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Executive summary

- In the pursuit of cleaner mobility, industry players are exploring a range of new technologies, including battery electric (BEV), hydrogen fuel cell (FCV), hydrogen internal combustion engine (H2E) and hydrogen-battery hybrid. Many believe that the best fit for any applications depends to the specifics of the use case.

- To date, the industry has favoured BEV for smaller passenger cars, with hydrogen seen as a better fit for long-haul heavy trucking, but not everyone is sticking to these hard and fast divisions.

- BMW has been dabbling in various forms of hydrogen propulsion for decades. Since 2013 it has cooperated with Toyota on fuel cell drives, a partnership that both sides have described at fruitful. BMW also operates its own competence centre for hydrogen in Munich, where it began small-scale production of fuel cells in 2022 to support a pilot fleet of FCV SUVs.

- H2E shows its advantages where high engine power output is required over a long distance or for an extended period of time. It's also robust under difficult ambient conditions, such as in dusty environments or extreme temperatures. In some instances, the H2E comes close to achieving the same overall system efficiency as the FCV.

- There are also supply chain resiliency arguments for the H2E. Composed primarily of steel and aluminium, it avoids many of the rare earth materials needed for BEVs.

- Both FCV and H2E can refuel in much less time than it takes to charge a BEV, but H2E offers a faster time to market and less disruption in the supply chain. The H2E is very similar to a diesel engine, so the vehicle architecture can stay the same. That's a huge benefit in terms of development time and cost for automakers.

- Some players suggest that the nascent development and expense of creating a global hydrogen economy makes the fuel impractical compared to more readily available battery technology. The cost of green hydrogen in particular remains a challenge, with some estimates putting it at around US$120 per 100km, compared to US$88-US$109 for diesel.

- Research suggests that building up a combination of both BEV charging and hydrogen fuelling networks offers the most affordable solution for the industry. A 2022 study by McKinsey concluded that establishing both charging and hydrogen fuelling networks in Europe could save 20-30% in infrastructure costs compared to a network of only BEV charging.

- To date more than 30 countries have released hydrogen roadmaps. While the industry consensus is that the hydrogen mobility market won't hit its stride for several years, both automakers and suppliers need to start preparing today.

Could taxis be the take-off point for EU hydrogen mobility?

Hype believes that taxi fleets could be the ideal platform for establishing hydrogen mobility hubs in key European cities. By Stewart Burnett

Although battery electric has enjoyed a head start over hydrogen in the race to bring about zero-emission fleets at scale, it may not be best suited for all applications. Charging times are lengthy, with even the fastest 350kWh chargers often taking upwards of two hours to fully charge a larger vehicle. Range limitations compound the issue even further, complicating applications where usage can be intensive.

As such, hydrogen is increasingly being considered as a viable alternative for certain use cases. Juergen Rechberger, Business Field Leader, Hydrogen and Fuel Cell at engineering firm AVL, previously told *Automotive World* that hydrogen is in a "very strong position" to serve the heavy-duty market. However, this is not the limit of its value to the commercial vehicle sector.

Because of their intensive usage and tendency to be situated around metropolitan hubs where refuelling infrastructure is typically more common, shared mobility fleets may prove an optimal use case for hydrogen. Hype has been working to realise hydrogen taxis in the Greater Paris area since 2015, most recently adding a fleet of wheelchair-accessible taxis to its ranks in June 2023, though a partnership with Stellantis. Using the region as a starting point, it aims to establish a European network of hydrogen mobility hubs.

Making hydrogen mobility accessible for all

As of November 2023, Hype operates the world's largest fleet of hydrogen taxis. In Paris, where the firm first began its pilot in 2015, more than 350 taxis are currently in operation. "Our primary mission is to accelerate the development of zero-emission solutions for essential fleets, addressing air and noise pollution in urban environments while decarbonising professional fleets," says Mathieu Gardies, Founder and Chief Executive.

When the company was founded in 2009, it focussed on battery electric solutions. However, Gardies notes, it found the limitations of charging speed and charger reliability too restrictive to its planned operations. "Hydrogen-powered vehicles

> Hydrogen-powered vehicles produce no noise or pollution and offer the convenience of quick refuelling, with a range of 500-700km

produce no noise or pollution and offer the convenience of quick refuelling, with a range of 500-700km," he states. These benefits make them particularly valuable for taxis, which often require the sporadic need to take long round trips.

By partnering with Stellantis, the firm aims to ensure that anybody, regardless of physical ability, can experience its vehicles. The 50-vehicle fleet consisting of Peugeot e-Expert Hydrogen and Citroen e-Dispatch Hydrogen vehicles due to hit Paris roads by the end of 2023 can seat five passengers, including one in a wheelchair. "Hype is the first enterprise to launch a fleet of hydrogen taxis that are wheelchair-accessible," Gardies highlights. Notably, the vehicles are not pure hydrogen vehicles but dual energy electric hybrids, containing both a fuel cell system and a "reasonably sized" plug-in battery with a maximum range of 400km. The company aims to complete the deployment of its initial wheelchair-accessible fleet by the end of 2023.

Infrastructural challenges

Although Hype is confident in the future of hydrogen, it acknowledges there are barriers preventing larger scale operations. "In the short term, one of the most pressing challenges is the rapid deployment of essential hydrogen

Hype aims to complete its first deployment of 50 wheelchair-accessibly hydrogen taxis by the end of 2023

mobility infrastructure," says Gardies. At present, he estimates, there are around ten refuelling stations in Paris and 250 across Europe.

Hype is proactively working to build more stations in Europe. "Our company is structured to meet ambitious short-term goals, particularly in densely populated urban areas," Gardies claims. "We can leverage our vast experience and efficient execution processes to deploy stations in record time."

At the time of writing, the company has pre-identified a pipeline of potential sites and secured access to critical technologies through its partnerships to mitigate potential equipment shortages. It has also seen an investment of €15m (US$16.06m) from infrastructure firm Vinci Concessions to build out stations in the greater Paris area alongside sister firm Vinci Energy.

It is targeting the addition of eight green hydrogen stations open to all, not just its taxi fleet, by mid-2024 and reaching a total of 26 stations by the end of 2025. This includes 20 large-capacity stations capable of distributing one ton of hydrogen daily.

Enabling larger-scale deployment

In the medium term, Hype's ambitions are global. "We plan to replicate our successful model in 15 regions across France and worldwide by the end of 2025," Gardies states. "Our approach for these new locations replicates the strategy employed in Paris while also leveraging a pertinent regional ecosystem."

The company tends to favour regions that have already initiated a hydrogen dynamic. For instance, in Le Mans, several public and private players (ACO, Sydev, Vendée Hydrogène, Lhyfe, and Le Mans Métropole) have initiated a variety of projects, including putting ten to 15 hydrogen buses into service by 2025. "This collaborative approach forms the foundation of our expansion into other regions," says Gardies.

