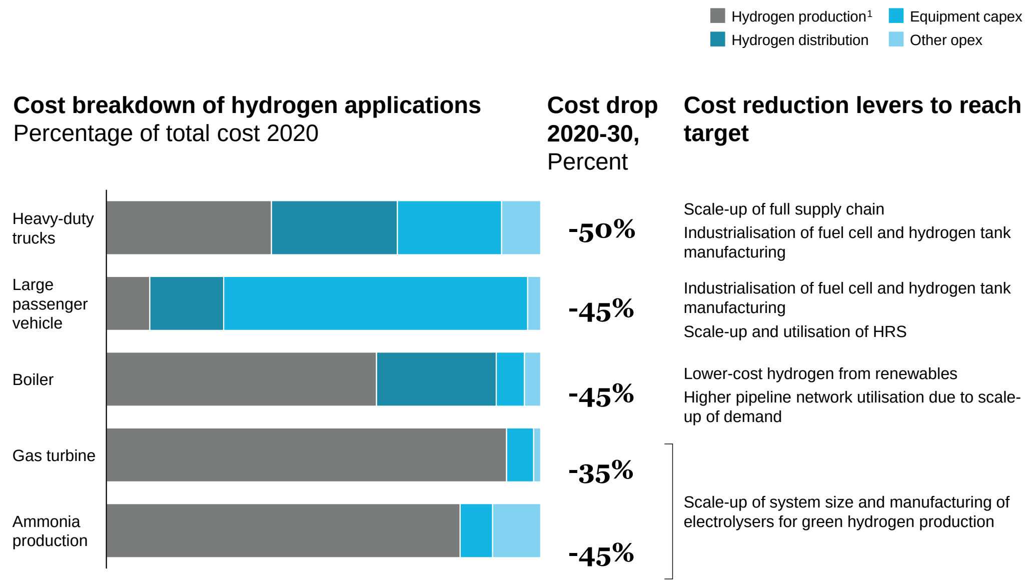
Drivers of cost competitiveness

Application TCOs typically comprise hydrogen production, distribution and end-use equipment costs. The degree to which each of these elements impact the TCO of an applications differs by application (Exhibit 7). For non-transport applications, more than 80 per cent of of the TCO is driven by hydrogen production and distribution. In contrast, end use equipment costs may comprise up to 70 per cent of transport application TCOs, depending on the usage profile.

In the following sections, we consider each of these factors. We first consider the importance and implications of production scale on equipment capex. We then explore the impact of consumption volume on the utilisation of distribution infrastructure. Finally, we showcase the importance of scale in reducing hydrogen production costs.

Exhibit 7 | Drivers of hydrogen's cost competitiveness



1. Assumes 50/50 blend of low-carbon and average renewable hydrogen

Implications of scale on equipment costs

Scale will reduce equipment costs significantly across the hydrogen value chain. Hydrogen technologies currently have niche status, and there is significant potential for both achieving economies of scale in the manufacturing process and improving the technology further. In solar and wind power, for example, each doubling of cumulative production in the past led to cost reductions of 19 to 35 per cent. Exhibit 8 shows the estimated learning rates for electrolysers and fuel cells compared to solar, onshore wind and batteries.

