

HYDROGEN PRODUCTION FROM ELECTROLYSIS: ITS POTENTIAL AND COSTS

Decarbonising Trucks, Trains, Boats and Planes
REA

3 December 2019

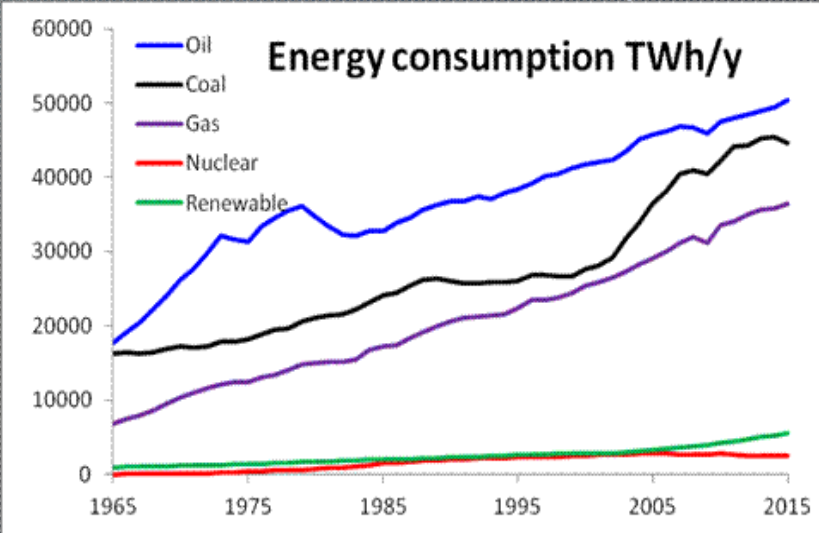
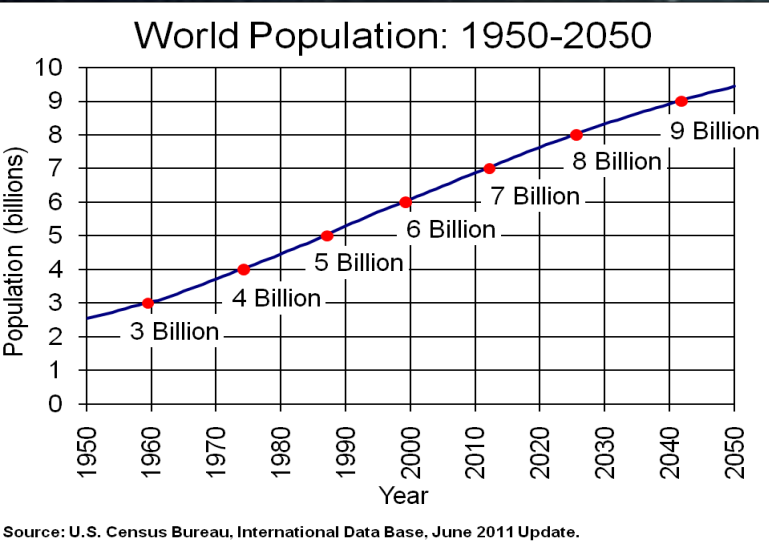
Marcus Newborough



Presentation Contents

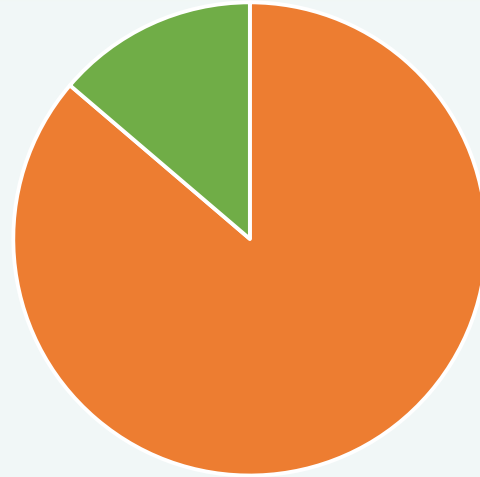
- Green hydrogen for a zero-carbon energy system
- Hydrogen properties
- Economic trends
- FCEV and HRS
- Future Trends





WE NEED MOLECULES AS WELL AS ELECTRONS

EU-28 : Energy Consumed as Molecules and Electrons (14,200 TWh)



■ Primary energy consumption excluding fuel use for electricity generation (Molecules)

