Hydrogen and New Zealand's Heavy Vehicle Fleet

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MBIE REPRESENTATIVE AND VICE CHAIR - INTERNATIONAL ENERGY AGENCY HYDROGEN TECHNOLOGY PROGRAMME

Content

- International Perspective
- Hydrogen Production, Infrastructure and Costs
- Future Implications

ACKNOWLEDGEMENTS

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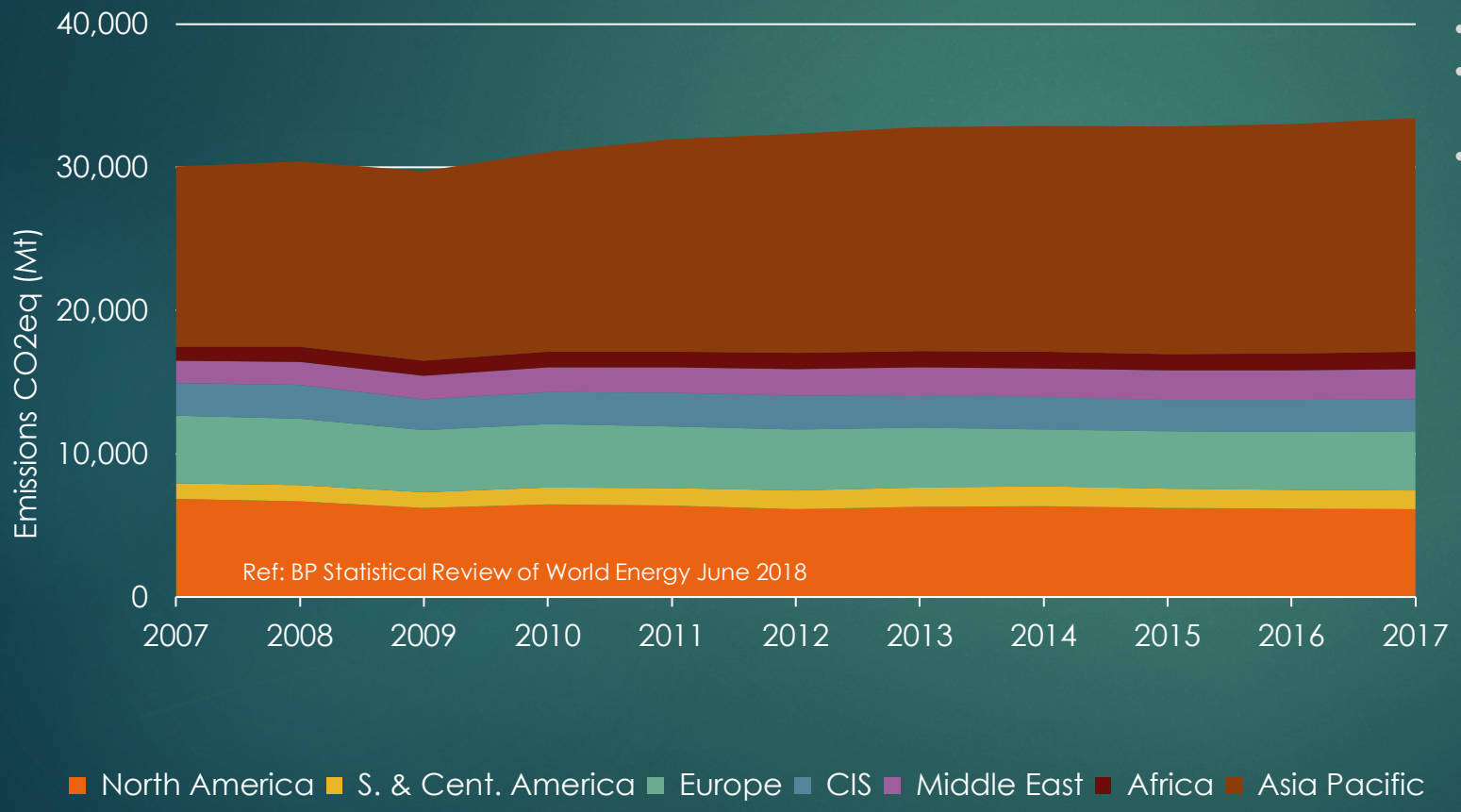
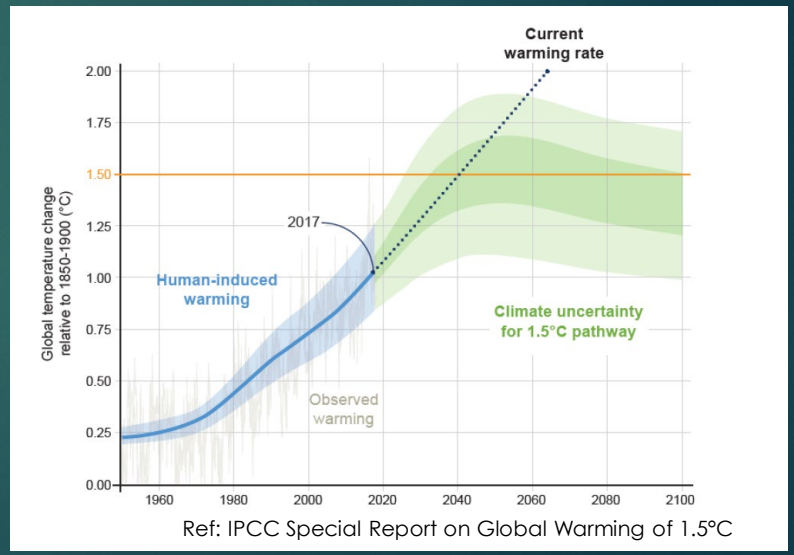
International Perspective

What's Driving Zero Emission Fuels – Greenhouse Gas Emissions



- New Zealand has 2050 target to reduce emissions to 50 per cent below 1990 levels (60% below current levels).
- Transport is 20% of total emissions
- Heavy vehicles are about 20% of transport emissions.
- Burning a litre of diesel emits about 2.7 kg of CO2eq.

https://www.transport.govt.nz/multi-modal/climatechange/



Ref: IPCC Special Report on Global Warming of 1.5°C

European Commission 2050 long-term strategy – 2018 will mean zero emission car and truck fleets by 2050.

