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Hydrogen Fuel Cell System Design Considerations for Automotive Applications

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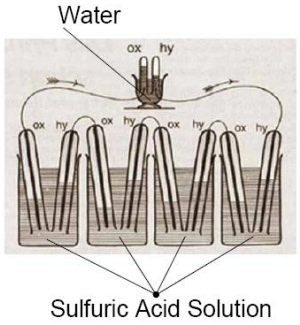
Brief History of the Fuel Cell

1801
Sir Humphry Davy
Fuel Cell Concept
Developed

1838
Sir William Grove
Phosphoric Acid
Fuel Cell (PAFC)



1932
Francis Thomas
Bacon OBE
Alkaline Fuel Cell
(AFC)

1960's
NASA – Project Gemini –
First commercial use of
a Fuel Cell

1966
Chevy Electrovan

2008
Honda FCX Clarity
(First FC Dealer
Network)

2020's
Toyota Mirai &
Hyundai Nexo

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Common Types of Fuel Cell

	Proton Exchange Membrane (PEMFC)	Solid Oxide (SOFC)	Alkaline (AFC)	Phosphoric Acid (PAFC)	Direct Methanol (DMFC)
Fuel Type	Hydrogen	Hydrogen, Methane	Hydrogen	Hydrogen	Methanol
Typical Output (kW)	0.01-250	0.5-2000	0.1-50	50-1000	0.001-100
Operating Temp (°C)	40-90	600-950	40-200	200	60-130
Typical Efficiency (%)	40-55	40-72	50-70	40-45	40
Gravimetric Power Density (kW/kg)	2	1	1.5	0.18	0.1
Lifing	30,000	40,000	5,000	40,000	20,000
Other Notes	• Lower temp • Quick startup	• High efficiency • Higher temp enables CHP • Slow startup	• Lower cost • Sensitive to CO2 in air	• High tolerance to impurities • Higher temp enables CHP • Slow startup	• high tolerance to impurities • low power density
Typical Use Case	Automotive, UAV's	Large Scale Stationary Power	Space	Large Scale Stationary Power	Portable Power

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What is a Fuel Cell?

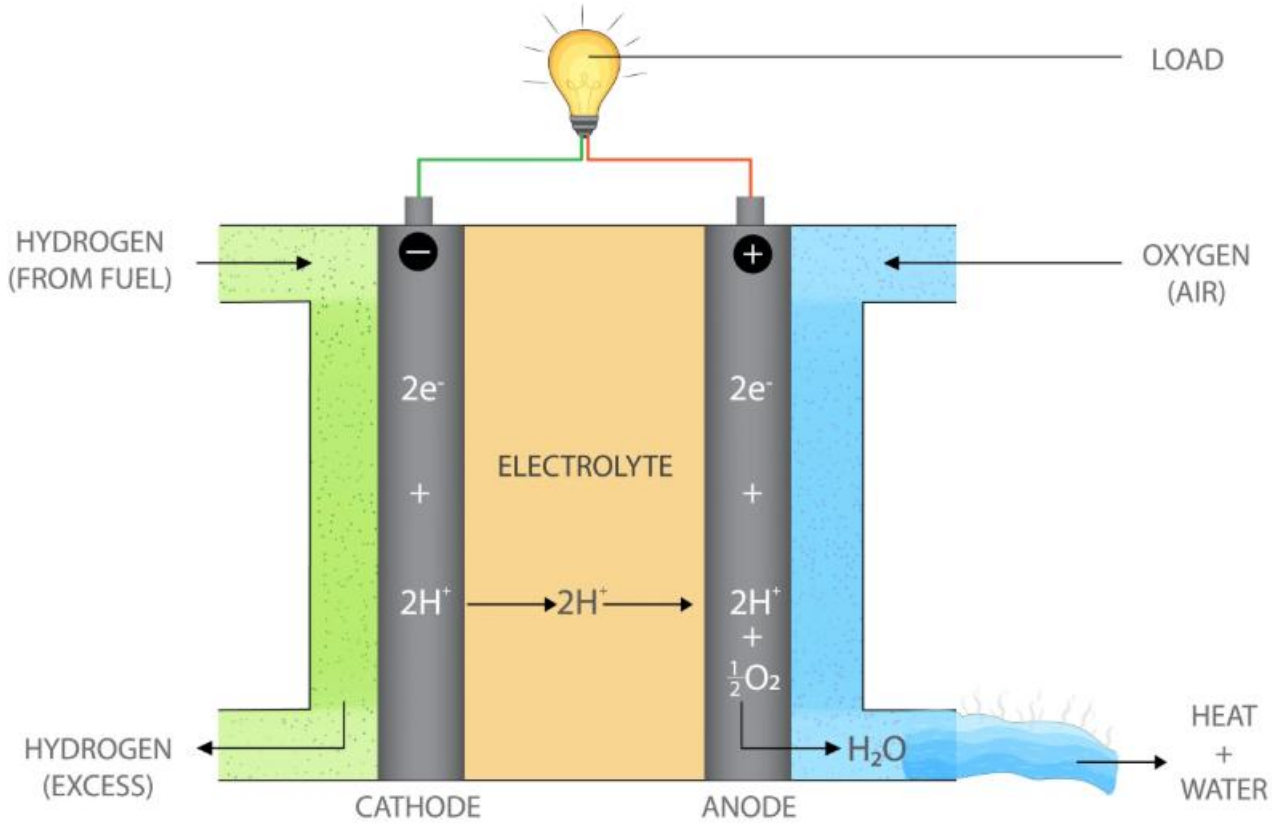
- Chemical reaction between Hydrogen and Oxygen

- Components
  - Anode = Hydrogen
  - Cathode = Oxygen
  - Catalyst = Platinum
  - Electrolyte = Proton Conducting Membrane (Polymer)