> "We plan to replicate our successful model in 15 regions across France and worldwide by the end of 2025

Hype's focus is not solely on taxis. Rather, it is interested in facilitating various applications, ranging from last-mile delivery and waste collection vehicles to buses, coaches and long-haul transport. Its ambitions also extend to deploying charging infrastructure to support future heavy-duty hydrogen trucks across key freight corridors. According to Gardies, the first of these corridors will connect Brussels to major cities in the Atlantic Mediterranean region, including Bordeaux, Le Mans, Lisbon, Porto, Madrid and Barcelona.

However, Hype maintains that its priority is taxis. "To accelerate the scaling of hydrogen mobility, the development of light mobility–particularly the transportation of people–plays a pivotal role in laying the groundwork for heavy-duty," Gardies emphasises. It has proven success in this sector and believes it can be replicated on a global basis, building essential infrastructure along the way. By building more regional hydrogen taxi hubs, Hype concludes it can contribute essential–albeit incremental–progress to realising hydrogen-powered mobility at a larger scale.

Hydrogen CVs needed for "high intensity" routes, says Hyvia

Renault-backed hydrogen company Hyvia expects its long-distance fuel cell vehicles to complement battery electric vehicles. By Lee Monks

Electric vehicle (EV) sales are at an all-time high and forecast to grow still higher. Between 2017 to 2022, the International Energy Agency (IEA) records that EV sales jumped from around one million to more than ten million. Furthermore, figures from online data platform Statista suggest global EV revenues will rise from US$561.3bn in 2023 to US$906.7bn by 2028, a CAGR of 10.07%.

But what of hydrogen? In its Global EV Outlook 2023 report, the IEA states that hydrogen fuel cell electric vehicles numbered 72,000 by the end of 2022, up 40% on the previous year, yet unquestionably a comparatively minor share of the total vehicle parc.

David Holderbach, President of Renault-backed green hydrogen solutions company Hyvia, doesn't see this as an issue–nor any problematic rivalry between hydrogen and battery electric. "Hydrogen is complementary," he suggests. "If you don't have intensive vehicle needs, EVs can do the job. If you need high speed, high intensity, and non-stop activity with volatile range requirements, then you need hydrogen."

Renault

Hyvia–which promises "turnkey solutions for zero emission mobility" to companies wanting to operate more efficient commercial fleets–opened its doors in June 2021 in France. Currently based in Flins, Batilly, Villiers-Saint-Frederic, and Gretz-Armainvilliers, it offers a "complete hydrogen ecosystem", which Holderbach describes as the production, storage and distribution of green hydrogen and a wide range of utility vehicles.

"We have full access to Renault Group's vast vehicle platform, its expertise, and its know-how," he suggests. "Power Vehicle Innovation (PVI), also part of Renault Group, helps us develop vehicles with a quick turnaround. Starting from scratch, it was a challenge, so we've benefitted enormously from what Renault's provided."

Due in no small part to Renault's help, Hyvia's evolution has been swift. In June 2022, one year following Hyvia's creation, all its hydrogen vehicles passed homologation. "We were the

first company in France to homologate such vehicles," Holderbach states.

The Hyvia ecosystem

The vehicles comprising Hyvia's hydrogen fleet are the Renault Master Van (for standard commercial use), the Renault Master Chassis Cab (for modifiable professional uses, such as refrigerated transit of perishables) and the Renault Master City Bus. "The City Bus is currently operating in different parts of Europe, including Germany and France. A good example is the bus running in Lyon, which is one of many European cities in the process of banning internal combustion engine vehicles."

"The most popular and widely used example of what we're doing is the commercial van," Holderbach says. The van features a 33kWh battery and four 1.6kg hydrogen tanks and can cover 400km once fully refuelled, which only takes five minutes. By comparison, battery EVs take significantly longer to charge with less range. According to a July 2023 article by fleet management company Fleet Alliance, the best van on the market in terms of range (Renault's Zoe Van) can cover 395km but takes just under an hour to reach 80% charge capacity.

Aside from vehicles, supplying hydrogen is the other main component of Hyvia's ecosystem. "Plug Power provides the hydrogen station and warehouse hydrogen storage. This completes the full ecosystem we can offer the European market." Hyvia arranges logistics, installation, and support regarding regular hydrogen supply, as well as aftersales services.

Future share

Hyvia expects to develop a 30% market share in the hydrogen light vehicle commercial market by 2030—an ambitious goal that Holderbach admits is dependent on the negotiation of multiple obstacles. "We need bigger players onboard to help with the next step forward," he says. The company's partner list currently

Hyvia offers a complete hydrogen ecosystem, including vehicles and hydrogen charging solutions

> We have full access to Renault Group's vast vehicle platform, its expertise, and its know-how

includes Orange, Engie, Equans, and Airbus. Holderbach is also in discussions with the French government and associated regional legislative authorities about scaling up operations. "The cost for small batches of vehicles compared to mass-production is comparatively high, and we need subsidies to kickstart the next stage of our growth," he adds.

Another potential obstacle is the cost of green hydrogen. Although Holderbach didn't provide exact figures, previous estimates from January 2023 costed hydrogen at around US$120 per 100km, compared to US$88-US$109 for diesel. "We're working with Plug on how to bring costs down. Hydrogen is quite a competitive market, and while the electricity we buy is at a reasonable price, we need to rescale. Reducing the total cost of ownership is crucial." The company is also in the process of implementing Hyvia Financial Services, which Holderbach claims will "allow us to support customers making the hydrogen transition, not just regarding vehicles but also stations."

He accepts that hydrogen is currently a small sector but insists on its importance to the future of mobility, citing March 2023 EU legislation that will require a hydrogen fuelling station every 200km within the TEN-T (Trans European Transport Network) by 2030. Should Hyvia find the subsidies to expand further across Europe as planned, it could be a crucial catalyst for hydrogen on the continent. "Battery vehicles are only part of the equation," he concludes. "Among those that need to go long range and charge rapidly, the penetration for hydrogen will be higher."

What are the chances of a BMW hydrogen fuel cell SUV?