Countries banning fossil fuels

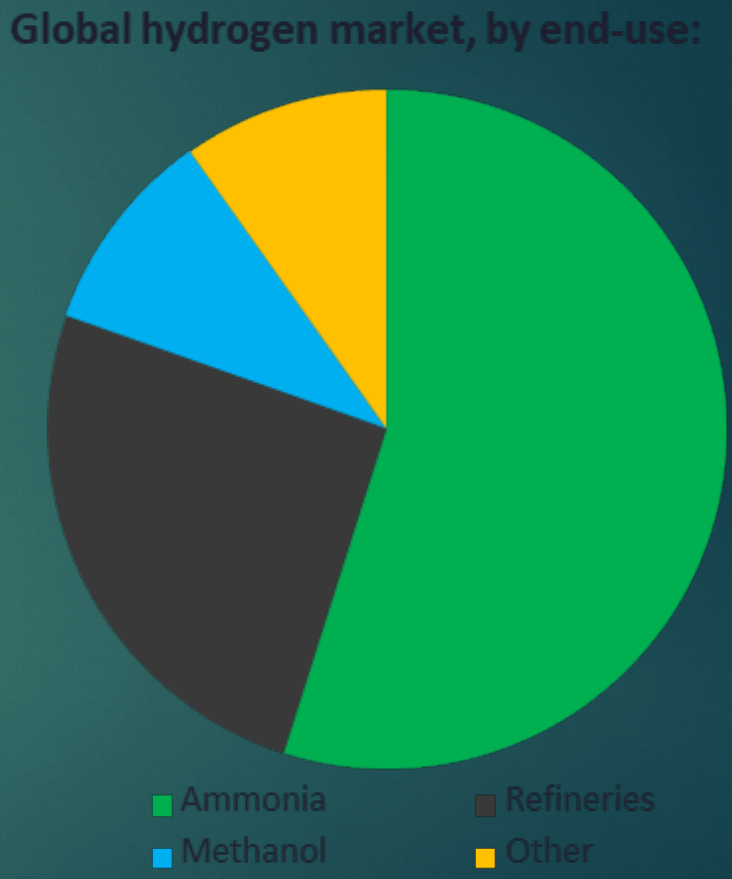
Country	Ban announced	Ban commences	Scope	Selectivity
China	2017	no date set[8]	Gasoline or diesel	New vehicle sales
Costa Rica	2018	2021[9]	Gasoline or diesel	All vehicles
Denmark	2019	2030[10]	Gasoline or diesel	New vehicle sales
France	2017	2040[11]	Gasoline or diesel	New vehicle sales
Iceland	2018	2030[12]	Gasoline or diesel	New vehicle sales, followed by incremental phase-out of existing ICE vehicle registrations.
India	2017	2030[13]	Gasoline or diesel	New vehicle sales
Ireland	2018	2030[14]	Gasoline or diesel	New vehicle sales
Israel	2018	2030[15]	Gasoline or diesel	Imported vehicles
Netherlands	2017	2030[16]	Gasoline or diesel	New vehicle sales
Norway	2017	2025[17]	Gasoline or diesel	New vehicle sales
Sri Lanka	2017	2040[20]	Gasoline or diesel	All vehicles
Sweden	2018	2030[21]	Gasoline or diesel	New vehicle sales
United Kingdom	2017	2040 – England, Wales, Northern Ireland[18] 2032 – Scotland[19]	Gasoline or diesel	New vehicle sales

- 13 countries, 21 cities
- Mostly light vehicles
- By 2030, heavy-duty vans, 75% of new long-distance buses, and 50% of new trucks must be zero emission vehicles..

Ref: https://en.wikipedia.org/wiki/Phase-out_of_fossil_fuel_vehicles

Current Hydrogen Market

- International Energy Agency estimates global hydrogen market is forecast to increase from US$122 billion in 2018 to US$155 billion in 2022.
- Current use of hydrogen is 55% ammonia synthesis, 25% in refineries, 10% for methanol production, and 10% other.



Adapted from IEA (2019) The Future of Hydrogen

Automotive executives perspectives of hydrogen

2017

78% of executives absolutely or partly agree that FCEVs will be the real breakthrough for electric mobility

2018

#1 Fuel Cell Electric Mobility is seen as the number one trend toward 2025

Automotive executives also project a split by 2040 for BEVs (26%), FCEVs (25%), ICEs (25%) and hybrids (24%)

Ref: Lokke, J.A., NEL Hydrogen, NEL 2019

Benefits of Hydrogen

- **Offers several benefits over diesel and natural gas**
  - Lower operating cost per km
  - Zero greenhouse gas emissions
  - No noise pollution
  - No idling
  - Substantial increase of torque
  - Domestic and secure energy source
  - Renewable fuel


https://www.jillcarnahan.com/2018/10/14/15-science-backed-benefits-of-molecular-hydrogen-you-need-to-know-about/

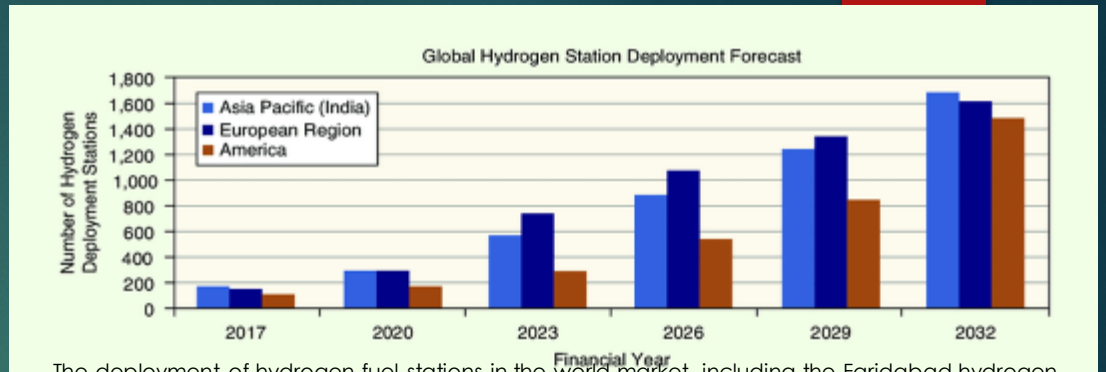
  - NB: A kilogram of hydrogen has about the same energy content as 3 litres of diesel.

- **OEMs are interested in this technology**

Adapted from Williamson, T. Benefits for Hydrogen for Trucks, H2@Scale End Use Applications: Fuel Cell Truck Powertrain R&D Activities and Target Review Workshop, July 30-31, 2018, Chicago, Illinois

H_2 Light Vehicles and Refuelling Stations

- Vehicles: 11,000 (53% USA, 38% Japan, 9% EU)(Mar 2019)
  - Hyundai Nexo, Toyota Mirai, Honda Clarity Cost: ~US$70,000 (excl. tax credit), 500 km – 750 km range
  - Mercedes-Benz GLC F-Cell for lease.
  - Audi and Kia vehicles in 2020 (March 2019)
- Refuelling stations: 369 (41% Europe, 37% Asia, 21% N. America)(Feb 2019)
- HFCV adoption is 8-10 years behind EVs



The deployment of hydrogen-fuel stations in the world market, including the Faridabad hydrogen-fueling station. (Data taken from the National Fuel-Cell Symposium 2016

Buses

- JIVE (Joint Initiative for hydrogen Vehicles across Europe) will deploy nearly 300 FC buses in 22 cities across Europe by 2023 costing US$720k each.
- 20 London double decker FC buses for 2020 at US$700k each
- Tokyo plans to deploy 100 hydrogen FC buses for 2020 Olympics

https://www.theguardian.com/uk-news/2019/may/10/london-to-have-world-first-hydrogen-powered-doubledecker-buses


https://www.fuelcellbuses.eu/wiki/fuel-cell-electric-buses-fuel-cell-electric-buses/about-fuel-cell-electric-buses

Trucks

- Arizona based Nikola has pre-orders for 8,000 hydrogen FC trucks with a range 750 – 1200 km. c.f. Nikola battery powered trucks with battery sizes of 500 - 1,000 kWh and ranges of 320 - 640 km but reduced by 25% in extreme conditions.
- Hyundai has entered an agreement to supply 1,000 hydrogen FC trucks to Switzerland from 2019 – 2024.
- This year Toyota and Paccar unveiled the first of 10 hydrogen FC trucks for use in the Los Angeles area.


https://www.telegraph.co.uk/cars/news/nikola-unveils-long-range-hydrogen-fuel-cell-lorry-designed/


https://www.ft.com/content/6eebd8da-bc7d-11e8-94b2-17176fbf93f5

https://nikolamotor.com/one


s://www.telegraph.co.uk/cars/news/hyundai-supply-1000-hydrogen-fuel-cell-lorries-switzerland/