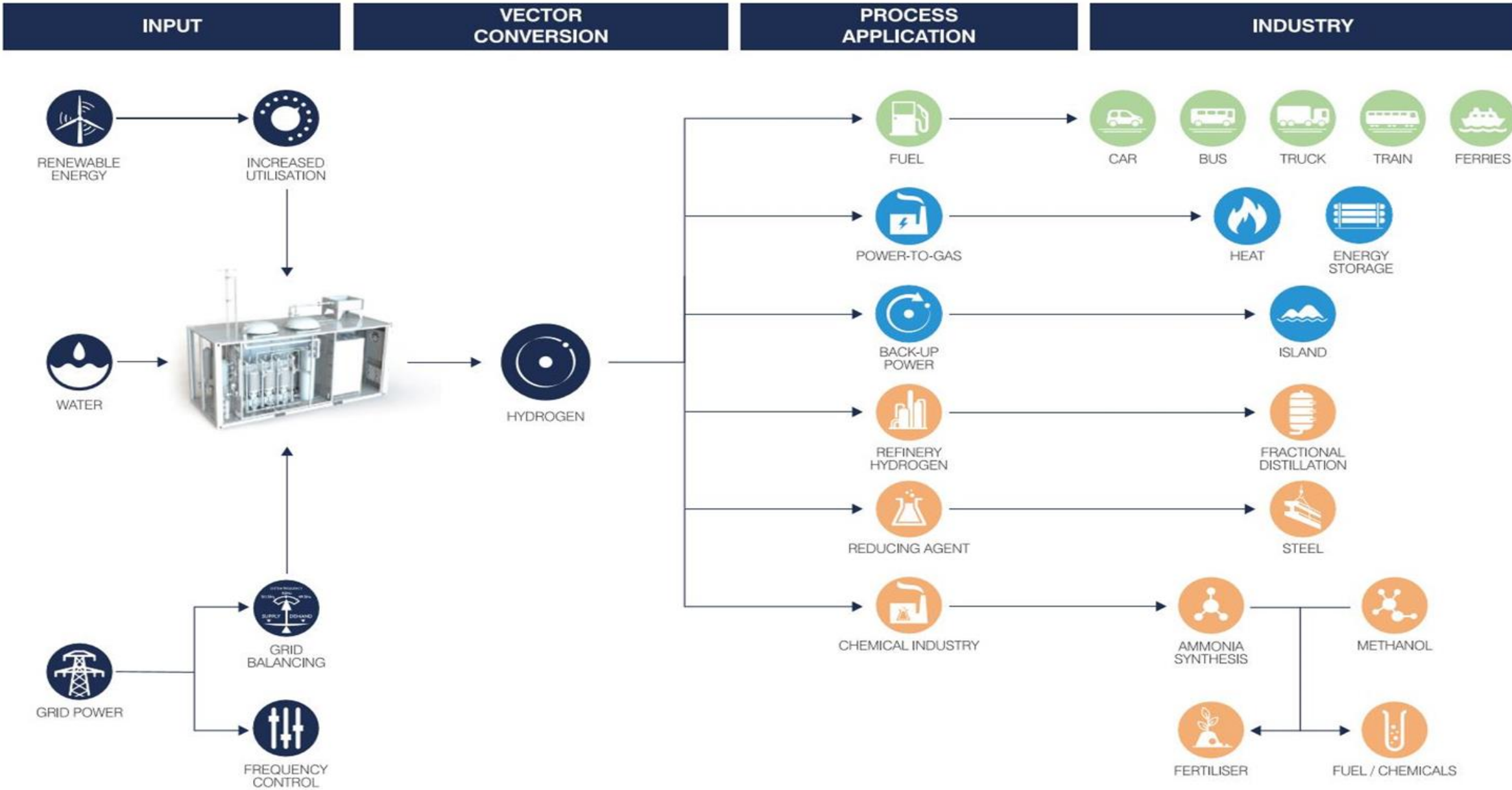
■ Electricity consumption (Electrons)

