A Primer:

Hydrogen Fuel for Public Transport

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Preface

The news from the UN's *Emissions Gap Report 2022* that "the international community is falling far short of the Paris goals, with no credible pathway to 1.5°C in place" is bleak reading. [1] Approximately one-fifth of carbon emissions arise from transport in general, of which around three-quarters comes from road transport, and half of that from passenger cars and buses.[2] In addition to battery-powered vehicles (BEVs), hydrogen-powered vehicles (HPVs) such as single and double decker buses can make a significant dent in Green House Gas emissions. This primer traces the hydrogen cycle from production, storage and distribution to usage by public passenger buses, and to disposal or recycling which remains a major challenge. Along the way it reviews costs, prices, regulations and case studies in which it reviews hydrogen policies and regulations in the UK, the EU, China and Hong Kong, Singapore and the Philippines.

Although hydrogen fuel cells can be used in many modes of transport, including aircraft, marine vessels, ferries and cars, trains, small and large HGV fork-lift trucks and long-distance trucks, the focus here is upon public single and double-decker buses. As buses in hotter climates require air conditioning, and the cool air escapes as buses stop to open doors, and then require additional propulsion to start again, their demand for power is incessant. If the terrain is hilly and/or their routes are long the demand for power increases accordingly, so conventional wisdom suggests that BEV buses are more appropriate for shorter routes and HPV buses for longer routes. In both cases however the seating capacity and therefore payload may be reduced to house the hydrogen-fed fuel cells. In the short term, the business (financial) case for HPVs may be less compelling than the social (economic) case, in which case subsidies, assistance with capex, or other commercial solutions may be required.

This primer is a contribution to a research application project (RAP-2) on decarbonising public transport as part of the Data Trust 2.0 project being planned by the HK PolyU.[3] It is entirely based upon secondary sources and does not claim to add new insights but to explain existing ones.

[1] UNEP (October 2022) *Emissions Gap Report 2022* https://www.unep.org/resources/emissions-gap-report-2022

[2] Our World Data (October 2020) *Cars, planes, trains: where do CO2 emissions from transport come from?* https://ourworldindata.org/co2-emissions-from-transport

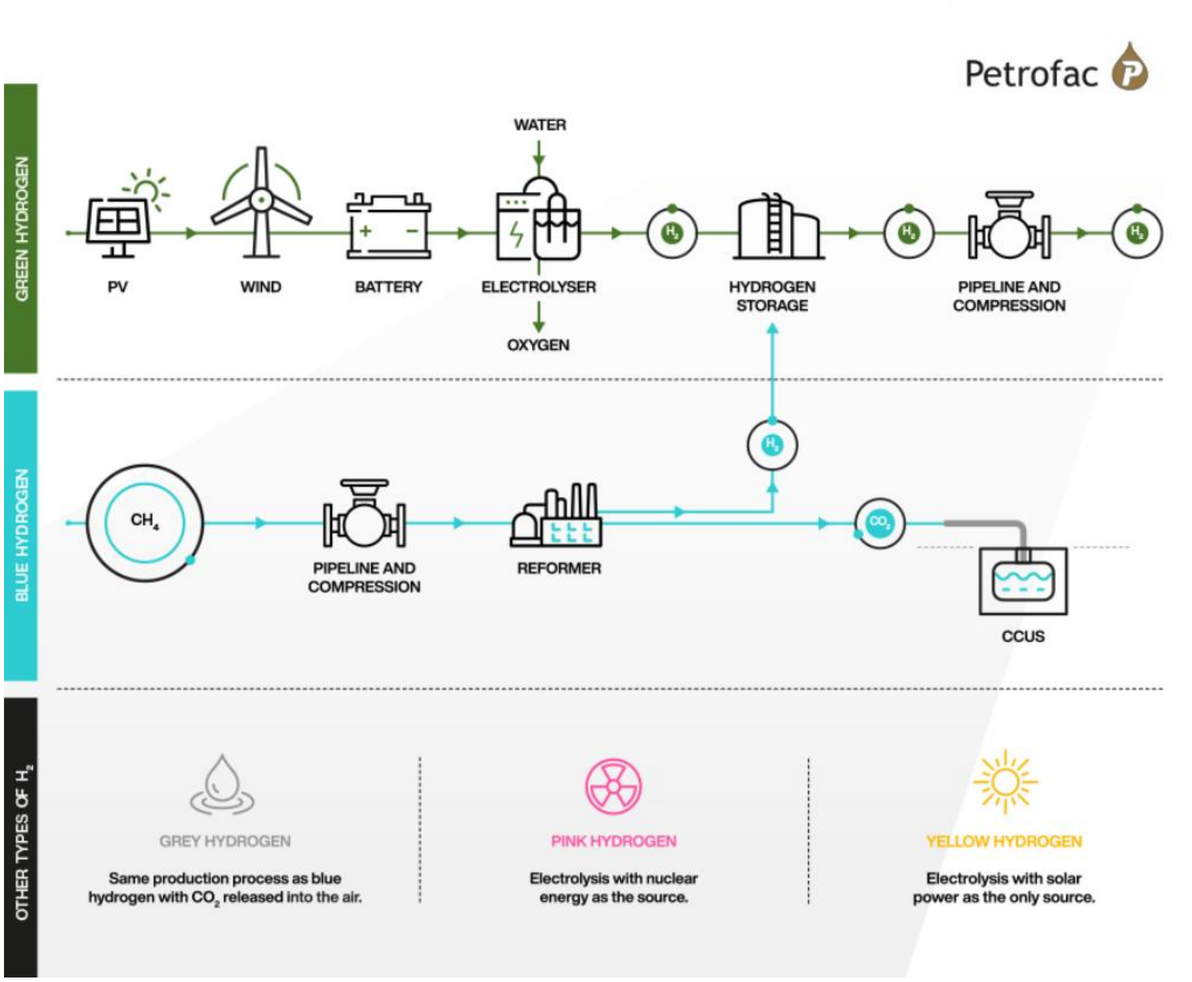
[3] Dr John Ure is director of the Fair Tech Institute of Access Partnership. He authored a paper *Decarbonising public Transport in Hong Kong* as chapter 4 in the final report of Data Trust 1.0 in October 2021 – see https://datahub.hku.hk/articles/report/Intermodal_Transport_Data-Sharing_Programme_Final_Report/17040194.

A Primer: Hydrogen Fuel for Public Transport

Why Hydrogen?

Hydrogen is not an energy source but an energy carrier, which means that its potential role has similarities with that of electricity.[4] It is the most abundant chemical element on Earth and is estimated to contribute 75% of the mass of the universe. It can be produced from many resources, such as natural gas and methane using a process known as steam methane reform, nuclear power as a source of electricity, biogas and renewable power such as solar, wind, pumped hydropower (dams and water towers) and ocean waves.

Hydrogen either can be sourced from carbon-fuels or from the power coming from renewables



Source: https://www.petrofac.com/media/stories-and-opinion/the-difference-between-green-hydrogen-and-blue-hydrogen/

Colour Coding

Coding hydrogen is a popular way to classify hydrogen according to its relation to Green House Gases (GHGs) and the types of fuel and energy-carrying resources used in its production, but is no guide to the economics and technical complexities of the hydrogen production, distribution, storage and usage.

[4] IEA (2019) *The Future of Hydrogen: Report prepared by the IEA for the G20, Japan* https://www.iea.org/reports/the-future-of-hydrogen

- **Grey hydrogen** is produced using a dirty fuel source such as methane, ethanol, propane, or gasoline and is accompanied by the production of carbon monoxide and dioxide.

Green House Gases (GHGs) and Gasification

Grey Hydrogen - Hydrogen is produced by a process of 'steam methane reform' from a methane source such as natural gas with the final products being hydrogen, carbon monoxide and carbon dioxide which makes it a carbon-dirty energy source. The process also uses electricity to generate a bar pressure to create the steam

"Most hydrogen produced today in the United States is made via steam-methane reforming, a mature production process in which high-temperature steam (700°C–1,000°C) is used to produce hydrogen from a methane source, such as natural gas. In steam-methane reforming, methane reacts with steam under 3–25 bar pressure (1 bar = 14.5 psi) in the presence of a catalyst to produce hydrogen, carbon monoxide, and a relatively small amount of carbon dioxide. Steam reforming is endothermic—that is, heat must be supplied to the process for the reaction to proceed. Subsequently, in what is called the "water-gas shift reaction," the carbon monoxide and steam are reacted using a catalyst to produce carbon dioxide and more hydrogen. In a final process step called "pressure-swing adsorption," carbon dioxide and other impurities are removed from the gas stream, leaving essentially pure hydrogen. Steam reforming can also be used to produce hydrogen from other fuels, such as ethanol, propane, or even gasoline."
https://www.energy.gov/eere/fuelcells/hydrogen-production-natural-gas-reforming

Black and Brown Hydrogen - uses black coal or lignite (brown coal) – any hydrogen made from fossil fuels through the process of 'gasification' is sometimes called black or brown hydrogen interchangeably. For example, Australia produces liquefied hydrogen from brown coal which is then shipped to Japan for low-emission use. https://www.nationalgrid.com/stories/energy-explained/hydrogen-colour-spectrum The transshipment of liquified hydrogen began February 2022 and is described as "a key milestone in the development of an international hydrogen market." IEA (2022) *Global Hydrogen Review* https://www.iea.org/reports/global-hydrogen-review-2022

- **Blue hydrogen** is produced in the same way as grey hydrogen, but the carbon product is separated by **capture and storage (CCS)**. As GHGs are not avoided it is sometimes referred to as 'low-carbon hydrogen.' "Currently, commercially viable CCS remains an aspiration rather than a reality, second, carbon capture can never be 100% efficient, and third, there is great uncertainty over the climate impact of upstream methane leakage." [Agaton, et al (May 2022) *Prospects and challenges for green hydrogen production and utilization in the Philippines* International Journal of Hydrogen Energy Volume 47, Issue 41, 12 May 2022, Pages 17859-17870 https://www.sciencedirect.com/science/article/pii/S0360319922016147]
- **Pink (or Red) Hydrogen** is produced from nuclear fission power for the electrolysis. The radioactive material is captured and stored. Calling it a clean fuel is controversial, but economically it may be the mid-term way to produce clean hydrogen. Equally, it can be used in the production and storage of Grey or Blue hydrogen production. The Holy Grail will be nuclear fusion, which is totally green, but progress is slow.[5]

[5] BBC News (February 2022) *Major breakthrough on nuclear fusion energy* https://www.bbc.com/news/science-environment-60312633

- **Green Hydrogen** is produced by splitting water by electrolysis resulting in only hydrogen and oxygen. The source of the electricity used must be from renewables (no carbon production) such as solar, wind power, pumped hydropower (dams or water stored in towers), natural thermal heat, ocean or oscillating wave chamber power, and in limited quantities of biomass. The ultimate infinite source (the Holy Grail) will be nuclear fusion.
- **Intermediary technologies** are being developed with patented catalysts to convert power stations into green hydrogen plants by replacing the coal-fired boiler. For example, an Australian company Star Scientific has developed the Hydrogen Energy Release Optimiser (**HERO**) catalyst technology for combining hydrogen and oxygen gas to continuous industrial heat without combustion. The company has signed a contact with the Department of Energy in the Philippines.[6]

Yet More Colours – but are they helpful?

