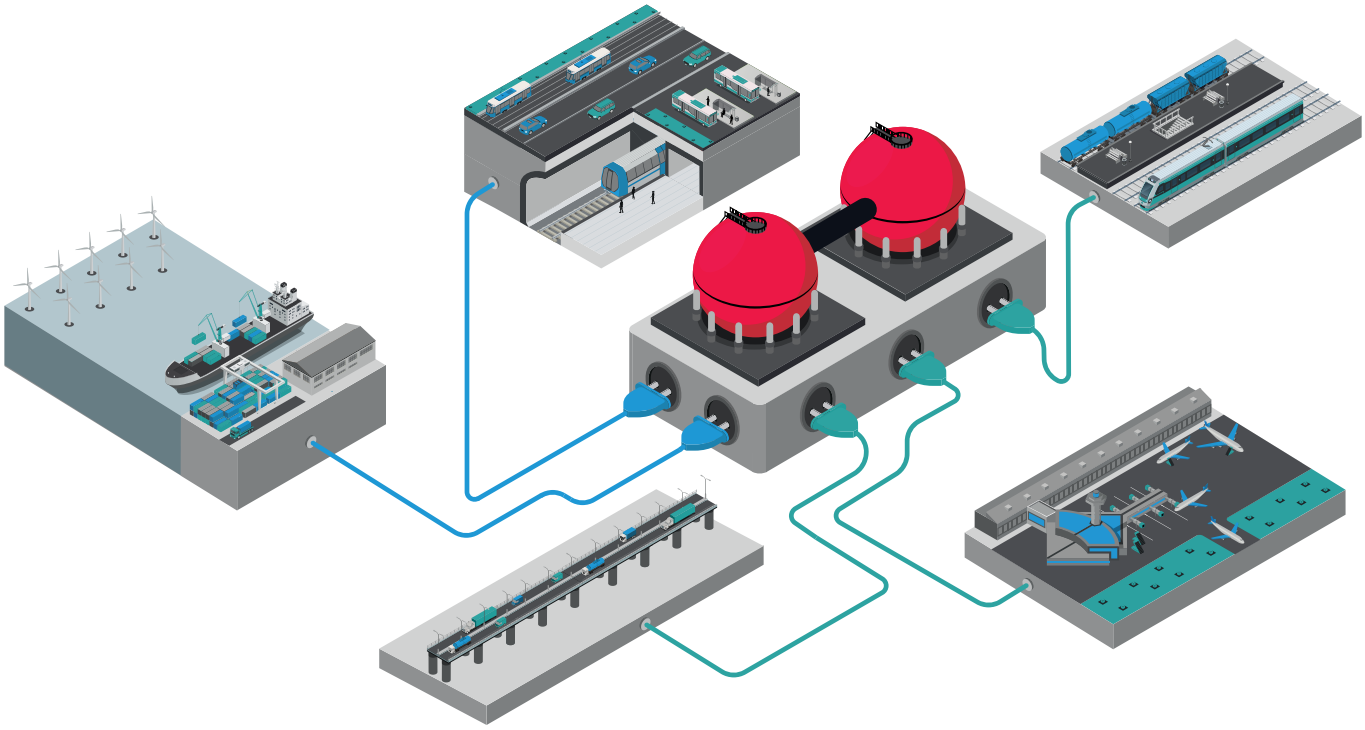
ARUP

Hydrogen Transport - Fuelling The Future

The Future of Energy



Through the combustion of fossil fuels, the transport sector is responsible for 20-30% of global CO_2 emissions.

Introduction

Hydrogen has a vital role to play in decarbonising transport and in enabling cities and governments to meet their carbon reduction targets.

What about batteries?

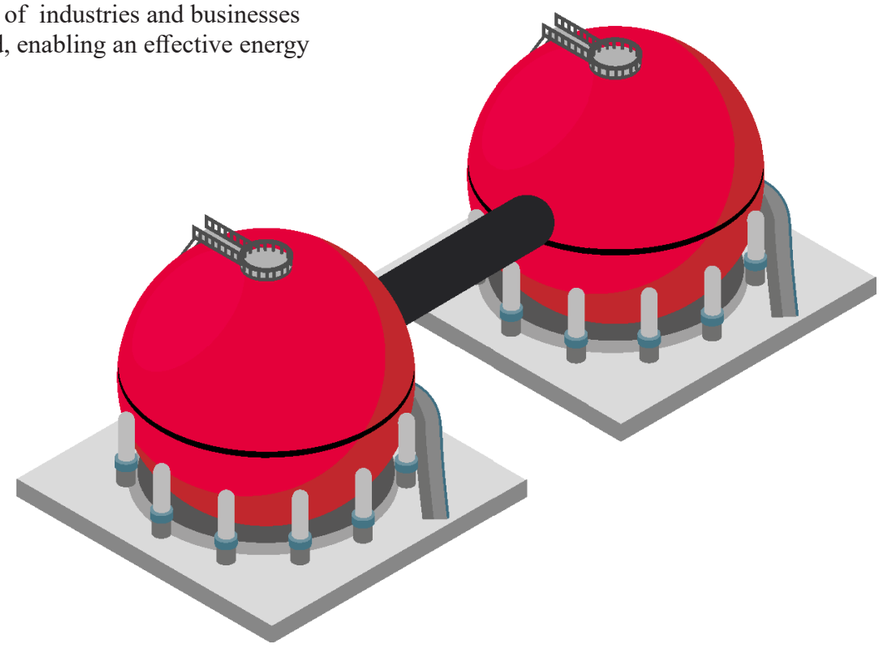
The two technologies are complementary, but hydrogen's rapid refuelling time and higher energy density give it an advantage over battery-only solutions in many situations – including for freight and heavy-duty passenger transport. This perspective focuses on the core modes of transport that can benefit from transitioning to hydrogen.

Realising these benefits and opportunities will require significant, long-term investment across the supply chain – from the energy supply to the applications using it.

In addition, the right policies and government incentives are essential to ensure hydrogen achieves its potential.

Hydrogen is critical for decarbonising industries and business across the world and supporting the future of energy. Hydrogen can unlock the decarbonisation of industries and businesses across the world, enabling an effective energy transition.

"Now is the time for the industry to take advantage of the value which a scale up of hydrogen deployment can deliver."



