Is Hydrogen the Answer?

David Shirres, Editor RailEngineer

February 2018

All diesel trains should be scrapped by 2040, Jo Johnson tells rail bosses

Speech

Let's raise our ambitions for a cleaner, greener railway

Minister calls for diesel-only trains to be phased out as part of new vision to decarbonise the railway.

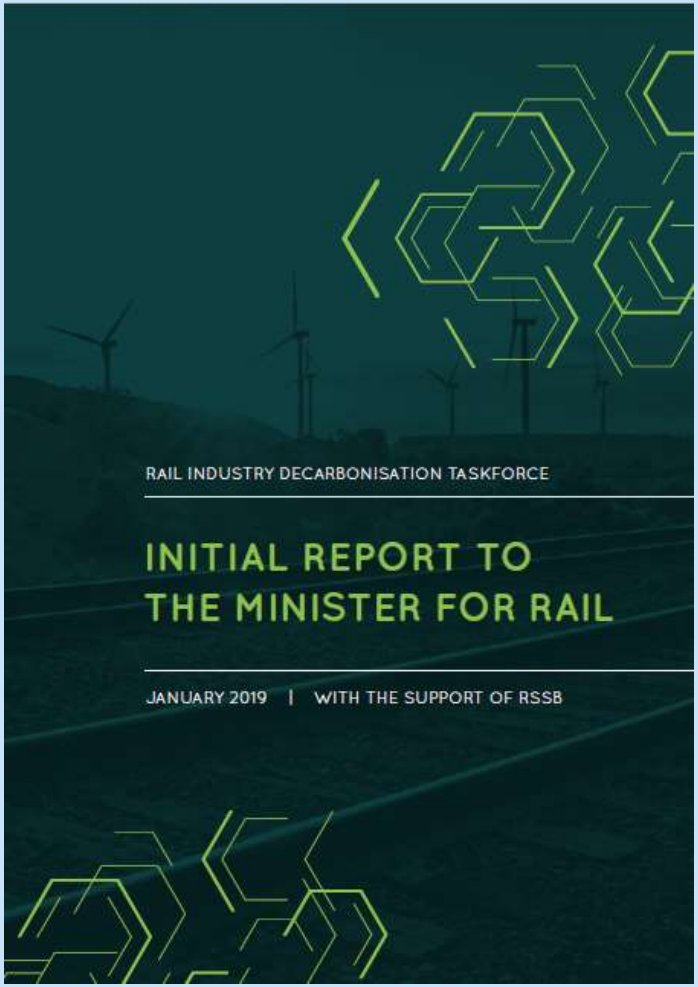
"I would like to see us take all diesel-only trains off the track by 2040."

"As battery technologies improve we expect to see batteries powering the train between the electrified sections of the network.

Or maybe in the future we could see those batteries and diesel engines replaced with hydrogen unit?

Alternative-fuel trains powered entirely by hydrogen are a prize on the horizon."

February 2019

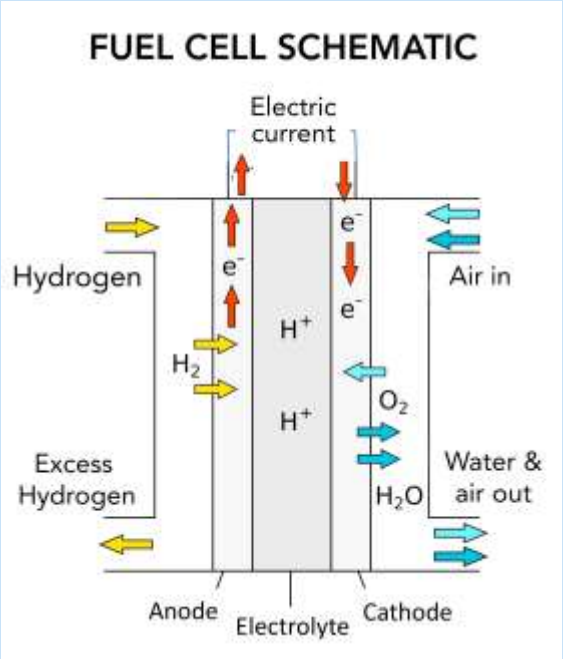


- The removal of diesel-only passenger trains from the rail network by 2040 is achievable
- Electrification is “the most carbon efficient power source”
- Other power sources such as bi-mode, hydrogen and battery are developing fast. A concerted effort is needed to deploy them to achieve the lowest system-wide carbon outcome