- **Yellow Hydrogen** is sometimes used to denote Green hydrogen produced using only solar power. But confusingly it has sometimes been used to denote Pink hydrogen[7]
- **White hydrogen** is a naturally-occurring geological hydrogen found in underground deposits and created through fracking. There are no strategies to exploit this hydrogen at present.
- **Turquoise hydrogen** is a new entry and production has yet to be proven at scale.[8] Turquoise hydrogen is made using a process called methane pyrolysis to produce hydrogen and solid carbon. In the future, turquoise hydrogen may be valued as a low-emission hydrogen, dependent upon the thermal process being powered with renewable energy and the carbon being permanently stored or used.
  https://www.nationalgrid.com/stories/energy-explained/hydrogen-colour-spectrum

  Note 1: "**Confusion over 'colours is stifling innovation,** with over-simplification and colour prejudice risking the premature exclusion of some technological routes that could potentially be more cost- and carbon-effective. There is a need for further dialogue which looks beyond colour to also explore carbon equivalence." [World Economic Working Paper (2021) *Hydrogen on the Horizon: National Hydrogen Strategies* in collaboration with the Electric Power Research Institute (EPRI) and PwC
  https://www.worldenergy.org/publications/entry/working-paper-hydrogen-on-the-horizon-national-hydrogen-strategies

  Note 2: IEA 2019 Report "In general, there are no established colours for hydrogen from biomass, nuclear or different varieties of grid electricity. As the environmental impacts of each of these production routes can vary considerably by energy source, region and type of CCUS applied, colour terminology is not used in this report."
  Note 3: CCUS = carbon capture, utilisation and sequestration

[6] Australian Government (April 2021) *Hydrogen hero: Australian company develops 'missing link' in hydrogen supply chain* https://www.dcceew.gov.au/climate-change/publications/hydrogen-hero-australian-company-develops-missing-link-in-hydrogen-supply-chain
[7] See references in Agaton, et al (May 2022) *Prospects and challenges for green hydrogen production and utilization in the Philippines* International Journal of Hydrogen Energy Volume 47, Issue 41, 12 May 2022, Pages 17859-17870 https://www.sciencedirect.com/science/article/pii/S0360319922016147 p.17862.
[8] Lux (May 2021) *Technology Landscape: Key Players in Methane Pyrolysis* https://www.luxresearchinc.com/blog/technology-landscape-key-players-in-methane-pyrolysis/

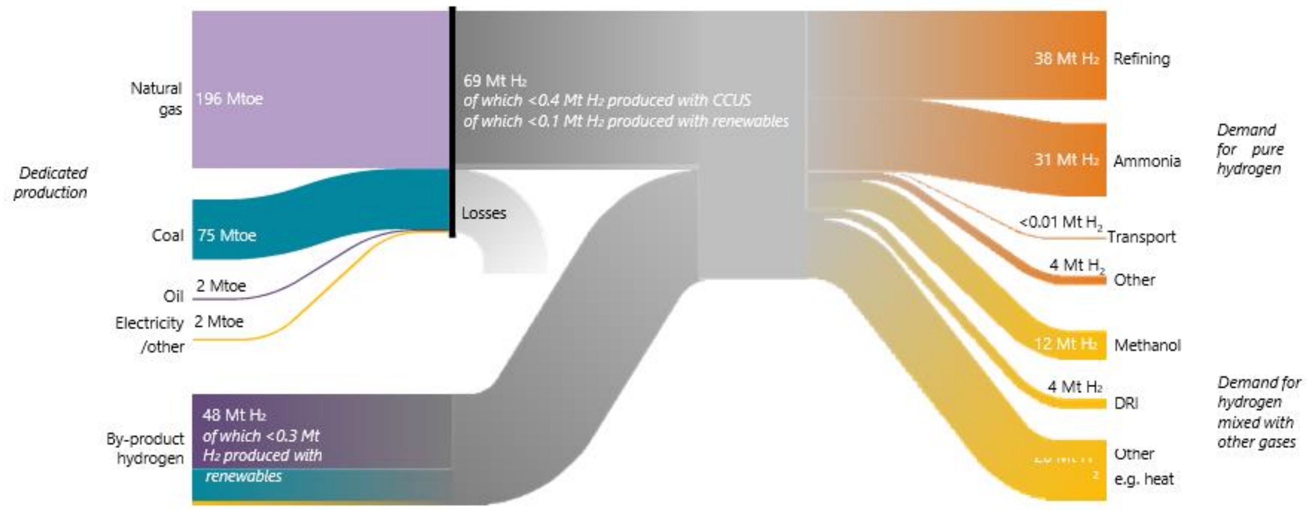
Hydrogen Production and its Costs

The overwhelming majority of hydrogen produced today is from fossil fuels, and around 60% of it is produced in facilities dedicated to hydrogen production. Most of this is from natural gas, some from coal, and a small fraction from renewables using electrolysis. Less than 0.7% of current hydrogen production is from renewables or from fossil fuel plants equipped with CCUS. Hydrogen is a by-product in the remaining third of production and subsequently needs 'cleaning' before being available for use. Most hydrogen is used within country.

Hydrogen is a chemical energy carrier, composed of molecules, not only electrons, and as chemical energy it can be stored and transported in a stable way. This gives chemical-based energy systems a stock-based element whereas an energy system based on electricity is more flow-based, meaning demand and supply need to be matched in real time, even over long distances. As the IEA report points out with regard to batteries, they also store chemical energy, "but not in the bonds of molecules that can be stored in bulk. In batteries, the chemical energy is a build-up of ions and electrons on cathodes and anodes in specially prepared combinations of chemicals; often these are complex chemicals with poor stability. The chemical energy in batteries degrades more quickly over time."[9]

Toe produce hydrogen a power source is required, usually electricity – in other words, electricity is required to produce hydrogen to produce electricity but in a form that can be more easily stored and transported. The conversion ratio of electricity to other energy carriers such as hydrogen is termed Power-to-X. Together, hydrogen-based fuels that integrate electrolytic hydrogen are sometimes referred to as "electrofuels" or, in the very specific case of power from solar energy, solar fuels.

Hydrogen Value Chains 2018

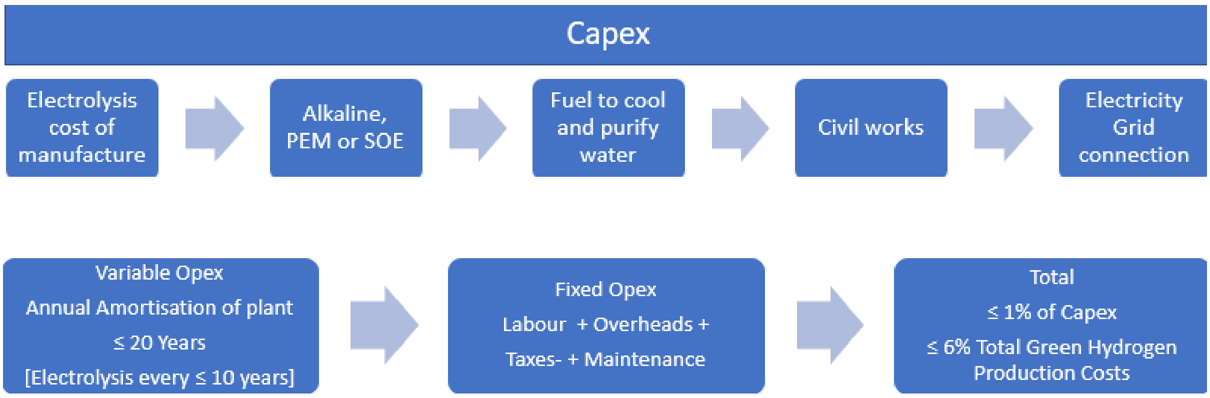


Source: IEA (2019) *The Future of Hydrogen: Report prepared by the IEA for the G20, Japan* https://www.iea.org/reports/the-future-of-hydrogen

[9] IEA (2019) The Future of Hydrogen: Report prepared by the IEA for the G20, Japan https://www.iea.org/reports/the-future-of-hydrogen

Costs of Green Hydrogen

The cost components of producing and storing green hydrogen are shown below as capex + opex. The **capex** for green hydrogen consists of the manufacturing costs of the electrolysis system, then the choice of the electrolysis operating system as Alkaline, PEM or SOE, the fuel costs upstream of cooling and purifying the water used in the production process – in the case of green hydrogen this involves the use of renewable sources of energy, and in blue hydrogen this involves steam-methane-reform as the most widely used method of separating hydrogen using carbon capture, utilisation and sequestration or CCUS – together with the civil building works of the extraction plant and finally the connection to the electricity grid.



Alkaline Electrolysis, Solid Oxide Electrolysis Cells (SOEC), Polymer Electrolyte Membrane (PEM)

"The technology has been around for hundreds of years. An electrolyser unit works by making use of two reactions which take place at two electrodes – the negatively charged cathode and the positively charged anode – when voltage is applied. The Oxygen Evolution Reaction (OER) produces oxygen at the anode, and the Hydrogen Evolution Reaction (HER) produces hydrogen at the cathode. An electrically conductive substance, known as an electrolyte, is used to equalise the charge of the gases produced, while a membrane keeps them separate, preventing mixing and contamination... The International Energy Agency (IEA) expect global electrolyser capacity to reach 17 GW by 2026, up from just 0.3 GW in 2020, and there is already a global project pipeline of more than 300 GW."

Alkaline

"A mature technology, capable of producing hydrogen at an industrial scale. A typical alkaline electrolyser uses a porous diaphragm and a liquid alkaline electrolyte to split water with an electrical current. The main benefit of this technology is its liquid electrocatalyst, which negates the need for costly metal materials. Alkaline electrolysis cells can be configured in large stacks, and are known for their long-term stability and lifetime."

SOE

"SOEC is a less mature technology than alkaline or PEM electrolysis, however it is essentially the reverse of a solid oxide fuel cell (SOFC). SOEC's are a three-layer solid structure, composed of a porous cathode, electrolyte and porous anode, plus an interconnected plate. An SOEC system produces hydrogen via a ceramic solid oxide electrolyte membrane that selectively transfers negatively charged oxygen ions to the anode. SOEC is performed at very high temperatures, typically 700-1000°C, and the repurposing of thermal heat energy or waste heat can significantly improve the efficiency by reducing the need for electrical energy. It has good PtX efficiency but can suffer from degradation due to high heat, but displays the lowest MW/h requirement per metric ton of ammonia produced – lower even than fossil fuelled processes."

PEM

"Another mature technology, which splits water under acidic conditions using a sulfonic acid polymer as the electrolyte. The main advantage of PEM is its ability to operate effectively at high current densities and variable power levels within seconds, and it pairs well with renewable energy. Other characteristics include low gas permeability, high energy efficiency and a fast rate of hydrogen production. The most significant challenge is the systems acidity, which means very scarce and costly noble metals are required for the electrocatalysts and coating layers."

Source: COWI (M arch 2022) *Electrolysis: the Backbone of the Green Transition* https://www.cowi.com/insights/electrolysis-the-backbone-of-the-green-transition

The **opex** includes the annual amortisation or depreciation charges of the plant typically over a 20-year stretch, including the electrolysis equipment over an anticipated lifetime of around 10 years, plus other overheads such as labour and management charges, maintenance, taxes, etc. One source suggests opex is characteristically no more than 1% of capex and 6% of total production costs.[10] The resulting price of green hydrogen is seen as falling over the coming decade as the supply of renewables rises and the costs fall. But these the data is highly influenced by several factors, such as in the short term, oil prices and shocks to the system such as wars, supply chain disruptions and climate change disasters, and in the longer term by how much current investment in renewables will be realised in practice. Higher oil prices, and by implication higher gas prices as users switch when they can, imply cost competitiveness for renewables, but price variations can be swift, dramatic and substantial. Compare these two article headlines: 'Experts explain why green hydrogen costs have fallen and will keep falling' March 2021,[11] and 'Green hydrogen prices have nearly tripled as energy costs climb' form July 2022.[12] Many of the targets mentioned for green hydrogen aim at $1-2/kg of hydrogen which according to the article in March 2021 compared with carbon-capture by steam methane reformation of natural gas (blue hydrogen) of around $2.40/kg. By 2022 this figure was closer to $10/kg. These are wild swings, and it is better to examine the trends in the production process that extend beyond just the price of energy. One such forecast is that green hydrogen should hover around $1.5/kg by 2030.[13]

The key cost components are presented in the following Table with forecasts to 2030 based upon extrapolations by the sources of investment commitments, but as of September 2022 only 10% of

[10] Recharge (September 2022) *OPINION | Why market dynamics will reduce the average price of green hydrogen to $1.50/kg by 2030* https://www.rechargenews.com/energy-transition/opinion-why-market-dynamics-will-reduce-the-average-price-of-green-hydrogen-to-1-50-kg-by-2030/2-1-1292801

[11] S&P Global (march 2021) 'Experts explain why green hydrogen costs have fallen and will keep falling' https://www.spglobal.com/marketintelligence/en/news-insights/latest-news-headlines/experts-explain-why-green-hydrogen-costs-have-fallen-and-will-keep-falling-63037203

[12] Utility Dive (July 2022) 'Green hydrogen prices have nearly tripled as energy costs climb: S&P' https://www.utilitydive.com/news/green-hydrogen-prices-global-report/627776/

[13] Recharge (September 2022) *OPINION | Why market dynamics will reduce the average price of green hydrogen to $1.50/kg by 2030* https://www.rechargenews.com/energy-transition/opinion-why-market-dynamics-will-reduce-the-average-price-of-green-hydrogen-to-1-50-kg-by-2030/2-1-1292801

these had reached final investment decision (FID) status.[14] Estimates are really 'guestimates' and vary quite widely.[15]