BMW concedes that battery EVs alone will not enable climate neutral mobility. Megan Lampinen explores its hydrogen plans

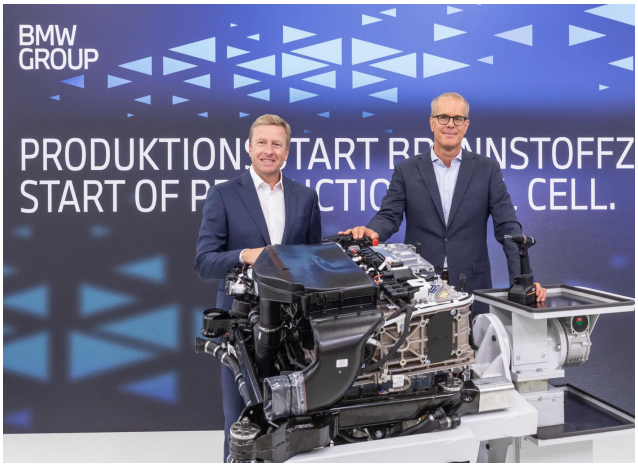
The automotive industry is scrambling to slash emissions from the tailpipe, making hefty investments into battery electric and hydrogen fuel cell vehicles. Both are technically electric vehicles but with different energy storage systems. To date, the industry has favoured battery electric for smaller passenger cars, with hydrogen fuel cell seen as a better fit for long-haul heavy trucking. But not everyone is sticking to these hard and fast divisions.

Spotlight on BMW

BMW Group has been steadily expanding its line-up of battery electric vehicles (EVs), and in the first half of the year sold 152,936 units, up 102% year-on-year. But as Chief Executive Oliver Zipse observed: "One technology on its own will not be enough to enable climate-neutral mobility worldwide." This is where hydrogen can play a role. In fact, Zipse regards hydrogen as "the missing piece in the jigsaw when it comes to emission-free mobility."

BMW has been dabbling in various forms of hydrogen propulsion for decades. In the late 1970s it offered the short-lived BMW 520h dual fuel car, which could run on either gasoline or liquid hydrogen. Other minor projects followed but never took off commercially. Since 2013 it has cooperated with Toyota on fuel cell drives, a partnership that both sides have described at fruitful. BMW also operates its own competence centre for hydrogen in Munich, where it began small-scale production of fuel cells in 2022 to support a pilot fleet of hydrogen fuel cell SUVs.

"We think the mainstream solution in the passenger vehicle segment will be battery electric, but we also see a need for hydrogen in that segment," says Juergen Guldner, General Programme Manager, Hydrogen Technology at BMW Group. "That stems from several factors, including the customer's needs, infrastructure, raw materials and the overall energy system."



The BMW Group manufactures fuel cell systems at its in-house competence centre for hydrogen in Germany

The argument for hydrogen

BMW's hydrogen cars are driven by the same electric motor as its battery EVs and offer the same impressive acceleration but without the long charging times. It takes just three to four minutes to refuel with hydrogen. On top of that, hydrogen in general can offer longer ranges than EVs, meaning less frequent trips to the pump. The combination of short fuelling times and longer range make it a good fit for drivers that travel frequently or don't have easy access to home or public charging. It also works well in regions with extremes of hot and cold temperatures, where vehicles consume more energy for HVAC requirements and hence drain the battery faster.

When it comes to infrastructure, hydrogen avoids the need for an extensive network of chargers but still requires fuelling stations. "Infrastructure has been holding back hydrogen in the passenger car segment," Guldner tells *Automotive World*. "It really has to be in place before the rollout can start." Most hydrogen stations are being designed to accommodate both heavy vehicles and passenger cars, which means the latter segment will benefit from the earlier momentum with trucking.

Notably, research suggests that building up a combination of both EV charging and hydrogen fuelling networks offers the most affordable solution for the industry. A 2022 study by McKinsey concluded that establishing both charging and hydrogen fuelling networks in Europe could save 20-30% in infrastructure costs compared to a network of only battery EV charging.

"The more electric charging you need, the more expensive it becomes," says Guldner. "But with hydrogen, each additional fuelling station basically costs the same. The price might actually go down as numbers grow. The main message from the report was that it is cheaper to do it in a combined manner than doing everything electric."

In early 2023, the European Union implemented a new regulation for the deployment of alternative fuels infrastructure (AFIR), outlining mandatory deployment targets for both EV charging and hydrogen refuelling infrastructure by 2030. "We see that trend in other regions of the world as well, such as Japan, Korea, China, the Middle East, and the US–mainly in California," he adds.

One other concern that could push some of the market into fuel cells centres on raw materials–

A fleet of BMW iX5 Hydrogen vehicles are being deployed internationally for demonstration and trial purposes

particularly rare earth metals needed for EV batteries. The smaller battery in a fuel cell car requires, on average, just 10% of the amount of scarce materials that an EV does. That means the same amount of raw materials can be used to make one battery EV or ten hydrogen fuel cell cars.

The pilot fleet

Considering these factors, BMW decided hydrogen was worth pursuing as a complementary technology to battery EVs. "Since the battery electric car and the hydrogen electric car have so much in common, we're developing them in parallel," says Guldner. "With hydrogen we're basically following the same steps that we did with the battery EVs, where we ran a pilot fleet of electric Minis and Active Es. That provided us with the learnings we needed to launch our first electric model–the i3–about ten years ago."

Today, BMW's pilot fleet of X5 Hydrogen SUVs are part of an international demonstration aimed to spotlighting hydrogen's potential. Built at the BMW Group pilot plant at its Research and Innovation Centre in Munich, the vehicles feature a 125kW fuel cell system and a small battery delivering an extra 170hp for a total power output of 295kW. The energy is stored in two 6kg hydrogen tanks and provides a range of around 504km.

"This fleet is the first step in understanding how the technology works in different climate conditions," he elaborates. Research to date has included cold weather testing in Sweden, hot weather testing in Dubai and monitoring along mountainous roads in the Alps. "We think that the technology works in all conditions, and are also gathering feedback on how it is perceived in different parts of the world," says Guldner. "It's all been very positive, with people saying that they like this technology and are interested in it."

> "The same amount of raw materials can be used to make one battery EV or ten hydrogen fuel cell cars

A business decision

BMW will use feedback from the trial to make a final decision on whether or not to commercialise hydrogen passenger cars. Guldner wasn't ready to speculate on the market cost of these models, but he conceded that "it's our homework to bring down the cost, and we're confident this can be done. There is considerably less raw material involved, and so much can be done by scaling up."

Aside from the cells, most of the fuel cell system components are already standard parts known to the automotive industry. "Valve housing, sensors, airflow system, compressor, the cooling system–all these are familiar and standard parts. They work the same in a truck a bus or a car. We will see scaling over the next few years, which will really bring down cost."

In its quest for a cleaner mobility offering, BMW is keeping its options open. A flexible approach, emphasises Guldner, is pivotal to success in these dynamic times. "BMW has a strategy of always being flexible and prepared to respond to changes in customer demand," he says. "That has been proven much more valuable than prediction, which is often wrong."

H2 ICE: a less disruptive decarbonisation short-cut?