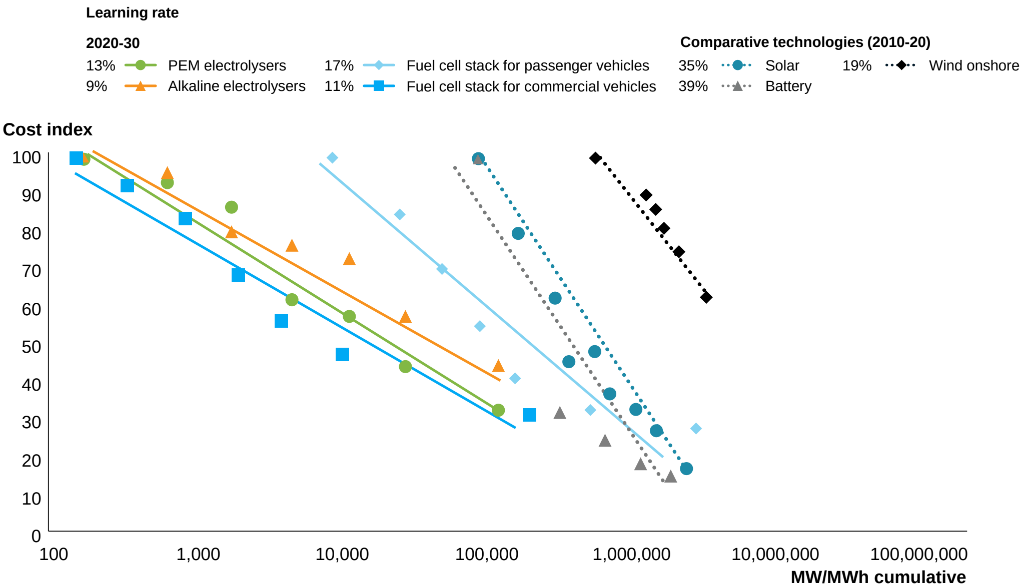
We estimate that fuel cell stacks for passenger vehicles will exhibit learning rates of about 17 per cent in the near future. The learning rates for commercial vehicles are lower, at roughly 11 per cent, primarily due to the lower volume of vehicles, but will still benefit from scale-up in other segments. Electrolyser learning rates are about 9 per cent and 13 per cent, respectively, for alkaline and PEM technology. Learning rate estimates for PEM are slightly higher, as this technology is less mature and therefore has higher cost-reduction potential. All of these estimates are independent of synergies between the technologies, which could further drive up the learning rates. For instance, the PEM electrolyser manufacturing may benefit from improvements in the PEM fuel cell production.

These cost reductions may seem aggressive at first, and uncertainties exist in both scale of deployment and technology. However, when comparing the cost trajectories with other 'new' technologies such as solar panels and lithium-ion batteries, both with historical learning rates above 30 per cent, they appear conservative, and we may in fact expect further upside.

Exhibit 8 | Learning rates for hydrogen applications

Capex development of selected technologies over total cumulative production

Indexed to 2020 values (2010 for comparative technologies)[1]



1. Installed base: assuming 50/50 split of electrolysers volume with 50-75% utilisation; assuming 115 kW for PV, 250 kW for buses and 300 kW for trucks; LCOE used for solar cost; batteries in MWh

SOURCE: McKinsey; IRENA; BNEF; Ruffini & Wei (2018) (learning rates); DoE

Learning rates are highest for emerging technologies (PEM) and high volume FC for passenger vehicles.

Learning rates for tanks are ~10-13%, somewhat lower than for fuel cells due to higher materials share of cost.

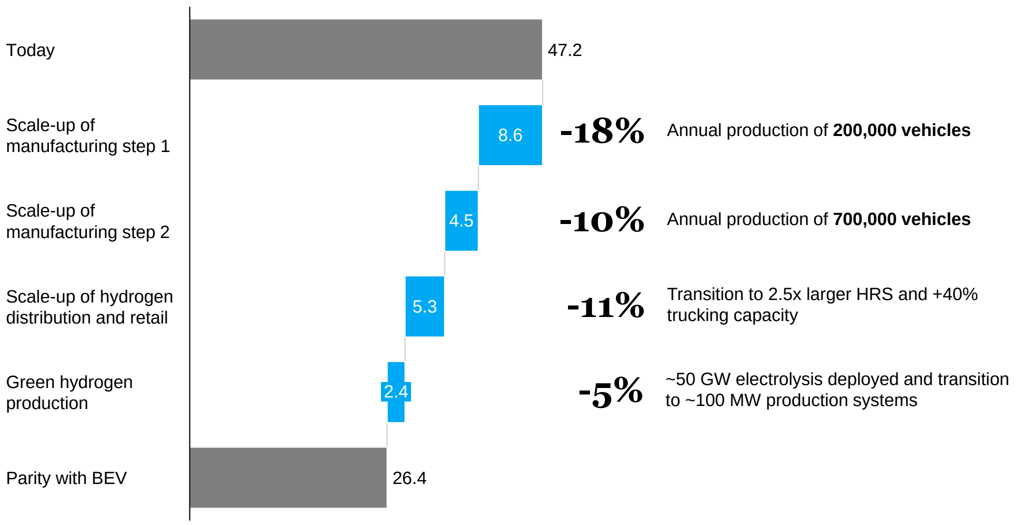
Implications of scale on utilisation and distribution costs