Inputs into Green Hydrogen Production[16]	Today	2030
Electrolysis capacity available for green hydrogen production	< 1.5GW[17] > 3GW[18]	>100-240GW[19]
Production capacity per kW of electrolysis capacity	21kg	58kg
Capex per kW of green hydrogen energy produced	$1,000-$1,4000	$340
Green hydrogen fuel price per MWh output	$32 per MWh	$20 per MWh
Green hydrogen fuel price	$2.7-7.8/kg	$2-6/kg
Distribution of green hydrogen by pipeline	1 M/t Blue	9-14M/t Green
Demand for hydrogen	94 M/t	140[20]-180 M/t[21]
Demand met by green hydrogen	0.01 M/t	28 M/t[22]

Demand for hydrogen will be the key factor determining the economics of hydrogen as scale rises. By end 2021, global demand stood at its historical peak at 94 Mt (million tons) – one-third of it from China[23] – driven mainly by the chemical sector and refining, mostly produced by unabated fossil fuels. New sources of demand such as transport, high-temperature heat in industry, hydrogen-based steel production or Direct Reduced Iron (DRI), power and buildings rose by 60% in 2021 but only to reach 40 kt (thousand tons) "which only represents 0.04% of global hydrogen demand. Most of this demand is concentrated in road transport, which observed a significant increase as a result of the accelerated deployment of FCEVs, particularly fuel cell heavy-duty trucks in China."[24] Currently, green hydrogen meets just 1% of this demand according to the Environmental and Energy Study

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[14] Hydrogen Council/McKinsey & Company (September 2022) *Hydrogen Insights* https://hydrogencouncil.com/en/hydrogen-insights-2022/

[15] One forecast sees the average size of electrolyser systems likely to exceed 600 megawatts by 2027 – see GTM (June 2020) *So, What Exactly Is Green Hydrogen?* https://www.greentechmedia.com/articles/read/green-hydrogen-explained

[16] Recharge (September 2022) *OPINION | Why market dynamics will reduce the average price of green hydrogen to $1.50/kg by 2030* https://www.rechargenews.com/energy-transition/opinion-why-market-dynamics-will-reduce-the-average-price-of-green-hydrogen-to-1-50-kg-by-2030/2-1-1292801

[17] The Ningxia Solar Hydrogen Project in China, with a total capacity of 150 MW, accounted for almost three-quarters of the global additions. IEA (September 2022) 'Electrolysers' https://www.iea.org/reports/electrolysers

[18] According to Merics (June 2022) China's nascent green hydrogen sector: how policy, research and business are forging a new industry https://merics.org/en/report/chinas-nascent-green-hydrogen-sector-how-policy-research-and-business-are-forging-new estimates for 2022 suggest Europe already has 2.5GW and China could expand capacity by 1.5-2.5GW- - see fn 39.

[19] Around 1GW in China, with 10GW planned, China plans 38GW by 2030 and the local hydrogen lobby calling for 100GW, after which green will overtake other 'colours'. See Merics (June 2022) China's nascent green hydrogen sector: how policy, research and business are forging a new industry https://merics.org/en/report/chinas-nascent-green-hydrogen-sector-how-policy-research-and-business-are-forging-new

[20] Mining Weekly (November 2021) *Hydrogen demand to rise to 140m tonnes in 2030* https://www.miningweekly.com/article/hydrogen-demand-to-rise-to-140m-tonnes-in-2030-2021-11-17

[21] EESI (April 2022) Green Hydrogen Briefing Series: Scaling Up Innovation to Drive Down Emissions https://www.eesi.org/briefings/view/042722tech

[22] Mining Weekly (November 2021) *Hydrogen demand to rise to 140m tonnes in 2030* https://www.miningweekly.com/article/hydrogen-demand-to-rise-to-140m-tonnes-in-2030-2021-11-17

[23] Merics (June 2022) *China's nascent green hydrogen sector: how policy, research and business are forging a new industry* https://merics.org/en/report/chinas-nascent-green-hydrogen-sector-how-policy-research-and-business-are-forging-new

[24] IEA (2022) *Hydrogen* https://www.iea.org/reports/hydrogen

Institute (EESI).[25] Prognoses vary. The Mining Weekly, for example, in 2021 forecast green hydrogen rising to 4% of demand by 2030 (see table). China it is reported aims to produce 2 M/t of green hydrogen a year by 2025.[26] The response of supplies of green hydrogen will be determined by two sets of factors: market factors influenced by the relative prices of renewables versus abated (CCUP) and unabated fossil fuels, and by state-driven subsidies, taxes, quotas, etc., as ways to meet climate change targets. These will be part of the equation.

Hydrogen Distribution and Storage

Hydrogen on the one hand contains more *energy per unit of mass* than natural gas or gasoline, making it attractive as a transport fuel; on the other it is the lightest element and so has a low *energy density per unit of volume*, meaning larger volumes of hydrogen must be moved to meet identical energy demands as compared with other fuels. This means there is a need for larger or faster-flowing pipelines and larger storage tanks. Hydrogen can be compressed, liquefied, or transformed into hydrogen-based fuels *that have a higher energy density*, but this (and any subsequent re-conversion) uses some energy. For example, the Haber process[27] can be used to react hydrogen and nitrogen at high temperatures and pressures to produce 'green' ammonia, NH3,[28] which is easy and rather safe to store in its liquified state,[29] but expensive in terms of energy for conversion back to hydrogen.[30] Nevertheless it is one of the predicted models for future storage and distribution.[31]

Pipelines vs Trucks

The physical means of transportation is rather determined by distance and terrain. For short distance distribution under 300km, compressed gaseous hydrogen (GH2) trucking is the lower cost, while liquified hydrogen is usually reserved for larger volume and longer distance deliveries, and hydrogen pipeline infrastructure for longer distances and centred on high-volume operations. [32] The re-purposing costs of natural gas pipelines for 100% hydrogen transportation are projected between €0.2 million and €0.6 million per kilometre.[33]

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[25] EESI (April 2022) *Green Hydrogen Briefing Series: Scaling Up Innovation to Drive Down Emissions* https://www.eesi.org/briefings/view/042722tech

[26] Reuters (March 2022) *China sets green hydrogen target for 2025, eyes widespread use* https://www.reuters.com/world/china/china-produce-100000-200000-t-green-hydrogen-annually-by-2025-2022-03-23/

[27] Jim Clark (April 2013) *The Haber Process* https://www.chemguide.co.uk/physical/equilibria/haber.html

[28] The Royal Society (February 2020) *Ammonia: zero-carbon fertiliser, fuel and energy store* https://royalsociety.org/topics-policy/projects/low-carbon-energy-programme/green-ammonia/

[29] ACS Letters (November 2021) *Limitations of Ammonia as a Hydrogen Energy Carrier for the Transportation Sector* CS Energy Lett. 2021, 6.12, pp.4390–4394 https://pubs.acs.org/doi/10.1021/acsenergylett.1c02189

[30] US Department of Energy (2006) *Potential Roles of Ammonia in a Hydrogen Economy* https://www.energy.gov/sites/prod/files/2015/01/f19/fcto_nh3_h2_storage_white_paper_2006.pdf#:~:text=in%20a%20hydrogen%20economy%2C%20particularly%20with%20regard%20to,and%20toxicity%20issues%2C%20both%20actual%20and%20perceived%2C%20as

[31] BloombergNEF (January 2022) *Hydrogen – 10 Predictions for 2022* https://about.bnef.com/blog/hydrogen-10-predictions-for-2022/

[32] The Green Box (December 2020) *Competitive Hydrogen Delivery: the cost of trucking*. https://www.greenbox.global/post/hydrogendelivery#:~:text=For%20short%20distance%20distribution%20under%20300km%2C%20compressed%20gaseous,infrastructure%20is%20generally%20centralized%20around%20high-volume%20merchant%20operations.

[33] Linkedin Ashik Kalam (June 2021) *Repurposing Natural Gas Pipelines for Hydrogen - What to expect?* https://www.linkedin.com/pulse/hydrogen-pipelines-how-does-repurposed-natural-gas-cope-ashik-kalam/

Storage
Storage has to take place at various points such as close to production prior to its distribution, for example, as liquified gas in a sea-going tanker or by truck, or as a mix of natural gas and hydrogen gas in a pipeline – in the UK this mix is at maximum 1% hydrogen but with experiments of up to 20% hydrogen[34] – and storage underground in old mines, caves, etc.[35] Providing hydrogen in refuelling stations can be achieved in different ways, such as on-site generation of hydrogen from pipeline natural gas, compression, storage and dispensing of high-pressure hydrogen, although most of these methods are still regarded more as demonstrations than as the final product, an example being France's Air Liquide refuelling station in Beijing, the world's largest hydrogen station with a capacity of nearly 5 tonnes per day.[36] On-site storage and refuelling facilities for the most part remain frontier technologies, although cylinder storage, which is above ground unlike the storage of gasoline, requires much less infrastructure.

Solid-state metallic hybrids are one set of emerging technologies to replace compressed hydrogen as the lightweight H molecule is easily bonded onto a metal. [37] For example, in Hong Kong, EPRO Advanced Technologies (EAT)[38] produce porous silicone (Si+) as a porous membrane (NaA1H4) starting with one molecule of silicon (A1) and two of water and through steam conversion ending up with two of hydrogen and one of silicon dioxide, a compound often used to keep foods from moisturizing. Solid metallic hybrids in containers are easily transported to places of usage, such as refueling stations – just add water and electricity up to a moderate heat, max 80C. [39] But for smaller refuelling stations, liquid hydrogen in canisters may prove more convenient. In this sense, size matters including employing fully-trained staff which strongly favours stations that can cater for a variety of public transport vehicles and heavy commercial vehicles to spread the costs, a point highlighted by Shell when it closed its UK hydrogen refueling stations in October 2022 "The focus for Shell in the UK is to see where there are opportunities to build multi-modal hubs for heavy-duty trucks, similar to a model we have built in California."[40] The first in the EU was opened 2021.[41] A map of refuelling stations across the EU can be found at https://h2-map.eu/ As public transport vehicles will have different operating routes, the bus terminals

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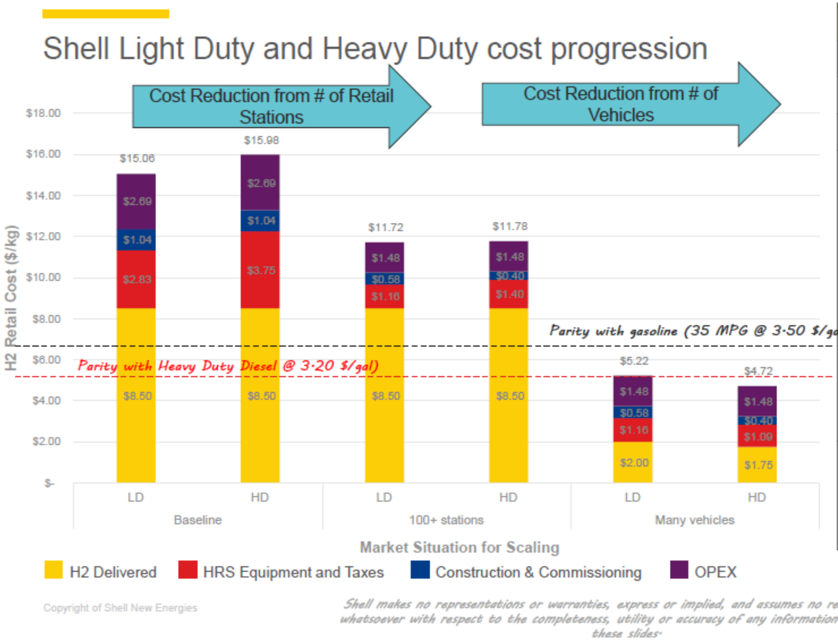
[34] CMS (2022) *Hydrogen law, regulations & strategy in the United Kingdom* https://cms.law/en/int/expert-guides/cms-expert-guide-to-hydrogen/united-kingdom
[35] IEA (October 2021) *Proving the viability of underground hydrogen storage* https://www.iea.org/articles/proving-the-viability-of-underground-hydrogen-storage
[36] Air Liquide (July 2021) *Hydrogen station in Beijing, China* https://www.airliquide.com/group/press-releases-news/2021-07-08/air-liquides-technology-chosen-worlds-largest-hydrogen-station-beijing-china
[37] Karbachi et al (April 2020) *Metal Hydrides and Related Materials. Energy Carriers for Novel Hydrogen and Electrochemical Storage* Journal of Physical Chemistry,7599–7607 https://pubs.acs.org/doi/10.1021/acs.jpcc.0c01806
[38] EAT (2022) *Let's Change the World Together* https://www.epro-atech.com/
[39] PV Magazine (July 2022) *The Hydrogen Stream: Porous silicon material for hydrogen production, storage* https://www.pv-magazine.com/2022/07/19/the-hydrogen-stream-porous-silicon-material-for-hydrogen-production-storage/
[40] Hydrogen Insight (October 2022) *Shell has quietly closed down all its hydrogen filling stations in the UK* https://www.hydrogeninsight.com/transport/exclusive-shell-has-quietly-closed-down-all-its-hydrogen-filling-stations-in-the-uk/2-1-1335049
[41] CMB (June 2021) *CMB.TECH opens world's first multimodal hydrogen refuelling station and presents the hydrogen truck* https://cmb.tech/news/cmb-tech-opens-worlds-first-multimodal-hydrogen-refuelling-station-and-presents-the-hydrogen-truck

may be the optimum locations for the stations and storage facilities.

