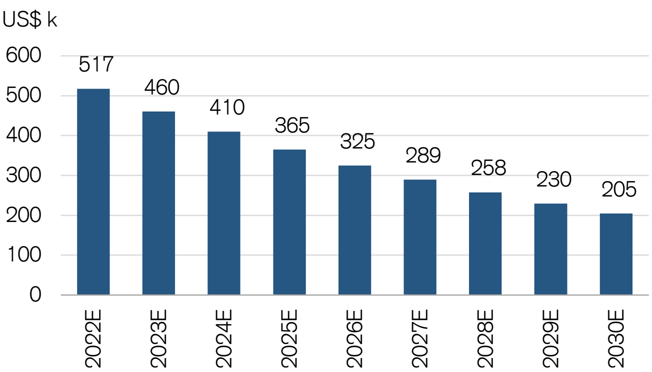
Source: WardsAuto, Markline

Figure 3: Fuel cell system and fuel cell stack cost outlook



Source: Credit Suisse

Figure 4: HDT price outlook—190kW fuel cell + 70kWh battery

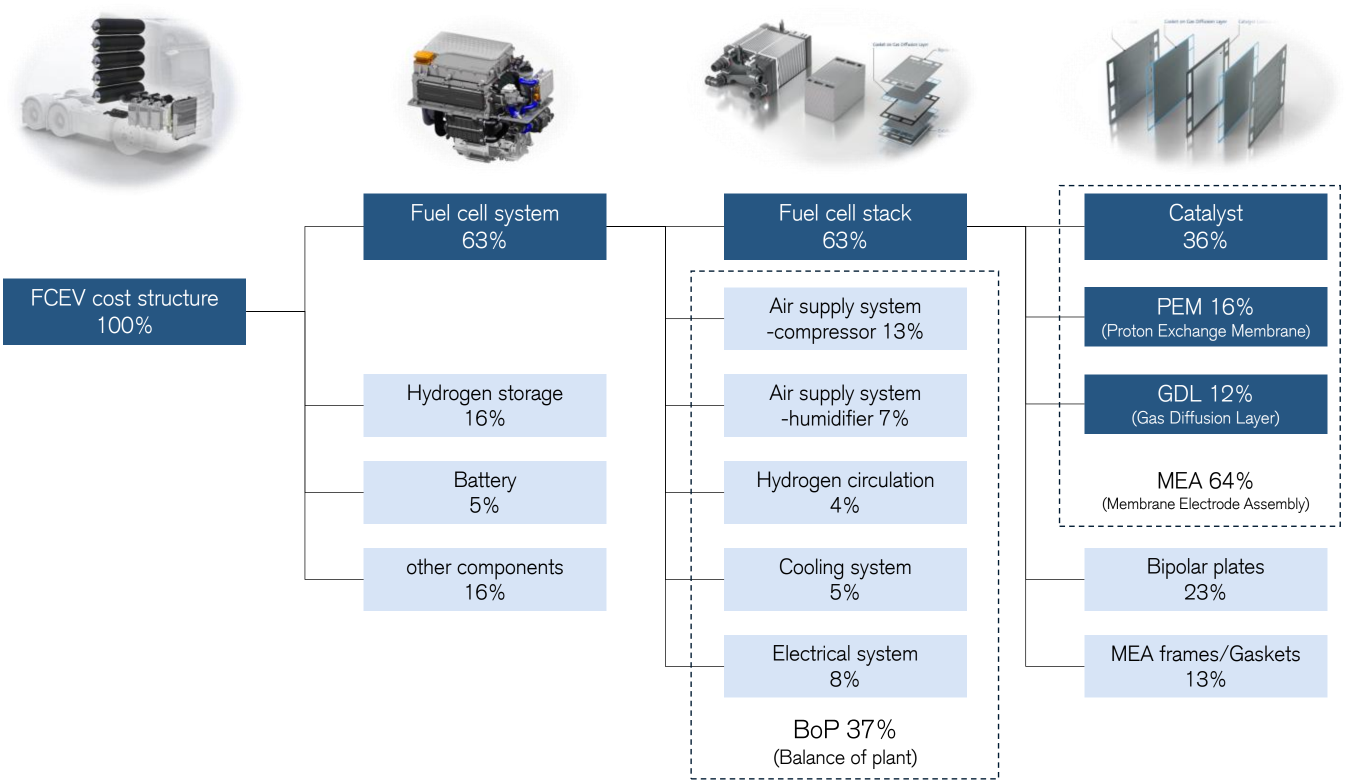


Source: Credit Suisse

Falling FCEV's core component cost

Falling FCEV's core component cost As the heart of the FCEV, the fuel cell system comprises a fuel cell stack and its ancillaries named BoP (balance of plant), including fuel processing system, air processing system, and thermal management system. Currently, the fuel cell system is very expensive due to its small annual production scale. For example, a 190kW output power fuel cell system is priced at US$190k (or US$1,000/kW) in 2022. We expect the fuel cell system cost to decline ~65% by 2030, thanks to: (1) the reduction or replacement of the expensive materials and metals; and (2) the scale-up of the FCEV value chain.

Figure 5: Fuel cell truck cost structure (2021)



Source: Company data, Credit Suisse

- **Reduction or replacement of expensive materials.** We believe the fuel cell system's materials and metal reduction or replacement is a key method to reduce the overall fuel cell system cost. On the one hand, technology innovation might lead to a solution to replace some expensive raw materials with cheaper ones. On the other hand, some manufacturing process improvement can also reduce raw material consumption by optimizing product design, production processes, and production techniques. The fuel cell system's material replacement includes using low and no platinum catalysts, stainless steel for bipolar plates, and non-precious metals for coated materials, and reducing fuel cell layers for the same output of fuel cell stack. Take the low Pt catalyst for example-reducing platinum loading is an important way to reduce the cost of fuel cell stacks. The leading overseas companies' catalyst can reduce their Pt usage to 0.1-0.2g/kW. This implies a large cost-cutting potential for fuel cell stacks.
- **Scale-up of the FCEV value chain.** We expect the fuel cell cost to reduce by another 20% by 2030, driven by rising FCEV annual production scale (thus resulting in a dilution of unit production costs). We estimate global FCEV's annual production volume to increase from 2022's 22k units to 567k units in 2030. According to the forecast from US Department of Energy, hydrogen fuel cell system's cost decreases significantly as production increases. Assuming a static technology level in 2025, the fuel cell systems' annual production volume increase from ~10k units to ~100k units would drive down the fuel cell system cost by ~20% from ~US$100/kW to ~US$80/kW.

Expanding HRS infrastructure network, from ~1k stations in 2022 to 9.1k in 2030

Rapidly growing hydrogen refuelling infrastructure should pave the way for FCEV development, as refuelling facilities are a major bottleneck for FCEV demand currently. Governments have funded, either fully or partially, the construction of HRSs to enable the deployment of FCEVs, including public buses, trucks, and passenger vehicles. Today there are about 730 HRSs globally providing fuel for about ~50k FCEVs. This represents a 35% YoY increase in the number of HRSs from 2020. Over 80% of the FCEVs on the road at the end of 2021 were passenger cars, with buses and trucks each constituting around 10% of global FCEVs.

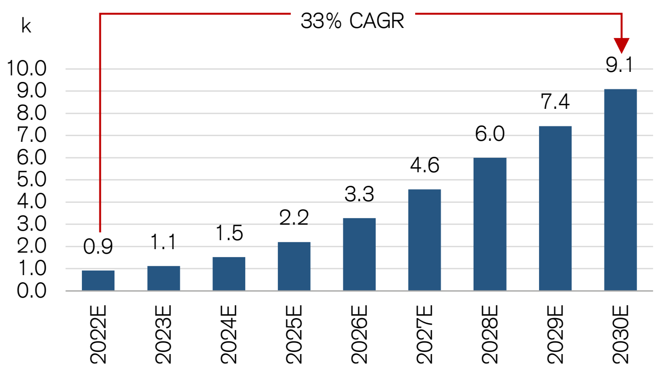
Thus, to attract prospective FCEV purchasers, building sufficient HRS and providing convenient refuelling services is critical. As a result, both public and private sectors (including state-owned electricity companies and oil companies) are investing heavily in global HRS networks to alleviate potential customer concerns. On the other hand, growing FCEV penetration should speed up the demand for HRS. We expect global HRS numbers to increase from ~1k stations in 2022 to 9.1k stations in 2030, mainly driven by heavy investments in Europe, Japan and China.

Favourable regulation tailwinds with generous cash subsidy: 20-50% of a vehicle's price

Government efforts to decarbonize transport have been a key catalyst supporting FCEV adoption. Support for hydrogen vehicles is similarly growing from a lower base, with government targets emerging (or at least goals, some of these from industry bodies seeking to promote hydrogen) and with some (patchy) inclusion in zero emissions incentive schemes. For example, China targets ~50k FCEVs on the road by 2025 (or 1mn FCEVs by 2035). Outside of China, Japan and Korea both have some of the most ambitious targets for FCEV adoption. Japan expects 800k units on the road by 2030 (we assume this is cumulative, equating to a ~25% market share), while Korea is planning for 6.2mn vehicles produced by 2040, 3.3mn for export, 2.9mn domestically, equivalent to ~2 full years of sales domestically. In Europe, the "Hydrogen Roadmap Europe" published by the Fuel Cell Hydrogen Joint Undertaking suggested 3.7mn fuel cell vehicles, 500k light commercial vehicles, 45k trucks and buses by 2030. In the US, California is set to introduce Zero Emission Vehicle (ZEV) regulations for commercial vehicles in 2023. Other than California, 15 states plan to enact similar legislation with 30% of MHD trucks ZEV by 2030 and 100% by 2050.

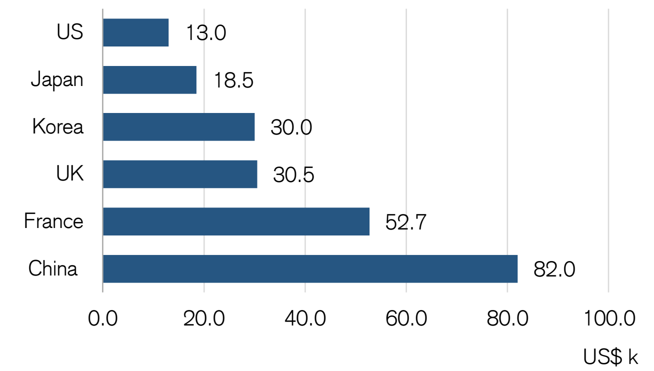
In order to achieve the above-mentioned volume targets, a large number of regions and countries offer cash subsidies and tax benefit schemes on FCEV technology to achieve FCEV adoption, ranging from US$82k in China to US$52.7k in France, and US$30k in Korea. In most cases, FCEV purchase subsidy could lower the purchase cost by 20-50%.

Figure 6: Expanding HRS infrastructure network globally



Source: Credit Suisse

Figure 7: FCEV purchase subsidy per unit in different regions



Source: Thinkercar

“What is FCEV key use case scenario? Cold winter regions and long-distance & heavy-loading transportation.

FCEV's key application to stay in CVs, while PVs mainly go for electrification

Pure electric vehicle (EV) is a better technology solution for PV in terms of cost and performance. On the other hand, hydrogen-powered FCEV could be a mid-to-long-term solution for commercial vehicle in certain scenarios like cold winter regions, and long-distance and heavy-loading transportation. This is due to its much higher energy density—1.5 times higher than petrol and diesel, and ~200 times higher than lithium batteries.

Although PVs currently dominate FCEV sales, FCEV penetration amid total PVs will stay minimal in 2030 (<0.3%) as pure electric vehicle (EV) is a better technology solution for PVs in terms of cost and performance. However, electric vehicles face great challenges in decarbonizing the commercial vehicles, as batteries are too heavy to meet the requirements of both long distance and heavy loading. Thus hydrogen-powered FCEVs could be a mid-to-long-term solution for commercial vehicles in certain scenarios like cold winter regions, and long-distance and heavy-loading transportation due to the much higher energy density—1.5 times higher than petrol and diesel, and ~200 times higher than lithium batteries. Development of FCEV technologies focussed on commercial truck makers is escalating, which has been seen from the partnerships amongst various OEMs. Thus we forecast global FCEV sales volume penetration amid commercial vehicles to increase from 0.1% in 2022 to 9.1% in 2030 and 50% in 2040.