Beyond reductions in equipment costs, a scale-up in hydrogen usage will also lead to improved utilisation of capex. This point can be illustrated with reference to passenger car TCO. Achieving cost reductions for fuel cell vehicles requires the scale-up of both manufacturing of components as discussed above (e.g. fuel cells and hydrogen tanks) and the total hydrogen supply chain.

The TCO for large passenger vehicles could decline by about 45 per cent by 2030, as shown in Exhibit 9, driven by three main factors: lower-cost vehicle capex, lower-cost distribution and retail of hydrogen, and lower-cost hydrogen production. These cost reductions are vital for reaching cost parity with BEVs.

Exhibit 9 | Cost reduction for large passenger vehicles

Total cost of ownership
USD cents/km



Insight

Majority of cost reduction in vehicle capex comes from scaling up to 200k annual production; to reach fully parity with full battery vehicles 600k annual production volumes are required.

As per the previous discussion on learning rates, vehicle capex reduction can make FCEVs competitive with other technologies. Today, fuel cell vehicles carry an approximately 70 per cent higher cost than BEVs in the large passenger vehicle segment with the same range. Reducing the cost of the car itself is thus key to securing cost competitiveness. These reductions are achievable. Our findings show that the cost of fuel cells is a 'step function'. An annual global production volume of only 200,000 vehicles could reduce the total cost of the fuel cell by about 45 per cent, resulting in a 18 per cent reduction in the TCO of the vehicle. A further increase to 600,000 production volume would reduce TCO by another 10 percentage points, corresponding to about 70 per cent cost reduction for the fuel cell itself.

Beyond the cost of equipment, the cost of hydrogen supplied is a key cost driver – particularly supply chain costs. In fact, hydrogen distribution and retail costs represent the most significant part of the cost of hydrogen faced by the large passenger vehicle end user, accounting for about 60 per cent of the outlay. Scaling up the value chain can significantly reduce this amount, resulting in an 11 per cent cost drop for a large passenger vehicle TCO. Three major factors are behind this cost reduction: the utilisation of HRS, a transition to larger stations, and reliance on high-capacity logistics (e.g. higher pressure trucks, pipelines) with higher utilisation.

A more efficient use of infrastructure would distribute costs across more users. For instance, an increase from 60 to 80 per cent utilisation of hydrogen refuelling stations would reduce the cost contribution for the station by about 25 per cent. Operators can achieve high infrastructure utilisation and corresponding lower costs earlier on by developing supply infrastructure in lockstep with demand, e.g. for vehicle fleets.

Likewise, going from small stations with 200 kg per day capacity to larger stations with 1,000 kg per day would reduce the cost contribution from hydrogen refuelling station by about 70 per cent, with further decreases projected as deployment increases and the station's investment and operational costs decline.

Implications of scale on hydrogen production cost

The final cost-reduction driver for the TCO of fuel cell large vehicles beyond scale in the supply chain is scale in production. This will lead to lower costs of hydrogen supplied. Today, renewable hydrogen from electrolysis costs approximately USD 6 per kg. Reducing this to around USD 2.60 per kg would help to achieve cost parity. This could drive down TCO by another 5 per cent.