Refueling pumps, similar in appearance to gasoline/petrol pumps, is a business within itself. The German company Linde, which has built more than 15 hydrogen refueling stations (HRS) for buses worldwide, claims its IC 50/90-P compressor which can deliver 1,000 – 1,500 kg/day, "enables infrastructure costs of just €1 / kg of H2 dispensed based on a utilization level of 80% (excluding the cost of the gas)."[42] One technicality that currently slows the refueling process for buses is their fuel systems are limited to H35 which refers to the pressure at which hydrogen is dispenses, meaning 35MPa Megapascals (MPa) or approximately 5,000 psi, compared with electric passenger cars using H70 nozzles or 70 Megapascals (MPa) or approximately 10,000 psi. It is anticipated bus nozzles will be upgraded to H50 or H70.[43]

Hydrogen Refueling Station (HRS) economics are suggested in a short pictogram roadmap by Shell.[44] The provision of both light and heavy-duty fuel, the latter competing with diesel for buses and heavy commercial vehicles, becomes competitive with gasoline/petrol HRS only when the economies of scale drive down H2 total delivery costs to below $3.20 a gallon sold.



Extracted Cost Savings		
	LD Station	HD Station
Total Vehicles	>100,000	>10,000
KG H_2/vehicle	4-10	35-100
Delivered H2	Higher volume of daily use yields **production savings and distribution efficiencies**	
KG/day	400	2000-4000
Tech Deployed		Liquifaction and Onsite SMR ***decreases delivery cost***
HRS Equipment and Tax	At-scale production of heavy equipment and cost learning	
		Liquifaction or on-site SMR ***slightly increases cost***
Construction	Cost learning & equipment efficiencies	
		Out-of-city construction **saves costs**

On-site SMR (blue hydrogen) or on-site electrolysis (green hydrogen) *at scale* is the key on the demand side is met on the supply side by reduced costs of storage and compressors. "We estimated the potential cost reduction in hydrogen compression, storage and dispensing as a result of capital cost reduction to reach 5% or more when hydrogen refueling

[42] Linde Engineering (2022) *Powering sustainable mobility for generations to come* https://www.linde-engineering.com/en/plant-components/hydrogen-refueling-technologies/index.html
[43] Hydrogen Fuel Cell partnership (April 2020) *April 2020 Hydrogen Station Update Webinar - Questions & Answers* https://h2fcp.org/blog/april-2020-hydrogen-station-update-webinar-questions-answers
[44] Shell (December 2018) *Shell Hydrogen Refueling Station Cost Reduction Roadmap* https://cafcp.org/sites/default/files/path-toward-competitive-refueling-infrastructure-for-hydrogen-brochure.pdf

station systems are produced at scale."[45]

Distribution Technology Progression		
Tech	**Use Case**	**Technical Requirement**
Efficient On-Site SMR	- 5 tons daily Steam Methane Reformation on or near site - Extremely low distribution costs	- High volume of purchase at heavy-duty stations

Source: Shell (December 2018) *Shell Hydrogen Refueling Station Cost Reduction Roadmap* https://cafcp.org/sites/default/files/path-toward-competitive-refueling-infrastructure-for-hydrogen-brochure.pdf

HRS Certification is required in the USA to set up a HRS to ensure conformity to the two operational standards, SAE J2601 and CSA HGV 4.3. The former checks the entire vehicle tank filling process for temperature and pressure levels in the vehicle's compressed hydrogen storage system.[46] The latter standard establishes the test method of the hydrogen fueling station dispensing system as it relates to achieving the protocols specified in SAE J2601 and SAE J2799.[47] A HyStEP (Hydrogen Station Equipment Performance) Device[48] is used to test that these HRS standards are met. Additional health and safety standards may also apply. The cost of establishing an HRS, of which just over 50 exist in the USA, one source suggests at USD1-2 million compared with the cost of setting up a gasoline station, of which there are many thousands in the US, of around USD200,000.[49]

Pumping the hydrogen through the nozzle is the last of action required but prior to that if the hydrogen comes in liquid gas form from a cylinder it needs to be passed through a vaporizer to heat into a gas. The hydrogen gas then has to be compressed up to half-pressure H35 (most buses) or full-pressure H70 (passenger EVs). It then, or if the hydrogen is already a highly pressurized gas produced on location by SMR (blue) or by electrolysis (green), needs to pass through a heat exchanger to prevent overheating before passing through the pump. Finally, the vehicle's onboard computer will measure the temperature, tank pressure and fuel level measured in kilograms. The refueling time is no longer than with gasoline/petrol.[50] This is the crucial difference with battery-driven EVs. Private passenger vehicles can afford to be recharged overnight, but taxis and mini-buses and on-demand passenger vehicles cannot.

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[45] Mayyas (2019) *Manufacturing competitiveness analysis for hydrogen refueling stations* International Journal of Hydrogen Energy, V.44.18, pp. 9121-9142 https://www.sciencedirect.com/science/article/abs/pii/S0360319919307505?via%3Dihub

[46] SAE International (May 2022) *Fueling Protocols for Light Duty Gaseous Hydrogen Surface Vehicles J2601_202005* https://www.sae.org/standards/content/j2601_202005/

[47] HIS (2022) *ANSI/CSA HGV 4.3* https://global.ihs.com/doc_detail.cfm?document_name=ANSI%2FCSA%20HGV%204%2E3&item_s_key=00692741

[48] H2 *Hydrogen Tools* https://h2tools.org/hystep-hydrogen-station-equipment-performance-device

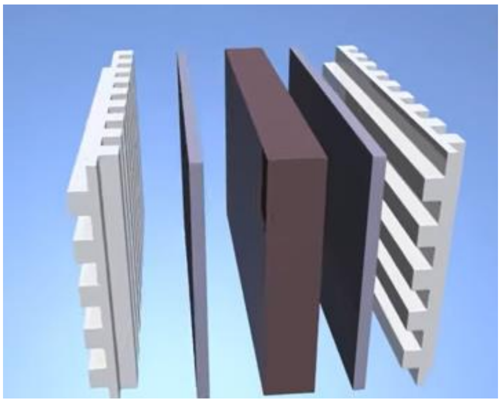
[49] Energy.Gov (2022) *Webinar: Overview of the Hydrogen Fueling Infrastructure Research and Station Technology (H2FIRST) Project* https://www.energy.gov/eere/fuelcells/webinar-overview-hydrogen-fueling-infrastructure-research-and-station-technology

[50] ROT (2022) *How A Hydrogen Filling Station Works* https://www.roadandtrack.com/car-culture/g6917/how-hydrogen-filling-stations-work/?slide=6

Hydrogen Fuel Cell in a Vehicle – How It Works

Pure hydrogen is fed into the anode (negative electrode) of the fuel cell and meets a proton exchange membrane (a PEM electrolyte) which is either a metallic membrane or a liquid like sulphuric acid. The PEM allows the protons to pass through and into the cathode (positive electrode) and mixes with oxygen, but not its electrons. The electrical motor helps the electrons by-pass the membrane into the cathode to join the oxygen which is about 20% of the mix and combine to create electric energy and $H_2 0$ or water – see YouTube video.[51] An added source of electrical power can be come from regenerative breaking, recycling the energy from the wheels created when breaking.

PEM and the fuel cell 'sandwich' of anode, electrolyte and cathode



Physical Properties of Hydrogen compared with Natural Gas[52]

Property	Hydrogen	Comparison
Density (gaseous)	0.089 kg/m³ (0°C, 1 bar)	1/10 of natural gas
Density (liquid)	70.79 kg/m³ (-253°C, 1 bar)	1/6 of natural gas
Boiling point	-252.76°C (1 bar)	90°C below LNG
Energy per unit of mass (LHV)	120.1 MJ/kg	3x that of gasoline
Energy density (ambient cond., LHV)	0.01 MJ/L	1/3 of natural gas
Specific energy (liquefied, LHV)	8.5 MJ/L	1/3 of LNG
Flame velocity	346 cm/s	8x methane
Ignition range	4–77% in air by volume	6x wider than methane
Autoignition temperature	585°C	220°C for gasoline
Ignition energy	0.02 MJ	1/10 of methane

Notes: cm/s = centimetre per second; kg/m³ = kilograms per cubic metre; LHV = lower heating value; MJ = megajoule; MJ/kg = megajoules per kilogram; MJ/L = megajoules per litre.

As the table shows, hydrogen has lower density than natural gas in either gaseous or liquid form, higher energy per unit mass, for example, the efficiency comparisons of a hydrogen fuel cell in a

[51] *How Do Hydrogen Fuel Cells Work?* https://www.youtube.com/watch?app=desktop&v=R6AdX-bdDaw
[52] IEA (2019) The Future of Hydrogen: Report prepared by the IEA for the G20, Japan https://www.iea.org/reports/the-future-of-hydrogen

vehicle are around 60% compared with 20% for an internal combustion engine.[53] However, the table also shows lower energy density which means more is required to produce the same energy output, and it is both more volatile and easier to ignite than methane, although the ignition energy is less. This means hydrogen storage requires extreme caution due to it being easily combustible although if it does ignite the spread of the flames is less than its methane equivalent.

In the value chain, after converting electricity to hydrogen, shipping it and storing it, then converting it back to electricity in a fuel cell, the delivered energy can be below 30% of the initial electricity input. Reducing the number of conversions lowers the losses. But as the IEA points out, if society places a high value on the reduction of carbon emissions, the economics can make sense.

Recycling Fuel Cells

The recycling of fuel cells uses pyrometallurgic methods, but they are polluting, generating fluorine and hydrogen fluoride emissions. New methods are being tried into "wet hydrogen fuel cell processing techniques" in addition to removing electrical components and minerals, such as platinum and ruthenium, before processing. [54] But currently "there is no tailor-made recycling process on an industrial scale for polymer electrolyte membrane fuel cells (PEMFC)… it is crucial to separate the polymer membrane before the melting process – but according to the researchers, there are no 'recycling processes that can be used efficiently on an industrial scale' for this purpose."[55] As fuel cells in use today are most likely to end their life on or before 2030, this represents an urgent ecological and technical challenge.

Hydrogen gas (H2)

Hydrogen gas (H2) is highly inflammable, its lean level of flammability being twice that of propane. Its simple chemical structure makes it easy to ignite, yet it is non-toxic, odourless, tasteless, and light thereby letting it penetrate more readily through protective materials, even iron and steel pipes and connectors. Although the dangers associated with fire and dispersal of fumes are less than with other fuels, the potential hazards place hydrogen among regulated chemicals. For example, its exposure to extreme temperatures and pressures needs to be avoided and closely monitored, and due to its lightness and lack of odour, sensors are needed to detect leakages, for example at production facilities and refilling stations. The materials used in hydrogen cylinders need to be especially well sealed.[56] For all these reasons, the use of hydrogen fuel cells in commercial and public vehicles and locations do and will require special sets of regulations to observe, rules to follow and staff training, and it will take jurisdictions, operators and users time to settle upon them. They will add costs to operators including the additional equipment costs, costs related to the design of the vehicles, their running costs, and the passenger payload which will fall as the space required to onboard the fuel cells is much greater than required by internal combustion engines and fuel tanks.