- Electrolyte only allows Proton to pass

- Outputs
  - Electricity
  - Heat
  - Water

- Moisture level is critical



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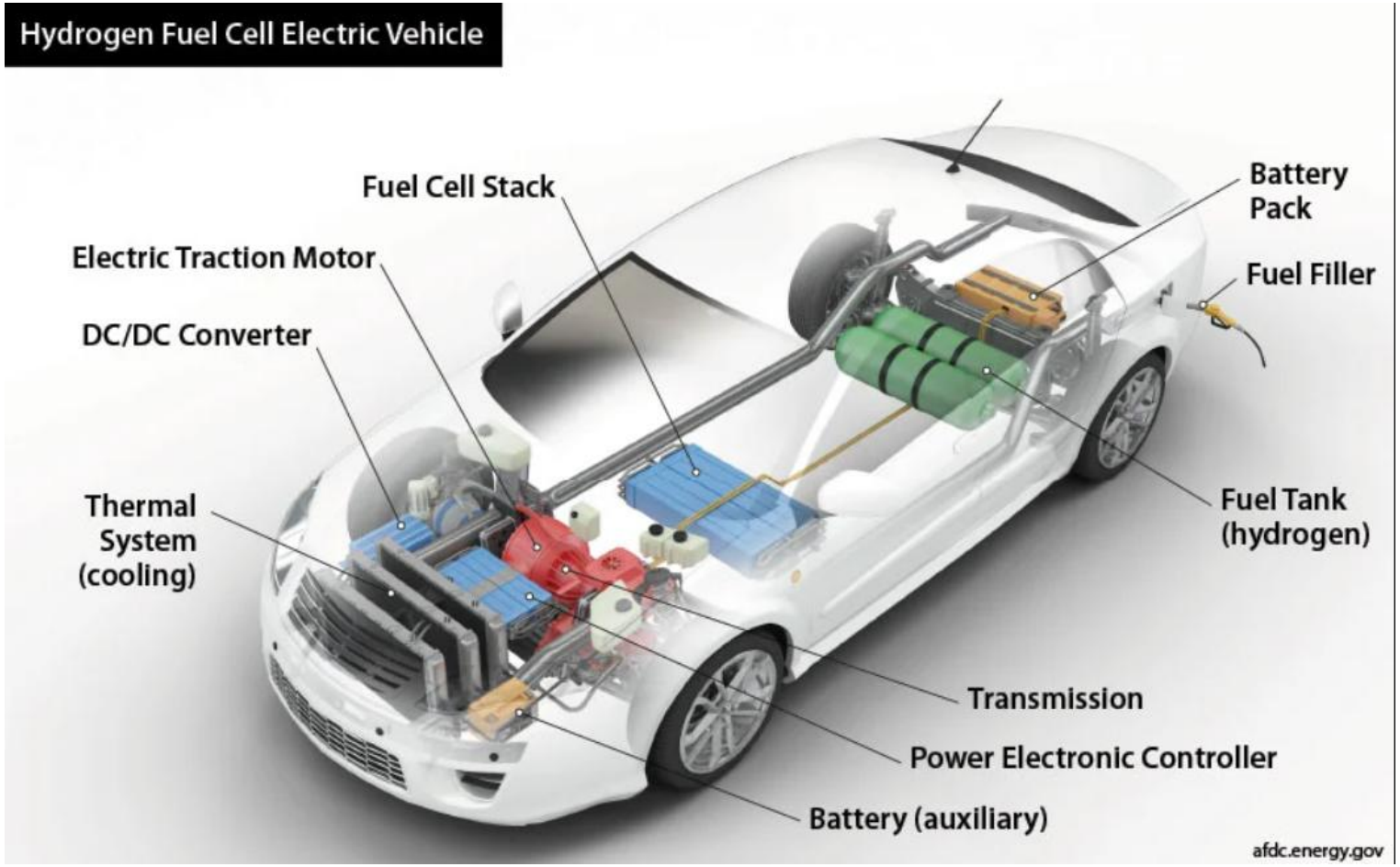
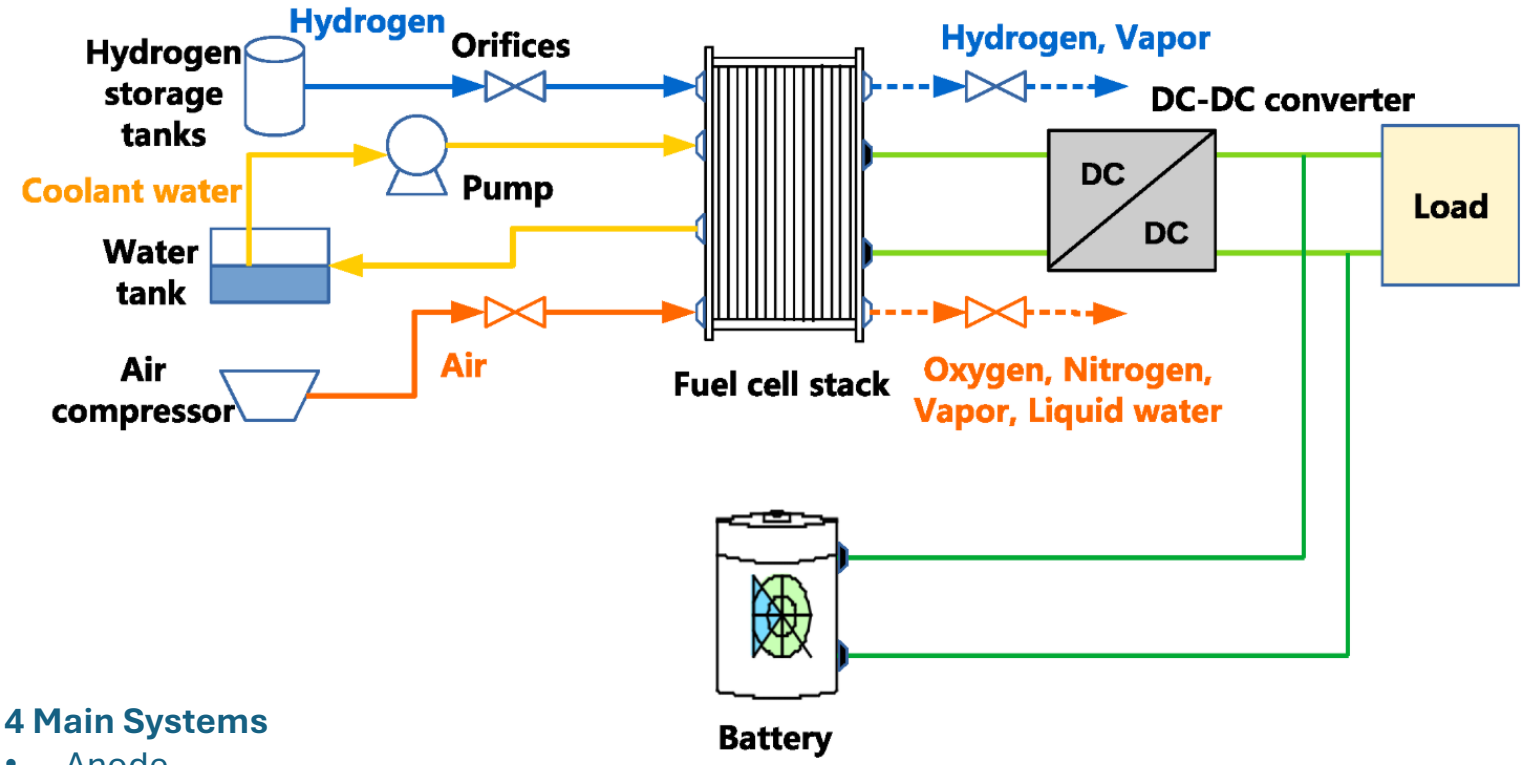
Fuel Cells in Vehicles