Source data: DG ENER, June 2017

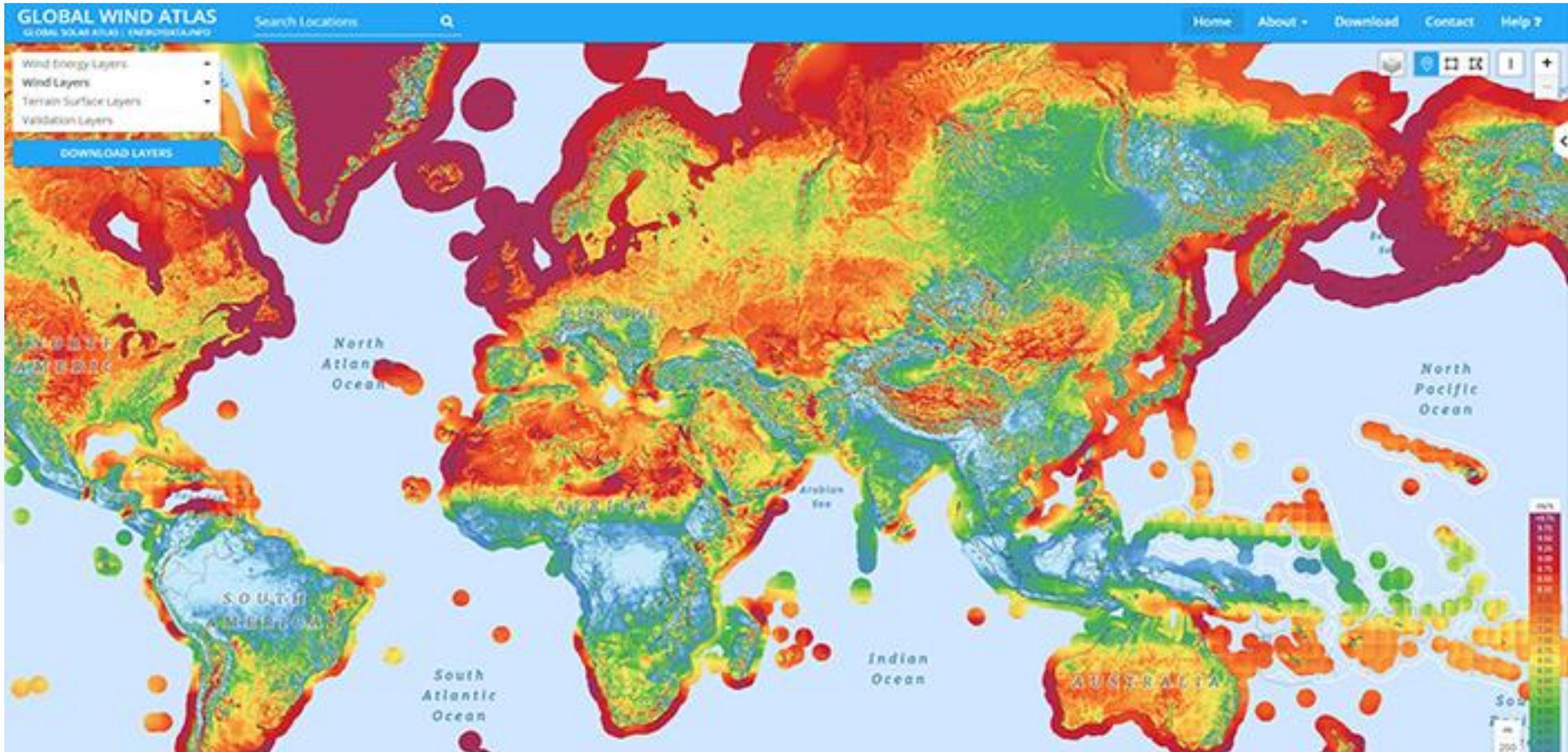
- Electrolysers convert electrons to molecules
- Electricity cannot be stored; renewable hydrogen can be stored and in vast amounts