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[53] US Department of Energy Fuel Cells Fact Sheet https://www.google.com/search?client=firefox-b-d&q=hydrogen+fuel+cell+in+a+vehicle+are+around+60%25+compared+with+20%25+for+an+internal+combustion+engine

[54] FuelCellWorks (July 2022) *What's the future for fuel cell recycling?* https://fuelcellsworks.com/news/whats-the-future-of-fuel-cell-recycling/

[55] Electrive.com (April 2020) *BReCycle project to analyse fuel cell recycling* https://www.electrive.com/2020/04/07/brecycle-project-to-analyse-fuel-cell-recycling/

[56] NRDC (January 2021) *Hydrogen Safety: Let's Clear the Air* https://www.nrdc.org/experts/christian-tae/hydrogen-safety-lets-clear-air

Myriad of Relevant Regulations

Across the globe countries have generic regulations governing dangerous substances, licensing regimes to ensure adherence of health and safety regulations, national and local government regulations, environmental regulations and so on, none or few of which relate specifically to the production, storage, distribution and use of hydrogen as a fuel. Hydrogen falls under all of the above. But as hydrogen becomes part of national strategies to reduce Green House Gases (GHGs) and as sectors such as transport shift towards hydrogen as a fuel cell, consolidated and revised regulations will be required for the following reasons:

- Investment in hydrogen technologies requires some level of certainty or expectation of what the future rules will be
- New production methods may require rule revisions especially regarding emissions, grants and licences
- As new storage and distribution technologies emerge regulations governing both will need revision, especially with regard to health and safety and environmental concerns
- Hydrogen fuel cell usage will call for new vehicle designs including automated systems that will require regulations over their use, safeguards and maintenance to prevent unforeseen and avoidable ignitions
- Existing regulations are spread over so many agencies at local and national levels some degree of consolidation will be required to navigate the rules and keep the cost of compliance within bounds

Case Studies

United Kingdom

The trial of hydrogen buses in the UK goes back to the turn of the century. But by March 2022 in London there were still only 22 HPV buses out of a total fleet of nearly 9,000, of which 4,500 were electric or hybrids. London's target is all zero emissions by 2034 and all new buses to be zero emission from 2021 onwards. The first HPV double-decker was introduced in London in June 2021,[57] although Aberdeen in Scotland claimed to be the first in the UK.[58] Cities across the UK have been steadily introducing low-emission buses, mostly diesel-battery hybrids and BEVs, but also HPVs. The Birmingham City Council for example, in 2021 unveiled the first of its 20 new HPVs,[59] and in 2022 the Surrey County Council placed an order for 34 HPVs to an estimated cost of £16.4 million.[60] The largest fleet of HPVs in the UK was launched in the West Midlands[61] for 124 HPVs with the help of a

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[57] Wikipedia (2022) *Low emission buses in London* https://en.wikipedia.org/wiki/Low_emission_buses_in_London

[58] Intelligent Transport (October 2020) *Aberdeen becomes home to world's first hydrogen-powered double decked bus* https://www.intelligenttransport.com/transport-news/109315/aberdeen-becomes-home-to-worlds-first-hydrogen-powered-double-decked-bus/

[59] Sustainable Bus (July 2021) *First hydrogen bus landed in Birmingham (UK)* https://www.sustainable-bus.com/fuel-cell-bus/birmingham-fuel-cell-wrightbus/

[60] Surry (February 2022) *To request an Approval to Procure for 34 Hydrogen Fuel Cell buses* https://mycouncil.surreycc.gov.uk/documents/s84191/Metrobus%20HFC%20scheme%20Feb%202022%20Final.pdf

[61] West Midlands Combined Authority (March 2022) *West Midlands to launch UK's largest hydrogen bus fleet after securing £30m Government funding* https://www.wmca.org.uk/news/west-midlands-to-launch-uk-s-largest-hydrogen-bus-fleet-after-securing-30m-government-funding/

government grant of £30 million from the Zero-emission Bus Regional Areas (ZEBRA) fund.[62] The ZEBRA fund announced nearly £71 million to support 335 zero-emission buses in five cities and local authority areas in October 2021, and a further £198 million in March 2022 to support 942 zero emission buses in another twelve local authority areas.

Hydrogen was given importance in the Government's 2020 *Ten Point Plan for a Green Industrial Revolution*, in terms of its low-carbon (blue and green hydrogen) production aiming for 1GW by 2025 and 5GW by 2030 – this target has been subsequently raised to 10GW in the *Hydrogen Strategy* policy paper updated 2022[63] – and in terms of zero-emission motorised transport.[64] It heralded the publication of the ZEBRA scheme to fund local authorities zero-emission public transport (see above) and a *National Bus Strategy* which was published March 2021.[65] The Strategy only makes a passing reference on page 73 to HPVs but commits to "consider all technologies fairly" which sounds like a technology-neutral approach. The intervention of the COVID pandemic naturally slowed down progress.

Regulations[66]

One advantage the UK has is its extensive gas domestic pipelines serving over 80% of homes and nearby buildings, and while regulations limit hydrogen mixed with gas to 0.1% trials of up to 20% are taking place, holding out the prospect of piped hydrogen distributed to HRS. However, in many ways the danger the UK faces is to get too entrenched in grey or blue hydrogen at the cost of renewables which to attract the necessary private investment in, for example, wind and wave power, are being invited into a Contract for Difference (CfD) which involves Government paying the difference an opening price (the wholesale price of methane) and a closing price (the retail price achieved by the producer).[67] The 2022 updated Hydrogen Strategy paper (see above) foresees a fully developed market for hydrogen by 2030, but that will require regulatory certainty, yet it also forecasts green parity with blue not before 2050.

The UK does not have well-defined regulations covering hydrogen and according to the CMS report an initial network regulatory framework is not expected before 2025. The main regulations are:

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[62] Department of Transport (March 2021) *Zero Emission Bus Regional Areas (ZEBRA) scheme* https://www.gov.uk/government/publications/apply-for-zero-emission-bus-funding

[63] The paper includes a list of nine transport projects and subsidies including widening the scope of the Renewable Transport Fuel Obligation (RTFO) to include hydrogen energy sources from non-biological renewables and grid-transmitted energy, and the ending of the Hydrogen for Transport Programme which supported six new HRS and upgrades of five others; see Department for Business, Energy and Industrial Strategy (July 2022) *Hydrogen Strategy update to the market: July 2022* https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1092555/hydrogen-strategy-update-to-the-market-july-2022.pdf

[64] HM Government (November 2020) *The Ten Point Plan for a Green Industrial Revolution* https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/936567/10_POINT_PLAN_BOOKLET.pdf

[65] Department of Transport (March 2021) *Bus Back Better* https://www.gov.uk/government/publications/bus-back-better

[66] CMS (2022) *Hydrogen law, regulations & strategy in the United Kingdom* https://cms.law/en/int/expert-guides/cms-expert-guide-to-hydrogen/united-kingdom

[67] Investopedia (August 2021) *Contract for Differences (CFDs) Overview & Examples* https://www.investopedia.com/articles/stocks/09/trade-a-cfd.asp

- **Gas Act 1986** regulated by the **Gas and Electricity Markets Authority** through the **Office of Gas and Electricity Markets (Ofgem)** which issues licences to suppliers, shippers and transporters of gas with safety high on the list of requirements
- **Various industry codes of practice**
    - Uniform Network Code as each licence holder has their unique code
    - Independent Gas Transporter Uniform Network Code covering independent transporters, such as those providing extensions to housing estates
    - Supply Point Administration Agreements for multi-parties when there is a change of supplier
    - Retail Energy Code enabling consumers to switch supplies
- **Hydrogen Injection into Grid** is limited to 0.1% but could be raised to 20% after trails
- **Real Estate Consent** covering the land in use by pipelines, HRS, storage, etc., and repurposing
    - **Planning Act 2008** for major works ROW, etc.
    - **Town and Country Planning Act 1990** for local works ROW, etc.
- **Town and Country Planning (Environmental Impact Assessment) Regulations 2017**
- **Health and Safety Executive (HSE)** requires the following conformity
    - **Gas Safety (Management) Regulations 1996** concerning the flow of gas through a network
    - **Pipeline Safety Regulations 1996** concerns pipeline integrity
    - **The Planning (Hazardous Substances) Regulations 2015** and/or **Control of Major Accident Hazards Regulations 2015 (COMAH)** where COMAH sets a higher bar for larger quantities requiring safety strategies
    - **Hazardous Substances Regulations** requires consent for >2 tonnes and >5 tonnes
    - **Dangerous Substances and Explosive Atmosphere Regulation 2002** requires protective systems including where hydrogen is stored
- European **International Carriage of Dangerous Goods by Road (ADR)** prohibits hydrogen passing through ten tunnels in the UK
- **Pressure Equipment (Safety) Regulations** requiring tank designs to meet standards
- **UK Vehicle Certification Agency** for road safety testing and drivers must be fully trained to transport hazardous substances

As the running of HPVs, and the delivery, storage and dispensing of hydrogen into vehicle tanks becomes more widespread and more transport companies enter the market, a review of and a better and less diffuse codification of regulations will be necessary.

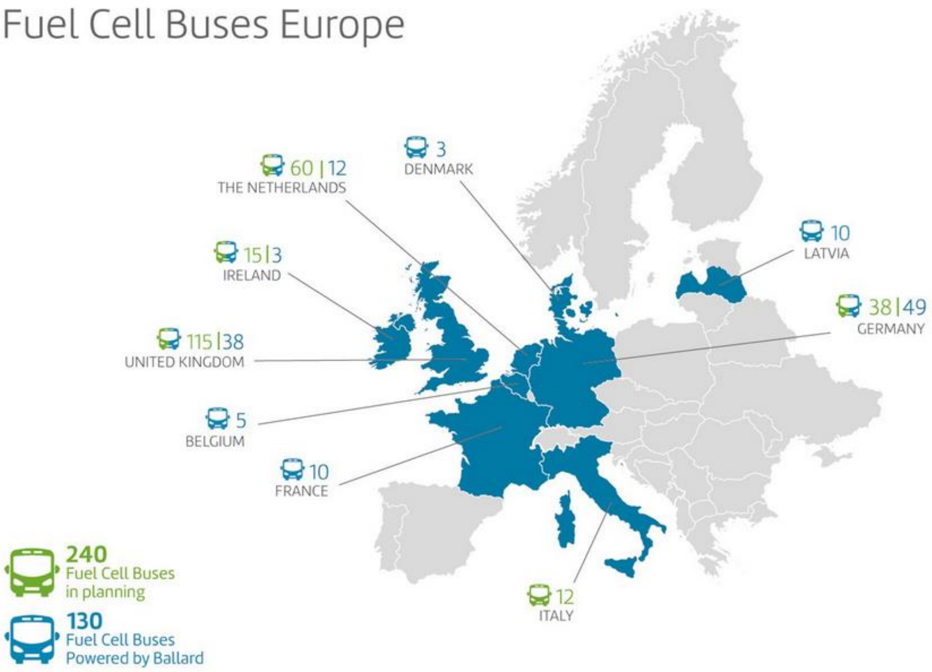
European Union

As of 2022, Russia's invasion of the Ukraine is hastening and driving the direction of EU policies towards gas supplies.[68] There seem to be three over-riding issues running through EU policy debates regarding hydrogen. First, within the wider goal of securing gas supplies, the EU wants to encourage green hydrogen production but without eating into net RE, a problem that hinges upon how the EU

[68] European Commission (2022) *Secure gas supplies* https://energy.ec.europa.eu/topics/energy-security/secure-gas-supplies_en

defines 'green hydrogen' for policy purposes,[69] as outlined in the REPower EU Plan.[70] The complex policy details were outlined in the EU's *Green Hydrogen Rulebook* but subsequently simplified in draft legislation in October 2022. [71] Second, the need regulate hydrogen separately from natural gas in terms of the safety, environmental and commercial aspects of production, storage, distribution and usage. Third, to develop a competitive market in hydrogen trading and empowering consumer choice. Member states have to adopt the proposals as each has its own set of laws and regulations, notably safety regulations governing all aspects the natural gas.[72]

HFC buses and other vehicles are starting to appear on the roads across Europe. The map below shows an estimate of HFC buses as of November 2021. Supporting HFCVs by December 2021 there were over 200 HRS and a further 100 under construction.[73] Germany also has the first hydrogen-powered trains,[74] including a specially-designed refuelling facilities.[75]



Source: https://blog.ballard.com/fuel-cell-buses-in-europe

[69] Nixon Peabody (June 2022) *The EU takes first steps toward defining green hydrogen* https://www.nixonpeabody.com/insights/articles/2022/06/01/the-eu-takes-first-steps-toward-defining-green-hydrogen
[70] European Commission (May 2022) *REPowerEU Plan* https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2022%3A230%3AFIN&qid=1653033742483
[71] Pinsent Masons (October 2022) *EU vote to ease green hydrogen production rules a welcome move for industry* https://www.pinsentmasons.com/out-law/news/eu-ease-green-hydrogen-production-rules
[72] ReedSmith (June 2022) *Hydrogen regulations by jurisdiction and changing transmission systems* https://www.reedsmith.com/en/perspectives/energy-transition/2022/06/hydrogen-regulations-by-jurisdiction-and-changing-transmission-systems
[73] eCity (December 2021) *Hydrogen refuelling stations in Europe* https://ecity.solarisbus.com/en/e-mobility/hydrogen-refuelling-stations-in-europe
[74] CNN (August 2022) *The world's first hydrogen-powered passenger trains are here* https://edition.cnn.com/travel/article/coradia-ilint-hydrogen-trains/index.html
[75] Siemens Mobility (2022) *The future of hydrogen technology starts today* https://www.mobility.siemens.com/global/en/portfolio/rail/rolling-stock/commuter-and-regional-trains/hybrid-drive-systems/mireo-plus-h.html