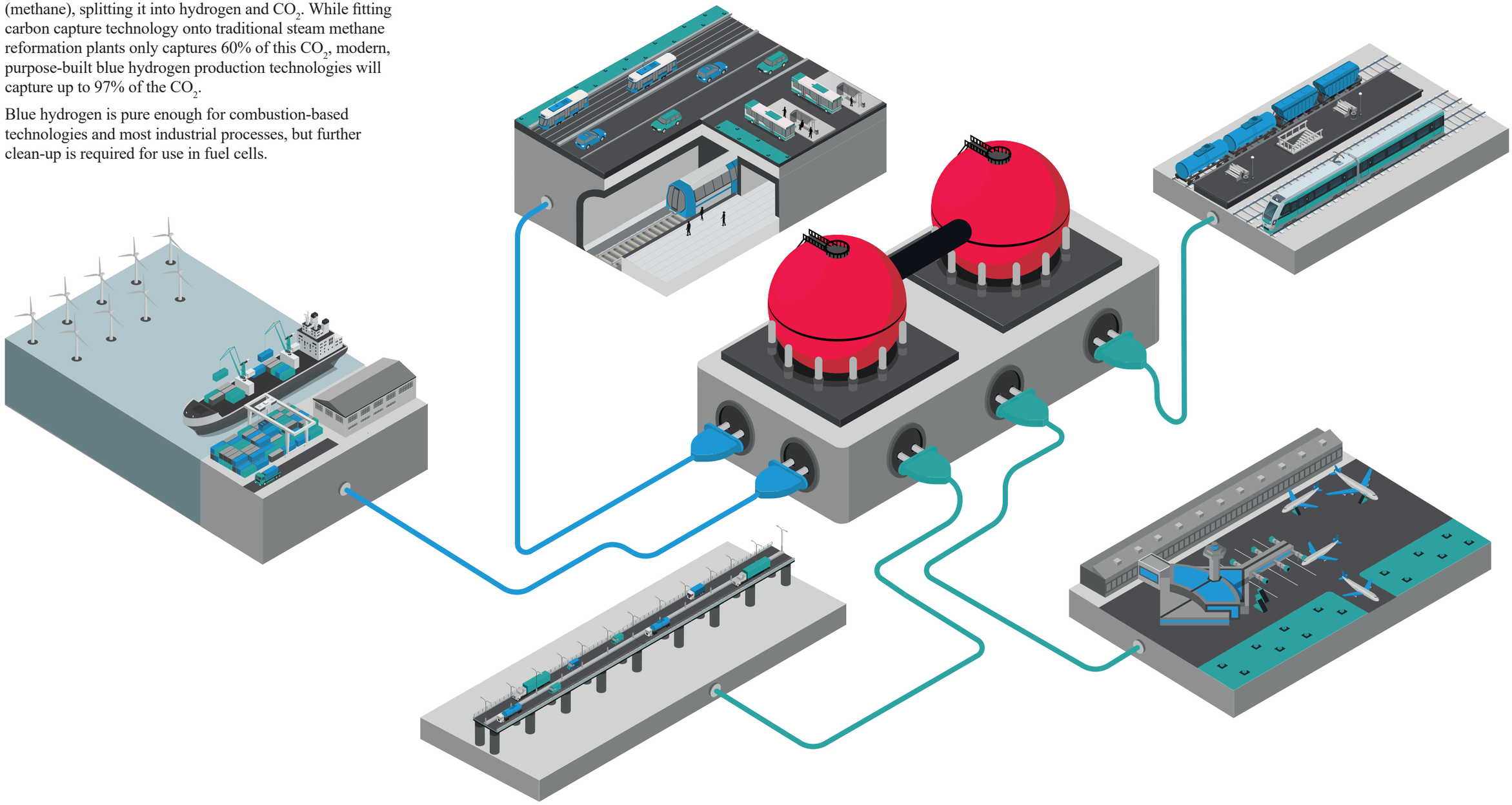
How will hydrogen for transport be produced?

Green hydrogen and Blue hydrogen

Green hydrogen is produced by using renewable electricity to electrolyse water, splitting it into hydrogen and oxygen. Green hydrogen is pure enough for fuel cells used in transport applications without further processing.

Blue hydrogen is produced from reformation of natural gas (methane), splitting it into hydrogen and CO_2. While fitting carbon capture technology onto traditional steam methane reformation plants only captures 60% of this CO_2, modern, purpose-built blue hydrogen production technologies will capture up to 97% of the CO_2.

Blue hydrogen is pure enough for combustion-based technologies and most industrial processes, but further clean-up is required for use in fuel cells.



Push and pull investment: what's driving demand?

The combination of low-carbon hydrogen production and hydrogen transport is fast becoming a technically and commercially viable proposition across the world.

As the technology rapidly scales up and becomes more mature, well-to-wheel costs are falling, especially for applications such as heavy-duty return-to-base fleets – for example, postal delivery trucks powered by hydrogen fuel cells.

Push factors

- Over recent years, many governments have set up dedicated hydrogen development funds. The recent European Green Deal and numerous net zero pledges have led to regulation and incentives that will push transport sectors towards hydrogen
- Levies and emissions trading schemes are driving up the costs of traditional fossil fuel based transport. Transport's reliance on hydrocarbons is also holding back greenfield and urban expansion developments because of emissions regulations; only zero-emission transport can break this stalemate
- Hydrogen's safety is comparable to hydrocarbons such as petrol and is well tested, understood and well managed.

Pull factors

- Manufacturers, hydrogen suppliers, energy companies and transport operators are investing in large-scale hydrogen applications. The Hydrogen Council estimated as a result, the total cost of ownership per km for hydrogen fuel cell electric vehicles is expected to fall up to 50% by 2030, with hydrogen electrolysis becoming cost-competitive with blue hydrogen produced from natural gas
- Industry estimates show manufacturers are scaling up and learning to produce more efficient fuel cells, which will reduce the cost of hydrogen fuel cell electric vehicles significantly
- Larger initiatives often centre around ports. These are usually located centrally and some have access to offshore wind power
- Initial large-scale deployments can be expected by 2025, when some of the first large-scale green electrolysers will be entering the market
- Large parts of Europe, West Coast USA, Australia, New Zealand, Japan, South Korea and China are emerging as first-tier adopters.

Modes of transport

The potential for hydrogen transport to reduce emissions means it attracts grants, public investment and risk-backing structures – accelerating development.

Much public-private and private-private partnering is ongoing for trials and initial investment, backed by government research and development, joint ventures and early-stage investment funds. This is creating significant breakout opportunities for the industry.

Although to-market times may be several years, manufacturers are scaling up production and opportunities are emerging quickly – driving low carbon hydrogen transport to commercial readiness and competitiveness.

Owners of these assets can invest independently of many external considerations – such as the need for widespread refuelling stations – making organisation quicker and easier.

Long-range ships and planes are likely to require alternative mixes of fuels, of which hydrogen can be part, but have exciting potential for development which could change the face of long-range travel and the associated emissions.

There are already viable options to use hydrogen for:

Passenger transport including buses and trains

Aviation

Return-to-base vehicles

Short-range ships

Heavy goods vehicles including large fleets

Push and pull investment: what's driving demand?

The combination of low-carbon hydrogen production and hydrogen transport is fast becoming a technically and commercially viable proposition across the world.

State of play

– China, Japan and South Korea are currently the most significant hydrogen fuel cell bus markets. In Europe the UK, Netherlands, France, Germany and Italy are leading the way in fuel cell electric bus technology – over 150 buses are in service or development with significant roll-out plans

– Over 20 manufacturers globally are already able, or gearing up, to build this transport mode

– Current bus models require 10 minutes refuelling for a 300-400km range – using only 20-30kg of hydrogen per day. They're particularly suitable for cities with variable, busy routes with a central depot and for longer rural, and undulating, routes

Common types of vehicles in operation include:

– A primarily fuel cell driven vehicle with small battery as an energy buffer

– A fuel cell power train with supercapacitor plus a battery as power and energy buffers

– A primarily large battery driven vehicle with a fuel cell as a range extender.