Nikola Two – Fuel Cell Truck

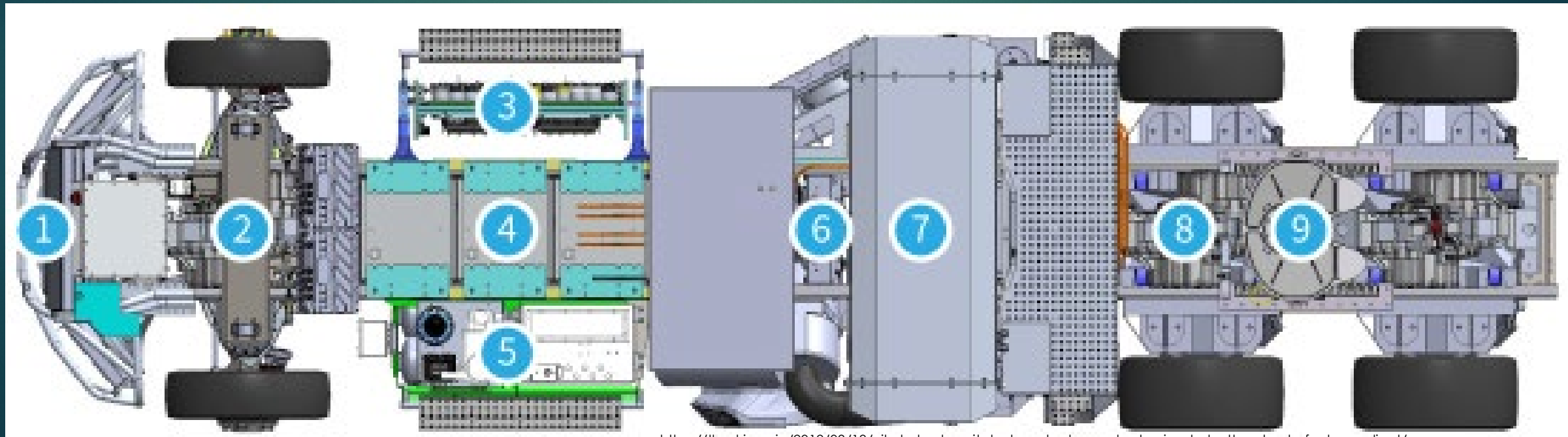
- 750 km – 1,200 km range
- 2000 ft.lbs torque
- 1,000 horsepower
- 125 – 250 kW battery
- 240 kW fuel cell

https://thedriven.io/2019/03/18/nikola-hedges-its-bets-on-hydrogen-by-turning-to-battery-trucks-for-beer-client/

Schneider, J. The Case for HD Fuel Cell and Large Scale Hydrogen Roll Out, Fuel Cell Truck Powertrain R&D Activities and Target Review Workshop, EERE, July 30–31, 2018, in Chicago.

Nikola Fuel Cell Truck

1. Radiators
2. Front motors and gearboxes
3. Power electronics
4. Battery
5. Chiller and air compressor
6. Fuel cell (PEM)
7. Liquid hydrogen fuel
8. Rear motors and gearboxes
9. Fifth wheel



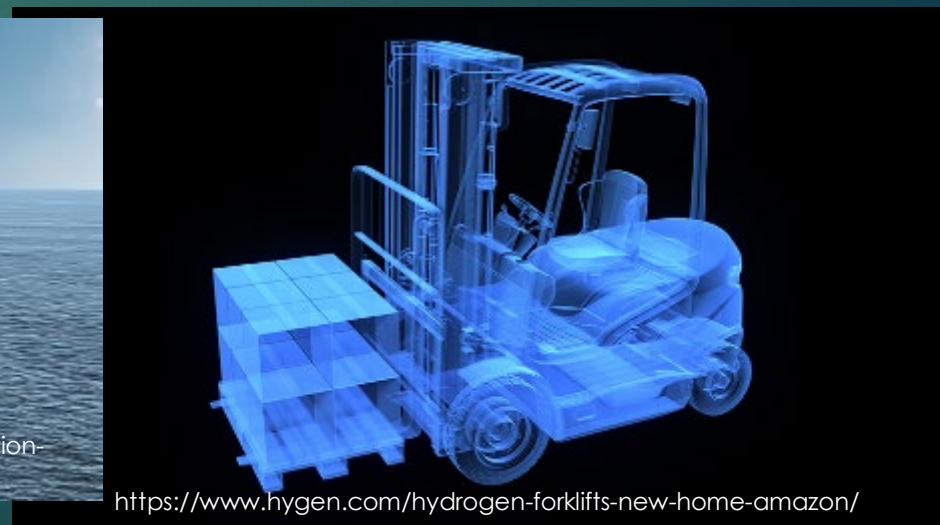
https://thedriven.io/2019/03/18/nikola-hedges-its-bets-on-hydrogen-by-turning-to-battery-trucks-for-beer-client/

Forklifts, Trains and Ferries

- Plug Power awarded two US$600-million contracts in 2017 (qz.com) for forklifts for warehouses at Amazon and Walmart on the basis that they:
  - dont require frequent replacements during operations.
  - operate in freezing temperatures.
- Alstom operates 2 hydrogen FC trains on 100 km line in Germany.
- First commercial H_2 powered 20m catamaran is currently under testing in San Francisco funded by California Climate Investments program

https://www.theguardian.com/environment/2018/sep/17/germany-launches-worlds-first-hydrogen-powered-train

https://www.maritime-executive.com/article/construction-begins-for-first-commercial-hydrogen-powered-ferry



https://www.hygen.com/hydrogen-forklifts-new-home-amazon/

Emerging technologies - Catenary Diesel Hybrid Truck

Siemens, Volvo, Scania, diesel hybrid experimental vehicle

Ref: https://qz.com/714381/siemens-says-it-can-power-unlimited-range-electric-trucks-using-a-150-year-old-technology/

Hydrogen production, infrastructure and costs

How is Zero Emission Hydrogen Produced

1. Steam methane reforming of natural gas with capture and storage (usually underground) of CO_2 (sequestration).

   $CH_4 + H_2O \rightarrow CO + CO_2 + 3H_2$ --- then $CO + H_2O \rightarrow CO_2 + H_2$