Bosch believes the hydrogen internal combustion engine will serve as one of the pillars of zero emission vehicle technology for commercial vehicles, writes Megan Lampinen

Diesel has long served as an all-rounder for commercial vehicles, working well with anything from a light van to a heavy-duty truck. But that concept may not hold out in the shift to CO2-neutral mobility. When it comes to the choice of battery electric (BEV), hydrogen fuel cell (FCV) or hydrogen internal combustion engine (H2E), it all boils down to use case. "The requirements for commercial vehicles are highly heterogeneous," says Andreas Kufferath, who is responsible for commercial vehicle engineering at Bosch. "Think of the varying conditions around load, power, range and temperature. There is no one-size-fits-all solution; we need all three complementary technologies to meet all use cases."

The case for the H2E

Like many industry players, Bosch expects the industry to embrace multiple technologies in the push to decarbonise. While BEV and FCV have attracted considerable headline space, many industry players are also pursuing H2E, and this includes Bosch.

"Technically, the H2E shows its advantages where we have to provide high engine power output over a long distance or for an extended period of time," he tells *Automotive World*. Think of a heavy truck making a trans-Alpine crossing from Germany to Switzerland, running with a full load for an hour. "At high power rates, the H2E comes close to or even exceeds the overall system efficiency of the fuel cell." It's also extremely robust under difficult ambient conditions, such as in dusty environments or extreme temperatures.

While both FCV and H2E can refuel in much less time than it takes to charge a BEV, H2E offers a faster time to market and less disruption in the supply chain. The H2E is very similar to a diesel engine–Bosch estimates a unit has about 80-90% of the same parts found in a diesel, so the vehicle architecture can stay the same. That's a huge benefit in terms of development time and cost for automakers.

The similarity in engine design also makes it much easier to tap into the established production and service networks for diesel. "These factors enable a very fast market entry," he emphasises. "That's important because we really need speed for decarbonisation."

There are also supply chain resiliency arguments for the H2E. Composed primarily of steel and aluminium, it avoids many of the rare

earth materials needed for BEVs. It also avoids the need for high-end microchips–Bosch built its technology on classical microchip technology.

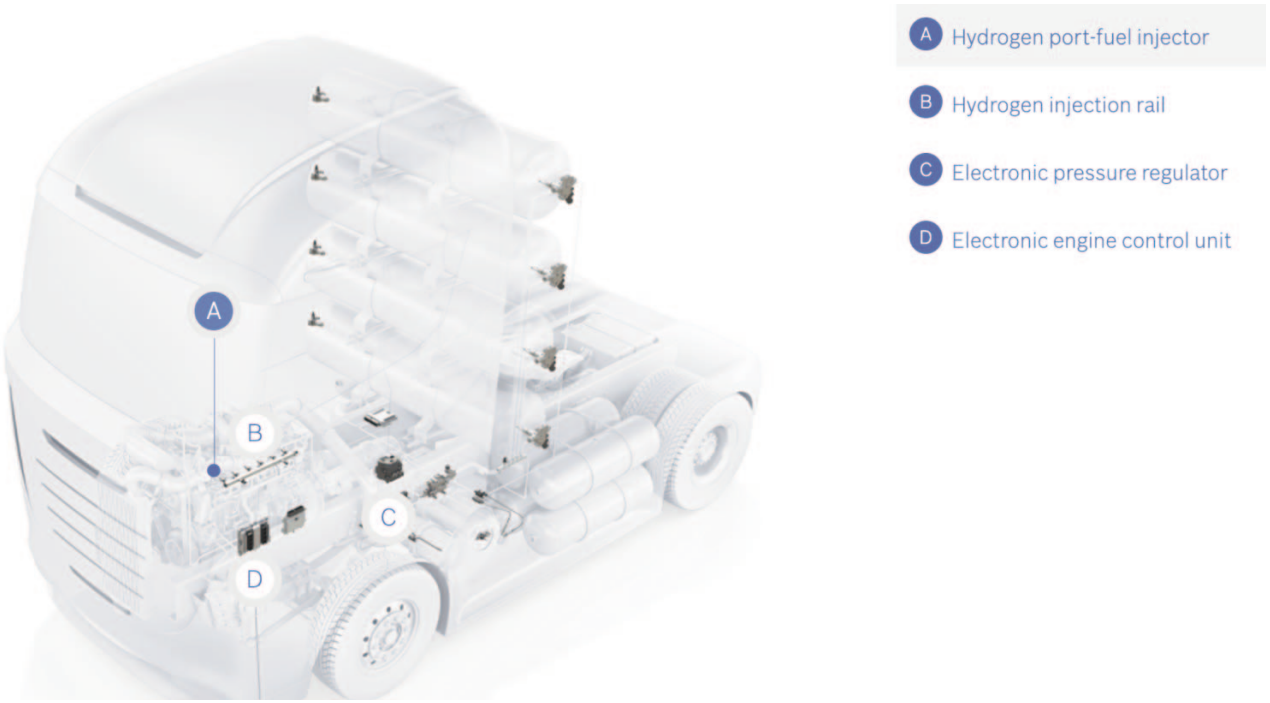
Air quality debate

One of the biggest objections to H2E to date has centred on emissions. "Combustion is considered antiquated and is associated with critical emissions," concedes Kufferath. "However, the emission topic needs a much more differentiated consideration."

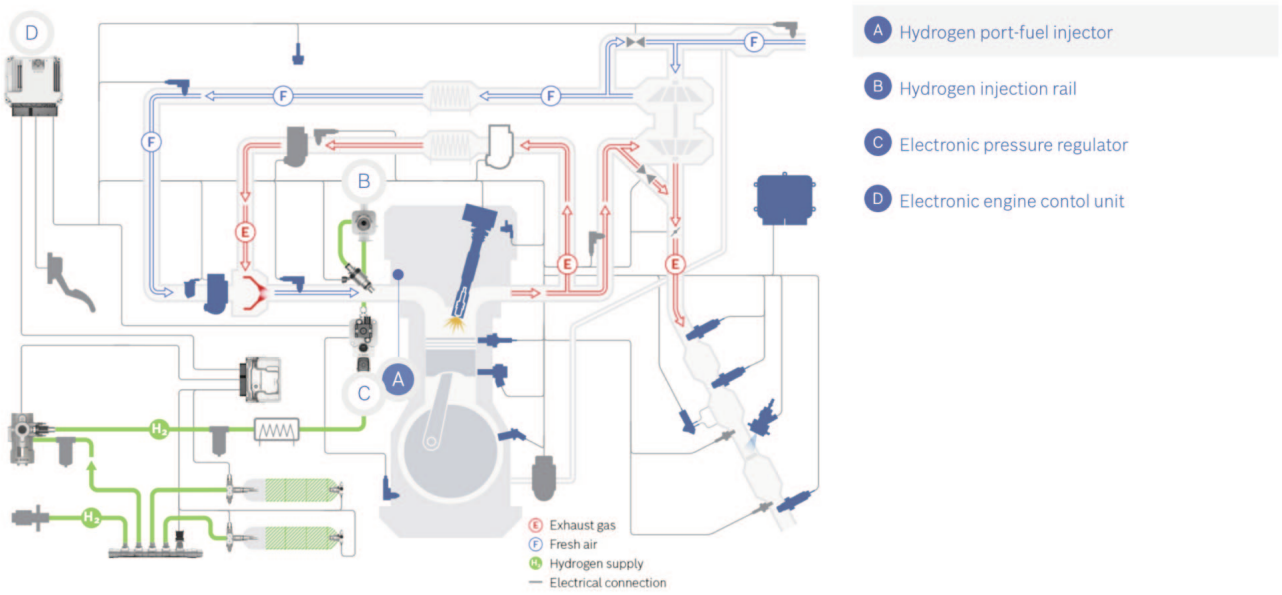
With tailpipe emissions down to a negligible level, the focus turns to particulates. Research from the UK Department for Environment, Food and Rural Affairs found that small particulate (PM2.5) emissions in a BEV commercial vehicle were in the same order of magnitude as a hydrogen engine or even a modern Euro 7 diesel under urban driving conditions. With exhaust emissions contributing just 1% or 2% of PM2.5 emissions, the bulk comes from tyres and road abrasion. In a BEV, there is no tailpipe emissions but the heavier weight of the battery results in slightly higher tyre emissions, putting it on par with the H2E in the overall total.