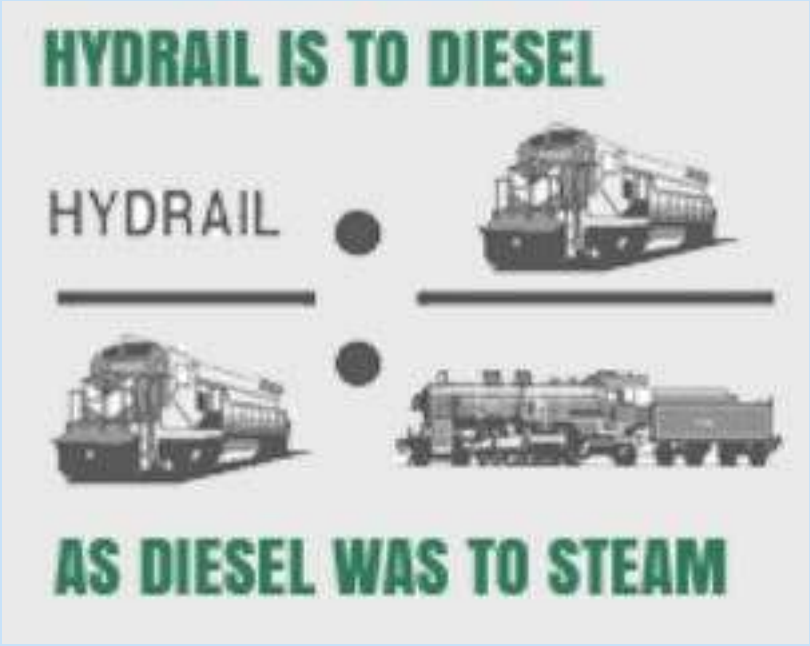
Hydrogen fuel cells

- The reverse of electrolysis
- Invented in 1838
- First practical use by NASA - £1,000 per kW
- Typically 52% efficient, compared with 35% for a diesel engine
- Significant advances in recent years, fourfold increase in volumetric power density in ten years up to 2011

	2001	2003	2009	2011
Power (kW)	25	20	16.5	33
Mass (kg) Power density (W/kg)	290 86	170 117	92 180	75 440
Volume (L) Power density (L/kg)	365 68	180 111	133 124	125 264
Efficiency %	38 - 45	40 – 54	48 - 54	48 – 55
Components	25	8	6	6