2. Electrolysis of water.

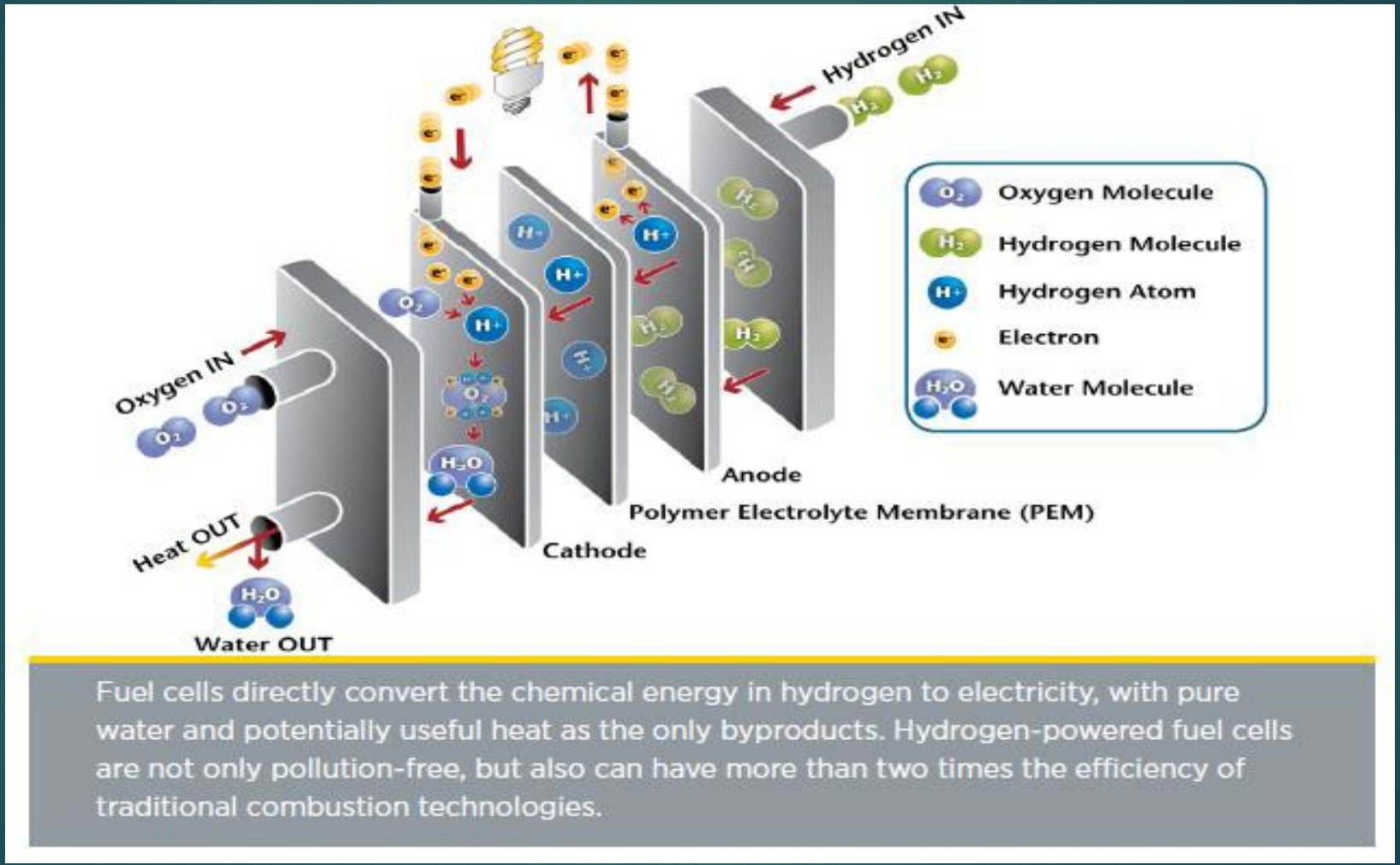
   Production of 1 kg of hydrogen requires 9 litres of water, and about 50 kWh of electricity and produces 8 kg of oxygen. $2\,H_2O \rightarrow 2\,H_2 + O_2$

3. Biomass gasification (e.g. H_2 from cellulose)

   $C_6H_{12}O_6 + O_2 + H_2O \rightarrow CO + CO_2 + H_2$ + residuals --- then $CO + H_2O \rightarrow CO_2 + H_2$

   or fermentation (e.g. H_2 from glucose) $C_6H_{12}O_6 + 2H_2O \rightarrow 2\,CH_3COOH + 2CO_2 + 4H_2$

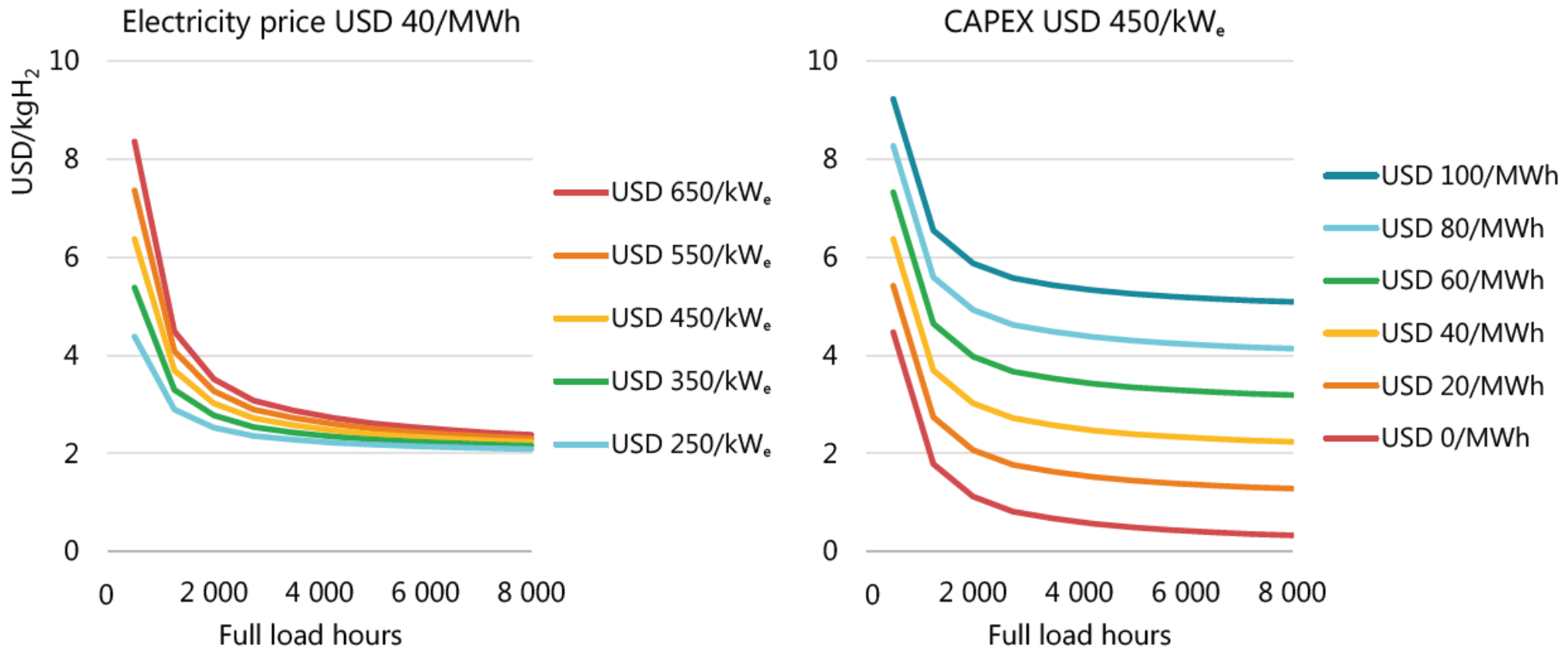
What is a Hydrogen Fuel Cell



US Department of Energy Fuel Cell Technologies Office, Fuel Cell, http:// www.hydrogenandfuelcells.energy.gov.