Opportunities

– The introduction of city-led or government-led policy will force operators to replace ageing fleets with zero emission buses sooner rather than later

– The total cost of ownership for hydrogen fuel cell electric buses continues to fall thanks to a reduction in low-carbon hydrogen costs, this could help cut the total cost of ownership significantly by 2030 for a 12-metre bus

– Bus procurement costs are reducing rapidly, with double-decker buses costing £400k in the UK in 2020, compared to £500k in 2019. A 12-metre bus cost £250k in 2020, down from £300k in 2019

– 2025 is likely to be the significant milestone, considering the tri-factor of:

1. Reducing total cost of ownership
2. Scaling up of manufacturing
3. Lower lead times for deploying new bus fleets and related hydrogen infrastructure

– Retrofitting existing diesel or compressed natural gas (CNG) buses to run on hydrogen could be an interim, lower-cost solution that still meets decarbonisation measures. New Delhi is implementing H-CNG – a hydrogen and compressed natural gas blend – as a transition measure in its still relatively young CNG bus fleet.

Challenges

– Although fuel cell electric bus costs have been reducing, they are not yet competitive with diesel or CNG solutions. To get costs down further, governments and manufacturers need to commit to larger scale deployment

– Authorities and operators need to invest in researching and planning a variety of new and different models for how bus routes are run and operated, often outside their comfort zones. The increased uncertainty about total cost of ownership for bus operators – in maintenance, operations and fuel costs – adds to the complexity

– Likewise, bus operators will have to fit in more complex hydrogen supply arrangements, meaning they have to calculate risk and responsibility for a larger section of the value chain than they are used to

– Current bus lease and concession arrangements often do not account for new technologies, restricting innovation and misaligning incentives.

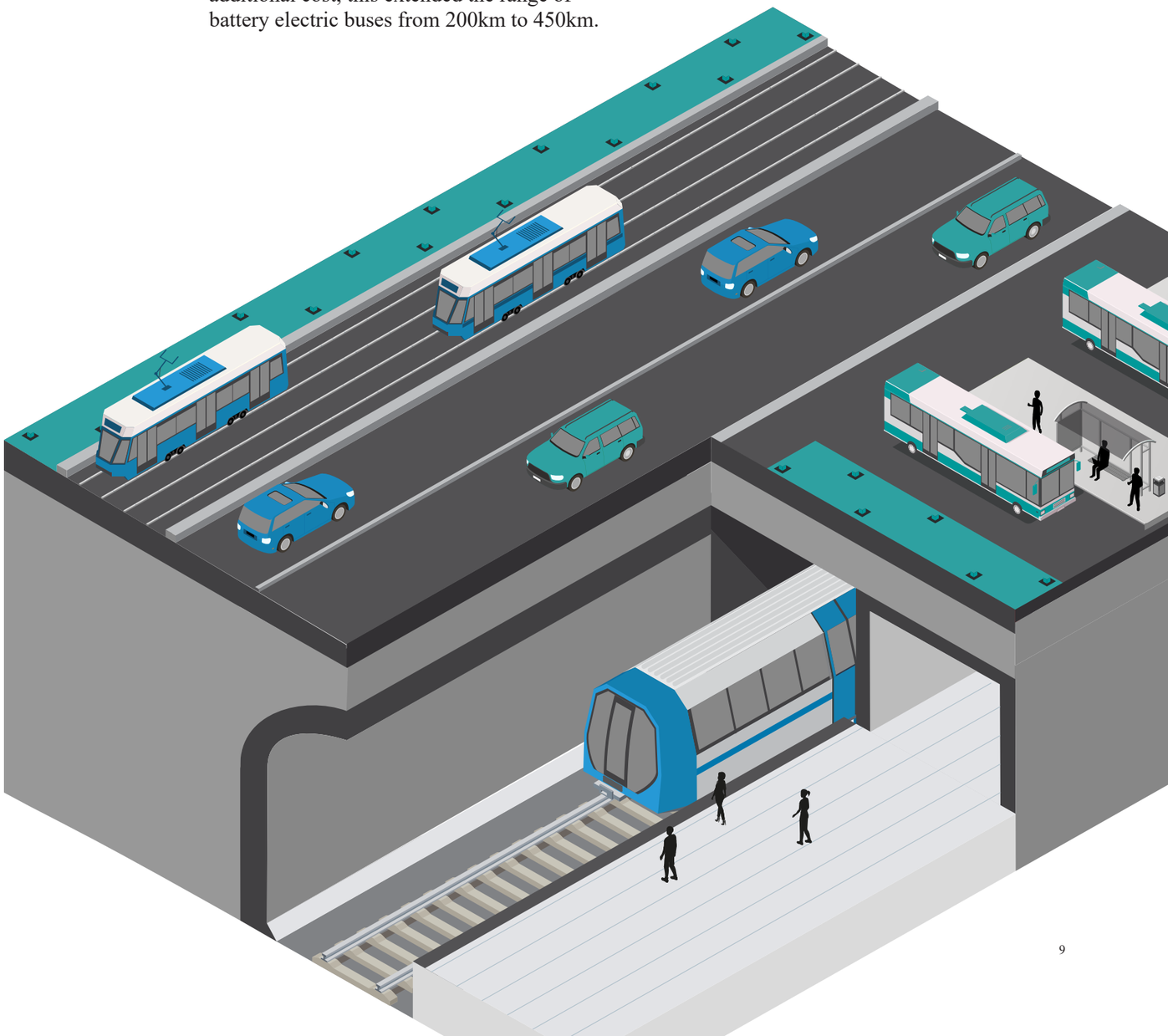
Example deployments

– The EU's JIVE1 and JIVE2 projects cover 300 hydrogen buses across 22 cities – mostly smaller cities in the Netherlands, Belgium, Germany and France, but also including Barcelona, London and Aberdeen. These programmes involve close to €50m in subsidies and are due to be rolled out by 2022

– In 2020, Connexion in the Netherlands placed four battery electric buses with fuel cell extenders into service to complement longer rural routes. With only a marginal additional cost, this extended the range of battery electric buses from 200km to 450km.

Conclusion

To adhere to emissions regulations, many operators will have to explore fitting battery and fuel cell solutions. Two to three years ago battery electric solutions were seen as the key to zero-emission bus fleets. Now, complementary hydrogen solutions have taken off, and roll-out is scaling up exponentially in some Asian and European countries, incentivised by financial backing from governments.

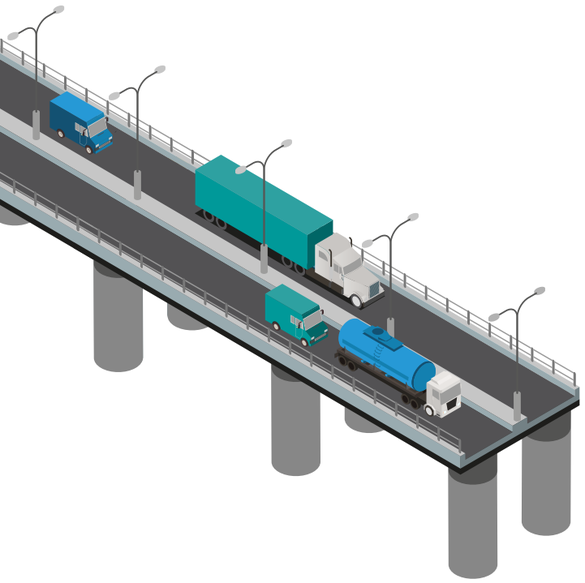


Heavy-duty vehicles and fleet operations

Heavy-duty transport – including heavy haulage trucks, large fleets and construction equipment – is becoming a sector of interest for decarbonisation. This industry could quickly become a significant growth market for hydrogen than the commercial bus sector, with a clearer commercial case compared with battery alternatives and a simple nodal refuelling network.