Hydrogen on the rails



2005 First annual international Hydrail conference held in North Carolina, largely an academic affair

2018 Hydrail conference in Rome, most speakers from hydrogen businesses

2006, Japan
World's first Hydrogen train
2 x 95 kW fuel cells

2010, Los Angeles, USA
130-ton diesel shunter
240 kW fuel cell

Hydrogen on UK (narrow gauge) rails

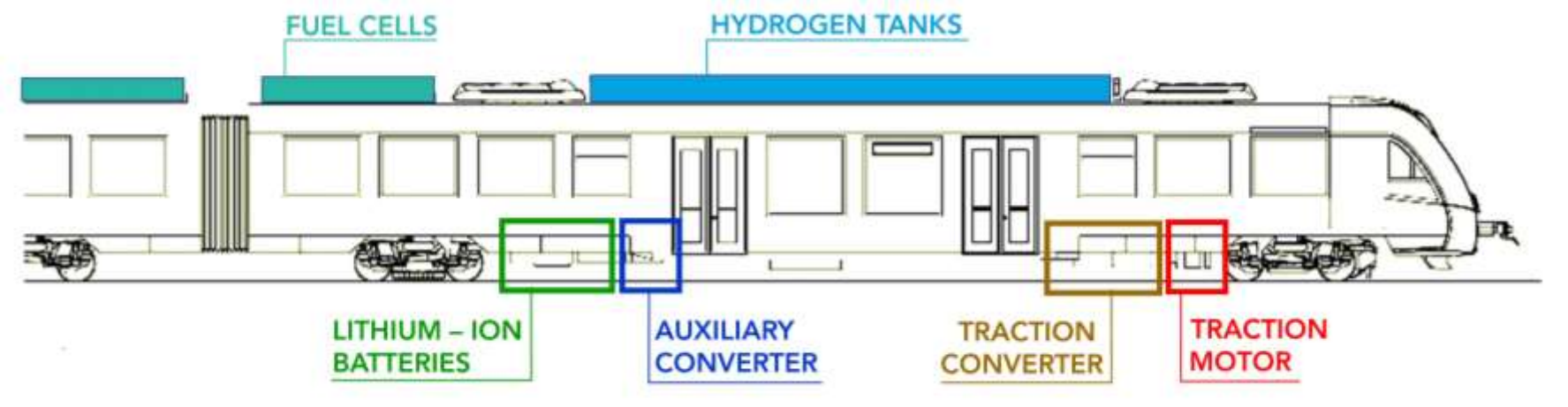
University of Birmingham's Hydrogen locomotive powered by a 1kW fuel cell at the IMechE's Railway Challenge on the Stapleford 10 ¼ inch miniature railway 1st July 2012

September 2018 – Hydrogen train enters passenger service

First train delivered as part of a €81 million contract signed in November 2017 to supply 14 Alstom iLints to Lower Saxony by 2021. Letters of Intent with 3 more northern German states for 44 trains

Lower Saxony generates a quarter of Germany's wind power and has an installed wind power capacity of 7,800 MW. It plans to increase this to 20,000 MW by 2050

Alstom's Hydrogen iLint



- 390 kW underframe-mounted traction motor
- Maximum speed of 140 km/hr, weighs 107 tonnes
- Hybrid unit, each coach has a 200 kW fuel cell that charges a 225 kW battery to give a peak power output of 425 kW per coach – peak 7.9 kW / tonne power to weigh ratio
- On routes with frequent stops, energy savings from regenerative braking of around 30%
- Roof tanks on each coach hold 89 kg Hydrogen at 350 bar giving a range of between 600 and 800 km. Refuelled in 15 minutes.

Alstom's Hydrogen iLint

Fuelling point

Fuel Cells

Hydrogen tanks

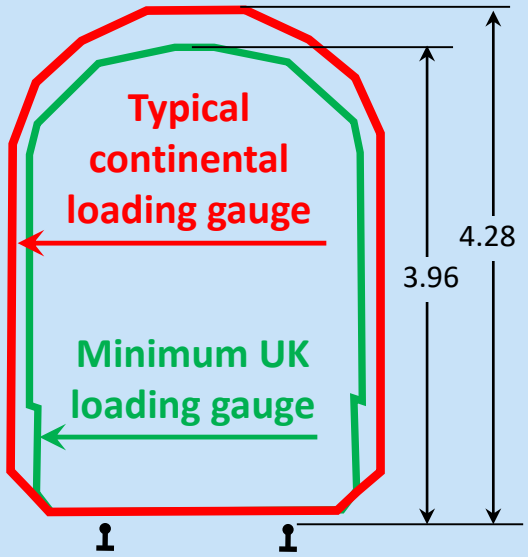
On train hydrogen storage

Substance	By volume (MJ/L)	By weight (MJ/kg)
Uranium	1,500,000	80,620,000
Diesel	35.8	48.0
Petrol	34.2	46.4
LPG	26	46.4
Hydrogen (at 350 bar)	**4.6**	**71**
Lithium-ion battery	0.9 to 2.2	0.36 to 0.9
Lead-acid battery	0.6	0.2

- Hydrogen has a low volumetric energy density compared with diesel, although still more than twice that of batteries
- Space available to carry fuel on self powered trains is a significant constraint, especially within the UK loading gauge

Alstom's UK Breeze proposal – January 2019

- Alstom unveil their UK hydrogen train design
- a redundant electric multiple unit conversion
- Range of 625 miles
- Top speed of 87 mph
- Trains could be running in 2022
- Fleet operation needed to justify investment in hydrogen infrastructure
- Unlike in Germany, hydrogen tanks are within the motor coach (10 – 15 % of space of a 3-car train)