Production Cost of Hydrogen from Water

Electrolyser capex may be less than 25% of H_2 production cost for high utilisation

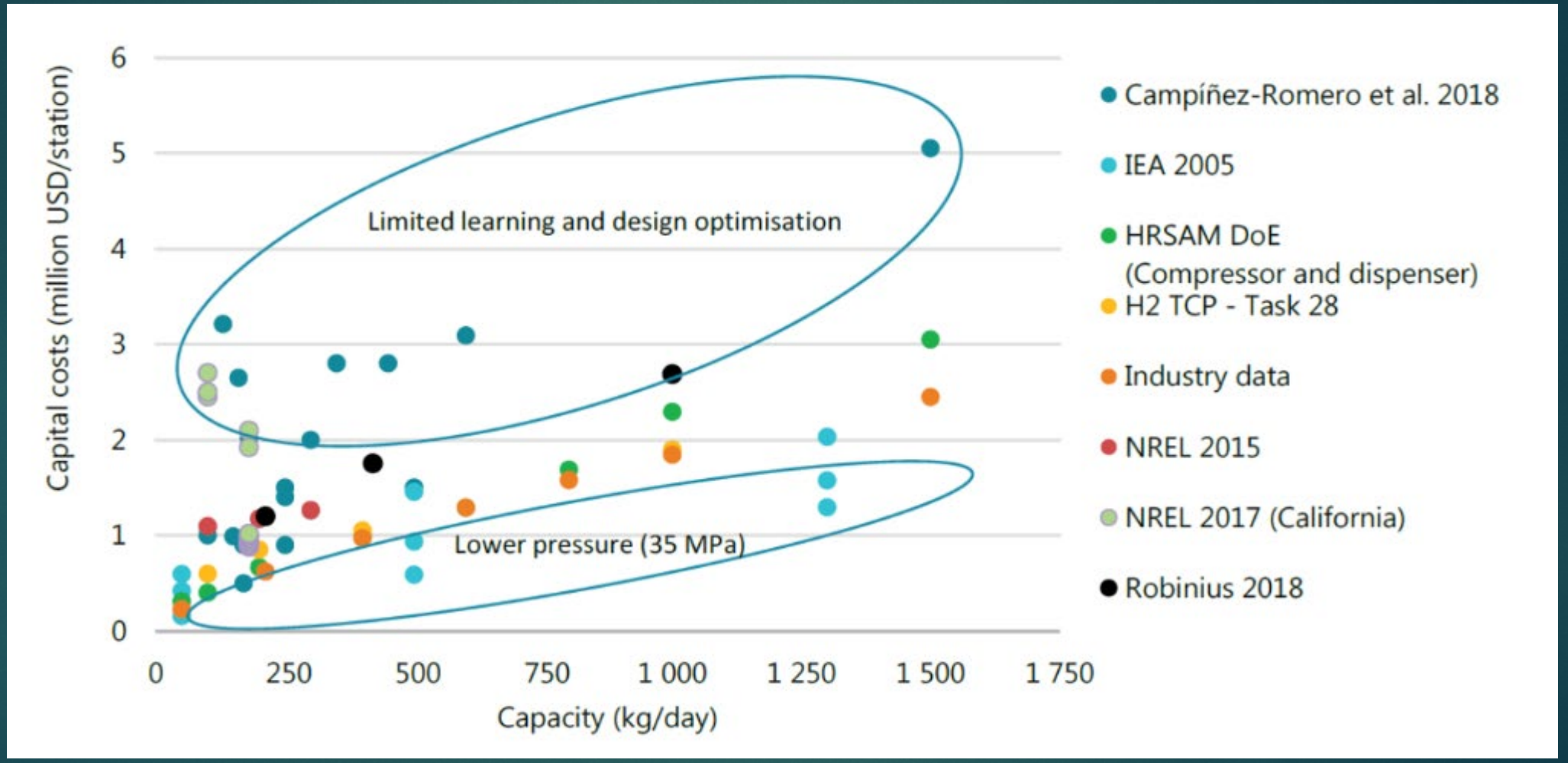


Notes: MWh = megawatt hour. Based on an electrolyser efficiency of 69% (LHV) and a discount rate of 8%.

Note NEL electrolysers operate at 80% efficiency NEL Electrolysers https://nelhydrogen.com/products/

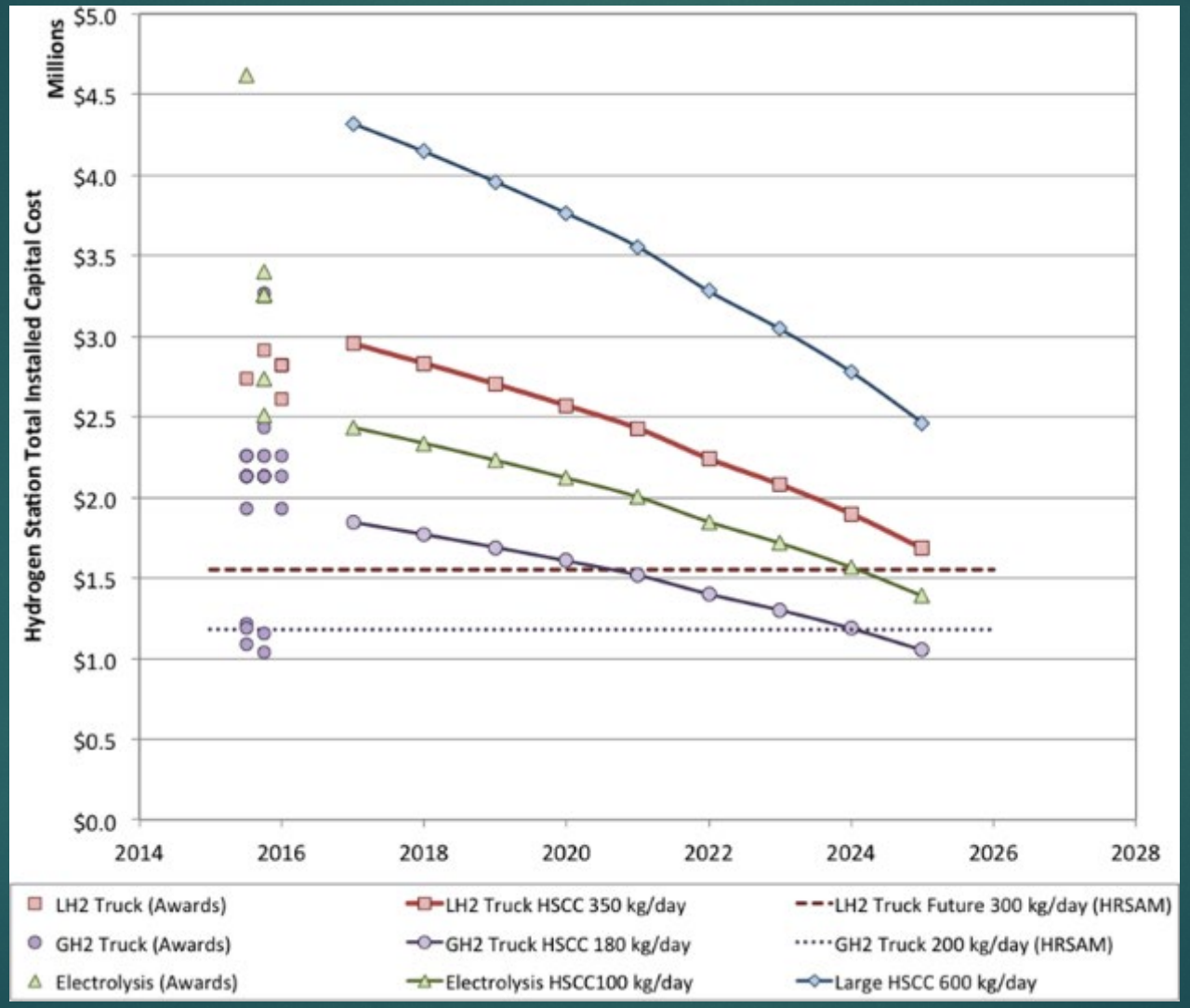
Ref: IEA. The Future of Hydrogen, 2019.