Best for long-distance or heavy-loading transportation

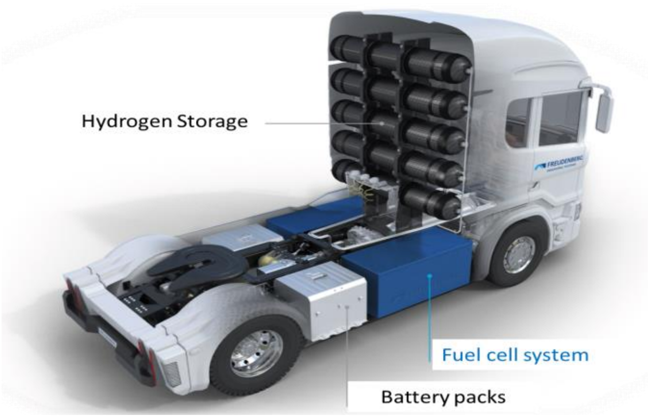
We believe new energy vehicles—NEVs (including pure electric vehicle or EV, plug-in hybrid electric vehicle or PHEV, and fuel cell electric vehicle or FCEV) will replace ICEVs (internal combustion engine vehicle) on lower cost and zero carbon emission. Among NEV technologies, EV enjoys a lower cost, in terms of purchase cost and usage cost (energy cost). However, we expect hydrogen powered FCEV to be an essential supplement to EV in long-distance and heavy-loading transportation applications, like large size passenger vehicle, bus and heavy trucks. FCEV is an electric vehicle powered by a fuel-cell electric powertrain, using the reactions of hydrogen and oxygen to generate electricity. Therefore it is fuelled with hydrogen from a pump rather than electricity drawn from the electrical power grid.

- **Commercial vehicle:** Due to a heavy battery pack, EVs are difficult for long-distance and heavy-loading transport. For example, a typical 40 ton electric heavy truck (e-HDT) needs an 800kWh battery pack to achieve a driving distance of 600km, whose curb weight will increase by 6 tons (the battery pack weight). The heavy battery pack reduces the HDT's cargo loading capacity by 18%, from 34 tons to 28 tons, while hydrogen is an ideal energy source for long-distance heavy-loading transportation due to its much higher energy density. Hydrogen's energy density can reach ~33kWh/kg, ~1.5 times higher than petrol and diesel, and ~200 times higher than lithium batteries. Technically speaking, every single hydrogen tank (carrying ~50kg hydrogen) can provide a driving range of ~500km for a HDT, with 2 tanks supporting ~1,000km and 4 tanks supporting ~2,000km driving range. As a result, the

Figure 8: Typical fuel cell system for passenger vehicle

Source: Thinkercar

Figure 9: Typical fuel cell system for trucks



Source: Thinkercar

overall fuel cell system weight is estimated at ~2 tons for 1,000km driving-range fuel cell HDT, considering the compressed hydrogen tank's weight. Looking ahead, the next-generation fuel cell HDTs could enjoy a much longer range of 800-1,000km by adopting 80kg liquid hydrogen tank.

- **Passenger vehicle:** It is a similar story for large-size passenger vehicles (PVs). The optimal driving range for an EV is ~400km with ~50kWh battery pack, considering the high cost of battery today. In 2022, the lithium battery price increased ~30% YoY to US$146 per kWh for an NCM battery pack and US$118 per kWh for an LFP battery pack in 1Q22 due to rising lithium price. FCEV cars can be cheaper for models with driving range above 600km if compared with pure EVs, under the battery price hike circumstance. However, the lack of HRS is a key obstacle for FCEV adoption. There are only ~700 HRS for FCEVs across the globe, while there are 1.8mn public accessible chargers for NEVs by 2021. Looking ahead, the competition between pure EV and FCEV relies heavily on the speed of cost reduction for the battery and fuel cell systems.

Currently passenger vehicles dominate FCEV market, and Japanese and Korean auto makers take the lead

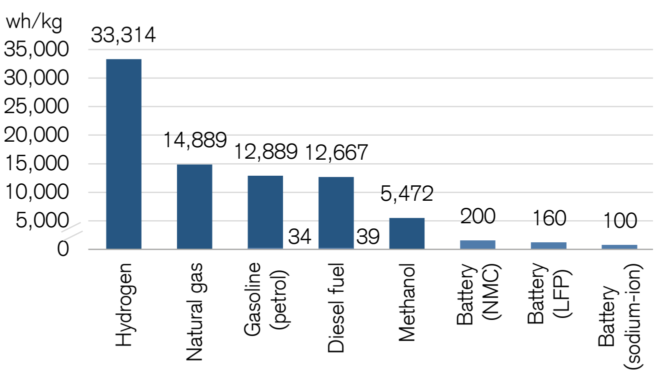
Global FCEV deployment concentrated on passenger vehicles, which accounted for 88% of FCEV sales in 2021, leaving the other 12% for commercial vehicles (bus and truck). We attribute the current passenger vehicles' dominant position in the global FCEV market to very aggressive government cash subsidy or tax reduction for fuel cell passenger vehicles, especially in Korea, the US and Japan. Meanwhile, the FCEV technology pioneers like Korean and Japanese auto makers started their fuel cell electric vehicle via mass producing passenger vehicles. For example, the first commercially produced hydrogen fuel cell automobile was introduced in 2013.

FCEV's key application will shift to CVs, while passenger vehicles mainly go for electrification

Although PVs currently dominate FCEV sales, FCEV penetration amid total PVs will stay minimal in 2030 (<0.3%) as pure electric vehicle (EV) is a better technology solution for PV in terms of cost and performance. The FCEV application will focus on the commercial vehicle market, as hydrogen-powered FCEVs could be a mid-to-long-term solution for commercial vehicles in certain scenarios like cold winter regions, and long-distance and heavy-loading transportation due to the much higher energy density. Meanwhile, development of FCEV technologies focussed on commercial truck makers is escalating, which has been seen from the partnerships amongst OEMs.

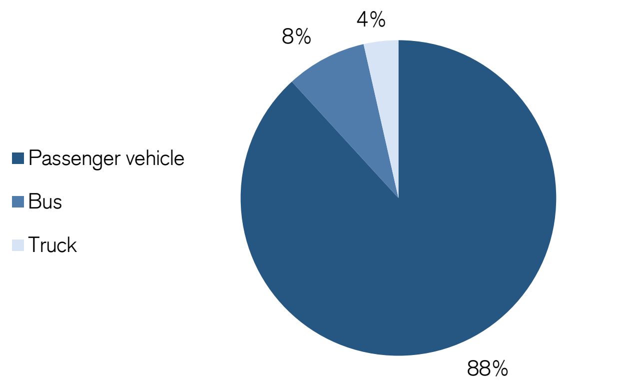
Thus, we forecast global fuel cell passenger vehicle sales volume to increase from 18k units in 2022 to 238k units in 2030, implying a CAGR of 38%. Key growth drivers for fuel cell passenger vehicle are the Korea and Europe FCEV markets, which are expected to account for 45% and 42% of the global share respectively in 2030. Meanwhile, we forecast global fuel cell commercial vehicle sales volume to increase from 4k units in 2022 to 329k units in 2030, implying a CAGR of 74%. Key growth drivers for fuel cell commercial vehicles are the China and Europe FCEV markets, which are expected

Figure 10: Energy density comparison with hydrogen (Wh/kg)



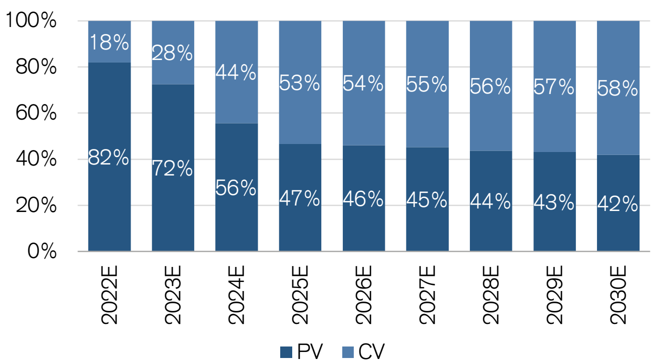
Source: Credit Suisse

Figure 11: FCEV sales breakdown by vehicle type (2021)



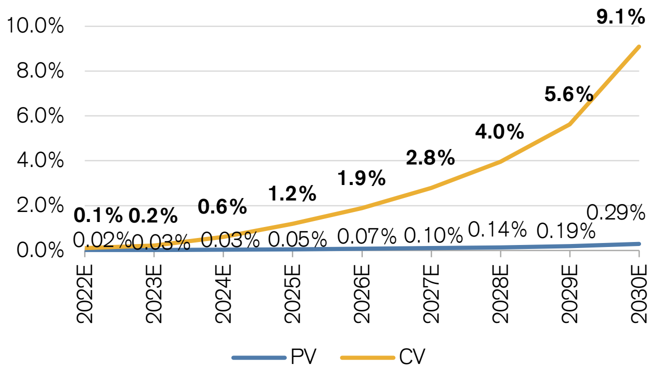
Source: Company data, Credit Suisse

Figure 12: FCEV sales breakdown outlook by vehicle type



Source: Credit Suisse

Figure 13: FCEV penetration outlook in CV and PV



Source: Credit Suisse

to account for 24% and 31% global share in 2030. As a result, we forecast global FCEV sales volume penetration amid commercial vehicle to increase from 0.1% in 2022 to 9.1% in 2030 and 50% in 2040.

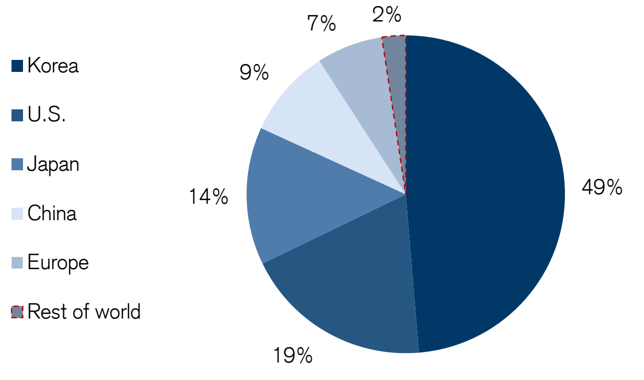
Global FCEV market share reshuffle: from Korea and Japan to China and Europe

Currently, Korea, the US, and Japan comprise 82% of global FCEV sales in 2021, with almost all of the sales coming from PVs, while China and Europe aim at fuel cell commercial vehicle uptake, which dominates the global fuel cell commercial vehicle segment. Resource-poor Japan sees hydrogen as a way to achieve greater energy security. At the same time, Japan also sees FCEVs powered by green hydrogen as the ultimate goal for zero-emission transport. Korea shared a similar goal. Developing FCEVs is the Korean government's effort to reduce greenhouse gas emissions, generating new growth momentum for its automotive industry, reducing its heavy reliance on imported oil. In other words, the Korean government wants FCEV to fundamentally transform the state energy system and secure new growth engines at the same time. Hence, Korea wants to take the lead in creating a hydrogen economy by connecting the technology with traditional manufacturing sectors, including the auto, shipping and petrochemical industries.

Global fuel cell commercial vehicles posted ~2k units of sales in 2021, which was mainly contributed by the Chinese market (76% global share). The Chinese government released an FCEV pilot operation incentive plan in key city groups mainly for commercial vehicles (bus and truck), offering a maximum of US\$55k/US\$82k incentive for each bus/truck for pilot operation. Considering the local government's supporting policy, the total incentive amount per vehicle might double in financially well-funded city groups. The Chinese government did not focus on fuel cell passenger vehicles' development due to China's leading position in electric vehicle (EV) already—China sold more than 50% global pure EVs in 2021. In traditional internal combustion engine vehicle and fuel cell electric vehicle technology, Chinese players have lagged their global leading peers in terms of core technology, i.e., powertrain, fuel cell stack, etc. However, the pure electric vehicle market is expected to create a level playing field and allow Chinese passenger vehicle companies to play a greater role. As most EV's powertrain—the battery and e-motor—were outsourced to third party suppliers, the technology differentiation is much more difficult among auto makers due to EV's simpler design and fewer parts. While in the fuel cell commercial vehicle segment, Chinese auto makers enjoy a superior cost advantage which is the most important purchase decision-making factor for commercial vehicle customers. FCEVs are the best alternatives for long-distance and heavy-loading transport commercial vehicles, as discussed earlier. As a result, we expect China FCEV sales volume to increase from 3.3k units in 2022 to 80k units in 2030 (implying a CAGR of 49%) with fuel cell commercial vehicle sales volume accounting for 98% total China FCEV in 2030.