State of play

- Hydrogen fuel cell technology for road-based vehicles is well established
- Long-range trucks, vans, heavy-duty vehicles and return-to-base-fleets are moving towards hydrogen fuel cell technology while battery technology is adopted for urban cars
- Vehicle tanks are typically at 350 or 700 bar pressure. There's no set limit for the refuelling time or the range, and there is flexibility to make the tanks bigger or smaller, and to add or remove them
- Larger HGV manufacturers including Scania and Mercedes, for example, have stated they will move investment away from progressing diesel technologies to establishing mature hydrogen fuel cell offerings.



Opportunities

- Hydrogen fuel cell technology is well suited to heavy trucks – often much more so than battery technology – due to the mass compounding effects of their haulage duties and ranges
- Return-to-base fleets such as aircraft tugs, fixed route HGVs, construction equipment and garbage trucks can use dedicated hydrogen refuelling stations. This increases efficiencies and economies and reduces both the risk of dependencies and the retail cost risk for the fleet operator
- For longer journeys, there is potential in dedicated hydrogen corridors where routine HGV routes are abundant, such as those being developed in Switzerland. The corridors will then also require hydrogen refuelling stations, where large scale can reduce risk significantly
- 'Well-to-wheel' stacked costs for heavier green hydrogen transport are expected to reduce to near those of hydrocarbon internal combustion engines by 2030
- Emission restraints and taxation are increasing in the UK and Europe, adding costs to hydrocarbon internal combustion engine business cases and constraining development
- Reducing fleet emissions may free up local emission allowances in city centres, industrial zones, ports or airports. Investments in fuel cell fleets could unlock development constraints, balancing the additional costs of these fleets with other benefits.

Challenges

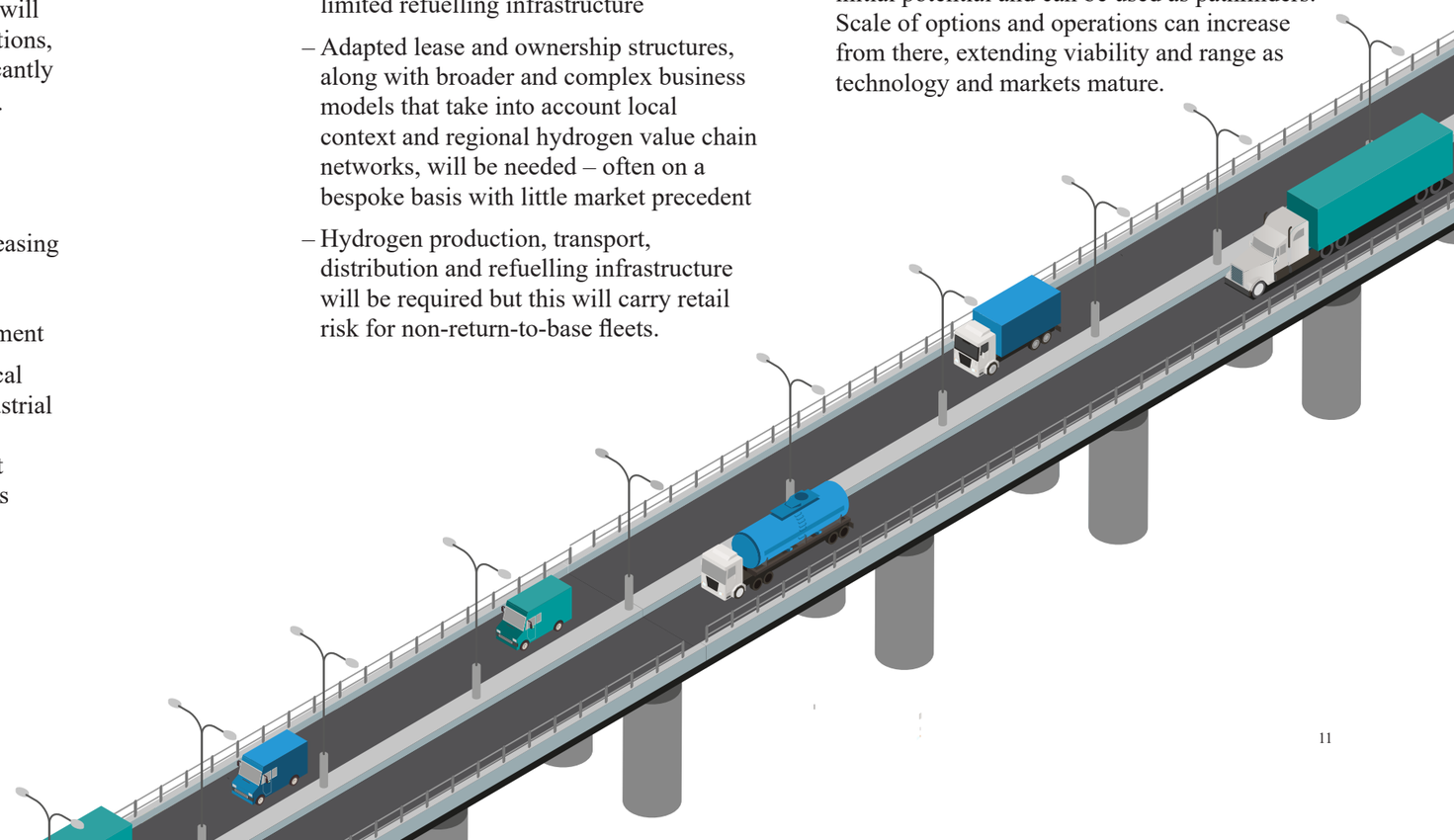
- Manufacturers developing heavy-duty trucks, vans and return-to-base fleets face the challenge of moving from initial prototypes to steady-state production
- Fuel costs currently account for half the total cost of owning a heavy truck, so reducing the price of hydrogen is key to making the technology cost-competitive
- Vehicle residual value is key for HGVs. If there is not a mature view and clear residual value, the cost for the first owner will be prohibitive
- For those HGVs with less predictable routes or without reasonably accessible hydrogen refuelling stations, the business case will not be very attractive until more affordable, small-scale refuelling options are available
- Deploying commercial hydrogen refuelling stations has significant retail and demand risk, limiting interest in developing these without government support. Conversely, private, small-scale uptake of hydrogen powered vehicles is restricted due to limited refuelling infrastructure
- Adapted lease and ownership structures, along with broader and complex business models that take into account local context and regional hydrogen value chain networks, will be needed – often on a bespoke basis with little market precedent
- Hydrogen production, transport, distribution and refuelling infrastructure will be required but this will carry retail risk for non-return-to-base fleets.