Hong Kong [76]

Hong Kong received its first tri-axle hydrogen powered double-decker bus – a Hydrogen Powered Vehicle or HPV – specifically designed and built for Hong Kong, in June 2022.[77] It was built in Foshan, China[78] with the fuel cells provided by Ballard, a Canadian company with growing investments the PRC's HFC business,[79] and received by Citybus from its new owner, Bravo Transport that became part of the Templewater private equity fund in 2020,[80] along with its operating partner, the Ascendal Group who run franchise bus operations in Australia, Singapore and London, including HPVs.[81] Hans Energy, which owns close to 16% of Bravo Transport, is constructing hydrogen refuelling station in West Kowloon to open 2023.[82] Hong Kong's other major bus operator, the Kowloon Motor Bus Company or KMB, is also to take delivery of ten air conditioned zero-emission buses in 2023 which are also specially designed tri-axle but are fully electric Enviro500EV, H2.0 buses supplied by Britain's Alexander Dennis Limited ("ADL"), a subsidiary of NFI Group Inc. ("NFI"), ADL's first electric double deck buses in the Asia-Pacific region.[83]

The widely held view in Hong Kong is that the future will be a mixture of BEV buses and HPV buses, the former for shorter routes, the latter for long routes. For example, ADL's suggests its H2.0 Zero fleet of hydrogen buses has a single refuelling range of 450-kilometer, although unlikely in Hong Kong's hilly terrain and humid conditions.[84] ADL's competitor, Wright claims over 400km for its single-decker HPV.[85] Bravo's estimation is 300km.[86] But currently H2.0 uses grey or blue hydrogen and Bravo anticipates by 2027 H2.0 using green hydrogen supplied by TownGas will be available. Until then, it is planned to start running the H2.0 bus in 2H 2023. However, Lawrence Cheung, the CEO of Automotive Platforms and Application Systems (APAS), established in 2006 by the Innovation and Technology Commission of HKSAR Government and hosted by the Hong Kong Productivity Council, suggests local electrolysis by TownGas to produce blue hydrogen using a mix of hydrogen and methane "which is already piped all over town" does not require HPVs to wait until green hydrogen is available.[87] Half a cake is better than none.

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[76] Lexology (August 2022) *Is Hong Kong's regulatory framework ready for hydrogen-powered vehicles?* https://www.lexology.com/library/detail.aspx?g=610230e0-4686-4281-ad3a-fa8861dbe875

[77] Templewater (June 2022) *Templewater is proud to announce the arrival of Hong Kong's first-ever hydrogen double-decker bus* https://www.templewater.com/news/templewater-is-proud-to-announce-the-arrival-of-hong-kongs-first-ever-hydrogen-double-decker-bus

[78] Ballard (2021)*Fuel Cell Zero-Emission Buses for Foshan and Yunfu*, China https://www.ballard.com/docs/default-source/motive-modules-documents/china-bus-case-study-website.pdf?sfvrsn=6451c280_6

[79] Electrive.com (October 2022) *Ballard to build fuel cell development facility in China* https://www.electrive.com/2022/10/04/ballard-to-build-fuel-cell-development-facility-in-china/

[80] Templewater (2022) *About Bravo Transport* https://www.templewater.com/investments/bravo-transport

[81] Templewater (2022) *Bravo Transport* https://www.templewater.com/investments/bravo-transport

[82] FuelCellsWorks (October 2022) *Citybus, New World Bus stake owner Hans Energy to Build Hong Kong's first Hydrogen Refuelling Station* https://fuelcellsworks.com/news/citybus-new-world-first-bus-stake-owner-hans-energy-to-build-hong-kongs-first-hydrogen-refuelling-station/

[83] AD (March 2022) *ADL continues Hong Kong innovation with 10 electric Enviro500EV for KMB* https://www.alexander-dennis.com/media/news/2022/march/adl-continues-hong-kong-innovation-with-10-electric-enviro500ev-for-kmb/

[84] Energy News (May 2022) *Arthur H2 Zero bus launched* https://energynews.biz/arthur-h2-zero-bus-launched/

[85] Wright (2021) *GB Kite Hydroliner FCEV* https://wrightbus.com/en-gb/gb-kite-hydroliner-fcev

[86] Adam Leishman, Mission ZERO, presentation to InvestHK 17-21 October 2022

[87] Transit Jam (April 2022) *This little-known Towngas ingredient could power Hong Kong's low-Emission bus fleet* https://transitjam.com/2022/04/19/this-little-known-towngas-ingredient-could-power-hong-kongs-low-emission-bus-fleet/

Regulation

But as elsewhere, Hong Kong laws are not yet ready for a widespread use of hydrogen in public transport vehicles, which has led to a hold up. Naturally, Bravo Transport chairman says Bravo "will continue to work with the relevant government departments closely to design legislation and guidance to obtain the necessary approvals for the bus's official public launch."[88] That is a process already started. On 6th February 2021 a government statement was issued as a Legislative Council (Legco) answer as follows, announcing the creation of an inter-departmental working group.

> As set out in the Hong Kong's Climate Action Plan 2050 announced in 2021, the Government would collaborate with franchised bus companies and other stakeholders within next three years to test out hydrogen fuel cell electric buses and heavy vehicles. The Government is liaising closely with different franchised bus companies and other operators to work out the details of the trial. In the past few months, we have also learned from various stakeholders about the issues that need to be considered and dealt with in the local application of hydrogen fuel cell EVs. The Environment Bureau will lead an inter-departmental working group to review various implementation issues, including the supply of hydrogen energy, necessary supporting facilities, safety considerations, training of technical personnel, regulation and legislation required, etc., to meet local requirements in an orderly manner.[89]

The current relevant laws are as follows:[90]

- **Dangerous Goods Ordinance** and its amendments classifying hydrogen gaseous and liquid forms as dangerous goods
- **Bridge and Tunnel** restrictions on the carriage of dangerous goods
- **Tsing Ma Control Area (General) Regulation** banning dangerous goods from being driven in any Hong Kong tunnels
- **Road Tunnels (Government) Regulations** banning dangerous goods from being driven in any Hong Kong tunnels
- **Criminal Procedure Ordinance** applies to offences under the above laws
- **Transport Department rules** banning dangerous goods over the Lantau Link lower deck area
- **Road Traffic (Parking) Regulations** forbids the carrying of dangerous goods and the Commissioner has the power to designate any indoor or outdoor area as a vehicle park. There are no exceptions to this regulation.
- **Road Traffic (Traffic Control) Regulations** prohibit the carriage of dangerous goods through 'prohibited zones'.
- **Gas Safety (Registration of Gas Companies) Regulations** which also defines Town gas as primarily a mix of hydrogen and methane.
- **Dangerous Goods (Consignment by Air)(Safety) Ordinance** which adopts the International Civil Aviation (Consignment by Air) dangerous goods code where hydrogen is a flammable gas.

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[88] Templewater (June 2022) *Templewater is proud to announce the arrival of Hong Kong's first-ever hydrogen double-decker bus* https://www.templewater.com/news/templewater-is-proud-to-announce-the-arrival-of-hong-kongs-first-ever-hydrogen-double-decker-bus

[89] Inland Revenue Department (February 2021) *Q&A in Legco* https://www.ird.gov.hk/eng/ppr/archives/22021601.htm

[90] Lexology (August 2022) *Is Hong Kong's regulatory framework ready for hydrogen-powered vehicles?* https://www.lexology.com/library/detail.aspx?g=610230e0-4686-4281-ad3a-fa8861dbe875

- **Dangerous Goods (Shipping) Regulation** regulates the movement, anchoring and berthing, and loading and unloading of ships, and the labelling, placard, packaging, documentation, including the ship's manifest for inspection, stowage and segregation requirements in the International Maritime Dangerous.
- **Fire Service Department** inspection of premises in compliance with fire safety requirements (section 94(1) Dangerous Goods (Control) Regulation).

Exemptions

- **Tsing Ma Control Area (General) Regulation** allows hydrogen if used as a vehicle propellant, but other parts of the regulations use the blanket term 'fuel', so this is currently open to interpretation by the authorities. For example, the Transport Department classifies LPG as a 'fuel'.
- **De minimis** – the Tsing Ma Control Area (General) Regulation permit vehicles 'carrying' less than 75 litres of hydrogen to pass through Hong Kong.
- **Prohibited zones** are often of a temporary nature and may include slipways leading to bridges, tunnels or highways.

That's a lot of laws and regulations, some of which apply to HPV buses directly, especially those relating to routes and hydrogen as a propellant, and some directly in terms of the supply of hydrogen. As TownGas is a domestic supplier the issue of imports, even from Mainland China, may not loom so large. The review of laws and regulations arising from the inter-departmental committee is being led by the Environment Bureau.

China

Despite the fact that China is the world's largest producer of hydrogen at over 30 million tonnes annually, most of this is grey, and despite China's enormous capacity to produce renewable energy, especially from hydro and solar, by 2021 according to China's energy regulator National Energy Administration (NEA), renewable energy accounted for under 30% of China's total energy consumption.[91] This compares with the world's top ten all above 40%, led by Norway at nearly 99%.[92] Until 2021 most hydrogen initiatives and regulatory guidelines were undertaken by local governments eager to bring in new business, and about "30 local governments mentioned hydrogen in their 14th Five-Year Plans and over 50 cities have issued policies to grow their local hydrogen industry. Nine provinces have so far issued major development plans for hydrogen and related industries."[93]

By 2025 the province of Inner Mongolia aims to produce 500,000 tons of green hydrogen a year, more than twice the national target announced in 2021. Until 2021 nationally China had no formalised strategy towards hydrogen production or fuel cells until the NDRC and the NEA published

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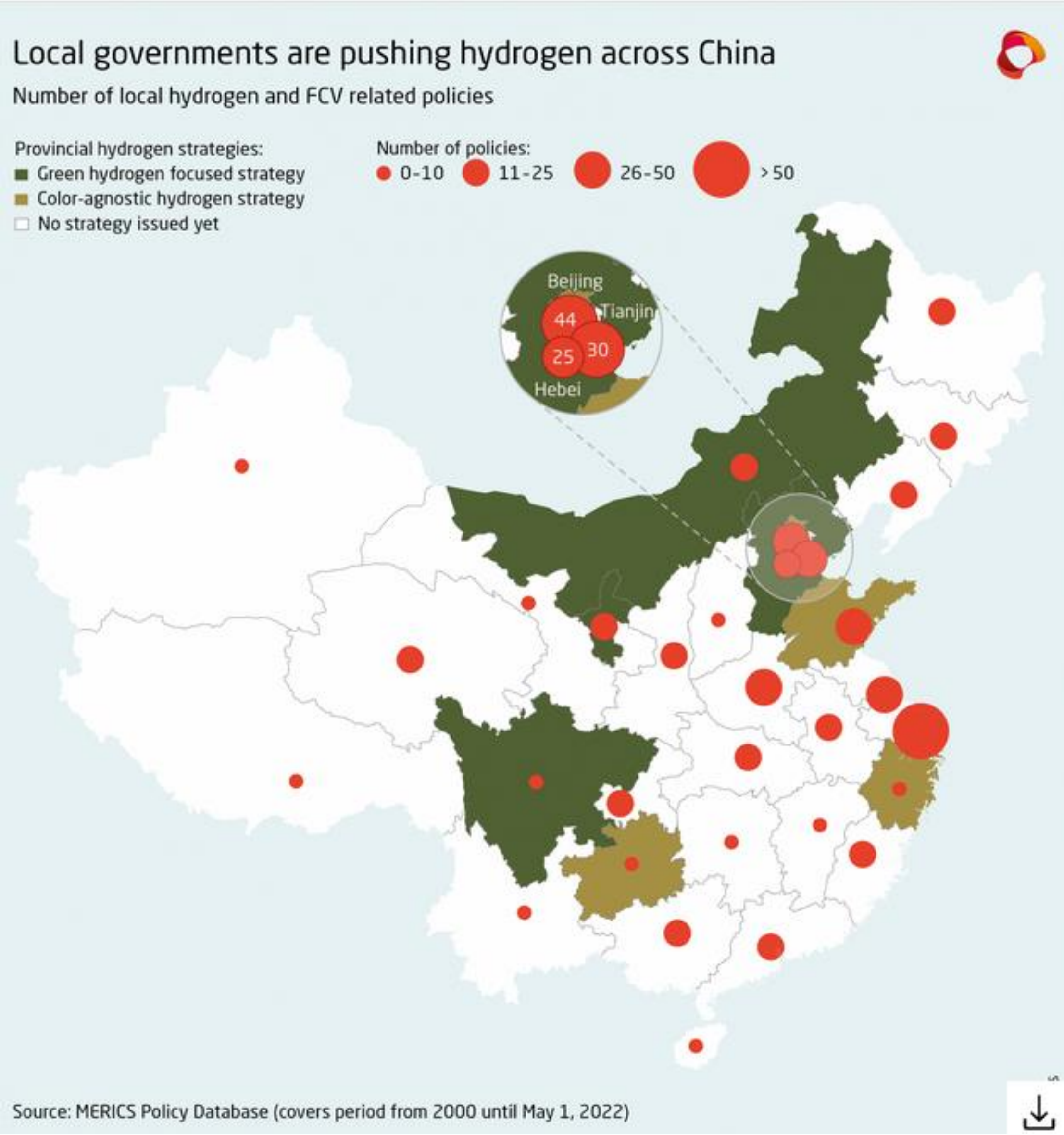
[91] S&P Global (September 2022) *China could exceed renewables generation target of 33% by 2025* https://www.spglobal.com/commodityinsights/en/market-insights/latest-news/energy-transition/092322-china-could-exceed-renewables-generation-target-of-33-by-2025