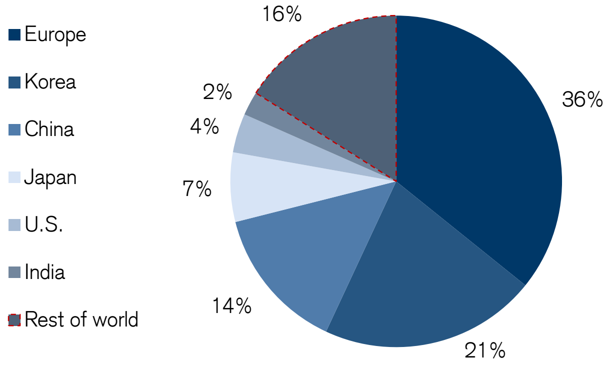
A similar situation can be seen in Europe. We note that for 2050 carbon net neutral targets, the industry will likely need to be selling only zero-emission trucks and buses by 2035 in order to have most CO_2 emitting vehicles off the road by mid-century. While battery electric is clearly winning as the preferred zero-emission technology for passenger cars in Europe, we believe FCEVs are preferred over pure EVs for long-haul operations, for the transportation of very heavy loads, and for operations where quick refilling is critical (such as when the same vehicle is used for multiple shifts resulting in limited downtime). More importantly, the fossil energy price hike is pushing up the operational cost of ICEVs, with heavy truck having the biggest impact because of their intense use. The total cost of ownership (TCO) of ICEVs would increase by 50% if the diesel fuel price were to rise from US\$1.0 per litre to US\$2.0 per litre, according our estimation. The increase in the TCO of ICEVs due to higher diesel fuel prices would make FCEVs competitive several years ahead of schedule. We expect fuel cell commercial vehicle sales in Europe to increase from less than two hundred units in 2022 to 103k units in 2030 (implying a CAGR of 123%), accounting for 51% of Europe's total FCEVs in 2030.

Figure 14: FCEV's sales breakdown by region (2021)



Source: WardsAuto, Markline

Figure 15: FCEV's sales breakdown by region (2030E)



Source: Credit Suisse

European FCEV market

Today's fuel cell vehicles are dominated by passenger vehicle

After many years of being considered a promising technology of the future, hydrogen fuel cell vehicles in Europe remain just that—a promising technology of the future. In 2021, total FCEV sales in Europe broke the 1,000 unit sales mark for the first time, which while a milestone, equates to a penetration rate of less than 0.01%. The vast majority of these vehicles were passenger cars, as while the commercial vehicle market is likely more promising in the longer-term, the technology and infrastructure are still very much in their infancy in Europe.

When we examine the current European market for FCEVs, approximately 50% of passenger car FCEVs sold in Europe were in Germany, while the top 5 countries accounted for ~80% sales. Two models accounted for ~96% of sales – one from Japan based OEM and another one from Korea based OEM. Of the German majors, only one OEM has an FCEV offering, though with the intent of only selling a very limited number (it claims full-scale production will not be until later in the decade when infrastructure is more mature), with two other key OEMs expressing their non-interest in the technology, as each is focussed on an all pure EV future. Despite the perspectives of the German OEMs, Germany does remain the most supportive country in Europe for the technology with ~60% of Europe's hydrogen refuelling stations (HRSs) and EV subsidies that include FCEVs, with these being key factors behind its higher sales rate so far. We see the French companies as being amongst the most bullish on fuel cell technology (though mostly on the commercial vehicle side), with many announcing investments/targets. However, sales of passenger car FCEVs in France have been quite limited, with only 62 units sold last year and just four YTD 2022 (through May).

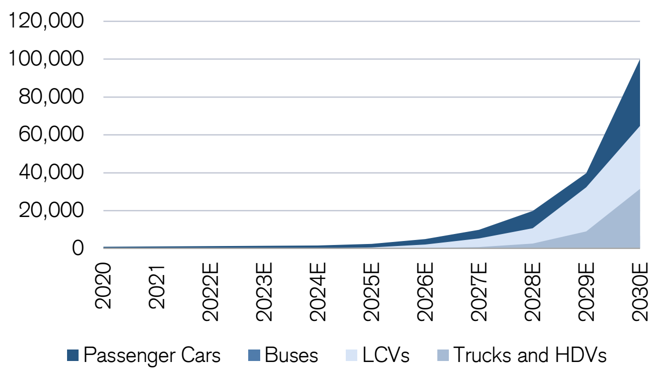
Despite sales so far being extremely low, there are reasons to believe FCEV could one day account for a notable percentage of European passenger car sales. First, the EU's "Fit for 55" plan proposes a mandated infrastructure build out for HRSs, which would help to elevate one of the top concerns car buyers have: limited locations for refills. Second, we believe the combination of hydrogen being a potential solution to Europe's reliance on Russia for energy and worries about a shortage of battery materials could lead to greater focus on fuel cell technology by both governments and OEMs. Third, we do expect to see a significantly greater penetration in fuel cell technology from the commercial vehicle/heavy duty truck industry (on a percentage of total market basis), which could also lay the ground work for hydrogen fuel cell becoming a more mainstream technology. Finally, as costs of green hydrogen drop and vehicle volumes rise to allow scale factors to drive down unit prices, we believe the economics of FCEV will begin to become more attractive, as well.

Regarding our passenger car FCEV estimates, given limited participation amongst European OEMs, significantly underdeveloped refuelling infrastructure, high costs, and much greater focus by the industry and governments on pure EV technology, we anticipate a relatively modest growth in FCEVs over the next few years. With just 292 passenger car FCEVs sold in Europe through the first five months of 2022 (down 16% YoY and trend of just 63 per month), we are estimating a full year volume of 1,200 (up 15.8% YoY). We then estimate 15% and 20% growth in 2023 and 2024, respectively, followed by a step-up to 50% growth in 2025 and a +100% trend over 2026-30 as infrastructure continues to be built out to meet the "Fit for 55" mandates and green hydrogen costs come down. For 2030, we project 100k passenger car FCEVs to be sold in Europe, which though still a very small number in terms of total vehicles sold on the continent, should equate at that point to an installed base of 350k or more, and thus start the next decade with a relatively sizeable base to build up the future growth.

Expecting great penetration rate rise in commercial vehicles

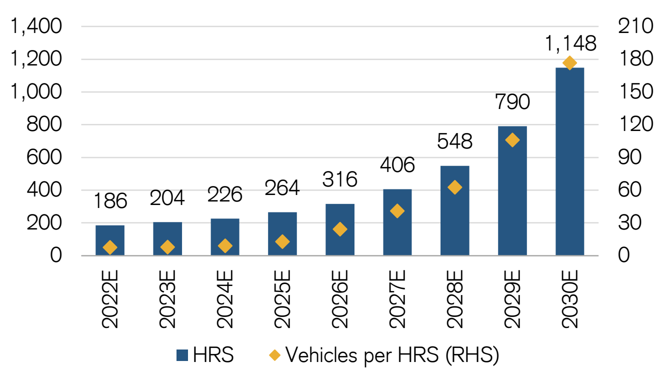
As noted above, our current view is that FCEV technology may see a greater market penetration over the next few years in the commercial vehicle segments, which are large contributors to greenhouse gas emissions in Europe and are today heavily powered by diesel (>96% for HD trucks). While battery electric is clearly winning as the preferred zero-emission technology for passenger cars in Europe, there are several obstacles to this being widely adopted in commercial vehicles including battery weight, battery costs, and long charge times. On an all-else-equal basis, we believe this would make FCEVs preferred over pure EVs for long-haul operations, for transportation of very heavy loads, and for

Figure 16: FCEV sales volume outlook in Europe



Source: WardsAuto, Markline, EV-volume, Credit Suisse

Figure 17: HRS outlook in Europe



Source: WardsAuto, Markline, EV-volume, Credit Suisse operations where quick refilling is critical (such as when the same vehicle is used for multiple shifts resulting in limited downtime). We believe pure EV would be preferred in short/medium haul operations, for trucks that are rarely weight constrained with their loads, and for operations where the vehicle has sufficient daily down time for recharging. We note that for 2050 carbon net neutral targets, the industry will likely need to be selling only zero-emission trucks and buses by 2035 in order to have most CO2 emitting vehicles off the road by mid-century. However, over the next few years, we expect the truck and bus market to continue to be heavily dominated by diesel-powered vehicles, while FCEV sales remain constrained by limited availability of product and underdeveloped infrastructure. We believe pure EVs will have an advantage over FCEV, given the growing acceptance of the product on the passenger car side as battery charging infrastructure builds out.

Regarding our commercial vehicle estimates, we expect relatively low growth over the next few years, with the pace increasing over 2026-30 as some of the currently high hurdles are reduced (namely, refuelling infrastructure and cost inputs). By 2030, we believe FCEV could be in a high growth mode and make up a small but meaningful portion of the overall commercial vehicle sales market.

Fuel cell passenger vehicle model availability and costs

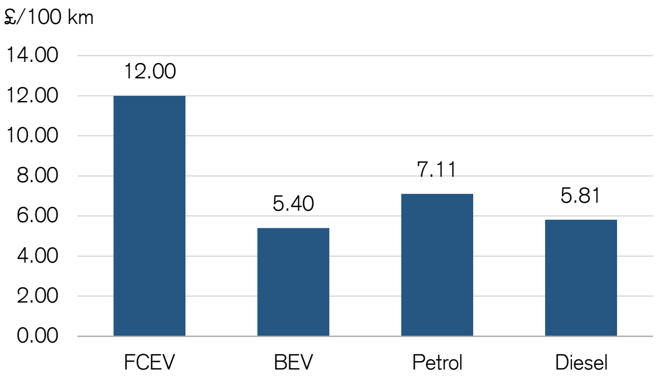
There are currently only two FCEV passenger vehicle models available in the European market for commercial sale, costing €63,900 and €77,290, which is a considerable premium to pure EV models in the same segment. Although we have seen some willingness from consumers to pay higher prices for xEVs, we believe that the price point for FCEVs is currently significantly high to encourage adoption, even without factoring in the lack of refuelling infrastructure. This presents a problem for OEMs who are currently not able to produce enough vehicles in order to achieve an improved scale, which could, in turn, be passed on through more affordable vehicles.

Hydrogen vehicles are also more expensive to operate than other drivetrain technologies according to an analysis conducted by AutoTrader. In order for FCEVs to be competitive with pure EVs, it is clear that the cost of hydrogen must come down substantially, which will not occur until sufficient production capacity is built, a likely medium-/long-term milestone.