Hydrogen production

Method	Worldwide Production	Cost (£ per kg H_2)
Steam reforming	96%	2.6
Electrolysis (1,2,3)	4%	3.8 (4)

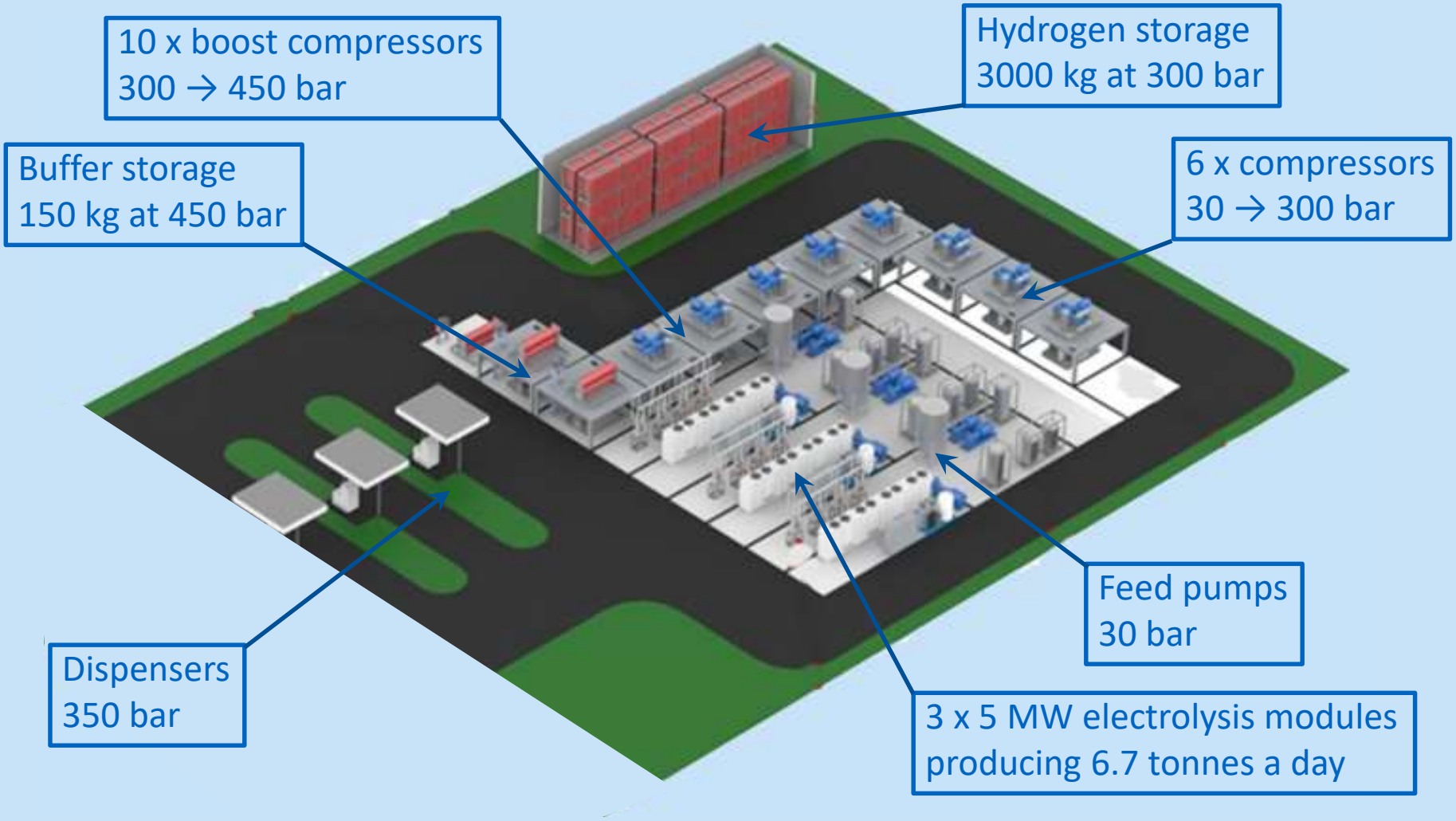
1) For small scale production, electrolysis likely to be a more practical option that offers a resilient supply
2) Can provide energy storage to address intermittency issues associated with renewable energy
3) Cost is predictable cost as it is the capital, operational and maintenance cost of the kit required
4) Typical electricity cost, less if off-peak energy used