Sector Coupling

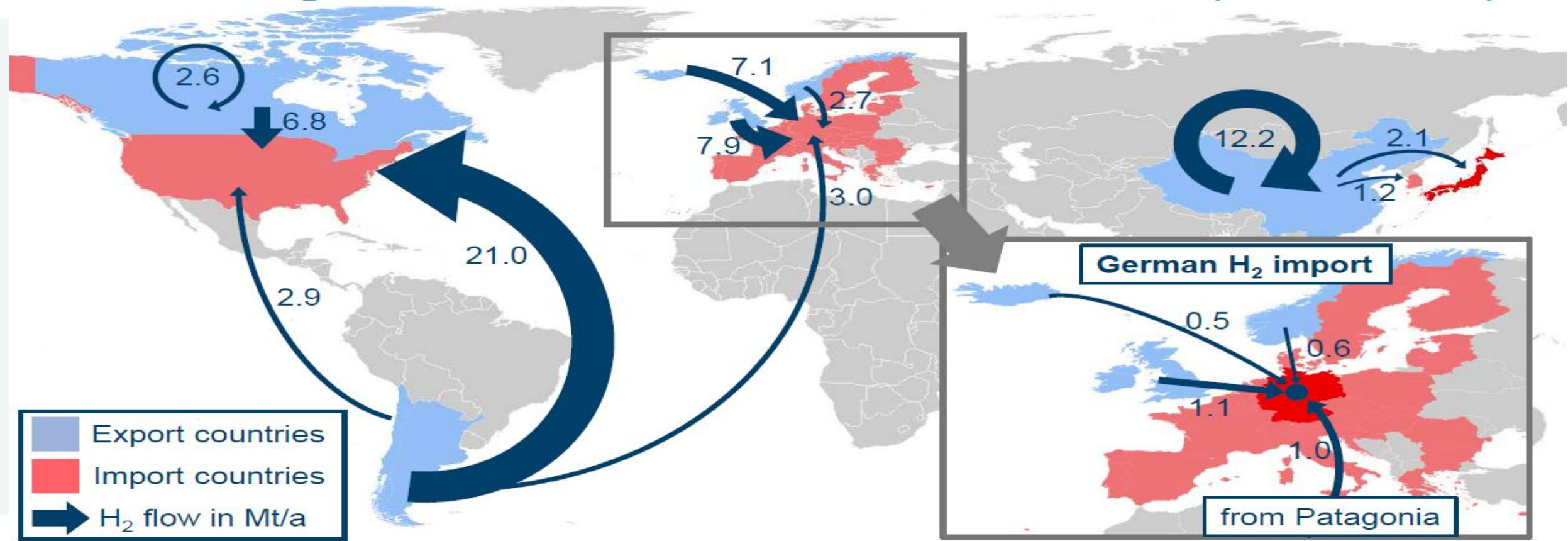
GREEN HYDROGEN FOR A ZERO-CARBON ENERGY SYSTEM



RENEWABLE ENERGY RESOURCES



Worldwide H₂ Flow Allocation with Minimized Overall Costs (75% Scenario)



	Germany	Japan	EU	USA	Canada	China	South Korea
Demand in Mt/a (75% Scenario)	3.14	2.05	17.58	30.61	2.55	12.22	1.15
Import LCOH in €/kg (*)	4.66	4.81	4.67	4.34	4.66	4.71	4.77

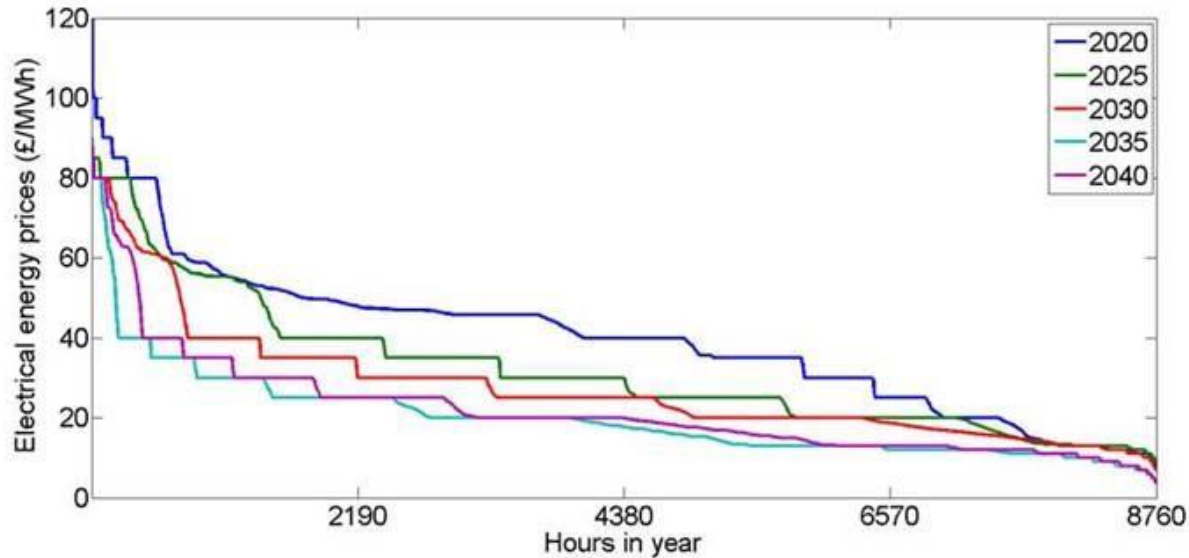
(*) Import LCOH incl. shipping costs

HYDROGEN PROPERTIES

- Very low density (1 kg H₂ at NTP occupies ~ 11.1 m³)
- Flammability limits: 4-75% by volume in air
- Detonation limits: 18-59% by volume in air
- Very low minimum ignition energy in air (0.019 mJ, ~ 20% of methane, petrol etc)
- Hydrogen/air flame almost invisible and low emissivity ($\epsilon < 0.1$, methane $\epsilon \sim 0.25$)
- High octane number (140 RON)
- Very high flame speed (~ 8 times methane)
- High flame temperature (2254°C, ~ 300°C higher than methane)
- Hydrogen combustion produces NO_x