Fuel Cells Systems



4 Main Systems

- Anode
- Cathode
- Cooling
- Electrical

Fuel Cell Stack

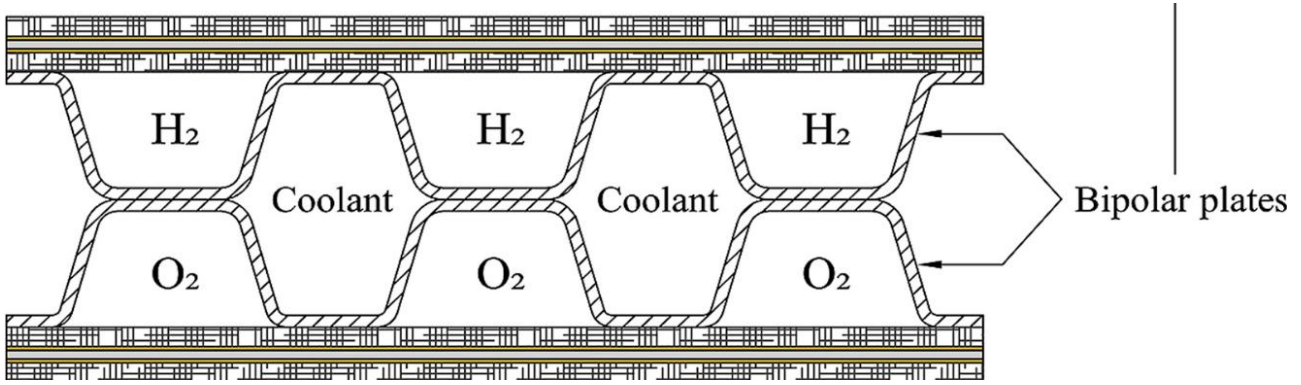
Bipolar Plate Assembly
- Consists of 2 bipolar plates, bonded together to create a “cooling cell”
- Plate thickness typically less than 1mm

Bipolar Plate Design Considerations
- Power Density
- Durability
- Recyclability
- Cost

- Typically either metallic or graphite carbon

- Metallic (Toyota, Hyundai)
  - Improved mechanical strength allows thinner plates (high power density kg & litres)
  - Increased corrosion (lower life)
  - Manufactured through stamping, machining or etching

- Graphite Carbon (Ballard)
  - Machined or moulded



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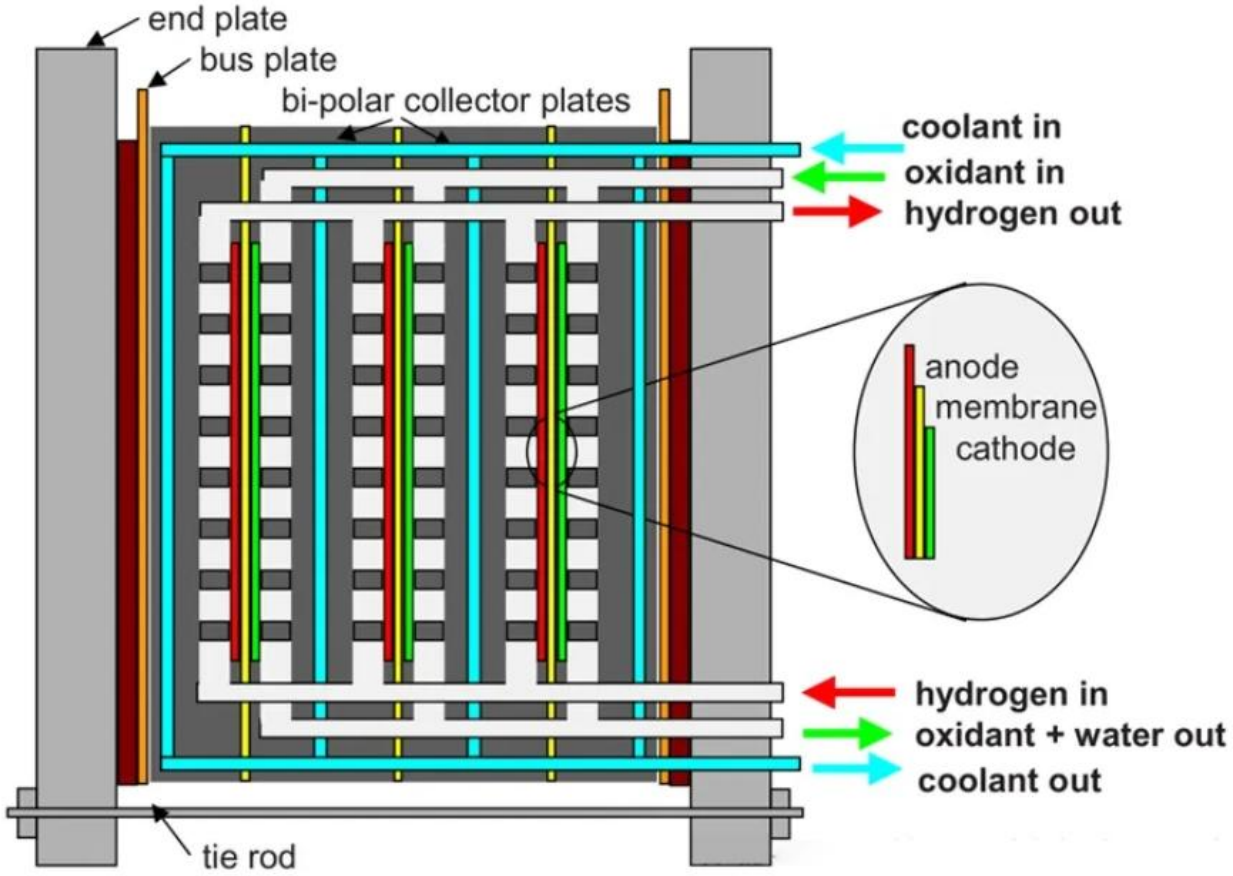
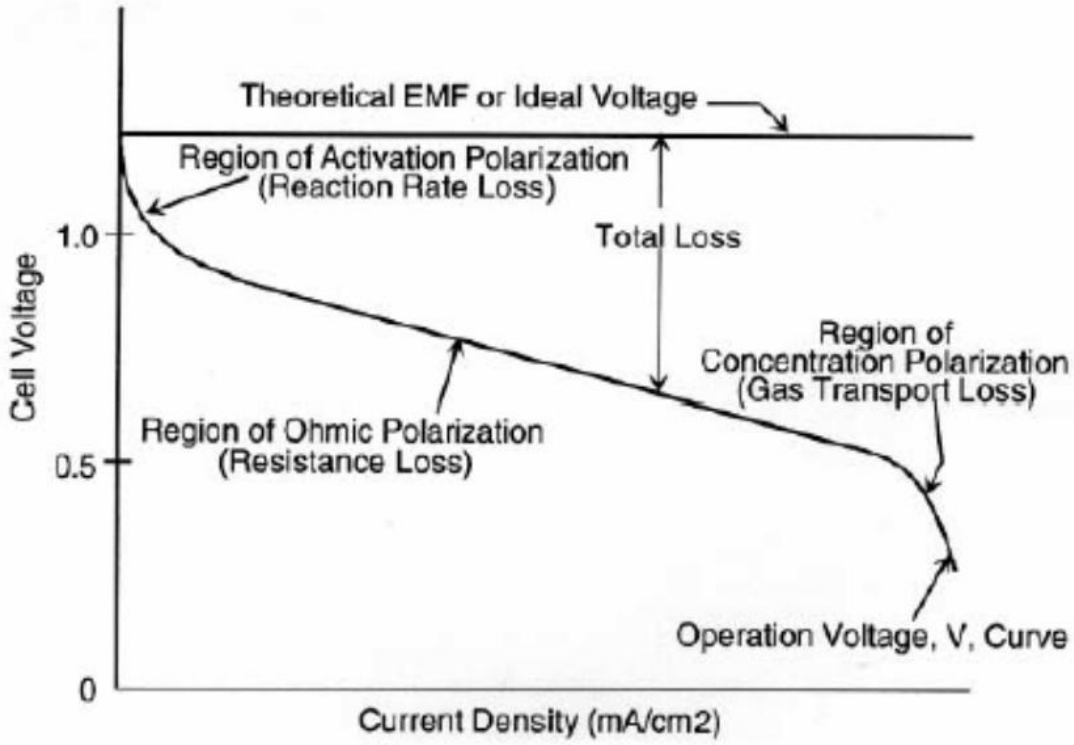
Fuel Cell Stack