Refuelling stations: A significant investment is needed

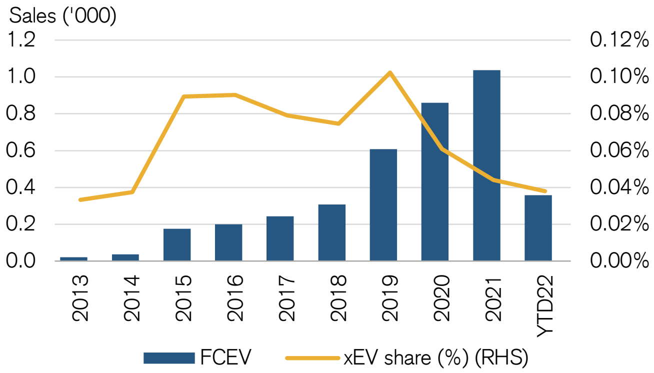
One of the most significant problems to overcome in Europe is the extremely limited network of hydrogen refuelling stations (HRS) available, which presents a "chicken-and-egg" problem. Currently, there are only 151 refuelling

Figure 18: Comparison of refuelling/recharging costs



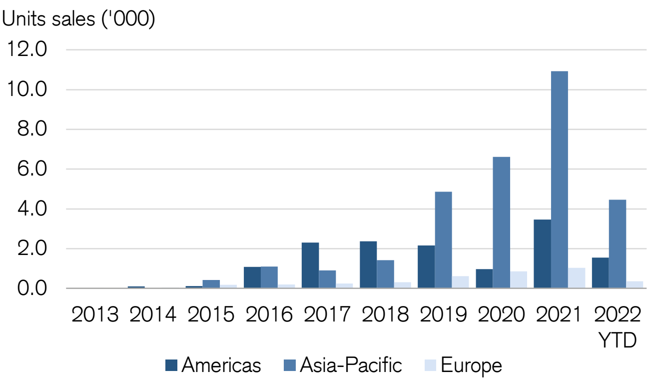
Source: AutoTrader, Credit Suisse

Figure 19: European FCEV sales have been increasing but are de minimis when compared to other xEV technologies



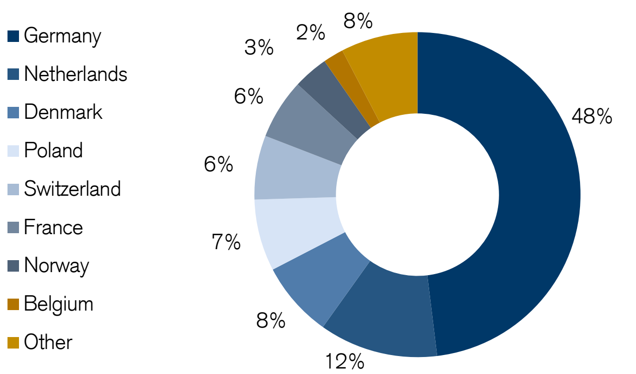
Note: Light vehicles only. Source: EV-Volumes, Credit Suisse

Figure 20: European FCEV sales lag other major regions



Note: Light vehicles only. Source: EV-Volumes, Credit Suisse

Figure 21: Germany is the leader in FCEV sales in Europe, owing to more supportive legislation and infrastructure



Source: EV-Volumes, Credit Suisse

stations in Europe (according to the EU Alternative Fuels Observatory), of which nearly 60% are located in Germany, owing to supportive national policy which looks to improve the transport infrastructure and hydrogen production. This means that most users would currently be unable to access the infrastructure required to use FCEVs on a day-to-day basis, and as a consequence, there has been limited demand for FCEVs. Similarly, the lack of hydrogen vehicles in use in Europe has resulted in few operators being willing to install an additional refuelling infrastructure.

The European Automobile Manufacturers' Association (ACEA) has estimated that 60,000 hydrogen trucks will be in use in Europe by 2030, which represents the minimum number of vehicles that will be required to comply with the current CO2 standards. In order to service this demand, Europe will require ~1,000 refuelling stations located across the continent, which would require a ~660% increase in stations over the remainder of the decade.

In order to overcome this problem, we believe that significant policy intervention is required to provide the necessary infrastructure to encourage FCEV ownership. The EU has established some funding partnership programmes involving private enterprises in order to develop hydrogen infrastructure; however, the scale of funding committed to these programmes is insufficient to match the required number of HRS. For example, using a conservative estimate of €1mn to construct a HRS, an additional ~€850mn would be needed to meet the ACEA's stated requirement, far in excess of any current funding pledged by any public or private organizations.

Europe FCEV regulations

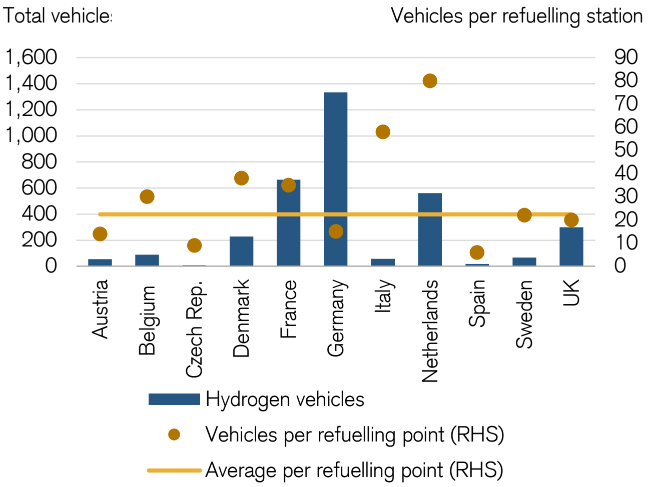
The EU has set out some of the most ambitious climate targets globally, following the approval of the **European Green Deal** in 2020, an overarching package of climate policies that ultimately has the ambition of achieving climate-neutrality by 2050.

One of the initiatives included in the Green Deal is the **Hydrogen Strategy**, which seeks to increase both the demand and supply of hydrogen in Europe, and the deployment of more hydrogen vehicles is seen as an important part of this strategy. The Commission sees hydrogen as a promising option where electrification is more difficult, such as in local city buses, commercial fleet and other heavy duty vehicles (HDVs), with hydrogen expected to provide 20% of the EU's low-carbon transport fuel mix by 2050.

A number of initiatives have been put in place to increase the uptake of hydrogen in road transport in Europe:

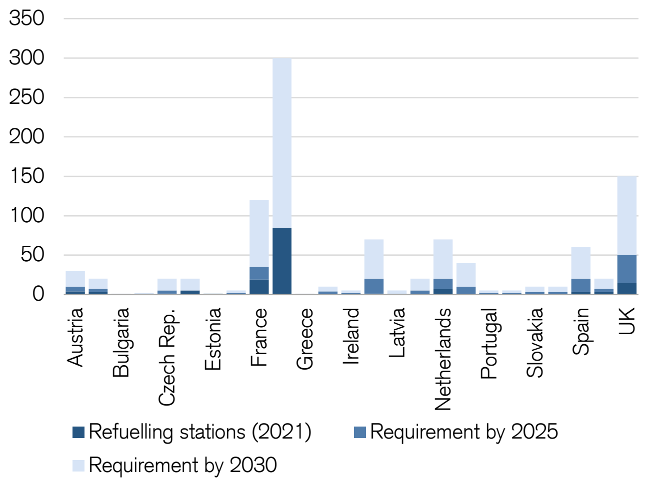
- The Clean Hydrogen Joint Undertaking was established in November 2021 (formerly the Fuel Cells and Hydrogen Joint Undertaking) and is a public-private partnership that supports research activities in hydrogen in Europe, with its three members being the European Commission, Hydrogen Europe (a collective of the fuel cell and hydrogen industries) and Hydrogen Europe Research (representing the hydrogen research community. The JU is used as a vehicle to deploy capital from Horizon Europe, the EU's €95.5bn research and innovation funding programme running from 2021 to 2027. The EU and private members are each committing €1bn from 2021 to 2027 (€2bn total), to fund hydrogen research projects throughout the EU, including in the transportation sector.
- Hydrogen Mobility Europe (H2ME) started in 2015 with H2ME1, running through to mid-2020, which provided 29 refuelling stations throughout the EU and over 300 vehicles. Its follow-up project H2ME2 started in mid-2016 and runs through to mid-2022, with the aim of deploying a further 1,100 vehicles and 20 refuelling stations. Together these projects will have a total cost of €170mn, €67mn of which is funded by the EU's Horizon Europe research programme, with the 1,400 vehicles representing a large proportion of Europe's FCEV fleet. The projects have involved more than 40 partners from nine countries across transport, hydrogen and energy industries.

Figure 22: Germany also has the highest number of refuelling stations in Europe



Source: EU Alternative Fuels Observatory, glpautogas.info, Credit Suisse

Figure 23: A significantly greater number of refuelling stations are required to service FCEVs by 2030



Source: EU Alternative Fuels Observatory, ACEA, Credit Suisse

Europe FCEV refuel infrastructure

While pure EVs are becoming increasingly popular in the light vehicle space, due to the high prices of FCEVs, mass consumer adoption appears unlikely over the near/medium-term. However, in the heavy duty vehicle (HDV) segment, where upfront costs are just one of many factors considered in the purchase decision, hydrogen offers a viable alternative to ICEs that overcomes some of the key issues presented by pure EVs in larger vehicles, helping to reduce CO2 emissions in a highly pollutant segment of the market. As such, the EU Commission has identified the HDV market as the most likely segment for early mass deployment of hydrogen technology, and believes that the initial focus should be on developing infrastructure that can cater to these vehicles, while also being accessible to light vehicles (LVs).

As an intermediate step towards the Green Deal's aim for climate-neutrality, the Commission has proposed **Fit for 55**, a set of policies intended to reduce the EU's emissions by 55% by 2030 (from 1990 levels). A key element of these proposals is the investment in infrastructure for alternative fuels such as hydrogen, which includes the **Alternative Fuels Infrastructure Regulation (AFIR).**

Following from the **Alternative Fuels Infrastructure Directive (AFID)**, which set high-level guidelines to the member states that opted to install hydrogen refuelling stations, the EU Commission initially proposed AFIR in July 2021 and the official approach was adopted in June 2022. If approved by the European Parliament, the Alternative Fuels Infrastructure Regulation (AFIR) would repeal the Alternative Fuels Infrastructure Directive (AFID) and set more stringent, mandatory requirements for hydrogen infrastructure. Currently, hydrogen refuelling points are only deployed in a few European countries and are largely unsuitable for heavy-duty vehicles, which prevents the use of hydrogen HDVs to transport goods in Europe; however, the AFIR proposal would go some way to rectifying these issues.

The proposal states that by 31-Dec-2030, the member states should ensure that:

- Publicly accessible hydrogen refuelling stations equipped with at least a 700 bars dispenser are deployed with a maximum distance of 200 km in-between them along the TEN-T (Trans-European Transport Network) core network. Members should pay particular consideration to the deployment of such stations in urban nodes or in hubs where other transport modes could be suppled.
- Neighbouring states should make sure that the maximum distance is not exceeded for cross-border sections of the TEN-T core network.
- The operator of the HRS should ensure that the station is designed to serve both LDVs and HDVs.

The EU Commission intends to review AFIR's provisions related to HDVs by 31 December 2024, with future requirements that may include minimum capacity requirements for HRS and extending the provisions to the TEN-T comprehensive network.

Figure 24: Various alternative fuel-targeted subsidy schemes and tax benefits are offered by countries

Maximum Subsidy (€)	BEV	PHEV	FCEV	Tax benefits
Austria	3,000	1,250	3,000	Zero emission tax exemptions and VAT deductions
Croatia[1]	9,310	5,330	5,320	No excise duties for EVs and special environmental tax exemptions
Finand	50,000	6,000	14,000	Minimum tax rate for zero-emission vehicles and tax deductions
France	50,000	50,000	50,000	Regionally determined tax exemptions
Germany	9,000	6,750	6,000	10-year tax exemption and reduction of taxable amount
Greece	6,000	6,000	6,000	Registration tax reduction and benefit-in-kind tax exemption
Hungary	7,350	7,350	7,350	Tax exemptions
Ireland	5,000	5,000	5,000	Reduced tax rate and benefit-in-kind concession
Italy	8,000	8,000	8,000	5-year tax exemptions
Lithuania	5,000	5,000	5,000	Tax exemptions and minimum rates
Luxembourg	8,000	1,500	8,000	Administration tax reduction and minimum rates
Netherlands	4,000	4,000	4,000	Exemptions and minimum rates
Portugal	6,000	–	6,000	Tax exemptions and VAT reduction
Romania	10,000	4,250	–	Tax exemptions for electric vehicles
Slovenia	7,500	4,500	–	Minimum tax rate
Spain	9,000	5,000	9,000	Exemption from emissions tax and personal income tax reduction
Sweden[1]	6,650	4,220	6,650	Reduced annual road tax
UK[1]	29,430	29,430	29,430	Benefit-in-kind tax reduction and capital allowances

Note: FCEV amounts include subsidies for all-electric drivetrains and zero-emission vehicles; the data source is as of 2021 with the max value shown;
[1] Subsidy amounts converted into Euros from base currencies using spot rates as at 10-Jun-2022.
Source: ACEA, Government agencies, Credit Suisse

Although the EU Commission's AFIR proposal goes some way to addressing the underdeveloped FCEV refuelling infrastructure in the EU, the ACEA does not believe that the measures are ambitious enough to enable CO2 targets to be met. In the position paper published by the organization, the ACEA has stated that the proposals should reduce the distance between hydrogen refuelling stations to 100km instead of the 200km proposed by the Commission. This is based on the expected number of FCEVs on the road by 2030 and the average mileage per vehicle, with the ACEA estimating that there will be 60,000 trucks on the road by 2030. The target date should also be brought forward to 2027 from 2030, with an intermediate target introduced for 2025 to coincide with the roll-out of a number of FCEVs from 2024.