[92] Be the Story (December 2021) *The cleanest countries: leading the way to renewable energy* https://www.be-the-story.com/en/environment/the-cleanest-countries-leading-the-way-to-renewable-energy/

[93] Merics (June 2022) *China's nascent green hydrogen sector: How policy, research and business are forging a new industry* https://merics.org/en/report/chinas-nascent-green-hydrogen-sector-how-policy-research-and-business-are-forging-new

the *2021-2035 Plan on Hydrogen Energy Development,*[94] and the inclusion of the entire hydrogen value chain in the 2022 *Catalogue for Encourage Industries for Foreign Investment*.[95]



The value chain in China is in need of growth but also modernisation. For example, as Europe is using Gen IV tube trailers for hydrogen transport and storage which operate at a pressure of 70 Megapascals (MPa) or approximately 10,000 psi, China's fleet of tube trailers still operates Gen III at 35 Megapascals (MPa) or approximately 5,000 psi. The higher the pressure the faster the refuelling process for vehicles. Building pipelines for a hydrogen gas mix distribution is also needed as most of the production is in the Northwest and North and most of the demand is in the Southeast, and this will involve both regulatory, land use, environmental and financial complexities. China currently has

[94] Xinhua (March 2022) *China maps 2021-2035 plan on hydrogen energy development* https://en.ndrc.gov.cn/news/pressreleases/202203/t20220329_1321487.html

[95] China Briefing (may 2022) *China Releases Draft 2022 Encouraged Catalogue, Signals New Opportunities* https://www.china-briefing.com/news/china-proposes-to-expand-encouraged-industries-for-foreign-investment-the-draft-2022-catalogue/#chinastransitiontoagreenlowcarbonandcirculareconomyHeader

well over 200 hydrogen refuelling stations (HRS) across the country, approximately 40% of the global total according to Lexology (Baker McKenzie).[96]

Policy and Regulation

The Plan 2021-2035 envisages a dedicated regulatory framework for hydrogen by 2025, coincidentally the same date as for the UK, and possibly for the EU, by which time the Plan aims for between 100,000 and 200,000 tonnes of green hydrogen, described by Merics as conservative and "dwarfed by the EU's annual target of one million tons."[97] Merics adds that the strategy is general industry development first, green later. By 2022 China, according to Merics, had 120 renewable hydrogen projects under development, most of them small scale but some on a large commercial scale, mostly pursuing PEM rather than alkaline membranes as currently dominate China's H2 . R&D is a major focus of the Plan, including business models required to encourage the necessary investment in hydrogen production and its storage, such as pricing support, and the development of electricity trading markets. Merics points out that despite China's surge in technology patent registrations over recent years, and that nearly 40% of China's academic papers on green hydrogen appeared 2010-2020, OECD data shows hydrogen-related international patents (excluding HFCs) from China remains far below those from the EU, the US and Japan. China is playing catch-up.

Investments in electrolysis equipment is the sector China is most likely to become a world leader, but while there are no direct subsidies to hydrogen producers, there is systematic financial help from central government to municipalities that encourage the use of HFCVs, up to CNY 1.7 billion according to Merics,[98] but as Lexology points out most cities offer their own subsidies, often 1 for 1 so in any one case this could total CNY3.4 billion.[99] This has resulted in a massive expansion of HFCVs, up nearly 50% in 2021 alone, and in the deployment of HFC buses. "Of the 5,000 fuel cell buses in operation worldwide, around 3,300 have been in installed in China alone, ahead of Europe (around 1,300), and North America (less than 100)… Part of the drive comes ahead of China's pledge for a 'carbon neutral' Winter Olympics… "[100] Between them, Beijing and the co-hosting city of Zhangjiakou are using over 1,200 HFC buses and have built more than 30 hydrogen refuelling stations.[101] By 2030 it is proposed China builds 1,000 HRS serving 1 million HFC vehicles.[102]

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[96] Lexology (July 2022) *China: Recent developments in the Chinese hydrogen market - Policy and market trends* https://www.lexology.com/library/detail.aspx?g=5075084a-36cd-47ae-b0ae-c5c886895279

[97] Merics (June 2022) *China's nascent green hydrogen sector: How policy, research and business are forging a new industry* https://merics.org/en/report/chinas-nascent-green-hydrogen-sector-how-policy-research-and-business-are-forging-new

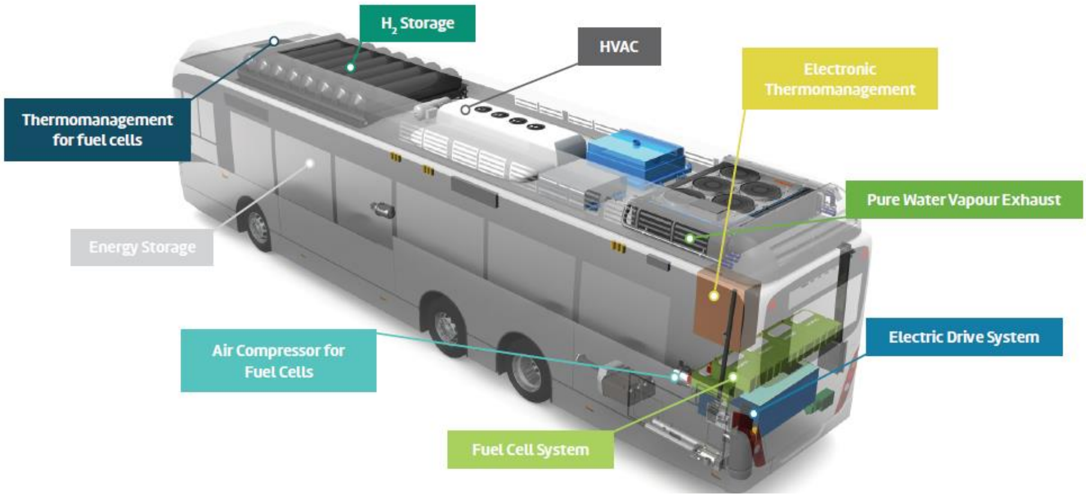
[98] Merics (June 2022) *China's nascent green hydrogen sector: How policy, research and business are forging a new industry* https://merics.org/en/report/chinas-nascent-green-hydrogen-sector-how-policy-research-and-business-are-forging-new

[99] Lexology (July 2022) *China: Recent developments in the Chinese hydrogen market - Policy and market trends* https://www.lexology.com/library/detail.aspx?g=5075084a-36cd-47ae-b0ae-c5c886895279

[100] Rethink Research (January 2022) *Buses and trucks accelerate as Chinese FCEV vehicles hit overdrive* https://rethinkresearch.biz/articles/buses-and-trucks-accelerate-as-chinese-fcev-vehicles-hit-overdrive/

[101] Sustainable Bus (February 2022) *More than 800 hydrogen buses at the Beijing Winter Olympics: a gold medal result* https://www.sustainable-bus.com/fuel-cell-bus/more-than-800-hydrogen-buses-at-the-beijing-winter-olympics/

[102]CMS (November 2021) *Hydrogen law, regulations & strategy in China* https://cms.law/en/int/expert-guides/cms-expert-guide-to-hydrogen/china



HFC Zero-Emission Buses by Ballard for Foshan and Yunfu, China

Regulations governing hydrogen in China are scattered across different laws and at different levels, national and local. 28 provinces has included pilot regulations in the *14th Five-Year Plan for National Economic and Social Development and the Outline Long Term Goals for 2035*,[103] and as pointed out by CMS, 2019 was the first-time hydrogen was explicitly mentioned in a State Council Government Work Report. CMS summarises as follows:[104]

> China currently has 12 national standards and 2 industry standards in the field of hydrogen energy safety; 4 national standards, 3 industry standards, and 1 local standard in the field of gas quality testing; 2 national standards and 3 industry standards in the field of gas purification; 33 national standards in the field of hydrogen storage containers; 19 national standards in the field of transportation; 8 national standards in the field of hydrogen refuelling stations; and 8 national standards in the field of fuel cell systems."[105]

Local regulations apply in most cases but the agency responsible varies across local jurisdictions. In the case of HRS, to open and operate they need Mobile Pressure Vessel/Cylinder Filling Permits from the Administration for Market Regulation in each city. The construction of HRS is governed by the General Office of the Ministry of Housing and Uran-Rural Development which released standards in 2021: Technical Specifications for Hydrogen Refuelling Stations and Technical Standards for Automobile Refuelling and Hydrogen Refuelling Stations which stipulate the design, construction and management of newly built HRS and the expansion of existing HRS.

The primary legislation remains a draft Energy Law issued in 2020 but hydrogen is only listed under new energy sources, and CMS expects licenses to be required. Hydrogen is classified as a hazardous

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[103] NDRC (2021) *14th Five-Year Plan for National Economic and Social Development and the Outline Long Term Goals for 2035* https://www.google.com/search?client=firefox-b-d&q=14th+Five-Year+Plan+for+National+Economic+and+Social+Development+and+the+Outline+Long+Term+Goals+for+2035
[104] CMS (November 2021) *Hydrogen law, regulations & strategy in China* https://cms.law/en/int/expert-guides/cms-expert-guide-to-hydrogen/china
[105] CMS (November 2021) *Hydrogen law, regulations & strategy in China* https://cms.law/en/int/expert-guides/cms-expert-guide-to-hydrogen/china

chemical under the *Catalogue of Hazardous Chemicals*. Under Regulations on the Safety Management of Hazardous Chemicals, business licences are issued under the Ministry of Emergency Management. A series of energy policy documents have been issued over the past two years, including one proposing closer cooperation with the EU.

Singapore

There are no regulations for hydrogen that currently go beyond those governing the production, transportation and use of dangerous substances.[106] As Singapore is relative flat, and the distances East-West and North-South are under 50km and a little over 30km respectively, it is ideal for battery-driven EV and buses and there is no urgency for hydrogen fuel cells for vehicles – see Singapore's Green Plan 2030, where the target is to achieve "green commutes" on 75% peak-period mass public transport, i.e. rail and bus.[107]

Most of Singapore's efforts are being focused upon building an infrastructure to support the use of green fuels, especially for recharging EVs. Following a consultancy report in 2021 that traces the possible pathways towards low-carbon hydrogen and CCUS "that could be relevant for Singapore, and the barriers to deployment that would need to be overcome",[108] the ministries involved issued a 'wait-and-see' joint statement:

- Hydrogen can serve as an energy carrier to store and transport renewable energy and has the potential to diversify Singapore's fuel mix towards low-carbon options for electricity generation and heavy transportation.
- Given Singapore's limited renewable energy resources, it is challenging for Singapore to produce green hydrogen at scale using only domestic green electricity.
- As such, Singapore would also need to explore various supply pathways for price-competitive low-carbon hydrogen (including importing hydrogen via shipping, piping from neighbouring countries etc.)