Hydrogen as a fuel, feedstock and decarbonising agent



- Closure of coal power plants
- Decreasing use of natural gas for power generation
- Non-synchronous generation (wind and solar) increasing
- Synchronous generation (heat engines) decreasing
- Increasing temporal mismatch between electricity supply and demand

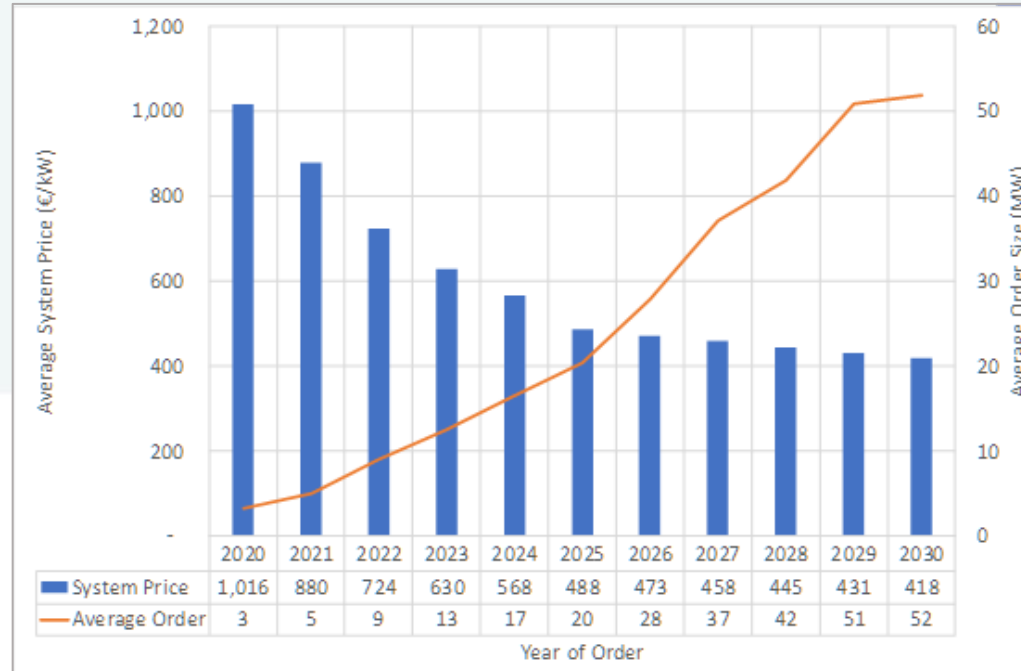
→ increasing need for grid balancing on all timescales (s, h, weeks, seasonal)

- Increasing renewables
- Average electricity price decreasing
- Greater availability of low price electricity
- Under-utilised electricity grid