Europe FCEV Subsidies and tax benefits

A large number of European countries offer subsidies and tax benefit schemes on electrified powertrain technology across various vehicle categories and use cases. In most cases, FCEV technology is supported to the same order of magnitude as other drivetrain technologies. However, this support is currently not as widespread.

Japan FCEV market

The first country to adopt a basic hydrogen strategy

Japan was the first country to adopt a basic hydrogen strategy. The Japanese government released the 'Basic Hydrogen Strategy' in 2017 and targets to build a hydrogen society. The Japanese government in 2019 further updated the Strategic Road Map for Hydrogen and Fuel Cells, and specified the detailed targets for 2025 and 2030, as well as the actions to be taken to achieve the targets. After the policy update, Japan has already set full range of targets along the hydrogen value chain, which covers hydrogen supply, hydrogen cost, fuel cell vehicle and hydrogen refuelling stations.

In addition to a clear future target of building a hydrogen society, the current status of hydrogen development in Japan is also advanced compared to other countries. Japan is the first to introduce the commercially viable fuel cell vehicles, as couple of OEMs started lease sales of fuel cell passenger cars to government departments in 2002. After years of continuous research and improvement, the performance of new models has significantly improved and one of the OEMs started retail sales of its fuel cell vehicles in 2014. Japan also has a vision for hydrogen power generation and wider application of hydrogen fuel cells in the future. The country has completed the production facility in Fukushima Prefecture in March 2020. The facility is equipped with a 10,000kW class hydrogen production facility and utilizes electricity generated from solar panels.

Figure 25: Japan has set a full range of hydrogen development targets covering the entire value chain

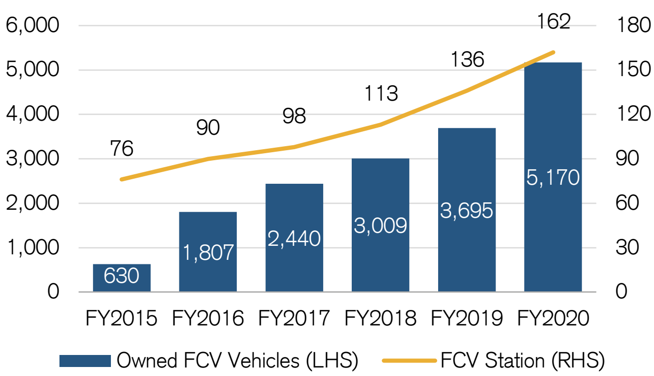
		2025	2030	Long-term
Use	No. of fuel cell passenger vehicles	200k	800k	
	No. of fuel cell buses	N/A	1,200	
	No. of fuel cell forklifts	N/A	10k	
	No. of hydrogen refueling stations	320	900	
Supply	Blue hydrogen	N/A	Supply cost <¥30/Nm3 (~US$3.2/kg)	Supply cost <¥20/Nm3 (~US$2.2/kg)
	Green hydrogen	NA	System cost of water electrolysis <¥50k/kW Efficiency of water electrolysis 4.3kWh/Nm3	

NA = Not applicable. Source: Ministry of Economy, Trade and Industry of Japan

Figure 26: Green hydrogen facility in Fukushima

Source: The government of Japan

Figure 27: Trend of FCEV vehicles and stations in Japan



Source: CEV, METI, Credit Suisse

Korea FCEV market

The Korean government wants FCEV to fundamentally transform the state energy system and secure new growth engines at the same time. Korea wants to take the lead in creating a hydrogen economy by connecting the technology with traditional manufacturing sectors, including the auto, shipping, and petrochemical industries.

The Korean government announced its Hydrogen Economy Roadmap in January 2019. The Korea government aims high, as it plans to increase the number of hydrogen powered vehicles, from ~4,000 in 2019, to ~6.2mn by 2040, and make the country the world's No. 1 manufacturer/exporter of hydrogen powered vehicles by 2030. The target for hydrogen refuelling stations is also ambitious, as the government plans to grow the number of stations, from merely ~14 in 2018, to 1,200 by 2040. In July 2020, the government announced its ambitious Korea New Deal plans that will invest W160 tn in the next five years in the following three areas: (1) the green new deal; (2) the digital new deal; and (3) the employment safety net. Of the total investment, green new deal accounts for 46%, digital new deal accounts for 36%, and employment safety net accounts for 18%. On 28 October, the government additionally announced to achieve carbon net zero by 2050E. Furthermore, in its roadmap the government announced that it will diversify the hydrogen supply portfolio, increase the supply volume to 5.26mn t in the next 20 years, and lower the market price of the energy source to less than W3,000/kg.

The roadmap is in line with the government's plan to reduce greenhouse gas emissions, generate new growth momentum for its automotive industry, and reduce its heavy reliance on imported oil. South Korea relies on oil imports from the Middle East for most of its energy needs. Hydrogen fuel has the strong potential to revive sluggish manufacturing businesses, including small and medium-sized companies, which in turn will create new jobs. The government aims to bring in fresh investment and create jobs in traditional industries, such as steel production, petrochemicals, and mechanical engineering through the roadmap.

In September 2021, Korea's 10 conglomerates formed a private hydrogen company initiative called Korea H2 Business Summit. They aim to accelerate the transition to domestic hydrogen society and leading global hydrogen economy with three main goals: (1) to reduce uncertainties in hydrogen value-chain investment, (2) to pursue balanced development in the hydrogen ecosystem, and (3) to provide resources and network to seize large-scale hydrogen business opportunities.

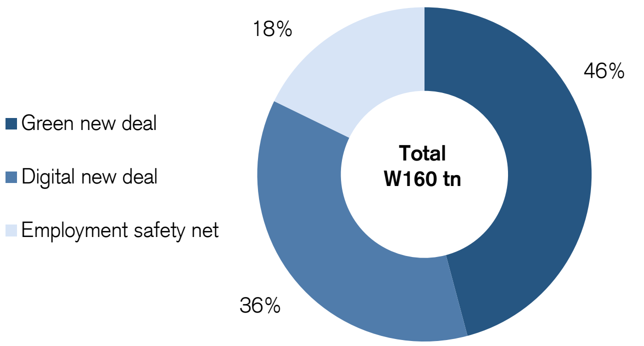
Figure 28: Key targets of Korea's hydrogen economy roadmap

	2025	2040
No. fuel cell vehicles	100k	6,200k*
No. of hydrogen refueling stations	N/A	1,200
Hydrogen production cost	N/A	3,000 Won/kg (~US$2.7/kg)

* Including export units. NA = Not applicable.

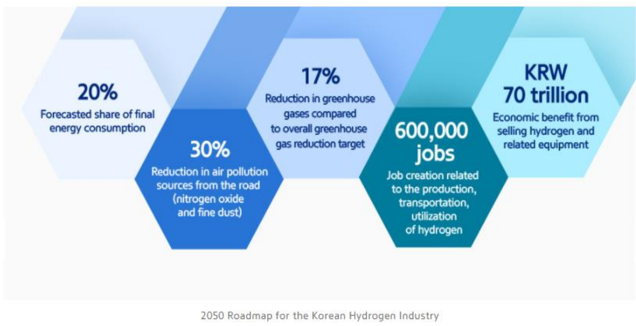
Source: Ministry of Trade, Industry and Energy of Korea

Figure 29: Breakdown of Korea New Deal



Source: South Korean government, Credit Suisse

Figure 30: 2050 Roadmap for the Korean hydrogen industry



Source: Industry data, Credit Suisse

China FCEV market

We expect China's FCEV sales to increase from 3.3k units in 2022, to 80k units in 2030, with most of the demand from commercial heavy-loading transport. In Mar-2022, China's top economic planner, National Development and Reform Commission (NDRC), released the 'Medium and Long Term Development Plan for the Hydrogen Energy Industry 2021-2035'. The plan aims to have 50k units of FCEV by 2025, which is largely in line with the five-city groups' FCEV pilot operation target to promote 45k units in four years.

China's central government launched the pilot operation of FCEV in pilot city groups, with the first city groups—Beijing (Bohai Sea Ring Area), Shanghai (Yangzi River Delta), Guangdong (Pearl River Delta)—effective from Sep-2021. In Dec-2021, another two city groups—Shijiazhuang (Hebei), Zhengzhou (Henan)—were approved for the new wave of pilot operation. In total, the launch indicates that the five city groups are eligible for a total amount of Rmb9.4bn (or Rmb1.9bn for each group) central government incentives to roll out their FCEV plans in the next four years. Besides the announced pilot city groups, we believe other cities (e.g., the northeast and southwest cities) will push for the gapped 10k FCEVs to be on the road by 2025. Combined with the Energy Saving and New Energy Vehicle Technology Roadmap 2.0, it mentioned that FCEV sales will reach ~1mn units by 2035. As a result, we expect the FCEV penetration rate in the commercial vehicle sector to increase from 0.2% in 2022, to 4.7% in 2030.

Expanding FCEV application scenarios, from city bus to trucks

We expect the truck's proportion in the fuel cell commercial vehicle market to increase from 44% in 2021, to 84% in 2030, and the bus proportion in the fuel cell commercial vehicle market to decrease from 56% in 2021, to less than 10% in 2030. Similar to pure EVs, the government is focusing first on city bus applications of FCEVs, which are easier to regulate and deploy on a large scale. Take the just-ended 2022 Beijing Winter Olympics, for example: of all the 1,100 FCEV pilot operations, 815 units are shuttle buses. On the other hand, the government also encourages application on trucks, which represent the most promising use cases for FCEV in the long term. The forklift and light truck are examples of early market successes for hydrogen fuel cells in trucks, as the power output of the fuel cell stack was only ~30kW in the early years. As the stack power output improved to 120kW in 2021, fuel cell HDTs (including tractors and dumpers) played an essential role in certain scenarios, such as urban utilities, ports, mines, and steel mills. In the latest FCEV pilot operation plan, Shanghai's local government has aimed to push 1,000 FCEVs on the road in 2022, of which 79% are trucks (54% HDTs, 25% medium trucks), and the rest are government official vehicles and city buses. In the long term, fuel cell HDT could gradually penetrate mainstream scenarios, given improving cost-competitiveness.

Chinese FCEV value chain

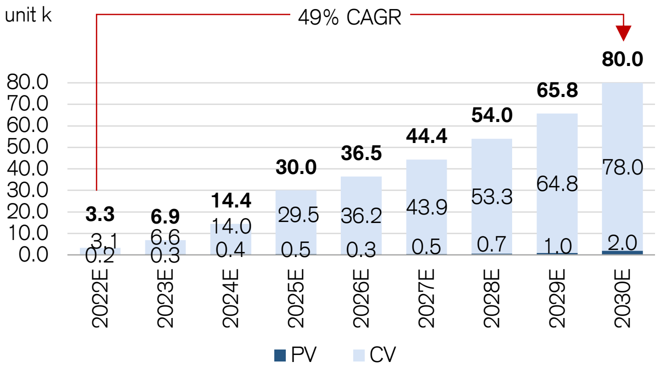
Based on the different degrees of vertical integration, there are three types of fuel cell system makers in China: (1) in-house developed fuel cell technology, together with equity relationships with downstream auto maker customers; (2) in-house developed fuel cell technology, but have no tie-ups with auto makers; (3) foreign technology fuel cell stack assembler with purchased core component—MEA or fuel cell stack.

Huge potential for domestic PEM supplier

Currently, one of the key reasons for the high cost of a hydrogen fuel cell system is that the local technology is not yet mature, therefore key components or raw materials are imported. Although some fuel cell system makers have vertically integrated into some upstream components (such as MEA and bipolar plate), few local suppliers are able to supply further upstream MEA's core materials, such as proton exchange membrane (PEM), catalytic layer and gas diffusion layer.

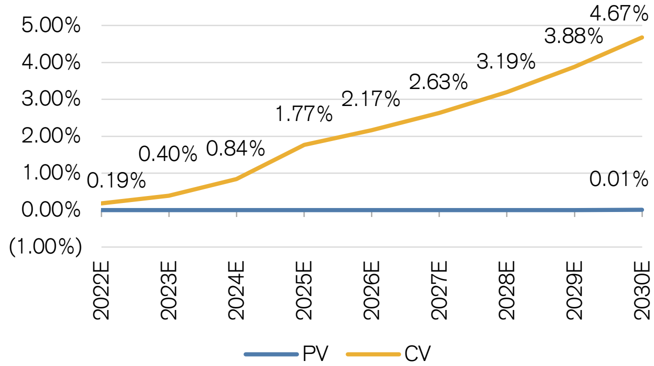
We see huge growth potential for domestic suppliers for MEA components, such as PEM. As a core part of MEA, PEM has a significant impact on the performance and durability of the fuel cell stack. As China's leading refrigerants and fluorochemical producer, Dongyue group (0189 HK) has leveraged its years of experience in fluorochemical and membranes and evolved into PEM—the heart of fuel cell stack. We estimate Dongyue's PEM products to achieve a 50% domestic market share by 2025, taking the market share from overseas brands (primarily Gore), driven by Dongyue's competitive pricing (30-40% lower than overseas brands).