H2 refuelling station capital costs



Adapted from IEA (2019) The Future of Hydrogen

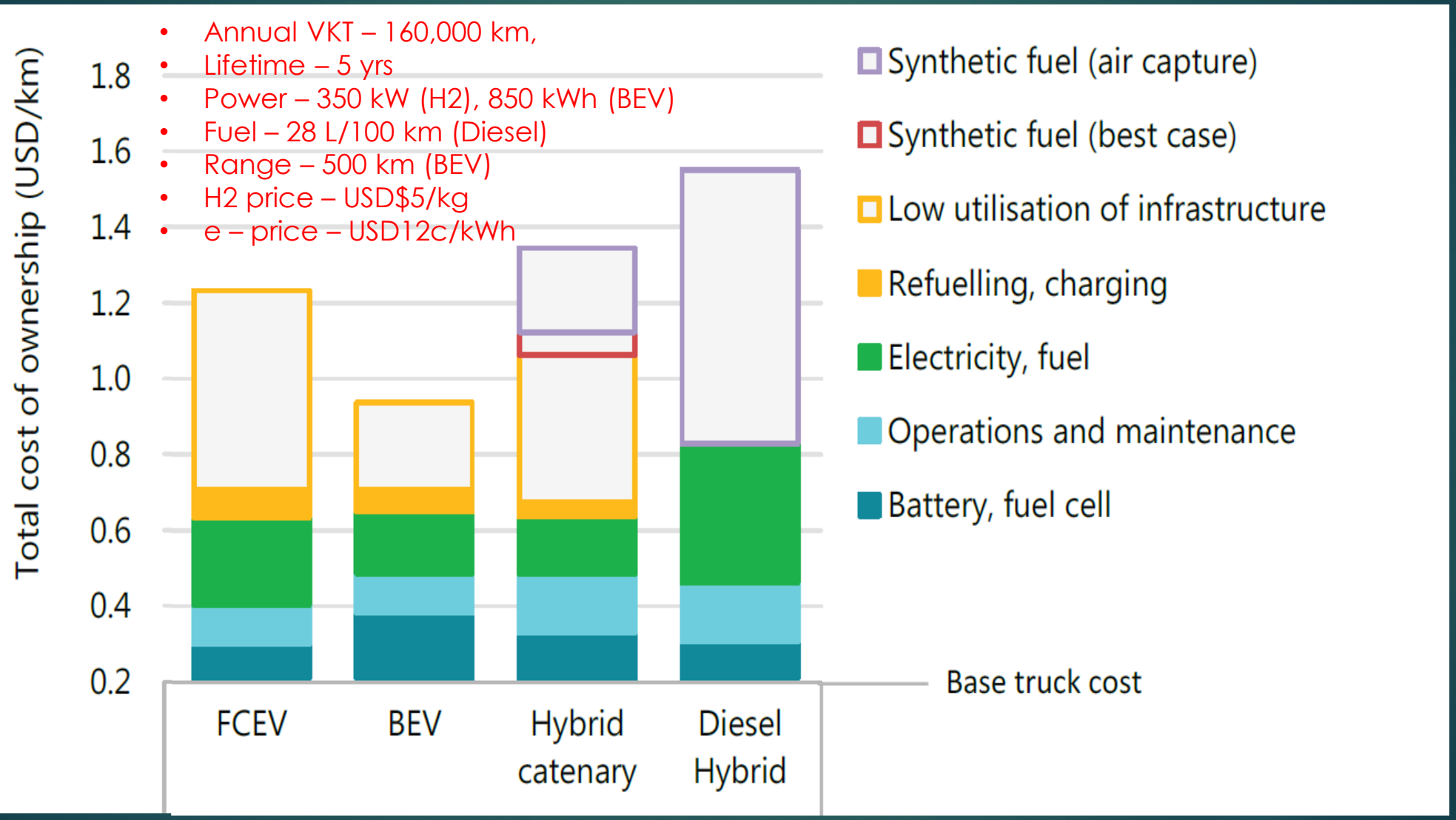
Learning Curves for Station Costs



Ref: California Air Resources Board. Assessment of Time and Cost Needed to Attain 100 Hydrogen Refueling Stations in California, 2015.

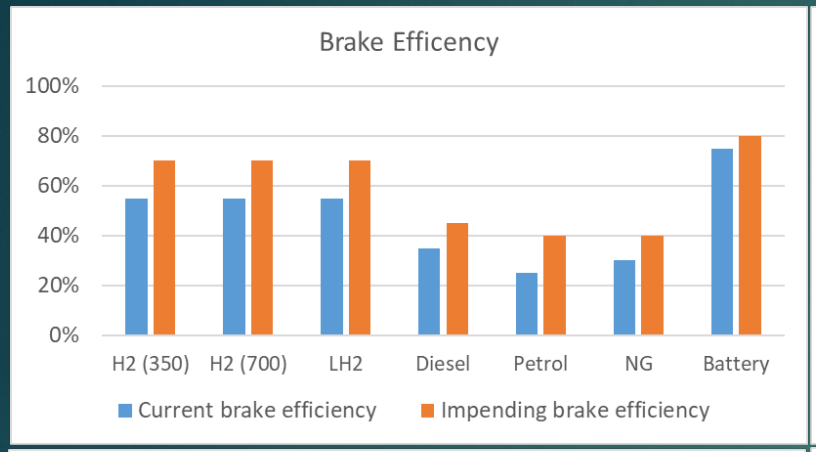
Near Future Heavy Vehicle Cost of Ownership

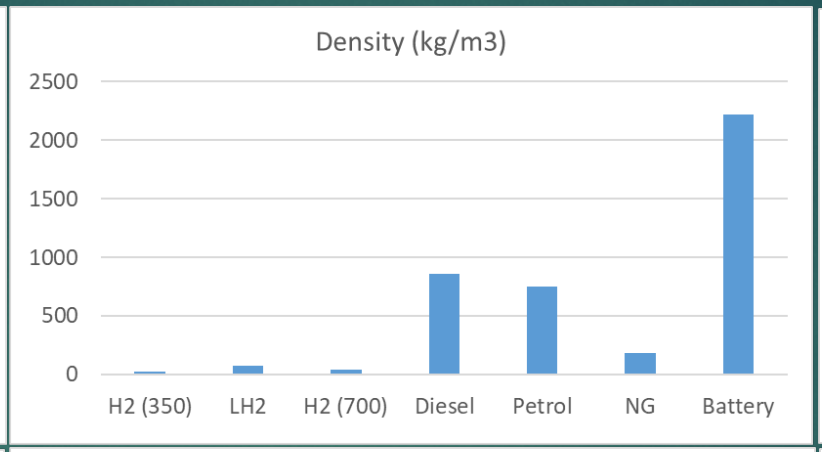
- Annual VKT – 160,000 km,
- Lifetime – 5 yrs
- Power – 350 kW (H2), 850 kWh (BEV)
- Fuel – 28 L/100 km (Diesel)
- Range – 500 km (BEV)
- H2 price – USD$5/kg
- e – price – USD12c/kWh