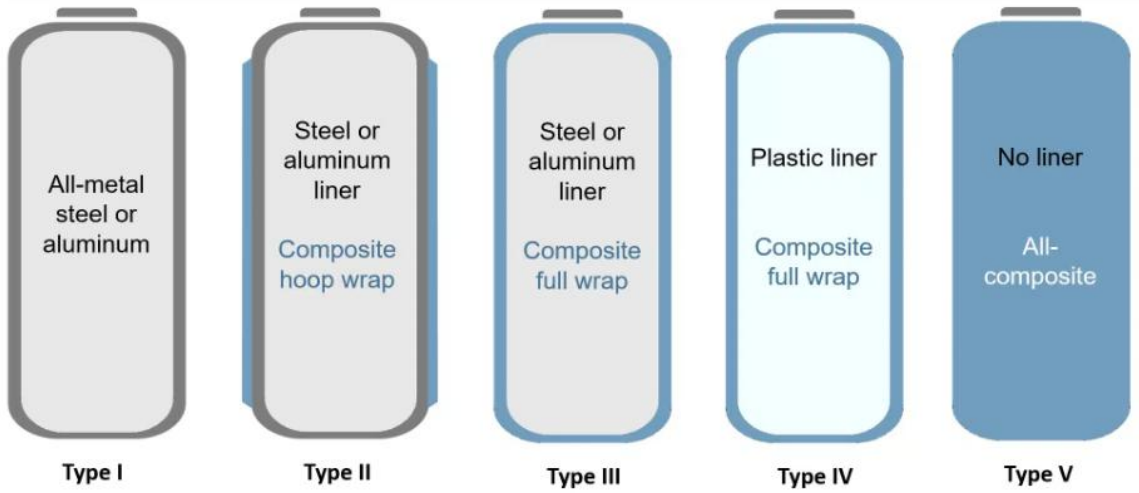


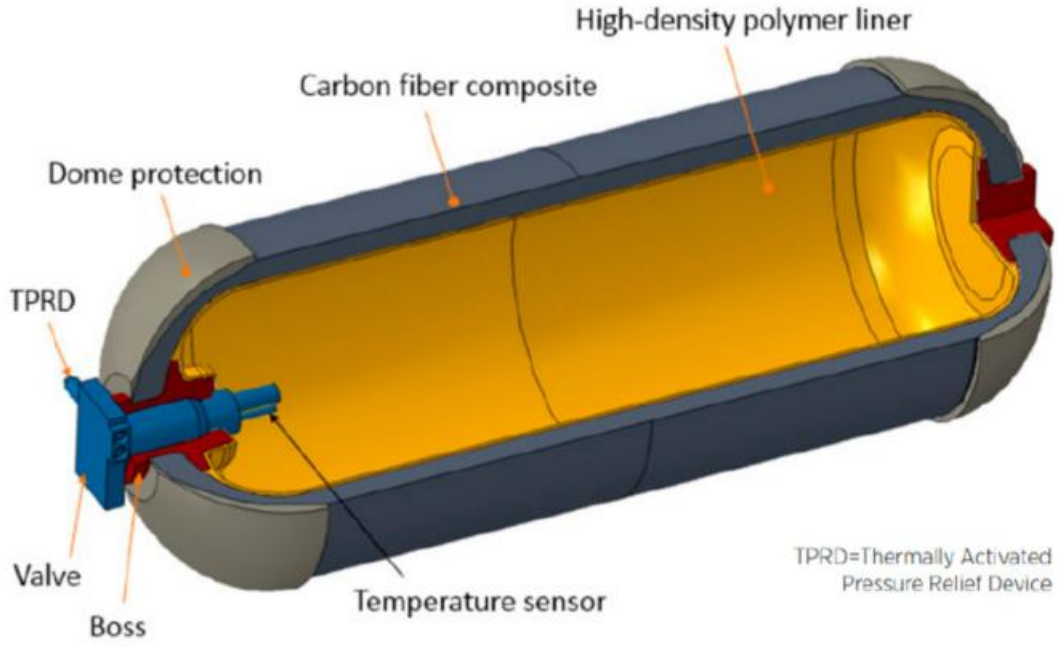


Efficiency = Vactual/**V**ideal

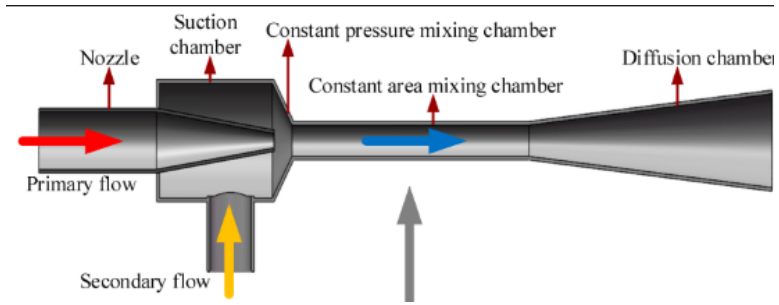
Anode System – Hydrogen Storage

- Typically Type III or Type IV PV's in automotive applications
- 350bar is most common but transition is being made to 700bar
- Most common regulation is UN ECE R134
  - 10,000 cycles
  - 2.25 Burst strength (1575bar)