Preparing for global uptake

Bosch is positioning itself as a player across the whole hydrogen ecosystem, with activities in many of the different stages of the value chain. For instance, its offering includes electrolysers and the complete power module for hydrogen fuel cell vehicles and the hydrogen injection system, electronic control units, sensors, and other technology for the hydrogen engine. While in the H2 engine many of these components share similarities with diesel engine parts, in some cases high-tech modifications are needed. "The diesel injector for commercial applications opens and closes more than one billion times over the entire lifetime cycle," he points out. "Diesel is extremely supportive on the lubrication side, whereas hydrogen has no lubricating properties so Bosch is developing an injector that does not require lubrication."



In an H2E, the basic structure of the fuel, air and exhaust system can be adopted from existing powertrain solutions using many familiar system components



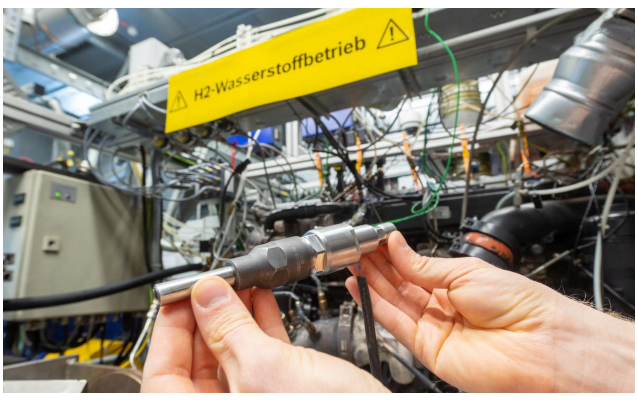
System overview of the H2E

Starting with a port-fuel injection approach, it aims to launch production in 2024. Direct injection units should follow in 2026. By this time, global developments with the H2E should have started to materialise. "The H2E is not a European niche development," Kufferath emphasises.

He also points to interest among automakers in China and India, noting how "the Indian Government has made a concerted effort to push this technology." The first heavy-duty H2E commercial vehicles with Bosch products will enter production in India in 2024. Momentum is also building in the US. "Following the Inflation Reduction Act some customers started pushing the H2E technology very hard and there are a number of projects now running in the US," he adds.

The Allianz Wasserstoffmotor (Hydrogen Engine Alliance) initiative was founded in 2022 and has since attracted 70 members, including automakers, suppliers and academic institutions. Its first big public event, Wasserstoff Motor Live, was held in Karlsruhe, Germany in June 2023 and shone a spotlight on the technology's market readiness. "This was not a PowerPoint presentation–you could drive these vehicles," said Kufferath.

Looking ahead, Bosch remains confident that the H2E will serve as one of the pillars of zero emission vehicle technology for commercial vehicles. While hesitant to pin down a specific forecast, Kufferath notes: "The technology will account for a relevant share of the market, otherwise we would not be making all this effort to develop the whole portfolio."



Bosch parts will appear on a commercial H2E truck entering production in India in 2024

Hydrogen mobility rewrites supplier playbook

Supply constraints could hamper uptake of hydrogen vehicles if the industry isn't careful. Megan Lampinen hears more

As automakers scramble to develop a zero-emission line-up, the pressure is on for suppliers to adjust their own offering and production capabilities. Hexagon Purus offers one example of what future-proofing from the supply side could look like. The company was carved out from Hexagon Composites in 2020 and is bracing for tremendous growth in both battery electric and hydrogen fuel cell vehicles.

It specialises in development and production of battery and hydrogen storage, with a product line-up including hydrogen Type 4 high-pressure cylinders for use in buses, ground storage, distribution, marine, rail, and aerospace applications, as well as complete vehicle systems and battery packs for fuel cell and battery electric vehicles and trucks.

"The future is electric," states Morten Holum, Chief Executive of Hexagon Purus. "When you look at transportation, there are so many benefits with an electric drivetrain, from reliability and efficiency to maintenance, noise, customer experience–the whole thing. There are two options to get there: you can store all of the energy in the battery pack, or you can store it in a combination of a battery and hydrogen gas."

Hexagon Purus offers lightweight composite cylinders for compressed hydrogen storage

A growth market

The company has grown fivefold since 2020 and annual revenues recently passed the €100m (US$106m) mark. Hydrogen distribution accounts for about half of its business, but the mobility side of things could take off down the line. Purus' customer list within the hydrogen mobility segment includes such big names as Nikola, CaetanoBus and Solaris. Its hydrogen cylinders can be found on buses in Europe and North America, with prototypes just now launching in Asia.

> We certainly see things that we can do to improve storage capacity but perhaps more important will be improvements in cost and environmental footprint

While today there are very few serial-produced heavy-duty hydrogen trucks on the road, Holum notes that "many OEMs are working on these programmes." Testing and validation on Hexagon Purus 700 bar hydrogen cylinders for Nikola began back in 2021, with the first hydrogen trucks rolling off Nikola's plant in Coolidge, Arizona in September 2023.