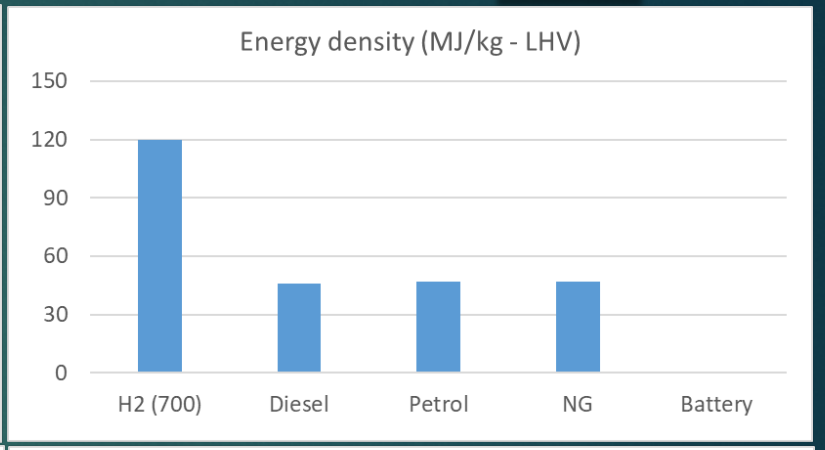


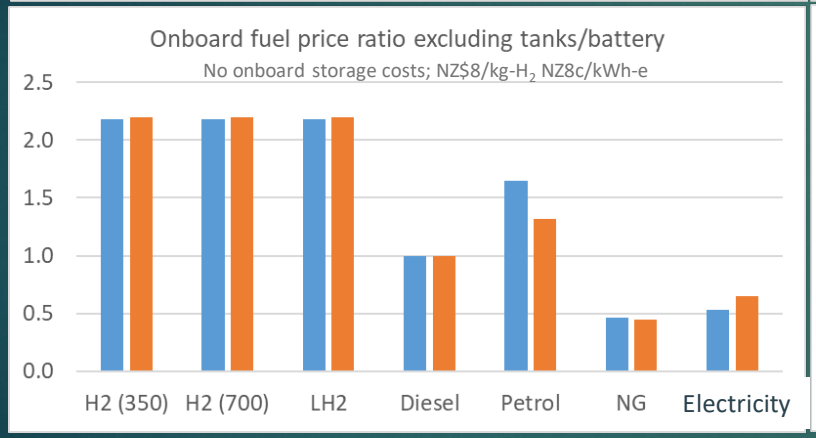
Adapted from IEA (2019) The Future of Hydrogen

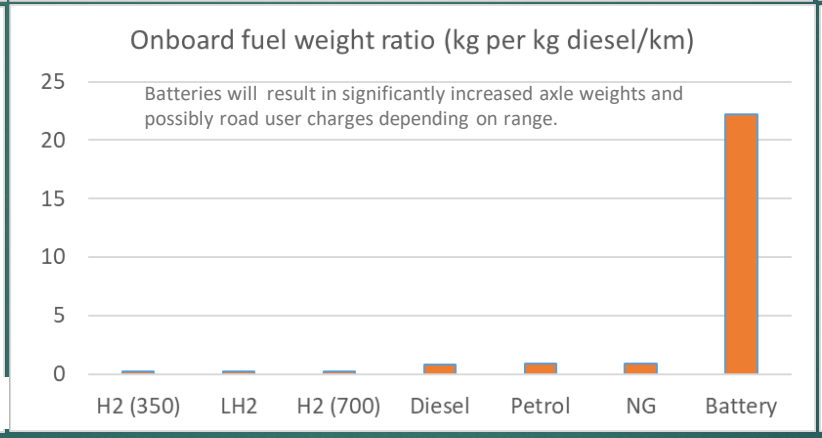
Fuels comparison with diesel

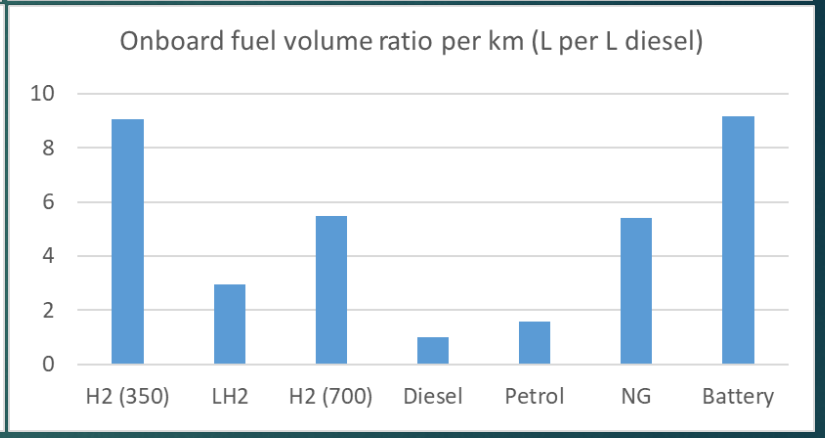










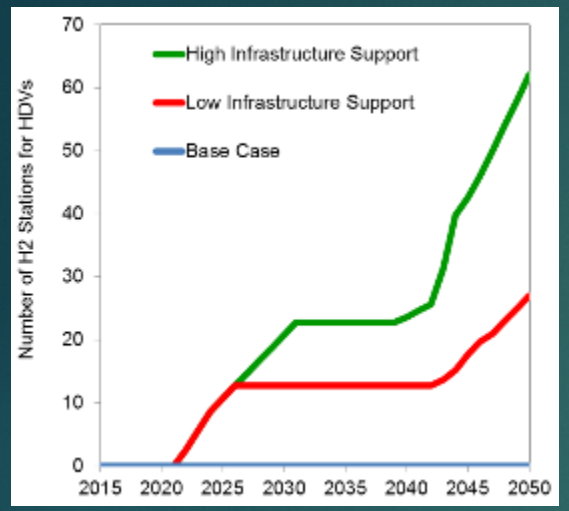


Data adapted from:

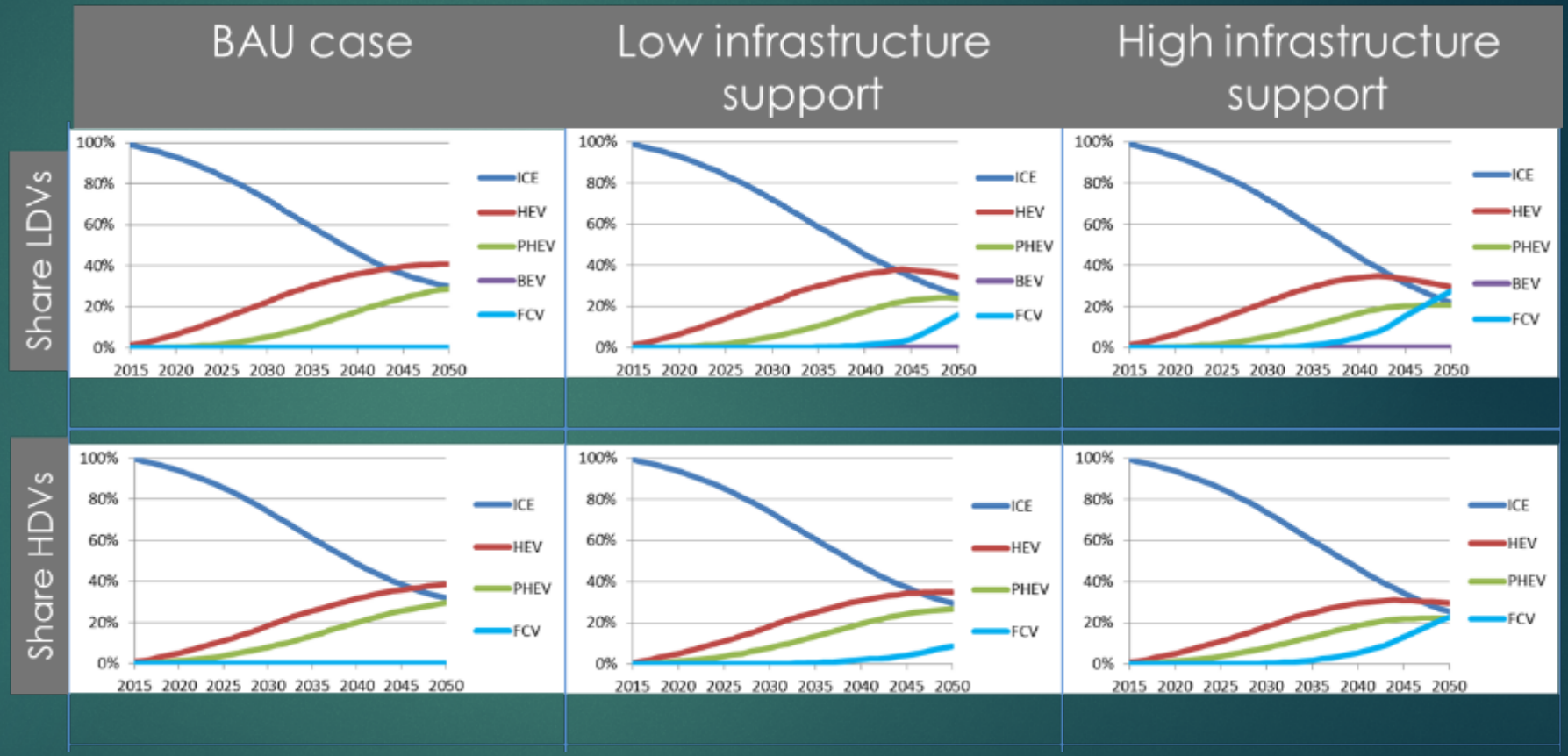
- https://matter2energy.wordpress.com/2013/02/22/wells-to-wheels-electric-car-efficiency/ (5% charging losses)
- US Department of Energy Fuel Cell Technologies Office, Fuel Cell, https://www.energy.gov/eere/fuelcells/fuel-cell-technologies-office
- Engine researchers: 50% gasoline-engine efficiency in sight https://www.sae.org/news/2019/04/high-efficiency-ic-engines-symposium-2019-delphi-gdci-engine
- Heavy-Duty Vehicle Diesel Engine Efficiency Evaluation and Energy Audit Oct 14 Final Report, Center for Alternative Fuels, Engines & Emissions, West Virginia University
- Using Natural Gas for Vehicles: Comparing Three Technologies – NREL https://www.nrel.gov/docs/fy16osti/64267.pdf
- https://evannex.com/blogs/news/tesla-s-battery-pack-is-both-mysterious-and-alluring-work-in-progress
- https://www.theverge.com/2019/4/4/18293989/innolith-ev-battery-breakthrough-lithium-ion