Anode System



PRV

Refill Port

Vent

Hydrogen Ejector

15bar

PresReg

700bar

OTV

Pressure Vessel

1bar

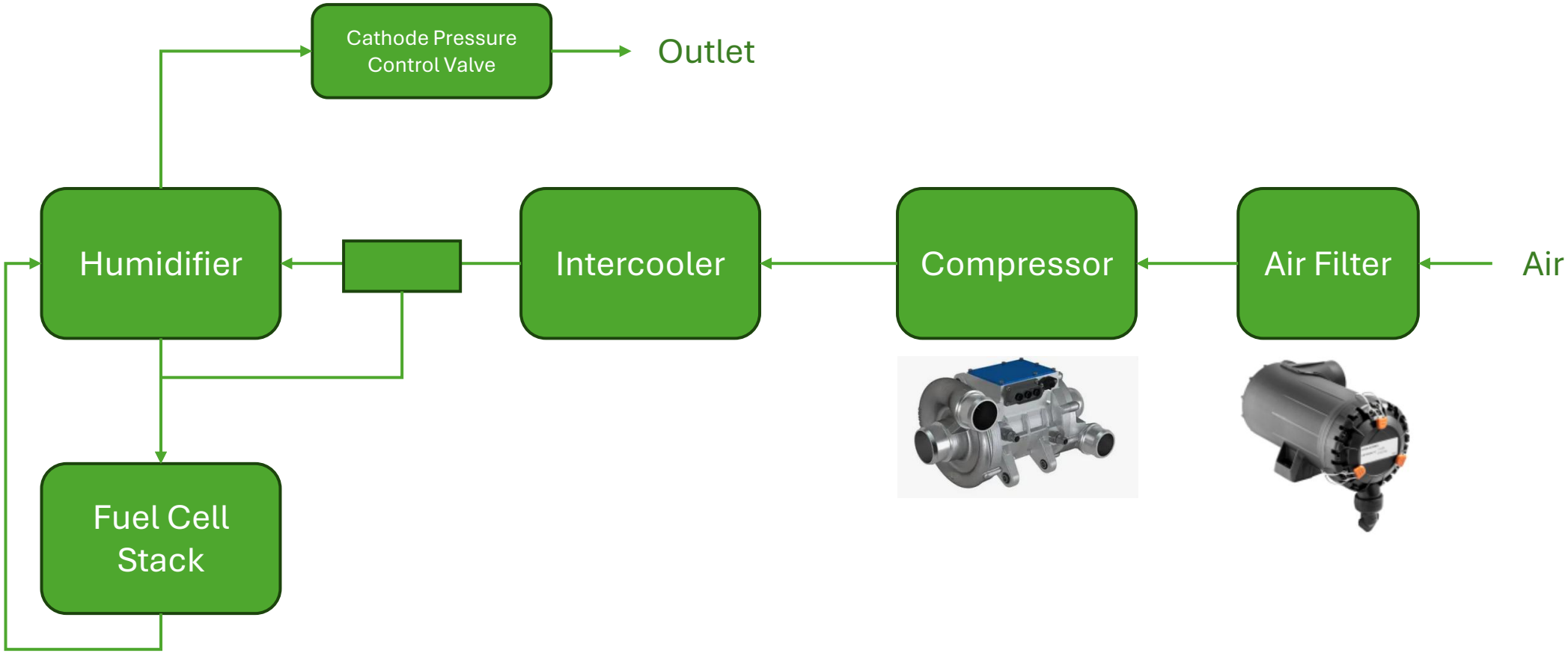
Fuel Cell Stack

Recirculation Blower

Purge Valve

Vent

Cathode System



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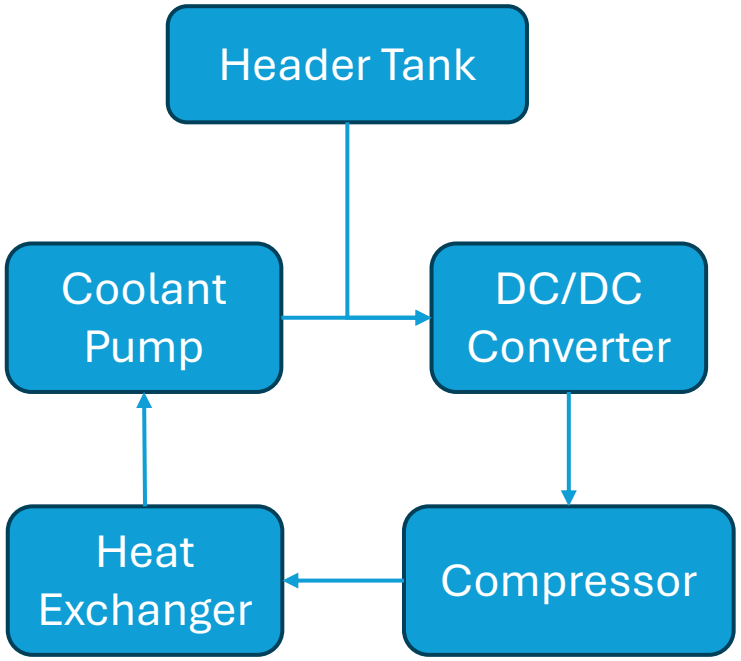
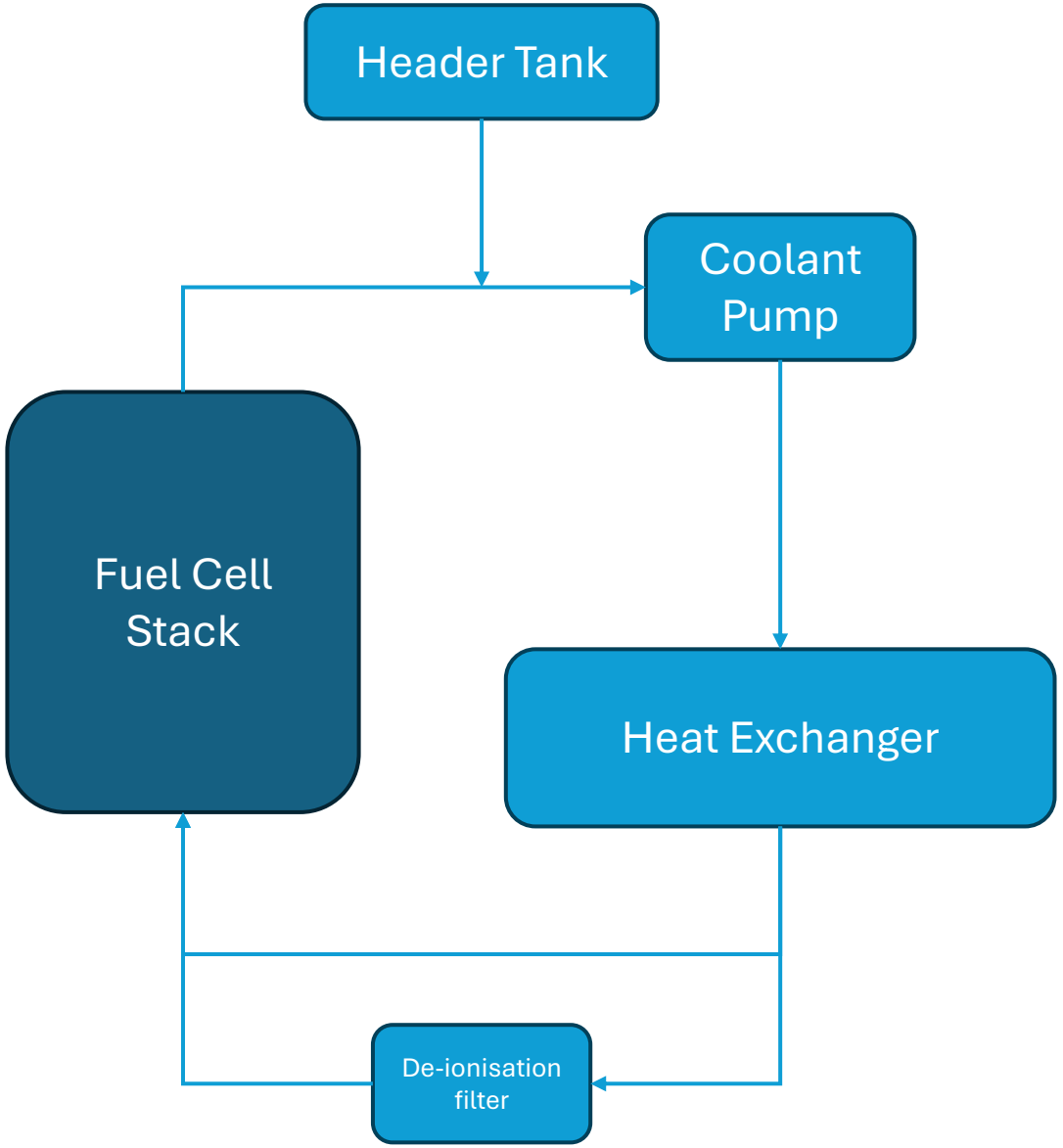
Cooling System