As the large passenger vehicle example illustrates, hydrogen production costs play an important role in the overall hydrogen equation. The cost of hydrogen production is even more important for all non-transport application that are fuel- and feedstock-intense such as gas turbines, boilers, and ammonia production. Some transport applications that are more fuel-intense, like heavy-duty trucking, have a similar sensitivity to hydrogen production costs. More generally, sensitivity to hydrogen costs increases the shorter the supply chain is.

Since hydrogen production cost matters greatly to competitiveness in most segments, it is important to understand its cost trajectory. Low-carbon and renewable hydrogen costs will likely decline significantly in the coming years. In the short term, low-carbon hydrogen from reforming plus CCS offers the lowest cost in regions with access to w storage. Volumes of low-carbon hydrogen should increase to about 12 million tons of hydrogen per year, with costs of about USD 1 to 2 per kg by 2030. Cost reductions of approximately 5 to 10 per cent should occur due to lower-cost CCS. Limited improvement potential exists since natural gas reforming is a well-established technology today.

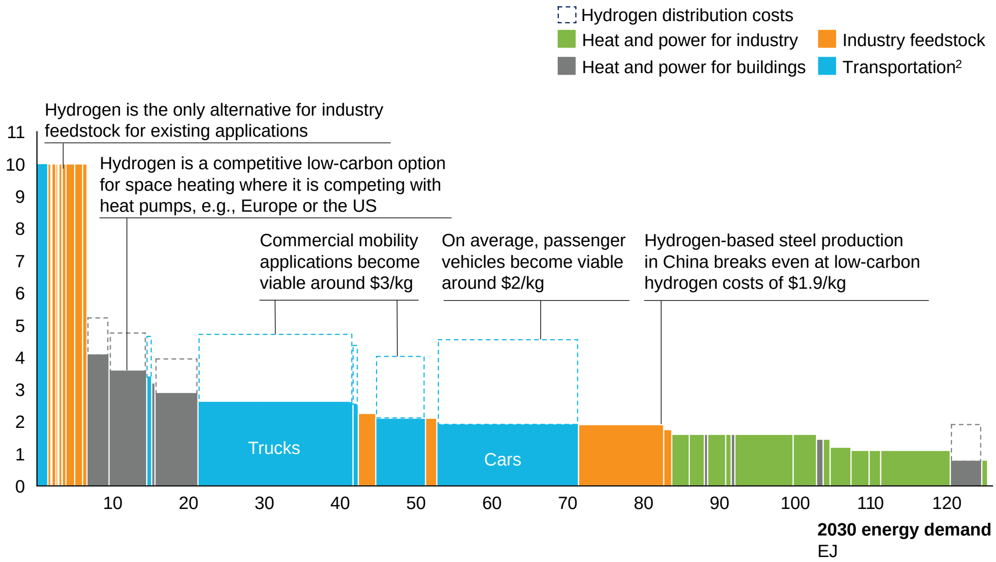
Within five to ten years – driven by strong reductions in electrolyser capex of about 70 to 80 per cent and falling renewables' levelised costs of energy (LCOE) – renewable hydrogen costs could drop to about USD 1 to 1.50 per kg in optimal locations, and roughly USD 2 to 3 per kg under average conditions. Achieving these electrolyser cost targets of around USD 400 per kW would require deployment of about 70 GW of electrolysis capacity, assuming a learning rate of 9 to 13 per cent.

Hydrogen production break-even costs by application

We estimated the break-even levels where hydrogen applications become competitive in comparison to low-carbon alternatives. We assessed four main regions, namely China, the US, the EU, and Japan/Korea, in detail. Exhibit 10 shows the cost of hydrogen at which each use case becomes cost competitive with the low-carbon alternative in 2030, and how much energy demand that theoretically accounts for. The transportation and distributed heating segments require specific infrastructure, and we have thus considered the corresponding costs separately when calculating the break-even point.