Emissions	C02 (grams / MJ)	Local pollutants
Hydrogen - reforming	57	None – exhaust is water
Hydrogen - electrolysis	0 (5)	
Diesel	74	NO_X, particulates etc

5) If electrolysis powered by renewable energy

Hydrogen production on site

A 15 MW plant could supply 30 trains or 300 buses

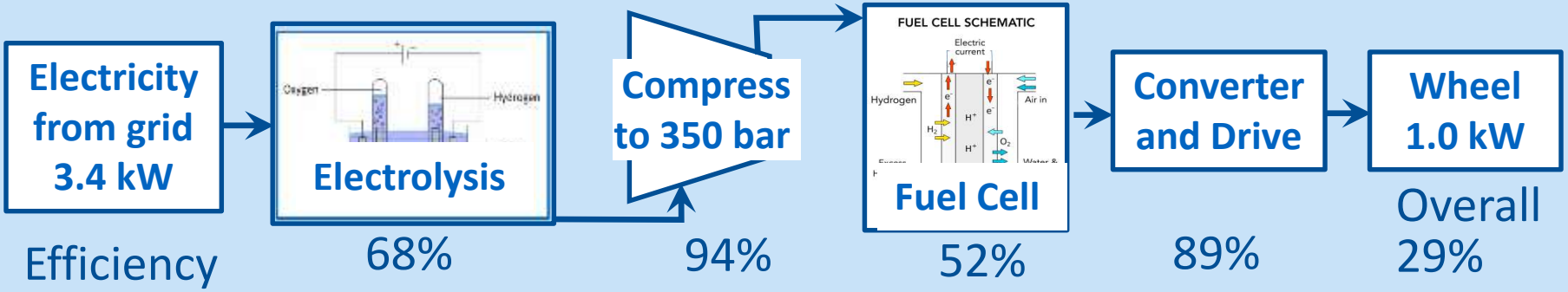


Off-shore wind power developments

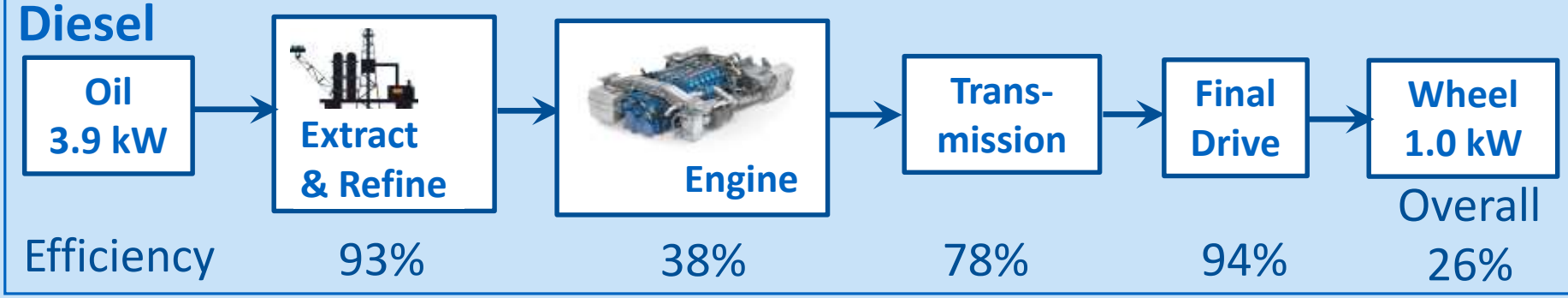
- Huge investment in turbines and specialist ships
- Now 154-metre turbines of 7MW are being installed 100 km from the shore
- With advanced remote condition monitoring very few turbine visits required
- Wind is now the cheapest form of utility-scale power generation
- In past six years, costs reduced from £200 to £52 / MWh