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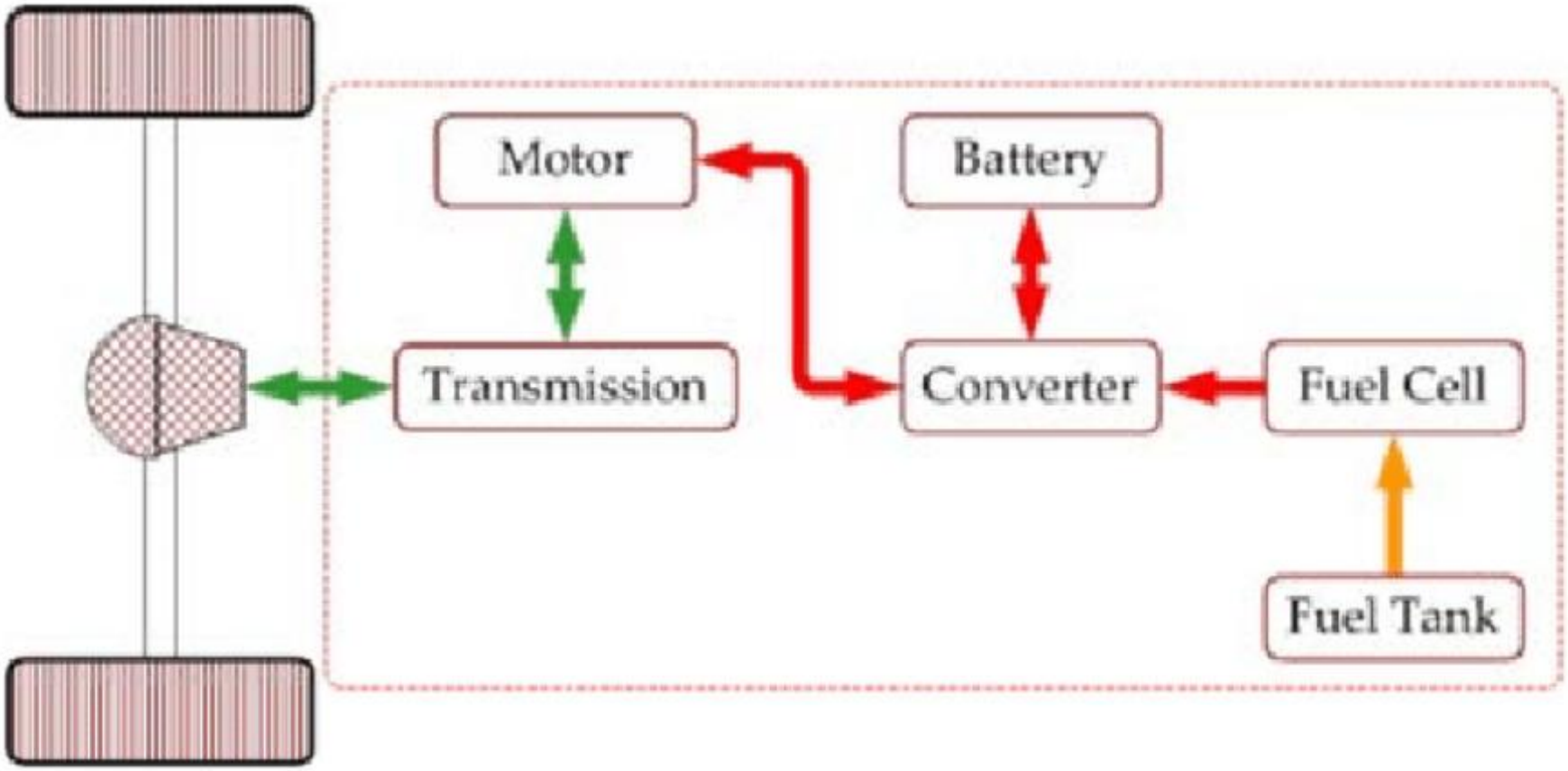
Electrical System



Hydrogen Safety

Key Risks

Flammability

- 4% concentration creates an explosive atmosphere
- Burns with an almost clear flame
- Nitrogen purge is required

Leakage

- Smallest and lightest element
- Pools easily, requires strategically placed concentration sensors

High Pressure Failures

- PV's undergo rigorous testing include bullet test in US regs
- Pressure vessels must be over 200mm for the exterior vehicle silhouette

Embrittlement

- Hydrogen causes embrittlement issues with most metals
- Brass, 316 Stainless and 6062 Aluminium are most common "Hydrogen Safe" materials.

HV Electrical

- Same HV risks as existing BEV's with added complication of Hydrogen

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Economics of Fuel Cell Systems

Where are we now?

Fuel Cells

- Currently £300/kW would be considered a good price
- Many suppliers struggling to get below £500/kW

Pressure Vessels

- Currently at £1000/kg of H2 stored
- CF is 70% of cost

Hydrogen

- Cheapest UK price is approx. £12/kg
- China already at £3/kg for grey sources

DC/DC Converters

- 800A DC/DC converters are available from China for approx. £7500
- EU supplied in the region of £15,000

Where do we need to get to?