Figure 31: China FCEV sales outlook



Source: Credit Suisse

Figure 32: China FCEV penetration outlook



Source: Credit Suisse

India FCEV market

FCEVs in India: A nascent foray

The government in India launched the National Hydrogen Mission in August 2021 for incentivizing manufacturing of green hydrogen in India. The mission aims to aid the government in meeting its climate targets and making India a green hydrogen hub, with a target production of 5mn t of green hydrogen by 2030 in India.

However, the supporting infra & technology for H2 FCEVs is still at a nascent stage in India, as the development efforts and plans of OEMs for this, with all H2 FCEV models are in prototype/pilot stage. However, if H2 FCEV technology picks up from here, together with the creation of the hydrogen ecosystem, we believe that CVs (heavy trucks and buses) are more likely to lead the adoption of H2 FCEV technology than PVs. Given CVs ply on relatively fixed routes, planning the distribution and refuelling infra for hydrogen would be relatively easier, which is a key hindrance to H2 FCEV adoption for cars. On the other hand, the advantages FCEVs offer, such as better support for long range and quick refuelling (vis-à-vis high charging time of pure EVs), are all amenable for CVs. We estimate a gradual start of H2 FCEV volumes in India, with a ~2% penetration in CVs by 2030 and larger adoption beyond that. We expect FCEV adoption in PVs to be negligibly small until 2030 and only pick up pace if and when the hydrogen ecosystem and infrastructure are widespread in India.

Government efforts in incentivizing H2 FECVs in India

The government has started the key initiatives stated below to promote development of H2 FCEVs and supporting infrastructure in India:

- **Fiscal support/incentives:** PLI scheme for advanced automotive technologies is a production linked incentive (PLI) scheme with a budgetary outlay of Rs259bn to boost domestic manufacturing of advanced automotive technology products and attract investments in the EVs (including FCEVs) manufacturing value chain.
- **National hydrogen energy mission-enabling infra/ecosystem:** To reduce Indian energy imports by over US$160bn by 2030 and accelerate towards the government target of achieving net zero emission by 2070, the government has launched the National Hydrogen Energy Mission in Aug-2021. The target is to produce 5mn t of green hydrogen by 2030 and make India a global hub for green hydrogen and fuel cell technology.
- **Pilot projects:** OEMs have developed several FCEV prototypes to test the viability of FCEVs on Indian roads in collaboration with the government, PSUs, and academic institutes.

US FCEV market

In general, we view fuel cells in the US as niche, given that pure EV will be the dominant form of decarbonization for light vehicles. To date, this has largely been reflected in investments/ commentary by automakers/other industry participants, and within the broader focus of policy makers. For this reason, in our forecast we see passenger vehicle FCEVs growing at a lower CAGR (22%) through the end of the decade than pure EVs (~30%), even with the much lower starting point in terms of 2021 volumes.

Indeed, in 2021 FCEVs represented only 0.02% of US sales at 3,341 units (per WardsAuto). These FCEV sales were spread across three models, manufactured by Japanese and Korean OEMs.

Notably absent from this list are the US OEMs, who have yet to introduce an FCEV offering, and are unlikely to do so given their focus on pure EV in achieving decarbonization. This will likely present a challenge to fuel cell infrastructure, as many OEMs are already on the path to a pure EV approach, including those which previously targeted fuel cells. Importantly, the 'network effect' likely needed to spur significant FCEV uptake in the US has yet to show a clear path to developing, underpinning our expectations for modest volume.

That said, the technology remains interesting in terms of the approaches to decarbonizing transit, and has the potential to develop further in the US, as its focus towards shifting away from ICE vehicles begins to catch up with China and Europe. We especially see opportunity for FCEV uptake in heavy transit.

- **Heavy duty (HD) transport as key FCEV opportunity:** While FCEV uptake in the US may be limited among passenger vehicles, we see potential for FCEVs being an appropriate route to decarbonizing heavy duty transport, as infrastructure needs may be tailored around specific routes, and also as refuelling times and energy storage may be more appropriate for large vehicles. Over time, this could improve fuel cell infrastructure for all potential FCEV applications, but this will likely be quite far in the future. Earlier this year we attended an instalment of the Impact Debates Series, 'The Future of Trucking' hosted by Mobility Impact Partners, where panelists representing diesel, pure EV, and FCEV approaches to heavy trucking debated how the varying options stack up against one another over the mid-to-long term.
    - The case was made for FCEV heavy trucks offering a sort of 'best of both worlds' combination of traits between diesel and pure EV trucks. However, fuel cells are likely the least mature (in terms of commercial development) of the powertrain alternatives, which represents one of the key challenges to scaling, as both the infrastructure and hydrogen supplies needed must be built nationwide. That said, the use of fuel cell heavy duty trucks stands to gain from the flywheel effect of fuel cell adoption in fork-lifts, airplanes, and passenger vehicles lowering overall costs via scale. Further, the presenter pointed to the performance advantages of fuel cell trucks vs. pure electric alternatives, as FCEV trucks are more closely aligned with traditional diesel fuel ICE trucks, but still on the right side of zero emission power.
    - The strongest case for fuel cell uptake came from the potential for fleet-wide adoption and long-haul heavy transit. Indeed, a fleet of trucks could share in hydrogen refuelling infrastructure at the fleet's bases, making implementation more economical. Long-haul heavy trucking may stand to benefit from some of the performance benefits of fuel cells (zero carbon emissions like pure EV, but with weights and capabilities closer to diesel trucks). Yet for long-haul routes to see uptake, appropriately located infrastructure along key routes will be necessary.
- **Policy environment for FCEVs:** As the US develops its policies surrounding decarbonization, FCEVs stand to benefit. Notably, policy surrounding alternative fuel vehicle uptake takes place at both the state level and federal level, and such a dynamic is relevant to FCEVs as well. For the most part, the policies either proposed or passed which promote FCEV uptake come amid policies incentivizing and/or mandating zero-emission vehicles (with pure EVs also being promoted).

  State: These policies include mandates on procurement by states to purchase zero-emission vehicles, consumer incentives, producer incentives, and infrastructure. For FCEVs specifically, Washington and Virginia have passed tax/investment incentives for FCEV producers, and Washington has passed hydrogen infrastructure development incentives. To date, California has led in FCEV development, and has allocated funds towards investment in 100 hydrogen refuelling stations, as well as mandating the sales of zero-emission medium and heavy-duty vehicles at increasing percentages throughout the next decade and into the 2030s, which will be solved via the use of pure EVs and FCEVs.

  Federal: In 2021, the US Department of Energy announced US$52.5mn of funding for projects related to next-gen clean hydrogen technologies. Further, in 2022 bipartisan legislation was proposed to support the adoption of hydrogen fuel cell technologies in trucks and other heavy-duty vehicles. While the progress of these policies towards being passed is unclear, the evidence of federal-level interest in promoting FCEVs is notable. That said, in our view, policymakers will likely remain more focussed on promoting the uptake of pure EVs for the foreseeable future.
- **Refuelling station infrastructure will be key:** Considering that one of the greatest constraints to FCEVs in the US will be appropriate availability of fueling stations, the development of this infrastructure is critical. On the EPA's website, a map shows public hydrogen fuelling stations in the US. Currently, the vast majority of these stations are in California, which has been quicker to develop this infrastructure than the rest of the country. Yet stations for hydrogen refuelling are planned and/or being built elsewhere, including in the Northeast and Hawaii. Moreover, cities which are leveraging hydrogen buses (such as Boston) are developing the refuelling infrastructure as necessary. At the time, OEMs offering FCEVs in the US are generally constrained to selling these vehicles in regions where hydrogen fuelling stations exist. This reinforces the need for a 'flywheel effect' in FCEVs, where refuelling infrastructure and vehicle sales reinforce the value of one another.

“When will FCEV reach cost parity with ICE vehicle? Fuel cell HDT will realize in 2029 on falling hydrogen fuel price.

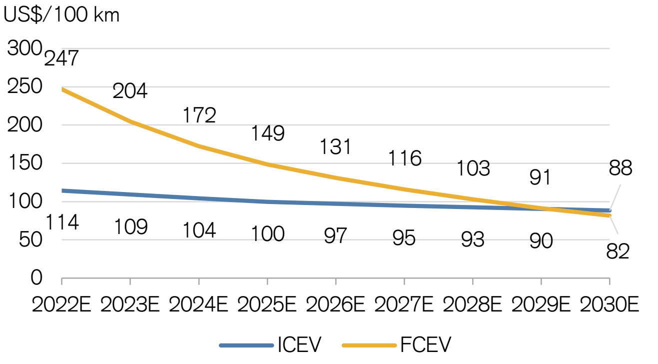
Fuel cell HDT to reach cost parity with diesel engine HDT by 2029 on falling hydrogen fuel price

The primary consideration of commercial vehicle fleet owners is the total cost of ownership (TCO) , 55% of which comes from fuel cost currently. We expect the hydrogen pump price to decline from US$10 per kg in 2022 to US$4 per kg in 2030, thus the TCO of a 40t fuel cell HDT to reduce to ~US$91 per 100km in 2029 (vs US$90 for diesel truck).

The primary consideration of commercial vehicle fleet owners is the total cost of ownership (TCO) on a 'payload carried per km' basis, ~55% of which comes from the fuel cost currently. We expect the hydrogen pump price to decline from ~US$10 per kg in 2022 to US$4 per kg in 2030 (~11% CAGR) with key drivers such as: (1) lower production cost due to increasing share of cheap green hydrogen supply—from US$4/kg to US$2/kg; (2) lower refuelling cost on HRS' instalment cost reduction and rising utilization—from US$5/kg to US$1.6/kg; and (3) lower transportation cost due to maturing liquid hydrogen storage technology—from US$1/kg to US$0.4/kg. As a result, we expect the TCO of a 40t fuel cell HDT to reduce from ~US$247 per 100km in 2022 to US$91 per 100km in 2029 combined with the falling cost of fuel cell system, when it will reach cost parity with a similar weight (size) diesel powered heavy truck. In addition, the fuel cell HDT's TCO is expected to be ~8% lower than that of diesel engine HDT in 2030.

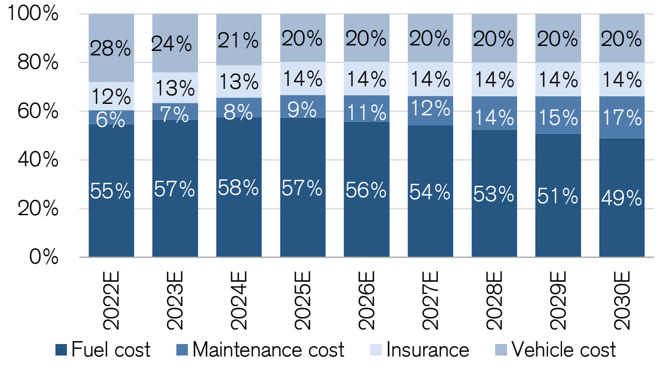
The TCO comparison is done for diesel and hydrogen-powered heavy-duty trucks (HDT) purchased between 2022 and 2030 during their first-time buyer use, assuming a maximum of 1.26mn km driving distance over the seven years after registration. For fuel cell HDTs, the key drivers for TCO reduction are falling hydrogen fuel prices, falling vehicle costs, and the falling insurance fee associated with the vehicle cost. In addition, the TCO of FCEV will benefit from the fast development of FCEV technologies, such as better fuel cell system efficiency, cheaper cost of hydrogen storage tank and longer lifetime of the fuel cell system. However, the diesel fuel cost is the key driver of TCO reduction of diesel powered HDT. Currently, diesel prices have surged significantly, especially in Europe, resulting in higher TCO for ICEVs. In the future, we expect the diesel fuel price to gradually decline due to the de-escalation of the situation in Russia and Ukraine. In addition, a number of favourable policy measures that encourage the adoption of FCEVs may also drive the timing of cost parity with ICEVs, such as purchase subsidies for FCEVS, exemption or reduction of road tolls for FCEVs and addition of CO2 external cost to road tolls (or diesel prices) for ICEVs.