The CMS report references a consultancy by Royal Dutch Shell in 2021 on the feasibility of using hydrogen fuel cells for ships by retrofitting a ship with what is described as a "new frontier in alternative fuels for shipping." [109] The report also points out that Singapore did trial a small fleet of fuel cell buses in 2013 but subsequently favoured battery EVs, and adds that "Singapore does not currently possess the large-scale facilities for mass hydrogen production, nor the tough, high-pressure, insulated fuel tanks that are required for large scale hydrogen storage. Indeed, the Singapore government has indicated that it will be challenging for Singapore to rely solely on the

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[106] CMS (2022) *Hydrogen Law, Regulations & Strategy in Singapore* https://cms.law/en/int/expert-guides/cms-expert-guide-to-hydrogen/singapore
[107] Greenplan (2022) *A City of Green Possibilities* https://www.greenplan.gov.sg/
[108] NCCS (June 2021) *Singapore Looks to Develop and Deploy Low-Carbon Technological Solutions* https://www.nccs.gov.sg/media/press-release/singapore-looks-to-develop-and-deploy-lc-technological-solution
[109] Shell (2022) *Shell to trial first hydrogen fuel cell for ships In Singapore* https://www.shell.com.sg/media/2021-mfdia-releases/shell-to-trial-first-Hydrogen-fuel-cell-for-ships-in-singapore.html

development of such infrastructure and facilities locally, and therefore Singapore will also actively pursue options for the import of green hydrogen as an alternative." A testbed for green hydrogen production is taking place on Singapore's Semakau Island which had its own grid.

Regulations

Handing hydrogen falls under three main laws and subsidiary legislation:

- **Fire Safety Act** covering storage, import, transportation, dispensation and conveyance over pipelines – the regulator is the Commissioner of Civil Defence
- **Maritime and Port Authority of Singapore Act** imposing certain restrictions on the transport of compressed hydrogen and on the areas permitted for anchoring, mooring and discharging or loading – the regulator is the Maritime and Port Authority of Singapore
- **Workplace Safety and Health Act** which classifies hydrogen as a 'dangerous substance' and 'major hazard installation' – the regulator is the Commissioner of Workplace Safety and Health

Policy

To a question in Parliament in 2022, the Ministry of Transport replied "Hydrogen fuel cell vehicles may have a role in decarbonising vehicle segments that require higher power and mileage. However, hydrogen fuel cell technology and its broader ecosystem will need to mature in areas such as vehicle efficiency, cost, availability of vehicle models and supporting infrastructure." [110] It may be noted that ComfortDelGro, a major land transport company in Singapore that now operates a global fleet of vehicles in seven countries,[111] is gaining experience by investing in hydrogen fuel cell buses in both London and Australia.[112]

Philippines

There are currently no HFCV in the Philippines nor therefore any HRS, and very few studies,[113] but there is potential for the Philippines to produce green hydrogen and it lies primarily in being an archipelago with access to renewable energy sources ranging from wave-power to wind-power to hydropower – reservoir, pumped storage and run-of-river sources – to geothermal to solar plus biomass, yet in 2022 renewables only made up 21% of the country's energy mix, although following the *Renewable Energy Act, 2008* – for a background to the 2008 Act and its history, see did see Peñarroyo (2015) [114] – an increase of 40% in renewable energy according to the Department of

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[110] Ministry of Transport (July 2022) *Written Reply to Parliamentary Question on Lesson Learnt from Compressed Natural Gas Scheme for Vehicles and Plans to Use Hydrogen Fuel Cell Technology* https://www.mot.gov.sg/news/details/written-reply-to-parliamentary-question-on-lesson-learnt-from-compressed-natural-gas-scheme-for-vehicles-and-plans-to-use-hydrogen-fuel-cell-technology

[111] ComfortDelGro (2018) *ComfortDelGro is one of the largest land transport companies in the world* https://www.comfortdelgro.com/about-us

[112] Straits Times (March 2022) *ComfortDelGro expands hydrogen fuel cell bus trial to Australia* https://www.straitstimes.com/singapore/transport/comfortdelgro-expands-hydrogen-fuel-cell-bus-trial-to-australia

[113] Agaton et al. (April 2022) *Prospects and challenges for green hydrogen production and utilization in the Philippines* International Journal of Hydrogen Energy V.47.41, 12 May 2022, Pages 17859-17870 https://www.sciencedirect.com/science/article/pii/S0360319922016147

[114] Fernando S. Peñarroyo (2015) Renewable Energy Act of 2008: Hits and Misses for the Philippine Geothermal Industry Proceedings World Geothermal Congress 2015 Melbourne, Australia https://www.academia.edu/67448428/Renewable_Energy_Act_of_2008_Hits_and_Misses_for_the_Philippine_Geothermal_Industry#:~:text=The%20RE%20Act%2C%20signed%20on%2015%20December%202008%2C,the%20exploration%20and%20development%20of%20geothermal%20energy%20resources

Energy's *Philippine Energy Plan 2018-2040*,[115] updated from the 2018-2020 Plan.[116] One source suggests the commitment for RE is 35% by 2030.[117]

The Plan under renewables places considerable space to discussing R&D into biomass despite it adding the least to RE, and suggests that in 2020 "renewables added around 70.0 MW, almost all coming from solar." This rather highlights the need to diversify and develop the alternative sources of energy for green hydrogen, notably electrolysis and CCUS. The Plan does list a number of projects in this direction, and one of them was in an investment by Shell in 2019, in which "Air Liquide Philippines, Inc. will supply the hydrogen and operate the hydrogen manufacturing facility for Pilipinas Shell."[118] Much of the green hydrogen is destined for the grid, such as a joint venture to support development of Batangas Clean Energy's 1,100 MW power plant which will utilise green hydrogen as fuel.[119] The Plan discusses three options for hydrogen, two of which involve HFC for vehicles constituting up to 10% of hydrogen usage. Following a study,[120] the DoE entered into MOUs with Australia-based Star Scientific for use of their HERO (Hydrogen Energy Release Optimiser – see above) to explore green hydrogen production,[121] and similarly with the Tokyo-based Hydrogen Technology Inc (HTI) and an expression of interest from an Israeli company to produce hydrogen off-grid and as a back-up.

The DoE announced through the Plan the Renewable Energy (RE) and Energy Efficiency and Conservation (EEC) institutionalization programs, the moratorium on new coal power projects, a mechanism allowing foreign ownership on large-scale geothermal projects under financial and technical assistance agreement or FTAA, the resumption of indigenous oil and gas exploration, the introduction of liquefied natural gas (LNG) portfolio, establishment of strategic petroleum reserves and exploration of Hydrogen's potential.

Transport and Standards and Regulation

The Plan also calls for research into HFCVs to meet and create new Philippine National Standards (PNS) for the sector. Part of the public transport problem for future green hydrogen adoption lies in the sheer number and therefore in the relatively small size of companies running bus franchises. In 2012 an ADB report estimated there were "433 bus companies operating 805 routes. The majority of bus companies own more than 10 units, with only 7 bus companies owning 100 units or more.

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[115] Department of Energy (2018) *Philippine Energy Plan 2018-2040* https://policy.asiapacificenergy.org/node/4299

[116] Department of Energy (2020) *Philippine Energy Plan 2020-2040* https://www.doe.gov.ph/pep?withshield=1

[117] NOW.GMBH.DE (November 2021) *Online seminar: the German-Philippine Chamber of Commerce and Industry (GPCCI) present the results of its feasibility study* https://www.now-gmbh.de/en/news/events/green-hydrogen-in-the-philippines-current-state-and-future-potential/

[118] Shell (May 2020) *First Integrated Hydrogen Manufacturing Facility in the Philippines* https://pilipinas.shell.com.ph/sustainability/pilipinas-shell-annual-sustainability-report-2019/first-integrated-hydrogen-manufacturing-facility.html

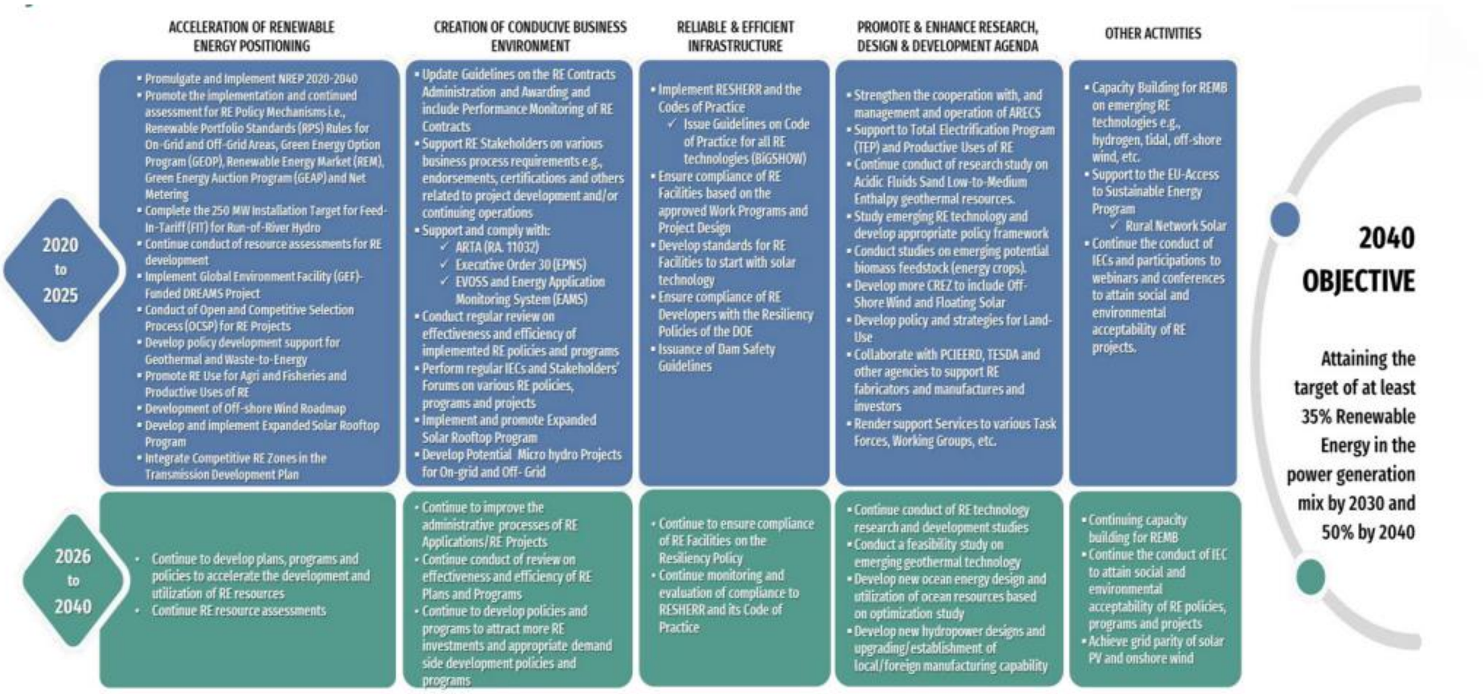
[119] View (January 2022) *Green hydrogen power plant project in the Philippines receives additional support* https://www.h2-view.com/story/green-hydrogen-power-plant-project-in-the-philippines-receives-additional-support/

[120] A Special Order179 "Directing the Creation of a Hydrogen and Fusion Energy Committee (HFEC) to Make a Study on Hydrogen and Fusion Energy including Infrastructure Development Methods and Strategies, Prepare a Framework on their Inclusion in the Energy Mix and for Other Purposes." Plan p.139

[121] DFAT (July 2021) *Reaching for the stars: Australian firm introducing green hydrogen technology to the Philippines* https://www.dfat.gov.au/about-us/publications/trade-investment/business-envoy/july-2021/reaching-stars-australian-firm-introducing-green-hydrogen-technology-philippines

Jeepneys serve 785 routes in Metro Manila, with many jeepney operators owning only one unit.”[122] Without substantial investment in infrastructure, in HRS and in HFC buses it will be difficult for the Philippines to make the transition.[123] The Plan has little focus on HFCVs and far more on BEVs.

The Renewable Energy Roadmap for the Philippines



Source: *Philippine Energy Plan 2020-2040*

The Plan does call for greater coordination of transport and energy standards: the DOE to engage “with concerned agencies such as the Department of Trade and Industry-Bureau of Products and Standards (DTI-BPS) in the implementation of Philippine National Standards (PNS) on fuels and facilities. Some of the PNS/DOE facilities standards include the Code of Safety Practices for liquid petroleum products (LPP) in retail outlets (PNS/DOE FS 10:2017), LPG refilling plants (DPNS/FS 2:2018), handbook on code of safety practices in LPG refilling plant, code of safety practices in LPP depots, and modules of instruction for LPG cylinder refillers.” Further the DoE is actively involved in focus groups and public consultations “in the implementation of the DOTr’s Public Utility Vehicle Modernization Program (PUVMP) on the use of advanced energy technologies in public transport, particularly HEV and EV technologies.”

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[122] ADB (2012) *Philippines: Transport Sector Assessment, Strategy, and Road Map* https://www.adb.org/sites/default/files/institutional-document/33700/files/philippines-transport-assessment.pdf

[123] An academic research report does suggest public support for cleaner public transport – see Guno et al. (March 2021) *Barriers and Drivers of Transition to Sustainable Public Transport in the Philippines* World Electronic Vehicle Journal https://www.mdpi.com/2032-6653/12/1/46/htm