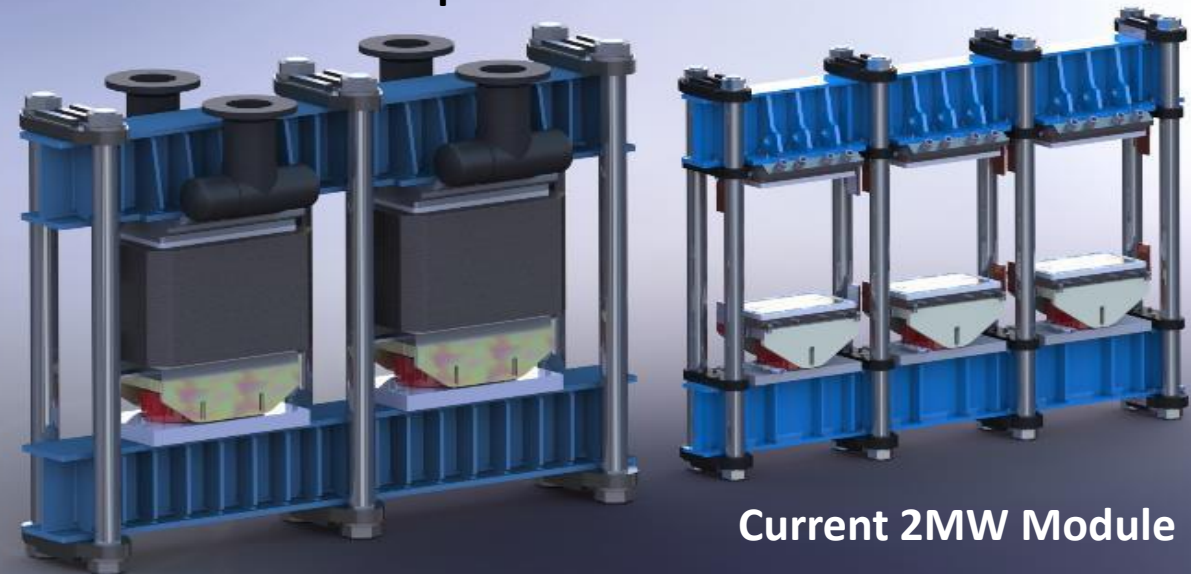


Using the electricity grid to produce hydrogen

- Proton Exchange Membrane technology
- Differential pressure operation (O_2 close to ambient)
- No tie-rods | Rapid assembly | Rapid exchange
- 2MW module today | Upscaling to 5MW module
- Integral water purification and gas drying
- Factory semi-automation
- Continuous R&D and technology improvements