Figure 33: Heavy truck (40t) TCO comparison—FCEV vs ICEV



Source: Industry data, Credit Suisse

Figure 34: Fuel cell heavy truck(40t) TCO breakdown



Source: Industry data, Credit Suisse

Falling hydrogen pump price on cheaper green hydrogen supply and falling HRS capex

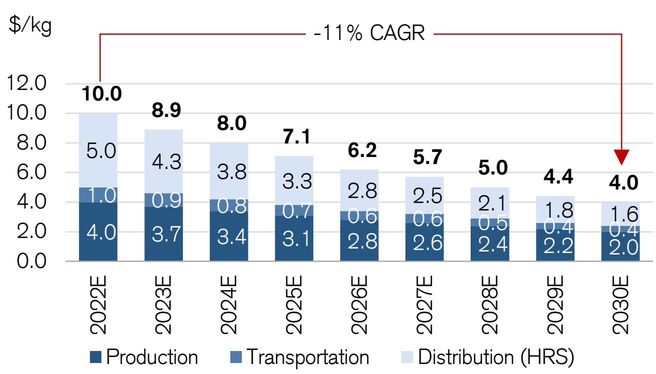
We expect the hydrogen pump price to decline from ~US$10 per kg in 2022 to US$4 per kg in 2030. Key drivers are as follows: (1) lower production cost due to increasing share of cheap green hydrogen supply—from US$4/kg to US$2/kg; (2) lower refuelling cost due to HRS' installment expense reduction and rising utilization—from US$5/kg to US$1.6/kg; and (3) lower transportation cost due to maturing liquid hydrogen storage technology—from US$1/kg to US$0.4/kg. Specifically, we estimate the renewable electricity price to decline from US$50/MWh in 2022 to US$20/MWh in 2030, resulting in the green hydrogen production price to decline from US$5/kg in 2022 to US$2/kg in 2030. Moreover, each HRS's instalment cost is expected to decline from US$2-3mn in 2022 to US$1mn in 2030, with utilization rate increasing from 10-30% in 2022 to 80-100% in 2030. As a result, hydrogen-powered fuel-cell HDTs' fuel cost per 100km is estimated to decline from ~US$135 in 2022 to ~US$54 in 2030. In particular, fuel-cell HDTs' fuel cost will reach the same level as diesel-engine HDTs' fuel cost by 2029, when the hydrogen pump price reduces to US$4.4/kg.

Lower production cost on increasing share of cheap green hydrogen supply

According to the International Energy Agency (IEA), grey hydrogen (i.e., natural gas as a feedstock) is currently the mainstream production pathway as it contributes three quarters of the existing global hydrogen production. However, we expect hydrogen production to gradually mitigate to green hydrogen production, given its zero carbon emission nature and cost reduction potential, given a lower cost of electricity from renewables and cheaper electrolyzers. We expect the hydrogen production cost to lower from US$4/kg in 2022 to US$2/kg in 2030, driven by the increase in green hydrogen production and the sharp drop in the green hydrogen price.

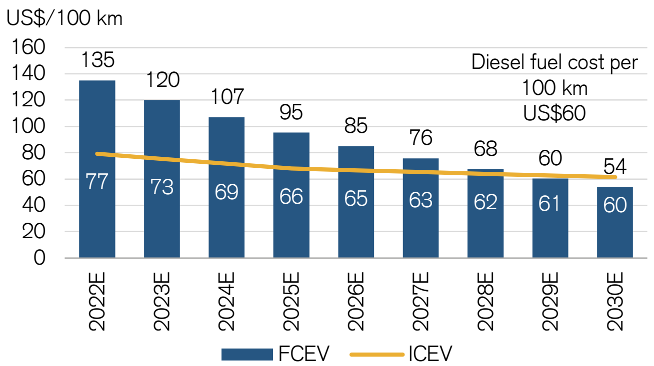
As a secondary energy, hydrogen can be produced using a diverse range of resources. To further differentiate the production pathways, hydrogen is assigned different 'colours' to recognise the environmental credentials of the production process: brown (coal gasification), grey (natural gas steam methane reforming), blue (equals grey hydrogen paired with carbon capture and storage), and green (renewable energy electrolysis). Currently, hydrogen production was mainly from grey hydrogen (74%), brown (26%), and green (0.1%). While green hydrogen is the real

Figure 35: Hydrogen pump price outlook



Source: Credit Suisse

Figure 36: 40t HDT's fuel cost comparison – FCEV vs Diesel



Source: Credit Suisse

Figure 37: The hydrogen production technology road map

Color of Hydrogen	Brown Hydrogen	Grey Hydrogen		Blue Hydrogen		Green Hydrogen	
						Renewable Power 2022	Renewable Power 2030
Production process	Convert **coal** into H^2 and CO^2	Convert **natural gas** into H^2 and CO^2		Brown/grey to store or reuse CO2 via carbon capture and storage (CCS)		Split water into H^2 and O^2 via electrolysis by **renewables** (e.g. solar and wind power)	
CO^2 emission	22-35kg	10-16kg		10% of emissions from brown/grey production		0kg	
Fuel cost	US$82/t	Carbon costs US$30/t		CCS cost US$85/kg		US$50/MWh	US$20/MWh
		In Europe ~$30/mmbtu	Normalized $6/mmbtu	In Europe ~$30/mmbtu	Normalized $6/mmbtu		
Production cost	US$1.7/kg	US$6.3/kg	US$2.4kg	US$6.8/kg	US$2.9/kg	US$5.0/kg	US$2.0/kg
Road map	The existing hydrogen production			Interim solution		The ultimate goal of hydrogen production	

Source: Credit Suisse

environmentally friendly type, the cost of green hydrogen is more than double the cost of grey hydrogen, given the current production technology. We expect green hydrogen price to drop from US$5/kg in 2022 to US$2/kg in 2030, replacing grey hydrogen and blue hydrogen to become the most cost compelling hydrogen production technology.

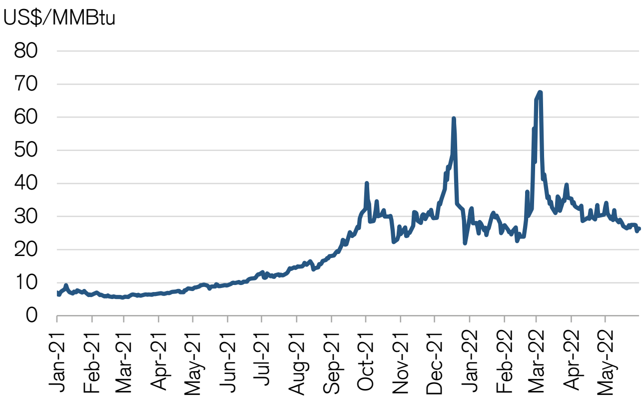
In 2022, green hydrogen would be cheaper to produce than blue hydrogen: (1) in rich-renewable power regions such as the Middle-East, (2) in Europe as the surging gas price will push up blue/grey hydrogen production cost. On the one hand, the cheapest green location today would be Qatar (US$2.6/kg), followed by Saudi Arabia (US$3.2/kg), Oman (US$3.5/kg) and UAE (US$4.5/kg) when using alkaline electrolyzers, with prices for PEM electrolyzers roughly US$1/kg higher. By contrast, blue hydrogen would cost between US$4.6 and US$4.8/kg in those nations. A similar situation exists in Western Australia, with green hydrogen costing US$2.6/kg, compared with US$4.6/kg for blue. On the other hand, natural gas price has increased four-fold since 2021. Dutch front-month gas, the European benchmark, fluctuated in the range of ~US$30/MMBtu (Metric Million British Thermal Unit) in May 2022, which has been climbing from ~US$6/MMBtu since the beginning of 2021 and shot up significantly due to the Russia-Ukraine conflict. As a result, surging gas prices more than doubled the cost of grey hydrogen production from ~US$2.4/kg at the beginning of 2021 to ~US$6.3/kg in May 2022 in Europe. By contrast, the PPA (power purchase agreement) derived green hydrogen's production cost remained constantly at ~US$5.0/kg. In short, the high gas price marking the previous twice-more-expensive green hydrogen is currently 20% cheaper than grey hydrogen in Europe.

Lower green production cost due to falling renewable electricity price for electrolysis

We expect the green hydrogen production cost to drop significantly via leveraging the increasing sufficient renewable energy. For green hydrogen, the most important cost component is the power cost (~55%), while electrolyzer capex is also material (22%). The remaining 23% consists of other items (balance of plant, compression and storage, water cost, opex). We expect the green hydrogen production cost to decrease from US$5.0/kg in 2022 to US$2.0/kg in 2030, driven by cheap renewable power, a cost reduction in electrolyzers and further electrolyzer technological developments.

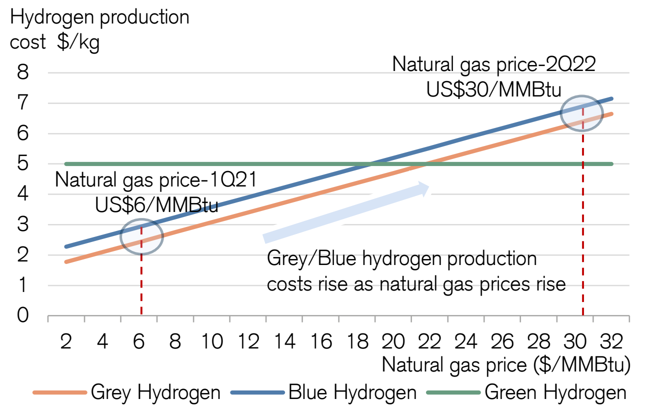
- **Power cost:** Our optimistic expectation is for declining energy prices for hydrogen generation from ~US$50/MWh to US$20/MWh by 2030, lowering the cost of power to hydrogen from US$2.8 per kg in 2022 to US$1.1 per kg in 2030. With the levellised cost of renewable power accounting for 55% of green hydrogen costs, a US$10/MWh decline in the power price would reduce the cost of hydrogen by US$0.56/kg. Currently, the offshore wind power costs of ~US$50/MWh adds US$2.8/kg to the overall cost (US$5.0/kg). However,

Figure 38: Netherlands TTF natural gas price (Forward Month 1)



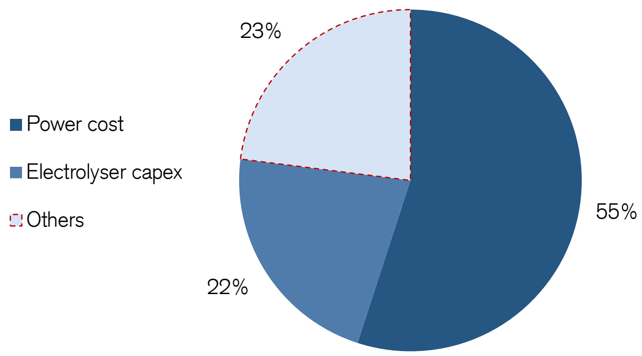
Source: the BLOOMBERG PROFESSIONALTM service

Figure 39: Grey/Blue hydrogen production cost vs Green



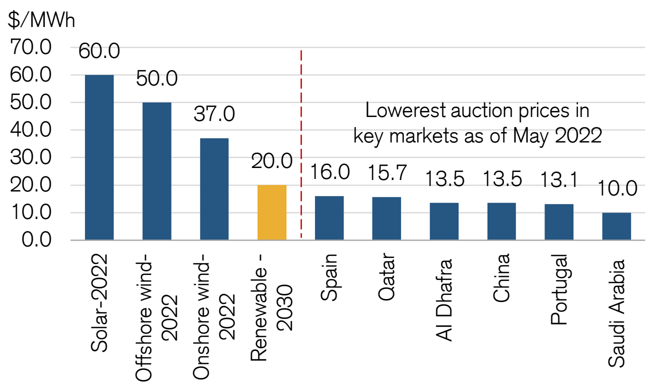
Source: Credit Suisse

Figure 40: Green hydrogen production cost breakdown



Source: Company data

Figure 41: Renewable power cost outlook



Source: Company data, Credit Suisse

cheaper renewable energy is already being observed in key wind and solar abundant regions, such as the Middle East, some parts of Europe and Asia. For example, Saudi Arabia claimed a record-low solar power deal at US$10/MWh, undercutting other global pacesetters such as the Al Dhafra solar power bid at US$13.5/MWh, Qatar's US$15.7/MWh, Portugal's US$13.1/MWh and Spain's US$16.0/MWh, and China JinkoSolar's US$13.5/MWh, although comparisons between power prices is notoriously difficult, given factors such as extent of subsidy support and the inclusion or exclusion of grid connection costs.