Example deployments

- In 2019, Hyundai formed Hyundai Hydrogen Mobility (HHM), a joint venture with Swiss company H2 Energy which will lease fuel cell trucks to commercial operators on a pay-per-use basis to transport their goods through this mountainous high-carbon-tax country. The green hydrogen to fuel the trucks is derived from hydro power
- JCB released the world's first hydrogen powered excavator in 2020. Volvo is working on its own version
- Hydrogen-powered forklift trucks have shown great potential, with over 25,000 reported to be in operation globally in 2019.

Conclusion

Although manufacturers are investing, the high cost of hydrogen fuels, uncertainty about residual value, the need for a vast number of hydrogen refuelling stations and the limited availability of hydrogen fuel-cell HGVs are considerable constraints to significant roll-out. Return-to-base fleets have the greatest initial potential and can be used as pathfinders. Scale of options and operations can increase from there, extending viability and range as technology and markets mature.



Rail and rolling stock

With commitments in place to decarbonise rail across the world, the days of diesel traction are numbered. Total electrification of the network through overhead lines would be suitable for heavy, fast and long-distance services but would be very expensive and intrusive. So complementary solutions are needed to fill the gaps where electrification is not viable.

While batteries could be a solution on routes under 100km, hydrogen fuel cells look to have most potential to smooth the interface between electrified and non-electrified parts of the network.

State of play

- Manufacturers are ramping up production capability and the UK government is making commitments to hydrogen
- Currently the leading options in Europe are hydrogen fuel cells supported by a battery pack. Hydrogen combustion conversion is at the research stage
- Safety assessment work is being undertaken, such as the work Arup has done for the RSSB, to explore the use of hydrogen for passenger rail trains

Opportunities

- Distances travelled, stabling times of rolling stock and the comparative cost of hydrogen and renewables are supporting interest in developing the sector
- Commuter and regional passenger routes where catenary overhead lines are lacking or limited
- Some countries have access to relatively cost-competitive renewable energy and can be early adopters of hydrogen rolling stock
- Low rolling resistance makes rail more energy-efficient than road or rail travel, so there is an opportunity to amplify decarbonisation through encouraging modal shift.

Challenges

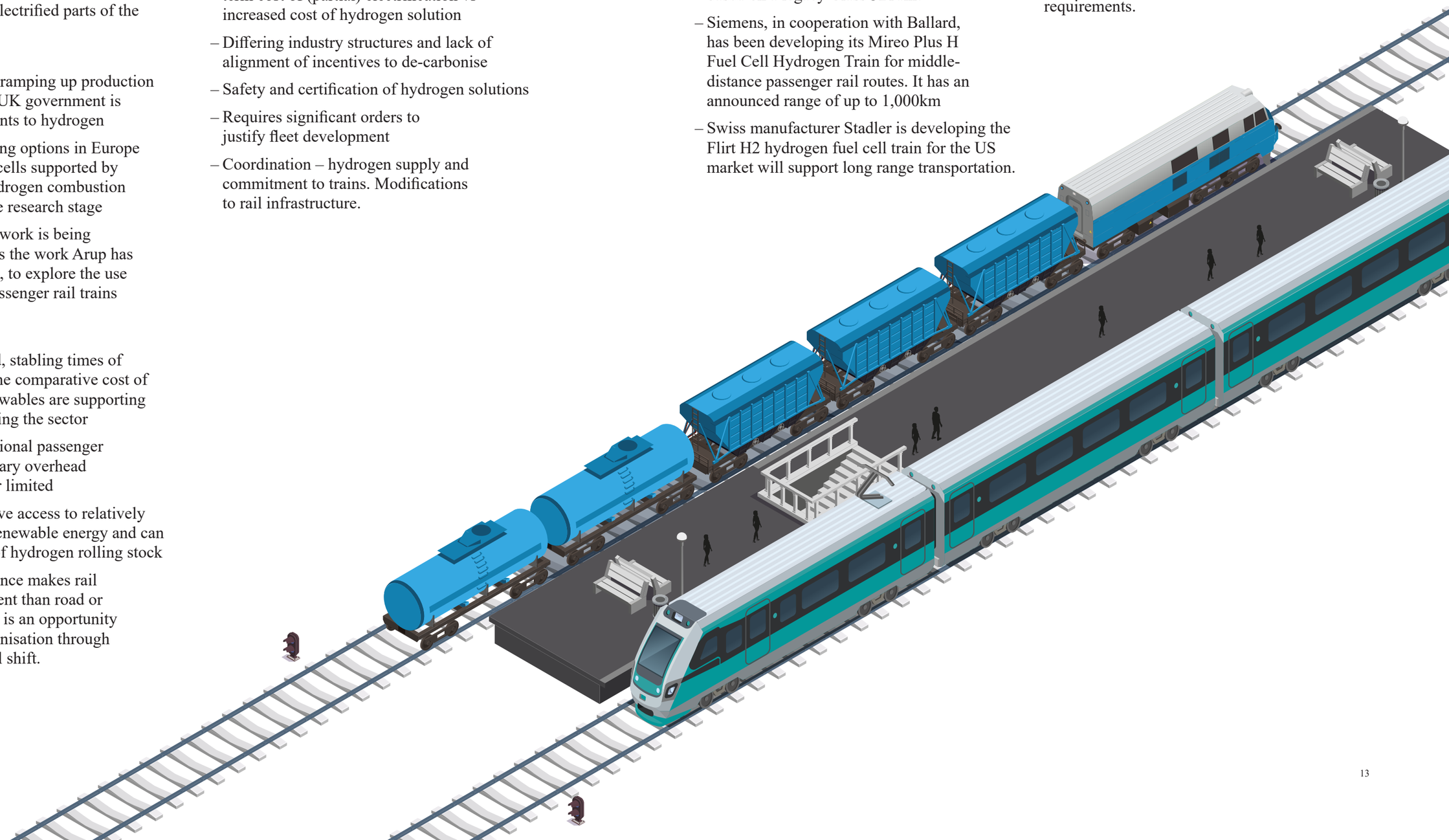
- This mainly will consider the long-term cost of (partial) electrification vs increased cost of hydrogen solution
- Differing industry structures and lack of alignment of incentives to de-carbonise
- Safety and certification of hydrogen solutions
- Requires significant orders to justify fleet development
- Coordination – hydrogen supply and commitment to trains. Modifications to rail infrastructure.

Example deployments

- The hydrogen fuel cell powered Alstom Coradia iLint passenger train entered service in Germany in 2019, with the Netherlands due to follow suit shortly
- Porterbrook has developed the HydroFlex fuel cell traction concept which has been tested in the UK on a legacy Class 319 unit, and Alstom has collaborated with Eversholt to develop their Breeze platform based on a legacy Class 321unit
- Siemens, in cooperation with Ballard, has been developing its Mireo Plus H Fuel Cell Hydrogen Train for middle-distance passenger rail routes. It has an announced range of up to 1,000km
- Swiss manufacturer Stadler is developing the Flirt H2 hydrogen fuel cell train for the US market will support long range transportation.

Conclusion

While electrification remains the ultimate aspiration of railway decarbonisation, the electrification gap is significant in its cost and complexity. There are many railway systems in the world which will not be able to electrify in time to meet regional, national and global decarbonisation targets. This leaves substantial opportunities to deploy fuel cell technology in both tactical and strategic situations, both as an interim measure and to satisfy end-state requirements.