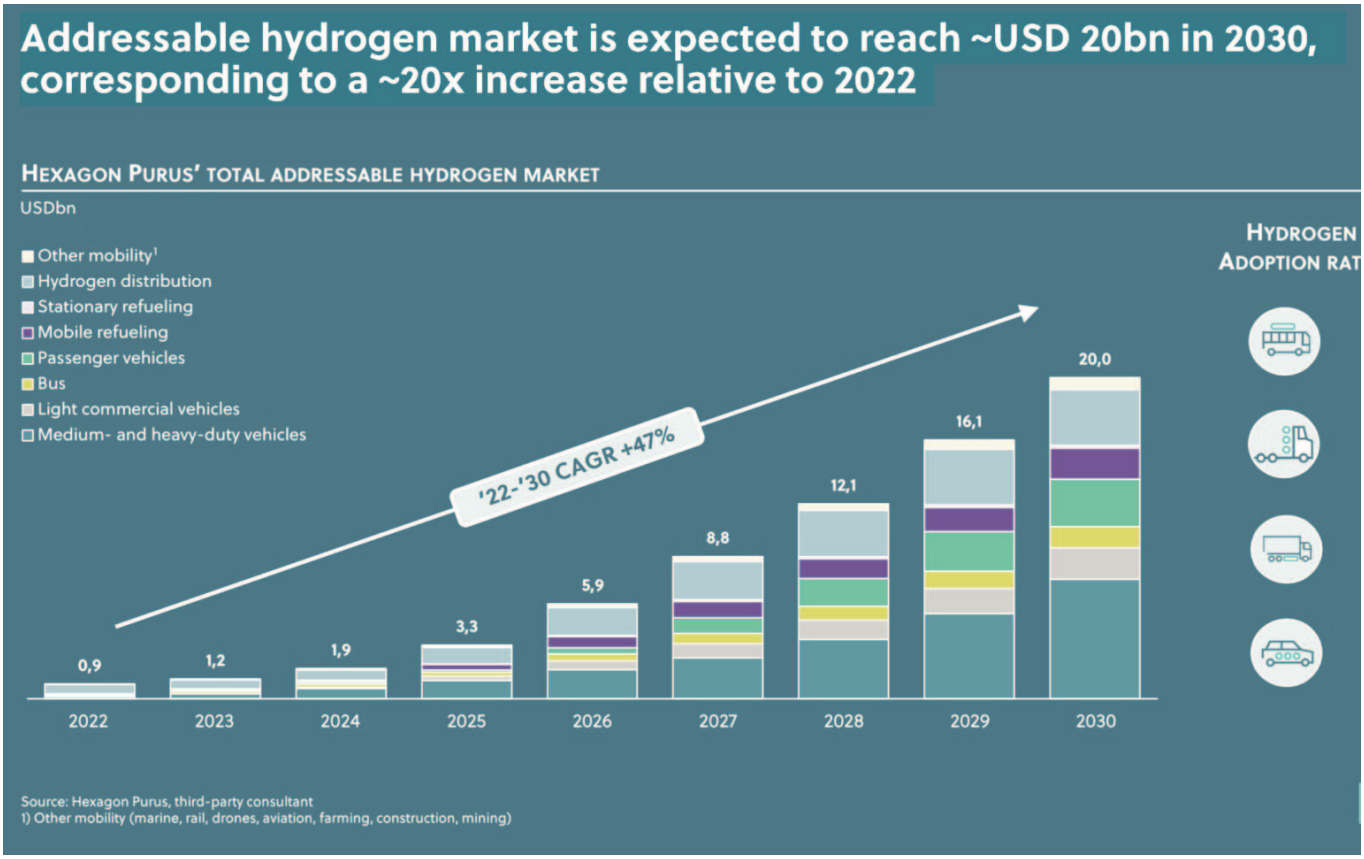
"We are on at least two hydrogen heavy-duty truck programmes that will arrive on the market before mid-decade but not many OEMs will have an offering here until around 2027 or 2028," he tells *Automotive World*. "That's when the market will likely reach the inflection point, but it will take time. And as an industry, we need time to scale because it's not an easy journey."

Further development

A growing number of automakers are exploring hydrogen as a tool in the energy transition, and to date more than 30 countries have released hydrogen roadmaps. Hexagon Purus estimates that more than US$70bn in government funding has been allocated to hydrogen investments. To prepare for a growing market, the company is expanding its product offering and production footprint.

In 2021 it acquired Wystrach, one of its long-time customers. The German-based hydrogen systems provider serves both the industrial and transportation segments, with customers such as Daimler, Linde and Air Liquide. The move brought in additional systems assembly capacity and knowhow, increasing scale and putting Hexagon Purus in a stronger position to capitalise on the coming market growth.

The Nikola Tre hydrogen fuel cell truck relies on type 4 hydrogen cylinders from Hexagon Purus



While Holum describes the acquisition as "very successful", he expects most of the company's growth to come organically in the near term: "I cannot rule out inorganic moves in the future, but it's not where we are focusing now."

This year alone will see several new sites opened. In January it launched a new location in the US state of Maryland for development of hydrogen storage cylinders. Another location in Kelowna, Canada opened in April, specialising in battery and hydrogen storage systems. Most recently it finalised a large hydrogen storage cylinder hub in Kassel, Germany. Construction is also underway on a combined cylinder and systems integration facility in China, which will begin operations in 2024.

"In order to keep up with the market, we really need to start scaling," Holum warns. "I don't think this industry will be demand-constrained for the next ten years. Instead it will be a supply issue; it's all about the industry's ability to deliver sufficient amounts of hydrogen and product."

It's not just production volumes that need to be developed; there is also scope for further improvement on the product itself. "We certainly see things that we can do to improve storage capacity but perhaps more important will be improvements in cost and environmental footprint," he says. "As we've seen with battery technology, costs decline as the industry reaches scale. We will also see further innovation around materials, technologies and efficiencies."

While he believes the hydrogen mobility market won't hit its stride for several years, environmental pressures will only grow stronger and suppliers need to start preparing today: "With global warming, use of resources and population growth, we don't have much time to deal with this. We can make many decisions in this decade to really get started, and I hope that more companies follow our lead and can make an impact."

Dual energy e-trucks broaden the scope of zero carbon fleets

While operators debate the comparative merits of batteries and fuel cells, a combination of both could be the most efficacious solution. By Will Girling

Although internal combustion engine (ICE) innovation is likely to continue for several years, the future of commercial vehicles (CVs) is increasingly framed around zero emissions. However, there is an ongoing debate around which powertrain is a better successor to diesel: battery-electric (BEV) or hydrogen fuel cell (FCEV).

For some commentators, the nascent development and expense of creating a global hydrogen economy makes the fuel impractical compared to more readily available battery technology. On the other hand, hydrogen's promise of lighter CVs capable of transporting heavier loads across longer distances offers a more flexible and directly comparable diesel experience. It is no surprise that OEMs like Volvo Trucks are investing in both, as well as ICE.

The solution, perhaps, is not to place the two technologies in opposition. Some players suggest that a dual energy, hydrogen-battery hybrid system could be the ideal middle solution for the road transport sector.