Fuel Cells

- Bosch targeting £13.50/kW in 2030
- EH Group “Sub £100/kW” at volume

Pressure Vessels

- APC 2030 target is £250/kg
- Potentially achieved safety factor reduction and CF cost reduction

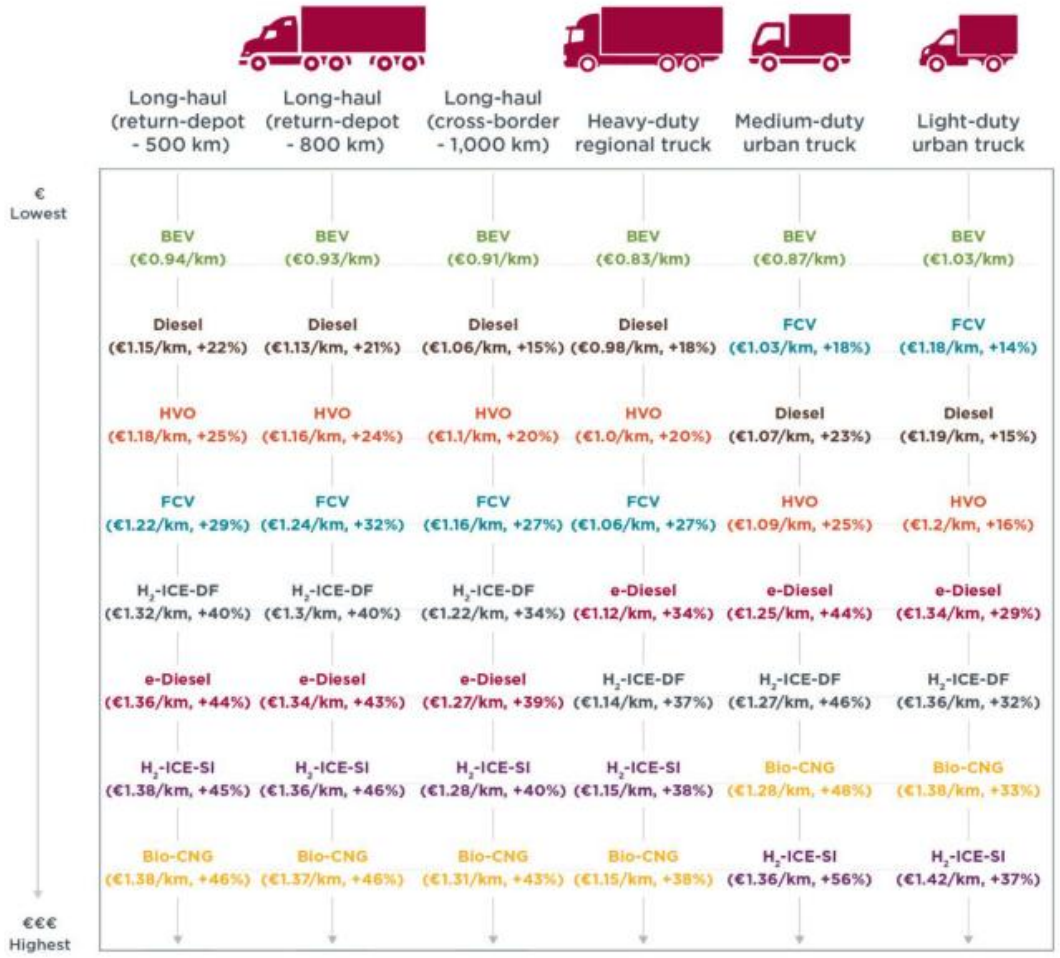
Hydrogen

- £5/kg generally considered the “magic number” for TCO parity but this is being put under more stress

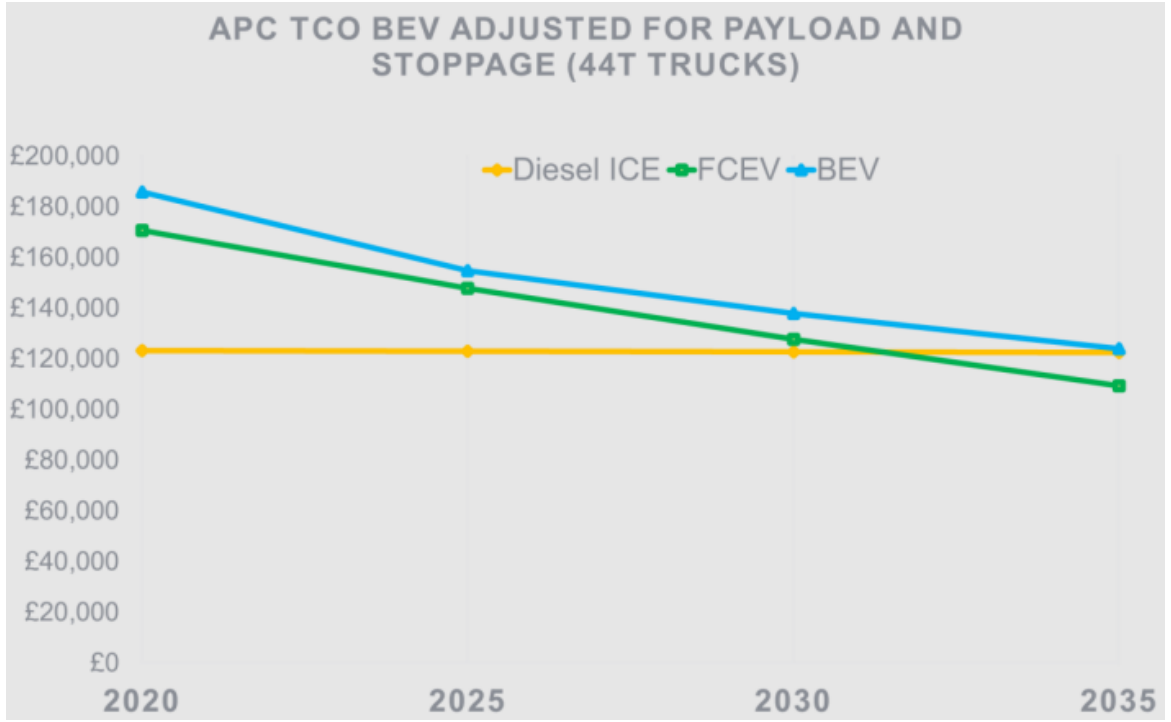
DC/DC Converters

- Automotive OEM’s pushing for sub-£1000 for an 800A continuous DC/DC converter

Total Cost of Ownership



ICCT European Truck Decarbonisation Pathways
TCO 2030



Advanced Propulsion Centre TCO model based on $2/kg by 2035

Fuel Cell Suppliers

BOSCH

- 100-300kW Systems
- Originally developing system for Nikola

cellcentric

- Volvo/Daimler JV
- 150-300kW Systems

SYMBIO
A FAURECIA MICHELIN HYDROGEN COMPANY

- 45-300kW Systems
- Part owned by Stellantis
- 200,000/year by 2030

TOYOTA

- 75,000/year by 2030
- Supply deal with BMW
- Mirai flagship product

BALLARD®
PUTTING FUEL CELLS TO WORK

- 120-360kW Systems
- Most common (bus, truck, van, train)