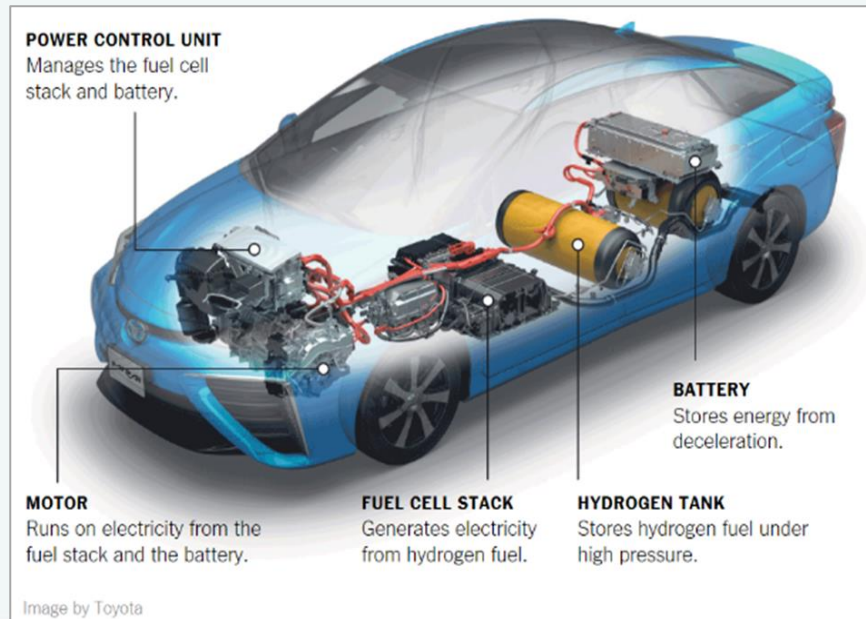


5MW Module Development



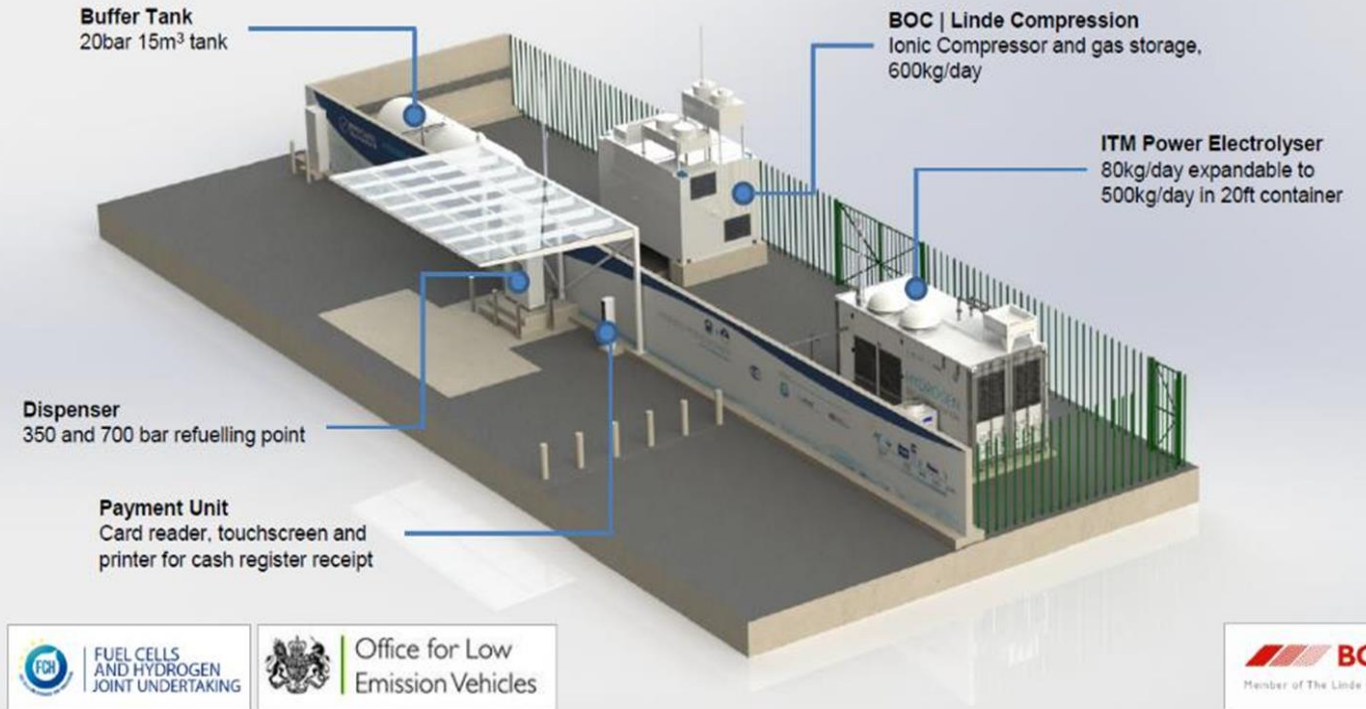
Current 2MW Module

- Refuel in 3 mins
- Up to 350 miles on 5kg of hydrogen
- Energy consumption ~40% of petrol car
- Zero emissions



FCEV: An EV drive train that's refuelled rather than recharged

WHAT IS AN FCEV REFUELLING STATION?

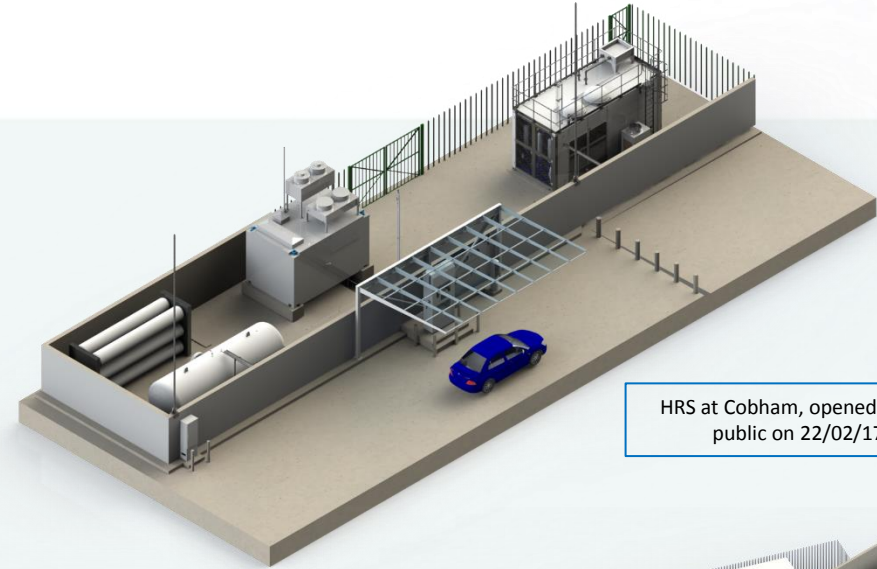


Electrolyser-HRS: Turnkey solution for establishing a hydrogen refuelling infrastructure