The challenge of hybrid

The concept of a hydrogen-battery hybrid is not new: Ford patented what it claimed to be the first such passenger vehicle in 2007, and Renault announced its own Scenic Vision concept car in 2023. The prevailing configuration combines a primary lithium-ion battery with a hydrogen fuel cell range extender. Despite this, the dual energy system has not been developed in automotive to the same extent as either of its separate components.

"Marrying those two systems together requires evidence that their respective benefits are in balance," says Stuart Cottrell, Head of Research at Tevva. "This is difficult to achieve." Between the relative unavailability of hydrogen fuel and an underdeveloped hydrogen ecosystem that has not yet reached the economies of scale necessary for affordable operations, it may simply be too impractical to pursue batteries and hydrogen simultaneously. "For that reason, I think many OEMs have shied away from it," he tells *Automotive World*.

Tevva currently offers a 7.5-tonne battery-electric truck with an average range of 180km. However, a hydrogen-electric version of the same model is in development and scheduled for production in 2024. Its specified 435km range demonstrates the significant performance boost that a hydrogen extender can provide. But how did the company strike an effective system balance?

The role of hydrogen

Cottrell states that an effective dual energy combination depends on a CV's duty cycle. For Tevva, this starts with a 110kWh battery capable of delivering 192kW of power and 596Nm of torque. "The idea is that renewable electricity charged into the batteries is relatively cheap, whereas the hydrogen is more expensive," he explains. "That means using hydrogen only when it's operationally needed–when a route is longer or unpredictable." By defining a fuel cell's role in this way, it becomes easier to integrate and measure the value of hydrogen.

A dual energy system could also help overcome a major challenge associated with CV electrification: restricted application. While electric freight technology manufacturer Einride claims that short haul comprises 50% of all road logistics activities, the low range, long charging times and reduced payload capacity of battery-electric trucks make them less desirable for medium and longer haul routes. "It's easy to extend range by adding more batteries, but then increased weight undermines what the electric truck was bought for in the first place: transporting cargo," says Cottrell. Tevva estimates that an extra 100kg of hydrogen has equal energy density to 600kg of batteries, mitigating the compromise to payload.

However, the pace of hydrogen infrastructure will play a decisive role in the success or irrelevance of dual energy CVs. Logistics chains require charging/refuelling networks extensive enough to make the TCO of e-mobility viable. Current efforts to build capacity for hydrogen include Element 2 in the UK and the US Department of Energy's H2USA project, which

Tevva's 7.5T hydrogen-electric truck—currently in development and scheduled for production in Q4 2023

> One of our dual energy vehicles drove from our base in Tilbury, Essex, to Berwick-upon-Tweed on the Scottish border and back quite comfortably

is mainly focused on the Californian market. Cottrell adds that fleet operators could also build their own on-site in depots, "although that would always be more expensive than using public infrastructure."

Players such as US-based FCEV manufacturer Hyzon are investing in both infrastructure and vehicle technology in a bid to prevent the adoption of a hydrogen becoming a 'chicken or the egg' problem for operators. Tevva is taking a similar approach, partnering with Motive Fuels in August 2022 to distribute hydrogen throughout its UK station network and build new dedicated stations.

A middle solution

Cottrell considers hydrogen-battery hybrid trucks to be a balanced solution appropriate for most transport use cases. For territories with high energy demand driving (such as cold or hot conditions that divert power to air conditioning functions) or limited power grids that make recharging BEVs challenging, a dual energy system could be particularly useful.

He concedes that the economics and practicality of intercontinental/long haul transport using any type of electric CV are currently vexed. For hydrogen, this will remain the case until a viable production industry materialises. This is unlikely in the medium term: the European Commission estimates that hydrogen only constituted 2% of the EU's energy consumption in 2022. However, Tevva's vehicle trials indicate that hydrogen-electric hybrid powertrains could perform well if sufficiently supported by infrastructure.

"One of our dual energy vehicles drove from our base in Tilbury, Essex, to Berwick-upon-Tweed on the Scottish border and back quite comfortably," states Cottrell. In fact, the hydrogen-electric truck completed the second half of this 712-mile roundtrip without needing to refuel/recharge at all. Under challenging driving conditions, particularly in low temperatures during winter, he believes a BEV would struggle to successfully replicate this performance.

While it shares some of economic challenges of hydrogen, the more limited consumption of a fuel cell extender system is less problematic than a full FCEV. At the same time, a dual energy system could enable electric CV fleets to overcome the performance restrictions of BEVs. In Cottrell's view, dual energy CVs are a true "middle solution" that is necessary for "expanding the horizons of zero emission fleets." Until hydrogen is cheaper, and batteries are lighter and more powerful, a hybrid of both could prove the most effective electrification option.

The US' IRA is bringing down the cost of scaling hydrogen

Although the hydrogen economy remains small in the US, the Inflation Reduction Act offers a powerful means of growing it quickly. By Will Girling

The challenge of achieving global transport decarbonisation targets has made it clear that the automotive industry cannot rely on any single solution. Hydrogen, whether used as an internal combustion engine (ICE) fuel or in a fuel cell-powered electric vehicle (FCEV), is becoming an increasingly attractive proposition to supplement batteries. Despite this, the hydrogen economy itself presents the greatest barrier to practical implementation.

In 2022, the global green hydrogen market was valued at US$4.5bn, according to Precedence Research. However, one-third of total capacity (20 million tons annually) comes from China alone. By comparison, the US industry produces approximately 691,000 tons–only 3.45% of the former's contribution. Its relative infancy means that any meaningful growth will require considerable investment in production infrastructure, storage facilities and transport logistics.

Nonetheless, Precedence Research forecasts exponential global market growth over the proceeding decade–US$134.4bn by 2032, a CAGR of 40.6%–and the US is anticipated to rise at a comparable rate (from US$662.2m to US$17.8bn) across the same period. At the heart of this momentum is one key piece of legislation: the Inflation Reduction Act (IRA).

> "Technological advances and innovative deal structures will bring down the cost of scaling very quickly

Tax credits drive investment

Mona Dajani, Partner, Global Head of Renewables, Co-Head of Global Energy & Infrastructure and Head of Hydrogen & Ammonia Practice groups at law firm Shearman & Sterling, has worked in the clean energy

> There is no downside for hydrogen developers: they can get in, make money, learn the technology, and build goodwill for the industry.

space for more than 25 years, including as an Ambassador for the US Department of Energy (DoE). She tells *Automotive World* that there has been a "huge uptick across the board" in national hydrogen projects since the IRA was signed into law in August 2022. This interest includes many stakeholders in the electric mobility value chain, such as utility companies and steel manufacturers.

"We're also seeing a lot of non-traditional entrants. While we are still waiting for the US Department of Treasury to provide the necessary guidance for stakeholders in hydrogen, the IRA offers a wide array of financial incentives that are driving investment in clean hydrogen and fuel cell technologies," she explains. These include a clean hydrogen production credit of US$3 per kilogram; an extension of the 30% fuel cell ITC through 2024, which will transition to an equivalent 'technology-neutral clean-energy investment tax credit' in 2025; an alternative fuel refuelling property credit, which will run through 2032 with a cap of US$100,000; a 30% purchase credit for commercial FCEVs capped at US$40,000; and a US$10bn fund for hydrogen manufacturing projects.