Maritime and ports

Ports are ideally situated to become hydrogen hubs – aggregating demand from their own operations, from maritime transport, land transport and local industrial uses. They can establish hydrogen production and storage for this purpose, as well as hosting vessels powered by hydrogen fuel cells or hydrogen combustion through alternative ship fuel. However, this promise will take time to fulfil in this slow-moving sector.

State of play

- Hydrogen fuel cells for smaller vessels are not yet commercially viable, but low and high-temperature fuel cells and solid oxide fuel cells are promising technologies
- Hydrogen is being used as a fuel within ports to reduce emissions from port operations. Hydrogen import and export facilities are being developed to link economies with different production capabilities
- The International Maritime Organisation's (IMO) limiting of ship fuel sulphur content worldwide to 0.5% from 1 January 2020 will really push the industry to considering switching to alternative fuels
- The IMO has also outlined ambitions to reduce carbon intensities on average by 40% by 2030 and 70% by 2050 and total emissions by at least 50% by 2050, while pursuing zero carbon.

Opportunities

- Ports' geographic locations, functionality and nexus role present opportunities to develop as hydrogen hubs, aggregating demand from their operations, land and ocean transport, and local industrial users
- In the short to medium term, hydrogen fuel cell technology is suitable for smaller, short-range craft such as local ferries and water transport fleets in cities
- Where land availability permits, ports can establish hydrogen production and storage facilities to provide decarbonised compressed hydrogen fuel to multiple users and for inland distribution via pipelines

Challenges

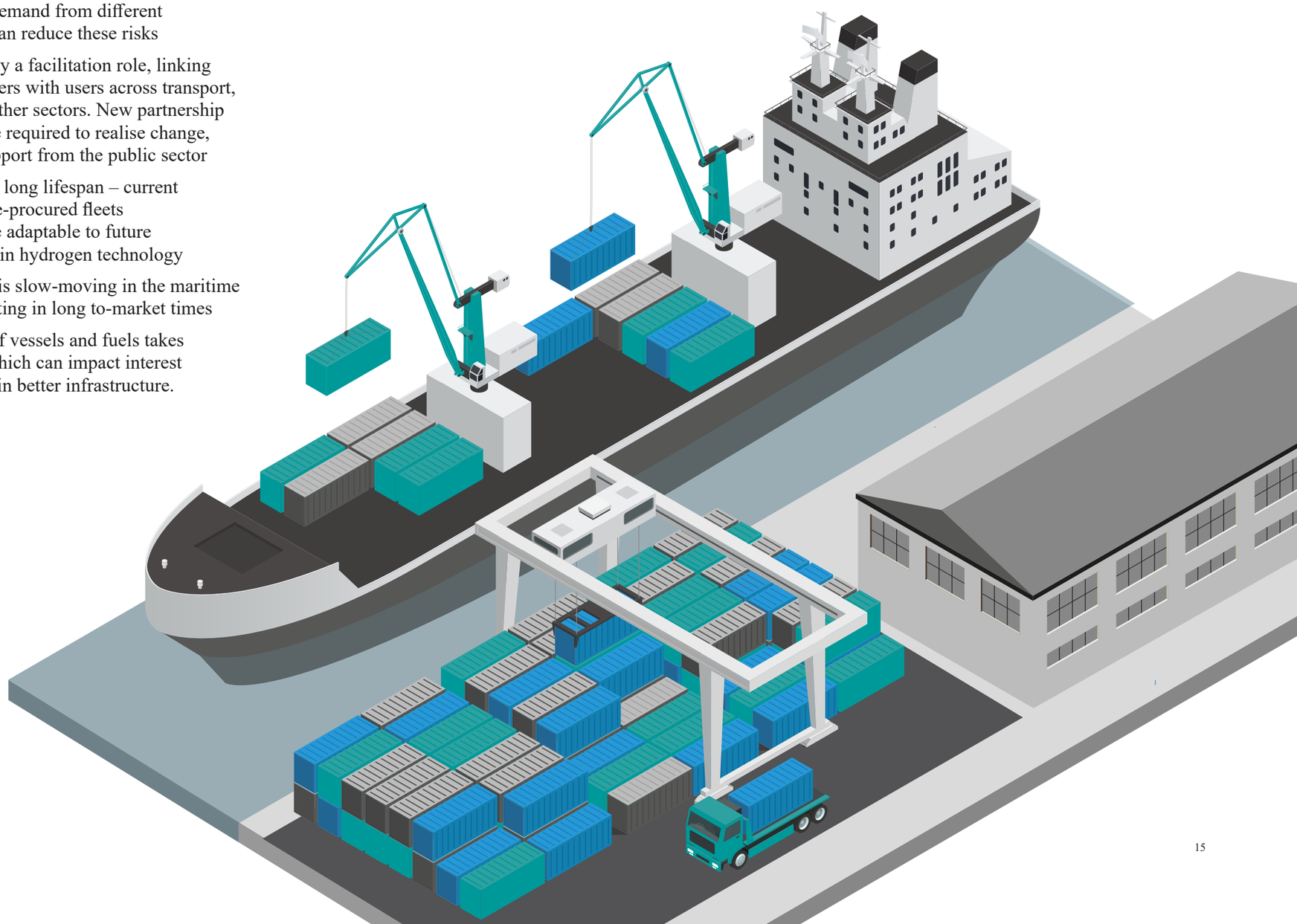
- Uncertain technology pathways and a fragmented international approach can deter investment in new energy infrastructure. Aggregating demand from different sectors ports can reduce these risks
- Ports often play a facilitation role, linking energy producers with users across transport, industry and other sectors. New partnership models will be required to realise change, along with support from the public sector
- Vessels have a long lifespan – current and soon-to-be-procured fleets will need to be adaptable to future developments in hydrogen technology
- Accreditation is slow-moving in the maritime industry, resulting in long to-market times
- Certification of vessels and fuels takes a long time, which can impact interest in investment in better infrastructure.

Example deployments

- The Port of Auckland in New Zealand is pioneering the decarbonisation of port operations, with studies underway Arup is supporting ongoing studies to help pursue decarbonisation
- The Port of Hastings in Australia is being developed as a hydrogen export facility
- The Ports of Amsterdam, Rotterdam, Antwerp and Hamburg are developing hydrogen refuelling stations for road fleets, including HGVs

Conclusion

The multi-model return to base nature of ports activities positions them well to become hydrogen hubs of the future. This will effectively decarbonise a broad range of activities which are otherwise difficult to tackle.



Aviation

While some major airports have achieved carbon-neutral operations, the carbon reduction journey for aircraft is more environmentally significant and more challenging. This has triggered multiple, and sometimes novel, initiatives in sustainable aviation fuels, battery technology, hydrogen fuel cells and electric motors, as well as radical new aircraft configurations.

State of play

- There have been demonstrations of E-VTOL vehicles, which represent a new sector for air taxis
- Some existing aircraft have been converted to test electric propulsion systems
- Design concepts developed for new aircraft and engine configurations accommodate future fuel and propulsion combinations, such as cryogenic hydrogen
- Sustainable aviation fuel is already being produced from waste or biomass sources, though it is more costly than conventional kerosene. The industry has a significant interest to decarbonise with this progress already being made.