Future Implications

Evolution of Vehicle Fleets and Fuel Demand



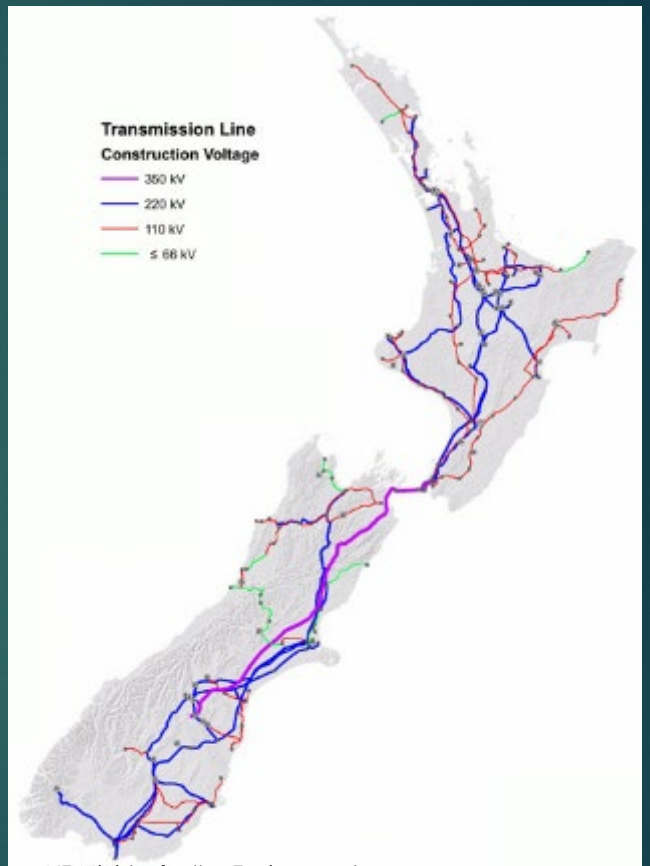
- Assumptions:
- Significant improvements are assumed in the fuel economy of new fleets over the study period.
- Future vehicle prices converge to the conventional ICE vehicle price by 2040.
- An annual growth rate of 2% is applied to the initial oil price of US$50 per barrel to reach US$100 per barrel in 2050.
- The carbon tax is increased from US$17.5 in 2015 to US$70 per tonne CO_2eq. in 2050.



Ref: Leaver, J. D., Shafiei, E., & Davdisdottir, B. (2016). Simulating the Impact of Infrastructure Support on the Market Penetration of Hydrogen Vehicles in New Zealand. World Hydrogen Energy Conference, Zaragoza, Spain.

Electricity requirement to replace diesel with hydrogen in the heavy fleet

- In 2016 heavy vehicles consumed about 59 PJ fuel[1]
- Assuming an electrolyser efficiency 80%[2] a ~31% increase in national electrical energy generation is required if hydrogen vehicles were to replace new diesels.
- This does not mean a 31% increase in generating capacity as not all generation assets operate at full capacity.



NZ Ministry for the Environment
https://www.mfe.govt.nz/publications/

Refs:
1. McGlinchy, I., MoT (2016), The New Zealand vehicle fleet: fact and fiction
2. NEL Electrolysers https://nelhydrogen.com/products/
3. MBIE Data tables for electricity.
4. https://www.drivingtests.co.nz/resources/fuel-co2-calculator-carbon-dioxide-emissions-in-kg/

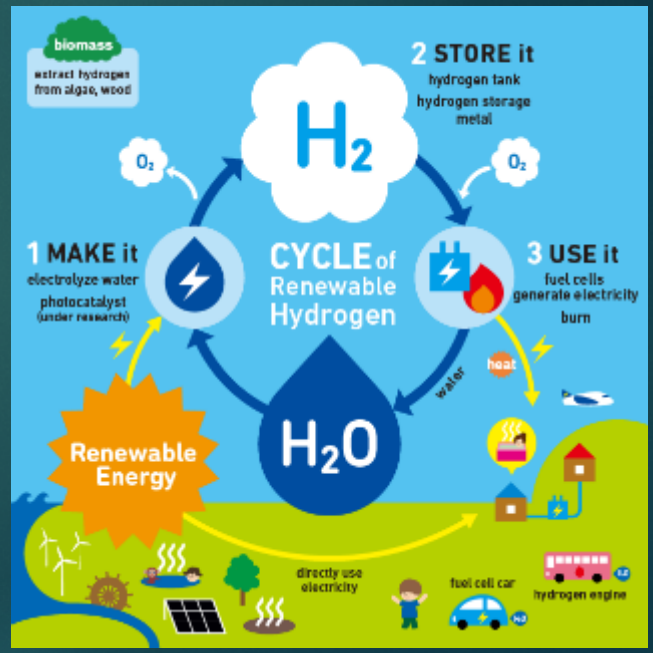
Drivers and brakes for uptake of hydrogen fuel

Drivers

- Political will/public opinion for zero emissions by 2050
- Establishment of hydrogen hubs to maximise use of capital e.g. ammonia production, industrial heat, green methane, synfuels, hydrogen storage for grid support, export
- Initial funding support (local/central govt.) for hydrogen refuelling stations

Brakes

- Improvements in efficiency of fossil fuelled engines
- Low oil and carbon prices
- Export competitors especially Australia
- Improved battery performance and recharging infrastructure
- Existing short term ROI's (3-5 years???)



Renewable Hydrogen Network (RH2 Network)

Thank you