Exhibit 10 | Cost curve for hydrogen production across segments and regions

Breakeven hydrogen costs at which hydrogen application becomes competitive against low-carbon alternative in a given segment
USD/kg



1. Regions assessed are the US, China, Japan/Korea, and Europe
2. Transportation segments breakeven calculated as weighted average

SOURCE: McKinsey; IHS; expert interviews; DoE; IEA

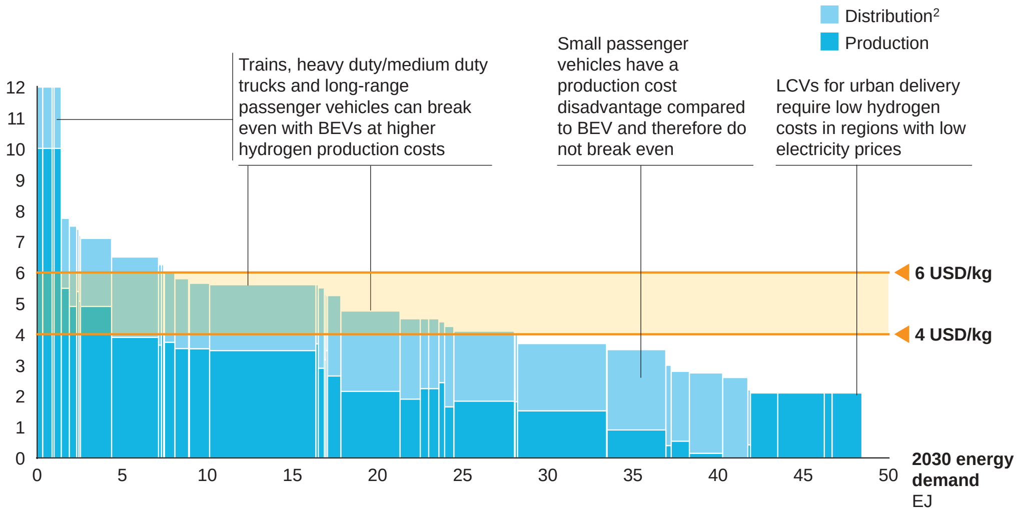
We find that hydrogen can unlock approximately 8 per cent of global energy demand with a hydrogen production cost of USD 2.50 per kg, while a cost of USD 1.80 per kg would unlock as much as roughly 15 per cent of global energy demand by 2030. This does not imply that hydrogen will satisfy all of this energy demand by 2030, but it does showcase that hydrogen will have a significant role to play as a clean energy vector in the future energy mix. As mentioned in our prior report, we expect hydrogen may fulfil about 18 per cent of final energy demand by 2050.

It is important to differentiate between applications that allow for CCS on-site, e.g. power generation, industrial heating, and steel production, and applications where direct CCS is not an option, such as domestic heating. For power and industry applications where CCS is feasible and CO_2 storage is accessible, break-even hydrogen cost falls below USD 1.5 per kg. This is particularly true in regions where conventional fuels such as natural gas and coal are abundant and low cost, such as the US. For distributed usage like building heating, where on-site CCS is not an option, hydrogen prices of about USD 3 to 4 per kg would break even, with heat pumps as the decarbonisation alternative. For these applications, low-carbon hydrogen with centralised CCS or renewable hydrogen from electrolysis will have clear benefits.

Mobility stands out among the other segments, and is shown in Exhibit 10 as a weighted average across regions and sub-segments, e.g. heavy-duty trucks and delivery vans are aggregated to ‘trucks’. We break these segments out in Exhibit 11 below to provide more detail. Our findings show that hydrogen costs can be higher for long-range mobility segments without compromising competitiveness with the best low-carbon alternative, BEVs. Mobility applications are generally less sensitive to hydrogen production costs than other segments, due to longer hydrogen supply chains and higher cost contribution of equipment. Consequently, in transportation, the hydrogen industry can unlock a growing share of demand even at hydrogen production cost levels of above USD 2 per kg before supply chain and refuelling costs.