- **Electrolyzer capex costs:** A US$100/kW drop in electrolyzer capital cost, meanwhile, would reduce the cost of hydrogen by another US$0.1/kg. There are two types of electrolyzers that are commonly used for green hydrogen production: one is alkaline electrolyzer (ALK), and the other is proton exchange membrane (PEM). PEM differs from ALK as instead of performing electrolysis over a water-electrolyte solution, PEM electrolyzers use a solid specialty-plastic membrane (solid polymer electrolyte, or SPE). ALK electrolysis enjoys a cheaper capex cost, but is less compatible with renewable generation than PEM (slower startup and narrower operating range). We expect electrolyzer costs to reduce from US$800/kW and US$1,200/kW for ALK and PEM, respectively, in 2022 to US$300/kW and US$500/kW, respectively, by 2030. Therefore, the average electrolyzer cost would reduce from US$1,000/kW in 2022 to US$400 in 2030, lowering the electrolyzer capex costs to hydrogen from US$1.1/kg in 2022 to US$0.4/kg in 2030. Generally, electrolyzer makers set a more aggressive cost reduction target: Nel is targeting c.US$350/kW for alkaline in 2025, and ITM is looking at US$550/kW by 2025.
- **Electrolyzer efficiency:** Finally, an increase in electrolyzer efficiency to 70% from 65% would reduce the cost of hydrogen by a further ~US$0.2kg-0.4/kg. The Hydrogen Council reports estimate that ALK/PEM efficiency of ~70% is possible by 2030 from technological progress, versus levels of ~65% currently. The IEA similarly expects LHV efficiency in water electrolysis to improve from 64% currently to 69% in 2030, and to 74% in the long term.

Lower refuelling cost on HRS' instalment cost reduction and rising utilization

With HRS's high instalment cost and limited utilization rates, hydrogen refuelling costs are ~US$5/kg currently (or 50% of total cost at hydrogen pump), implying a significantly higher total cost vs conventional gasoline and diesel fuel (15% of retail price). We expect hydrogen refuelling costs to reduce from US$5.0/kg in 2022 to US$1.6/kg in 2030, mainly driven by (1) HRS' instalment cost reduction from US$2-3mn per station in 2022 to US$1mn in 2030, (2) increase in HRS' utilization rates from 30% in 2022 to 80% in 2030.

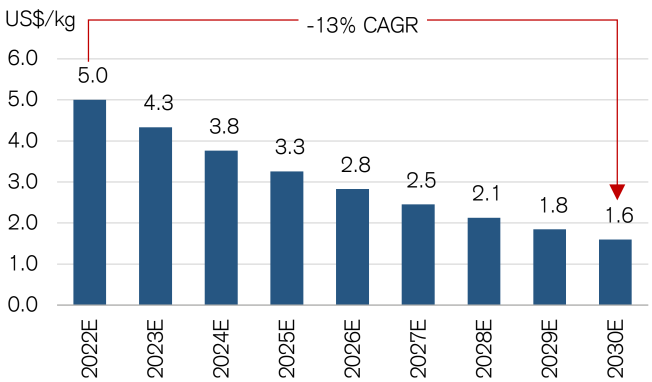
HRS' instalment cost reduction

Refuelling station units simply provide the required processing (e.g., compression, cooling) to fuel vehicles with either gaseous or liquefied hydrogen. From a cost perspective, compression (and liquefaction) equipment is consistently the greatest contributor to cost (45%), followed by storage (20%) and then the cost of refrigerator (12%) and dispensers (11%). Stations' instalment cost is US$2-3mn per station currently, with smaller capacity stations' cost of US$1-2mn per station (for 200-400kg/day) and larger capacity stations cost of US$2-3mn per station (for 800-1,000kg/day). However, we expect the HRS' initial costs to fall over time to US$1.0mn per station on average, driven by economies of scale via mass-production of the above-mentioned key equipment, such as compressors, storage systems and dispensers. We expect the number of HRS to increase by eight-fold from 2022 to 2030 (from ~1k stations in 2022 to ~9.1k stations in 2030), driven by government support projects and hydrogen fuel demand growth from the increasing FCEV fleet.

Rising utilization rate of HRS

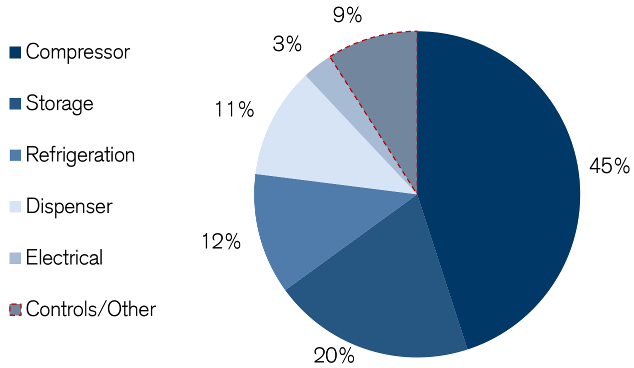
Currently, the low utilization rate of HRS is primarily caused by the limited uptake of fuel cell vehicles. As of 2021, there were ~50k FCEVs on the roads and ~700 HRS across the world, implying ~70 FCEVs per HRS, resulting in only 10-20% utilization rate of HRS. We expect the capacity utilization rate to increase to 80-100%, along with fuel cell's commercial vehicle fleet size increasing with a greater demand for hydrogen refuelling. As a result, the HRS' capex cost will decline via dilution of the heavy instalment cost, land usage right rental cost and other SG&A expenses.

Figure 42: Hydrogen refuelling cost outlook (US$/kg)



Source: Company data, Credit Suisse

Figure 43: HRS' instalment cost structure



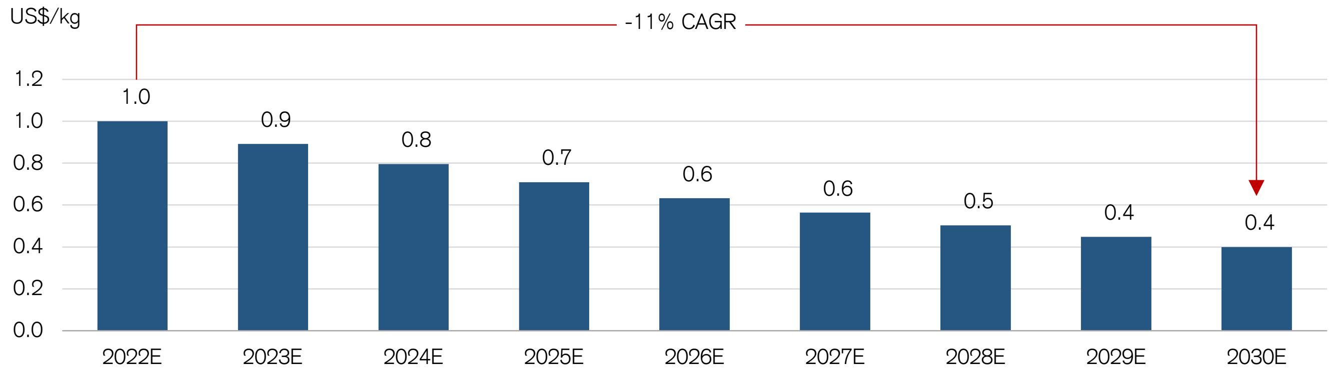
Source: Company data

Lower transportation cost on maturing liquid hydrogen storage technology

We estimate the hydrogen transportation cost to reduce from US$1.0/kg in 2022 to US$0.4/kg in 2030 due to the transportation method upgrading from gaseous trucking to liquid trucking. Hydrogen is difficult to store or transport due to its low volumetric energy density. This also creates obstacles for a wider range of hydrogen applications. Hydrogen is mainly transported by: (1) the trucking of compressed hydrogen; (2) the trucking of liquefied hydrogen; (3) pipelines and (4) on-site electrolysis, which does not require transportation. In general, transporting hydrogen in liquid form is the most cost effective alternative for distances above 300-400km with a medium quantity as the transportation capacity is ten times that of gaseous trucking. Currently, liquid trucking is not widely used due to: (1) considerable costs of liquefaction and cooling in the current technology (cooled to –253° C) and (2) lack of economies of scale (4,000kg liquid trucking capacity vs 200kg per day of HRS capacity). However, we expect liquid trucking to become the mainstream transportation method of hydrogen by 2030, owing to the maturing liquid hydrogen storage technology and expanding HRS capacity.

- **Gaseous trucking:** Gaseous hydrogen is transported in compressed gas containers by truck. Typically used for small deliveries to HRS that are close to the hydrogen production plant with a small initial investment. However, gaseous trucking carries a smaller quantity of hydrogen and therefore has a higher cost when compared with fully loaded liquid trucking.
- **Liquid trucking:** Hydrogen is liquefied, then injected into liquid hydrogen tanks, and then transported by truck. It is the most economical method for distances >300km with medium quantity. However, the cost of liquefaction is high.
- **Pipeline H2 delivery:** As a pipeline network scales, it is possible to attach refuelling stations to the network. This has incremental capex implications vs gaseous delivery, given delivery will be at a lower pressure, requiring greater compression. As networks grow more substantially, this could well be among the cheapest delivery methods. Ultimately, only really in the case of widespread adoption of hydrogen applications (2030 onwards) would we expect this to be a primary supply form.
- **Onsite electrolysis:** HRS is in a location where small-scale renewables are located. The HRS can integrate electrolyzers to produce and store the green hydrogen on-site and therefore does not require transport costs. However, it might be a challenge to get cheap energy at, say, US$20/MWh on a small scale.

Figure 44: Hydrogen transportation cost outlook (US$/kg)



Source: Credit Suisse

Figure 45: Hydrogen transportation methods

	Gaseous H2 trucking	Liquid H2 trucking	Pipeline H2
Method	Tube Trailer	Liquid Trailer	Pipeline
Capacity	250-500kg	4,000kg	N.A.
Hydrogen density	1-2%	10%	N.A.
Energy consumption	2-6%	33%	1%
Advantage	Small quantities over short distances, a small initial investment	The most economical method for distances >300km with medium quantity.	The best option for large-scale transportation
Disadvantage	Smaller quantity therefore higher cost, loading/uploading takes time	Cost of liquefaction is high	Energy required for compressing and pumping hydrogen is considerable; High level of initial investment.
Cost	US$1/kg	US$0.4/kg	US$1.6/kg

Source: Credit Suisse

Other technologies that drive down the TCO

Besides the falling hydrogen pump's price and fuel cell system's cost, we also highlight some other technological progress that lead to lower fuel cell HDT's TCO, including: (1) reducing hydrogen consumption per km on rising fuel cell system efficiency, (2) cheap hydrogen storage tank, and (3) extended lifetime of the fuel cell system, etc.

- **Reducing hydrogen consumption on rising fuel cell system efficiency.** We expect the fuel cell system's energy efficiency to improve from the current ~45% to ~60% in 2030 by increasing system output voltage, while keeping the material cost low. Thus, we expect the hydrogen consumption for fuel cell HDT to reduce from the current ~14kg per 100km to ~10kg per 100km in 2030, resulting in a lower operation cost.
- **Reduced hydrogen storage system expense by replacing gaseous hydrogen storage to liquid.** Current compressed gaseous hydrogen in high-pressure storage tank can only support a driving range of 400-600km. Thanks to the technological innovation, the upcoming liquid hydrogen storage tank could carry more hydrogen. The target is to reduce the cost of an 80kg hydrogen storage tank—estimated to decline from the current ~$40k (for gaseous hydrogen) to ~$20k (for liquid hydrogen) by 2030.
- **Reduced depreciation cost on extended lifetime of fuel cell system.** We expect the fuel cell system's lifetime to increase from the current 12,000 hours to 30,000 hours by 2030, which will significantly reduce the vehicle depreciation cost. We highlight that diesel engine HDT's lifetime is estimated to be about seven years, or 20,000 hours.