- 30,000/year by 2027
- Nexo flagship product

Intelligent Energy®

- Evaporative Cooling Technology
- Based out of Loughborough Uni

HONDA

- JV with GM
- 150kW System
- Claimed 60% efficiency

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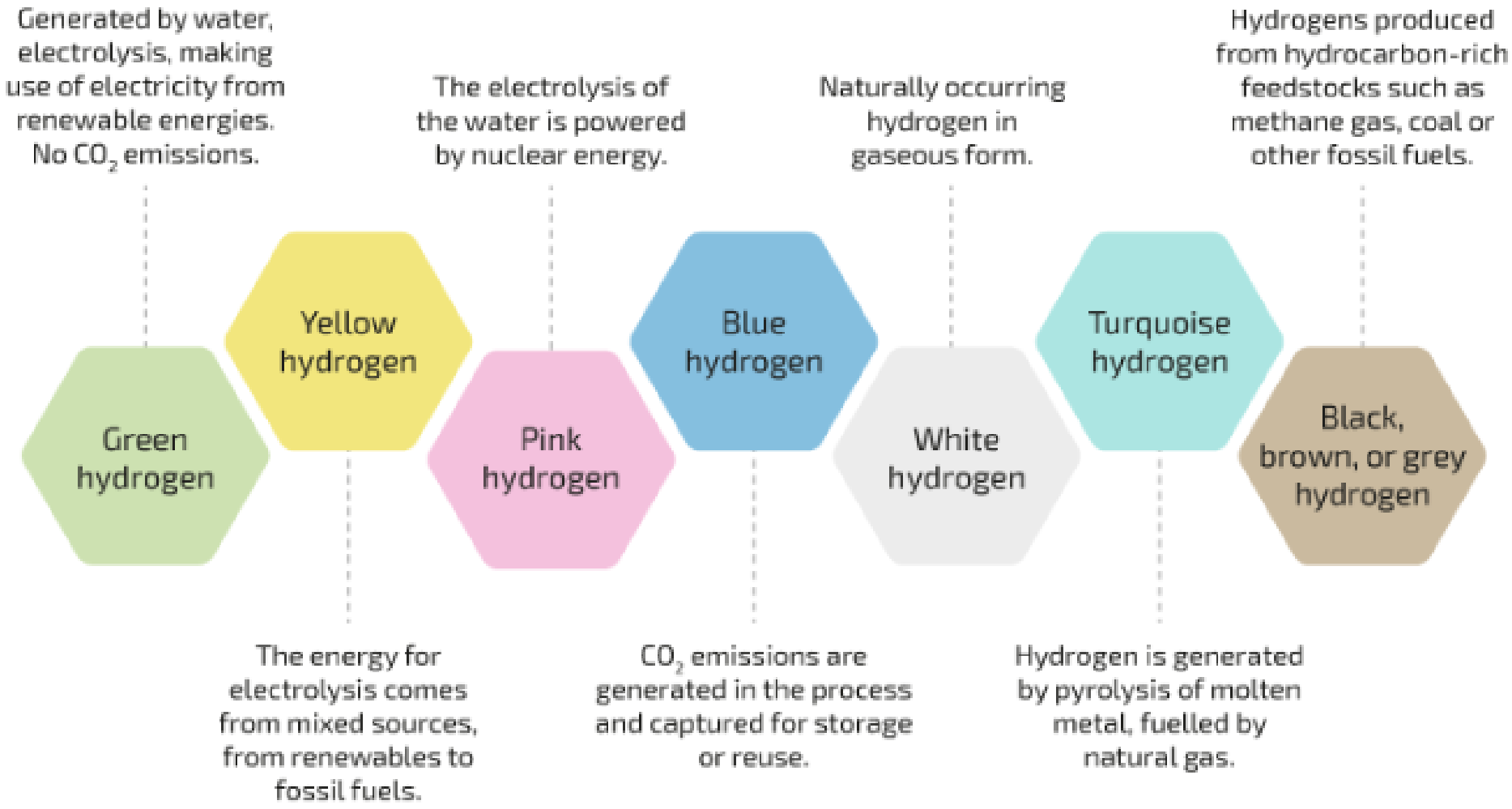
Hydrogen Types and Supply



The future of Fuel Cell Vehicles

Passenger Vehicles are in Development

BMW iX5

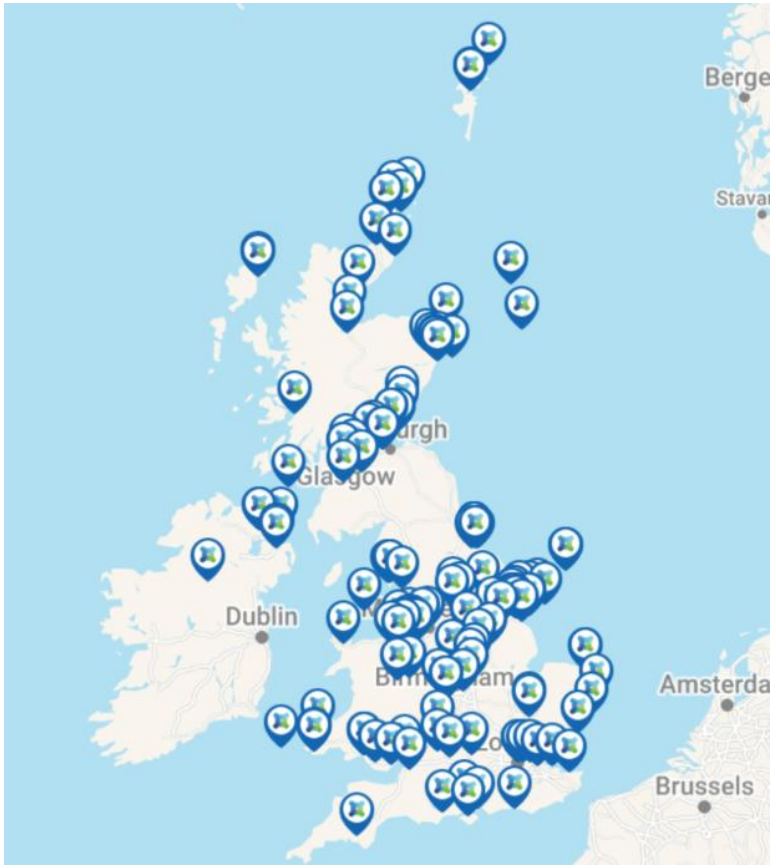
Next-Gen Toyota Corolla

HGV are the most likely route

Daimler

Scania

Significant investment is still needed



Source: Hydrogen UK

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Questions?

THANK YOU
Any Questions?