Exhibit 11 | Cost curve for hydrogen for transportation across segments and regions

Breakeven hydrogen costs at which hydrogen mobility applications becomes competitive against low-carbon alternative in a given segment in focus regions[1]
USD/kg at nozzle



1. Regions assessed are the US, China, Japan/Korea, and Europe
2. No distribution costs for aviation as it can be distributed as liquid fuel

SOURCE: McKinsey; IHS; expert interviews; DoE

We find that hydrogen can meet a large share of the mobility energy demand by 2030. Even with hydrogen costs at the pump of USD 6 per kg – including production, distribution, and retail – the fuel can meet about 15 per cent of transport energy demand cost competitively by 2030. We expect this cost profile to become viable in most regions and use cases by 2030. If costs were USD 4 per kg at the nozzle, hydrogen could even meet more than 50 per cent of the mobility sector's energy demand. Trucks, long-distance buses and large passenger vehicles are particularly competitive, as the cost of batteries required to secure the necessary range is very high for the battery alternatives.

Scaling up the full **hydrogen value chain** is the key to unlocking potential applications

60%

Cost reduction of hydrogen by 2030 for the end user

2 | Hydrogen production and distribution

Reducing hydrogen production costs will play a disproportionate role in unlocking the cost competitiveness of all hydrogen applications. The cost of producing clean hydrogen should drop by up to 60 per cent over the coming decade, with the optimal production option highly dependent on the region. For example, where natural gas is cheap and CO_2 storage is available, reforming and CCS offers a low-cost, at-scale source of production.

In addition to lower hydrogen production costs, distributed applications like mobility will benefit from reductions in delivery costs. With increasing utilisation and scale, hydrogen delivery costs should decline by up to 70 per cent over the next decade, making it possible for hydrogen to be dispensed at about USD 4.50 to 6 per kg.

In the following sections, findings on hydrogen production cost development and the most important cost-reduction factors are discussed. Developments in the cost of hydrogen distribution for different use cases are also explored.

Hydrogen production today

Today, most hydrogen comes from fossil fuels (grey hydrogen). Two primary options exist for producing hydrogen with lower carbon intensity: either via electrolysis powered by low-carbon electricity or natural gas reforming and coal gasification with CCS. For details on each type of production, see the sidebar: 'Low-carbon hydrogen production'.

Currently, the high production cost for less carbon-intense hydrogen – for instance about USD 6 per kg for renewable hydrogen from electrolysis – is hindering adoption. In total, less than 5 per cent of hydrogen volume today comes from low-carbon sources. However, recent cost reductions in renewable energy generation (for renewable hydrogen from electrolysis) and development in CCS (with natural gas reforming) are now paving the way for a growing number of low-carbon hydrogen applications. In renewable hydrogen production, for example, a total of more than 1 GW of electrolyser capacity has already been announced – a staggering 50-fold increase compared with 2015.

Low-carbon and renewable hydrogen production

Most hydrogen today is produced from fossil fuels and emits carbon (grey hydrogen). There are numerous options for producing low-carbon and renewable hydrogen. This report focuses on the two main options: reforming natural gas or coal and capturing the emitted carbon, and electrolysis using low-carbon power as an input. Biomass gasification is another promising source of low-carbon hydrogen production; however, it does not currently contribute a meaningfully large share of global supply.[4]

Two main technologies can produce hydrogen from electrolysis in combination with renewable electricity: proton-exchange membrane (PEM) and alkaline. Alkaline is currently the most mature technology, which uses a saline solution to separate hydrogen from water molecules by applying electricity. PEM is slightly less mature and uses a solid membrane to separate the hydrogen from water molecules via an electric charge.

[4] Binder, M., Kraussler, M., Kuba, M., and Luisser, M. (2018).