Opportunities

- Green hydrogen can be used either directly (combustion or fuel cell) or as part of a sustainable aviation fuel
- Hybrid aircraft propulsion, combining electrical power and combustion technologies, is an opportunity
- The fraction of sustainable aviation fuels could be increased beyond the current maximum 50:50 mix
- Green Hydrogen could be adopted as a primary fuel, thereby eliminating carbon – though the resulting water emissions are environmentally active, for example in the form of contrails.

Challenges

- Purely battery-powered aircraft are suitable for small payload and short-range applications but are not generally considered to be a feasible option for long-haul travel
- Cryogenic hydrogen takes up more space as a fuel than kerosene, reducing available space in conventional aircraft
- New and novel aircraft configurations may take a long time to be certified and their introduction into service, at scale, will depend on airlines' ability to replace conventional fleets
- Conversion to hydrogen or electrical paradigm will require major changes to generation, storage and supply arrangements, as well as to airport infrastructure and aircraft.

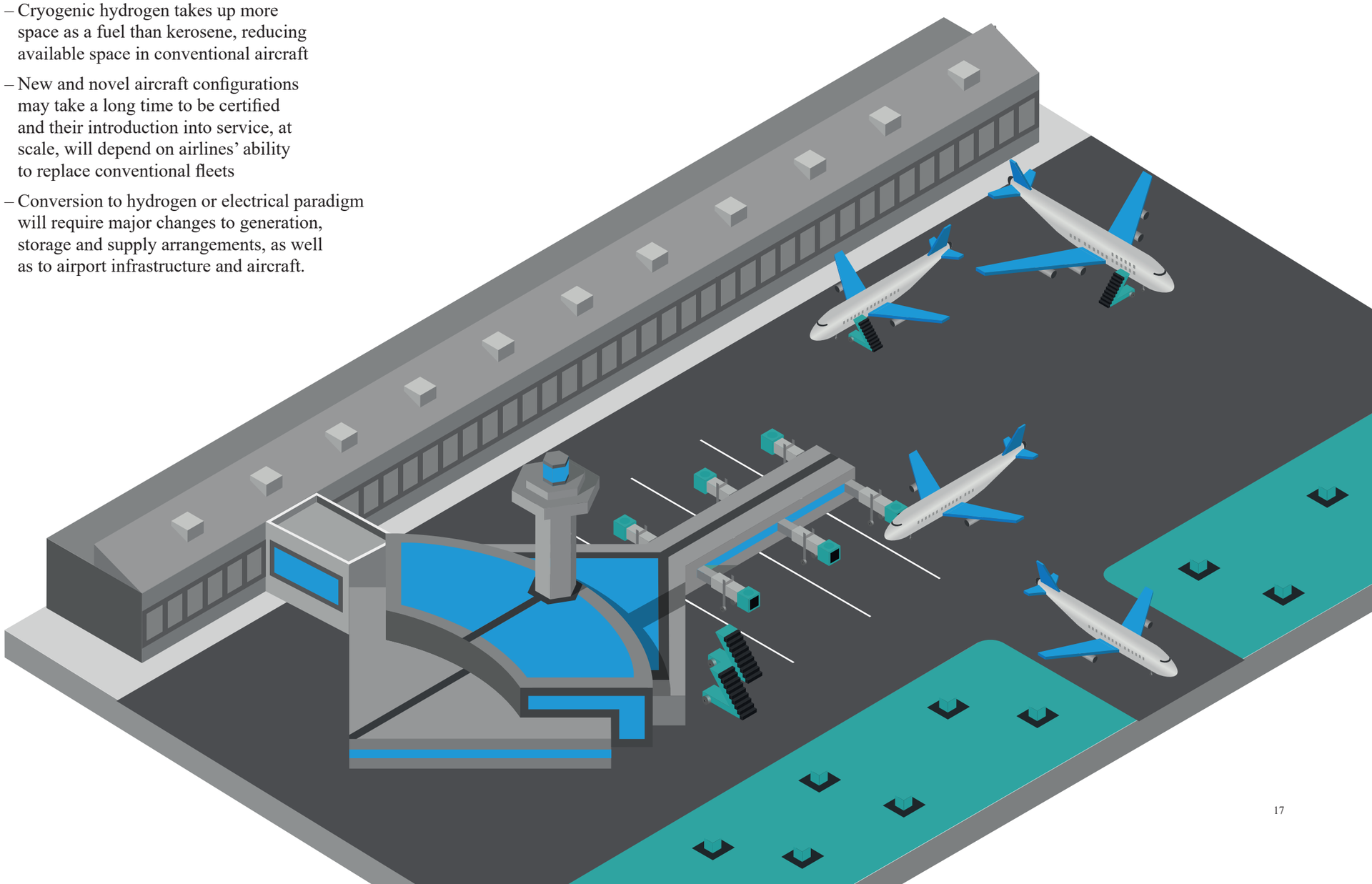
Example deployments

- H2GEAR, led by GKN Aerospace is developing a liquid hydrogen aviation propulsion system
- MULAG and Plug Power are working on hydrogen tugs at Hamburg airport
- HY4, a four-seat hydrogen fuel cell powered aircraft first flew in 2016 from Stuttgart Airport.

Conclusion

Both airports and aircraft hold great potential for decarbonisation and efficient operation through hydrogen deployment on landside, airside and aircraft applications.

Hydrogen is particularly applicable where there are numerous duty cycles which are not amendable to electrification.



The bigger picture

There is no doubt that making the most of the opportunities hydrogen offers for decarbonising transport is a big challenge in itself.

Transport asset owners will need to invest in new, and still maturing, vehicle technologies. What's more, they will also have to develop, establish or procure the well-to-wheel infrastructure chain for producing and storing hydrogen, and transporting and distributing it to refuelling stations.

Key considerations

Transport asset owners will need to invest in new, and still maturing, vehicle technologies. What's more, they will also have to develop, establish or procure the well-to-wheel infrastructure chain for producing and storing hydrogen, and transporting and distributing it to refuelling stations.

The technology

Green hydrogen electrolysis will be powered by electricity generated by energy-from-waste, biomass or renewables. Depending on a range of factors, the energy could be generated within an existing asset base, acquired through a connection to a generation source, or purchased from a supplier.

Infrastructure will be required to store, transport and distribute hydrogen in the form of a compressed gas, a cryogenic liquid, or using other chemicals or physical carriers. It can be moved by road tankers, rail, vessels and pressurised pipelines. Each option has its own benefits and downsides; and tailoring the right mix will depend on specific usage, local context, regional networks and geographical position. Buildability and reliability of the assets that make up the well-to-wheel infrastructure needs to be well understood.

The business models

Decisions about where to invest in the green hydrogen value chain of production, storage, transportation or distribution requires careful consideration.

Any scalable development will need to take account of key constraints.

These include:

– Cost

– Lead times to delivery

– Maturing nature of the technology

– Long value chain integration

– Impact of local conditions on fuel strategy.

– Uncertainty about useful life and residual value

Transportation business models will need to be tailored to local context and regional hydrogen value chains. Concession, lease and ownership structures will then need to be developed, often on a bespoke basis with little market precedent, to take account of these broader and more complex business models.

Individual transport asset owners will require only a relatively small amount of hydrogen compared to the production potential of electrolysers at 50MW+. Understanding local conditions, regional collaboration and physical networks will be key to achieving the required economies.