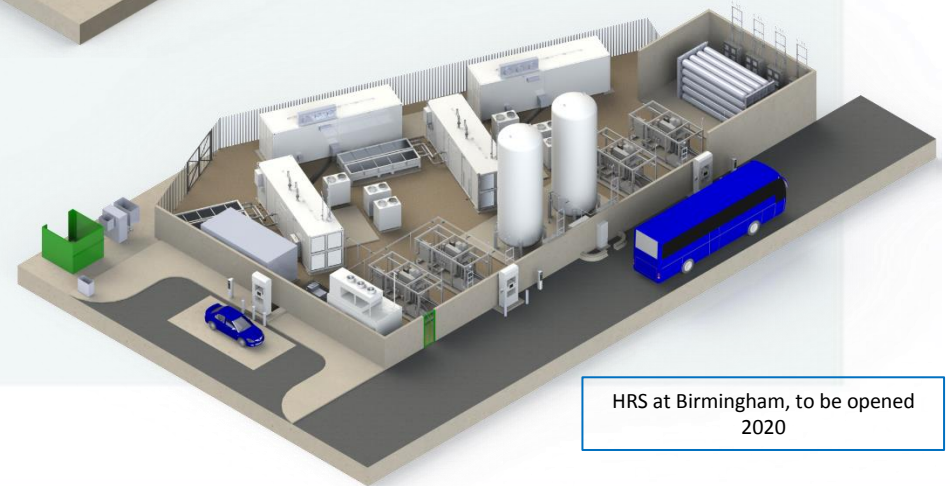
Hydrogen mobility

HYDROGEN REFUELLING STATIONS

- 8 UK electrolyser-HRS in operation
- 1 US electrolyser-HRS in operation
- 6 UK stations in construction
- Refuelling 700b and 350b FCEV
- Currently dispensing up to 20 tonnes H₂ p.a.
- Load aggregation for Grid Balancing



HRS at Cobham, opened to the public on 22/02/17



HRS at Birmingham, to be opened 2020



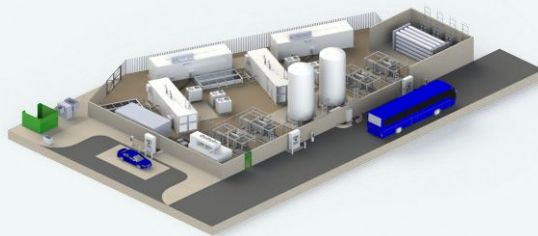
HRS at Beaconsfield, opened to the public 27/03/18

Hydrogen mobility

LARGE SCALE HYDROGEN REFUELLING STATIONS

Land | Sea | Air

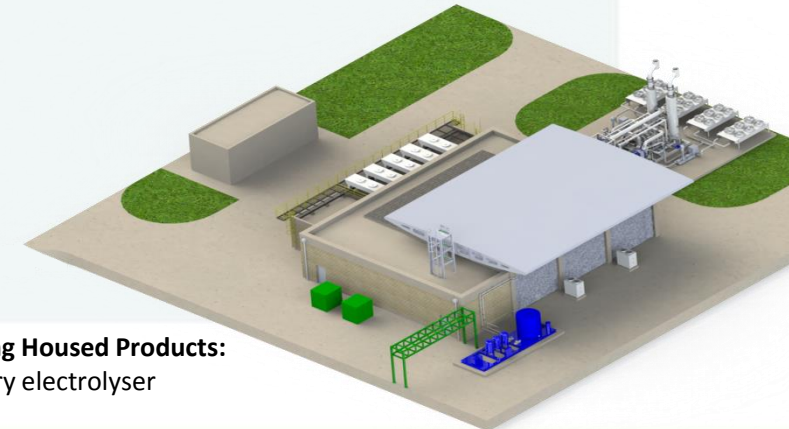
- Buses: 30 kg/day
- Trucks: 75 kg/day
- Trains: 180 – 400 kg/day
- Ferries: 500 kg/day



Containerised Products:
Bus refuelling station



Skid Mounted Products:
Train refuelling station



Building Housed Products:
Refinery electrolyser

Typical electrolyser requirements: 2MW | 10MW | 30MW | 50MW

- Expanding the UK network of HRS
- Developing and introducing heavy vehicles that can be refuelled rapidly
- Increasing recognition that green hydrogen is the transport fuel of the future
- Electrolyser upscaling and cost reduction
- Government policies enabling a 'green electrons + green molecules' sector coupling approach to decarbonisation
- An inter-seasonal storage market for renewable energy via underground storage of green hydrogen

HYDROGEN PRODUCTION FROM ELECTROLYSIS: ITS POTENTIAL AND COSTS

Decarbonising Trucks, Trains, Boats and Planes
REA

3 December 2019

Marcus Newborough