With such comprehensive government support available, Dajani believes there is no mystery to some analysts' positivity regarding the US hydrogen economy's prospects. "There is no downside for hydrogen developers: they can get in, make money, learn the technology, and build goodwill for the industry." In total, the nationwide hydrogen hubs announced by the White House in October 2023 are expected to create up to 334,200 jobs.

Heavy vehicles lead

Although she cannot specifically name any projects to which she is currently party, Dajani states that those focused on building up hydrogen-powered heavy-duty vehicle (HDV) fleets are particularly numerous. New York-based commercial FCEV maker Hyzon Motors previously told *Automotive World* that hydrogen's energy density and quick refuel times make drayage fleets an exciting application for the fuel. As the Port of Los Angeles (the US' busiest container port) seeks to make all fleets zero emission by 2035, this highly visible use case could help broadcast hydrogen's benefits and scale it even further.

HDV leadership in pushing hydrogen to forefront also extends to fuelling stations. Although the DoE currently records only 57, all in California, Dajani believes more will emerge to accommodate new long-haul freight logistics vehicles and buses. "These projects are exciting because they serve real-world use cases. Tax credits, and the ability to combine them, are what's driving them all." However, transport alone is unlikely to provide the scalability required to build a profitable hydrogen economy.

"For trucks and buses to operate on hydrogen, we need to see some critical cost reduction," Dajani states. The IRA might provide the financial incentives for research, but it is up to a multitude of motivated stakeholders across several industries to enable the necessary ecosystem to flourish. To achieve this, a greater degree of standardisation and mass production for critical components–from storage tanks to fuel cells, batteries, and cables–will need to be reached. But who is leading this change?

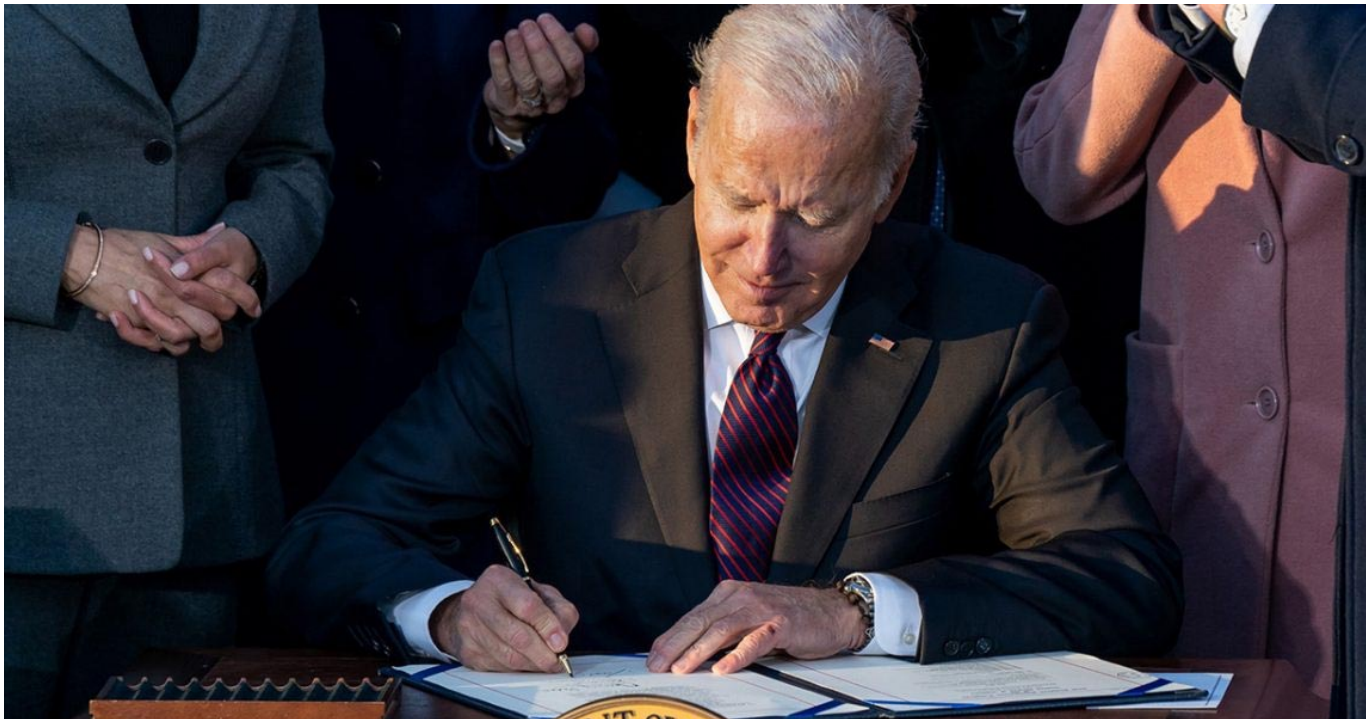
A 'take-off booster'

Dajani credits the oil and gas industry as "stepping up" in recent years to create a foundation for hydrogen fuel. Transport & Environment estimated in 2023 that oil companies have invested €6.5bn (US$6.9bn) in blue hydrogen–produced from natural gas and incorporating carbon capture. Although Aramco Chief Executive Amin Nasser stated in May 2023 that buyers were not forthcoming without government subsidies on the fuel, IRA tax credits could mitigate the problem in the US.

"In the long run, as we move to a zero emissions future and a decarbonised grid, there are only two power options: electricity and hydrogen," posits Dajani. Technology for the latter, she adds, is maturing faster than previously anticipated. "It's very much like the solar industry, which was on the fringe 20 years ago but is now mainstream."

Therefore, the IRA can function as a "take-off booster" for development, as well as a facilitator of energy security in the US. Although this will make hydrogen highly subsidy dependant in the medium term, Dajani is confident that it will soon reach a comparable level of affordability to solar. "At that point, I think technological advances and innovative deal structures will bring down the cost of scaling very quickly."

While concerns about the limited state of hydrogen infrastructure currently give battery electric vehicles an edge in the transition from ICE, she concludes that there is no reason that substantial investment cannot even the playing field. "It should also be remembered that fossil fuels are still highly reliant on government support. Globally, oil and gas receive more than US$7tr of explicit subsidies." At least in the US, thanks to the IRA, the automotive industry can champion hydrogen as a fuel subsidy alternative that contributes to, rather than detracts from, government carbon reduction targets.



Signed into law on 16 August 2022, the IRA provides an extensive range of subsidies that could supercharge the US' hydrogen ecosystem