A significant number of fuel stations are required worldwide to supply the significant uptake of hydrogen for heavy-duty trucks, fleets and buses. Careful spatial analysis would be required to determine optimum locations and technology.

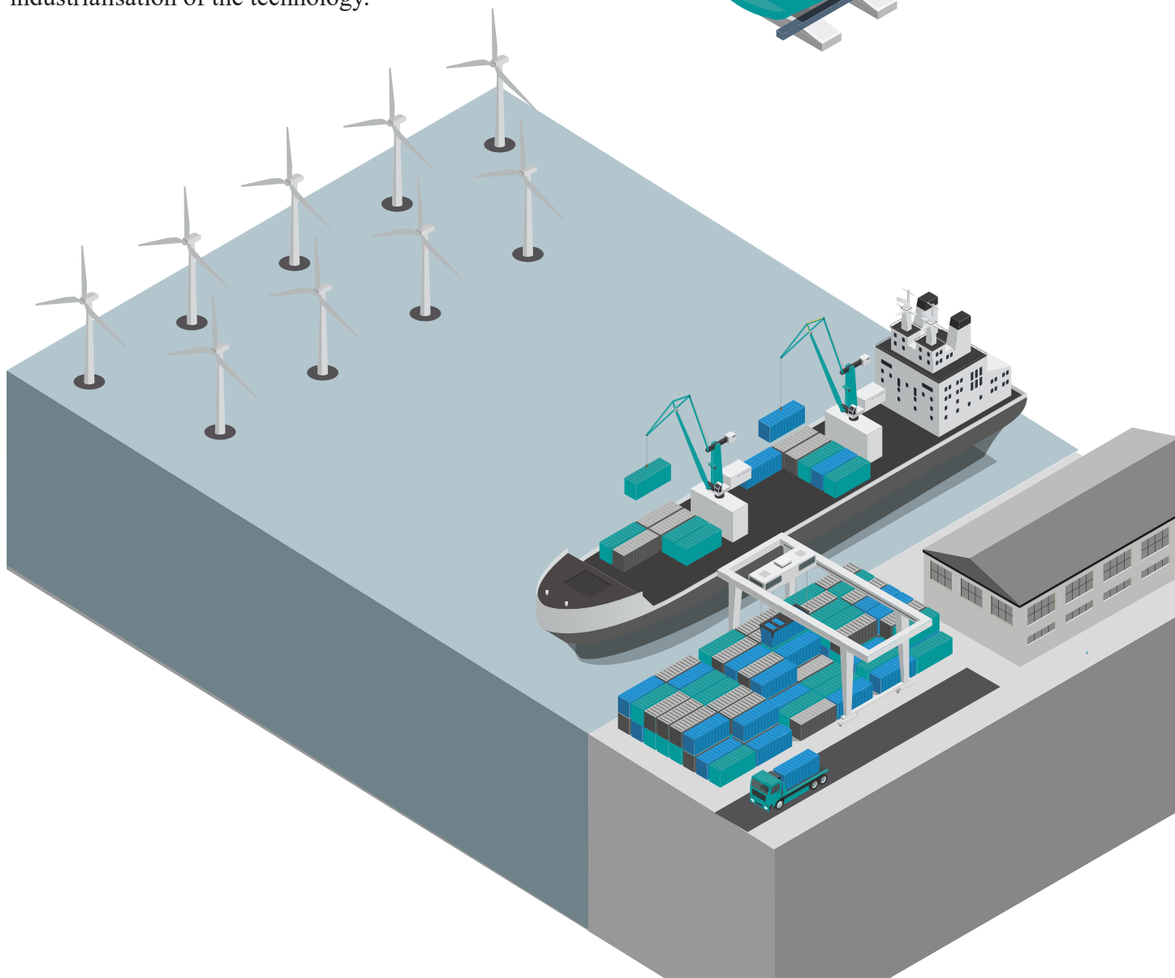
Sector development – integrating infrastructure

Ports have the potential to emerge as hubs for hydrogen production and supply for transport. Numerous ports across the world have the space, access to offshore wind power, lower regulatory constraints and are already significant transport and freight hubs.

With Arup as lead adviser, the Port of Auckland, Auckland Transport and Kiwi Rail are developing an electrolyser-based green hydrogen production and storage facility to provide compressed green hydrogen fuel to port vehicles and city buses.

Arcola Energy and a consortium of industry-leaders in hydrogen fuel cell integration, rail engineering and functional safety, including Arup, have been appointed to deliver Scotland's first hydrogen powered train.

A key objective of the project is to create opportunities for the Scottish rail supply chain through skills development and industrialisation of the technology.



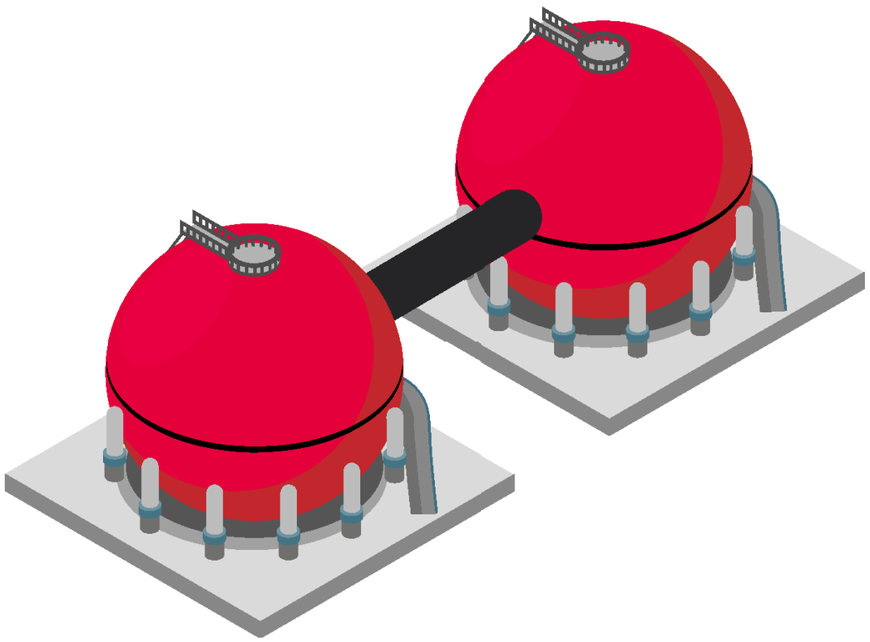
Why the time is now for hydrogen fuelled transport?

With transport accounting for 20-30% of global CO_2 emissions, the sector is essential to wider decarbonisation aspirations. In turn, hydrogen is key to decarbonising transport. While battery technology will be important, hydrogen is viable in situations where batteries aren't.

With this advantage, the development of hydrogen transport is being driven by:

- Low-emission policies and regulations – 18 countries now have hydrogen strategies
- Heavy government financial backing in pilot delivery
- Falling cost of renewables
- Resultant scaling up of manufacturers and electrolysers.

Thanks to these factors, hydrogen looks set to become cost-competitive with battery technology in 2025 and with hydrocarbons in 2030. Industry forecasts show that that the global market could grow to US $1 trillion over the next 30 years.



We are reaching the tipping point at which hydrogen will move from pilot projects to large-scale use and make a significant contribution to decarbonising transport.

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