Typical rail traction well-to-wheel efficiency comparisons

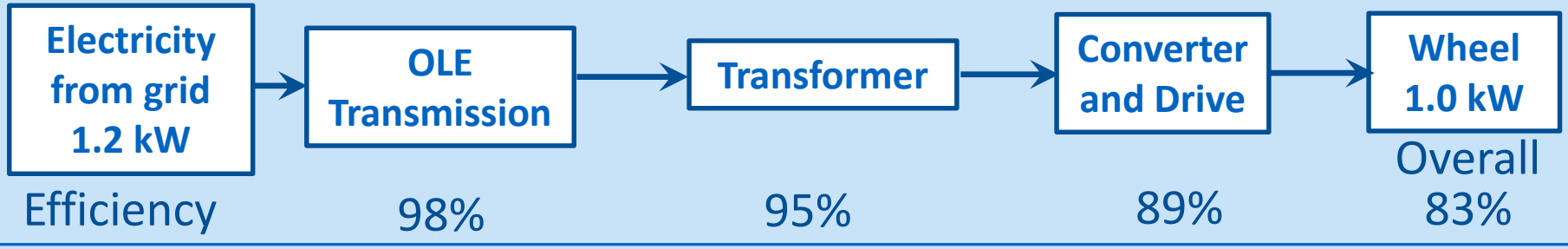
Hydrogen - on site production from renewable energy



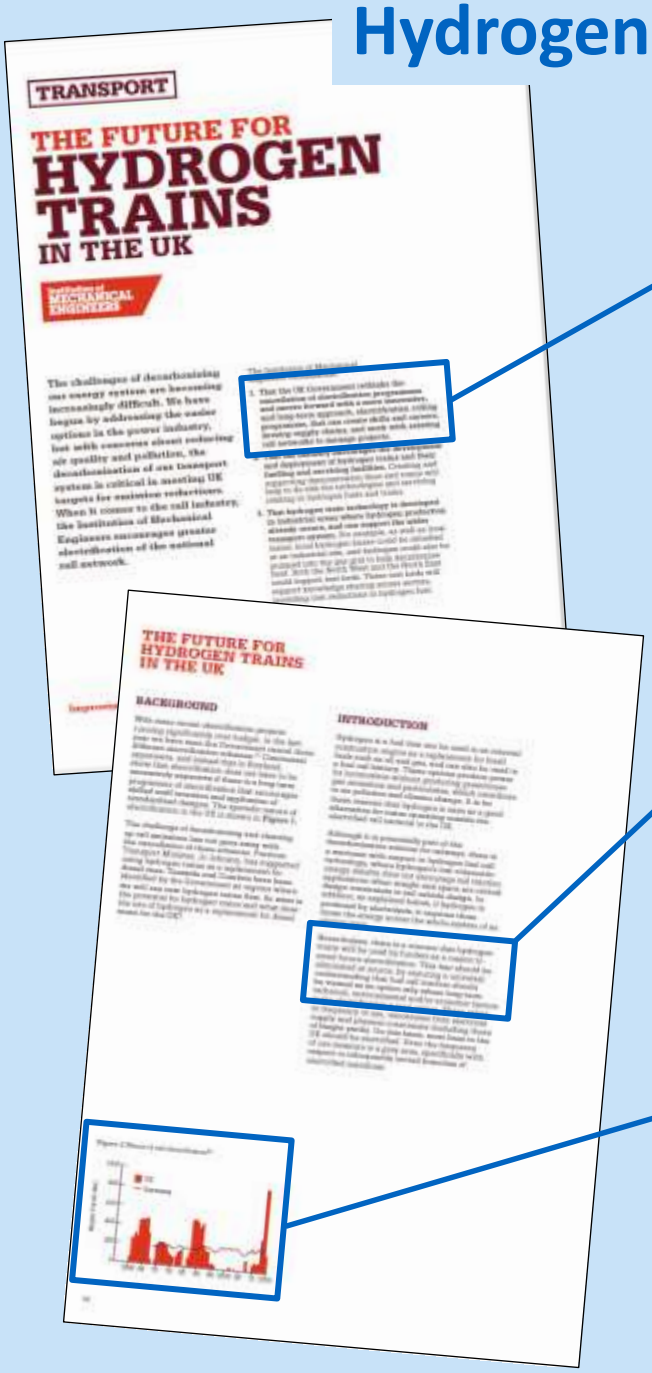
Diesel



Electrification from renewable energy

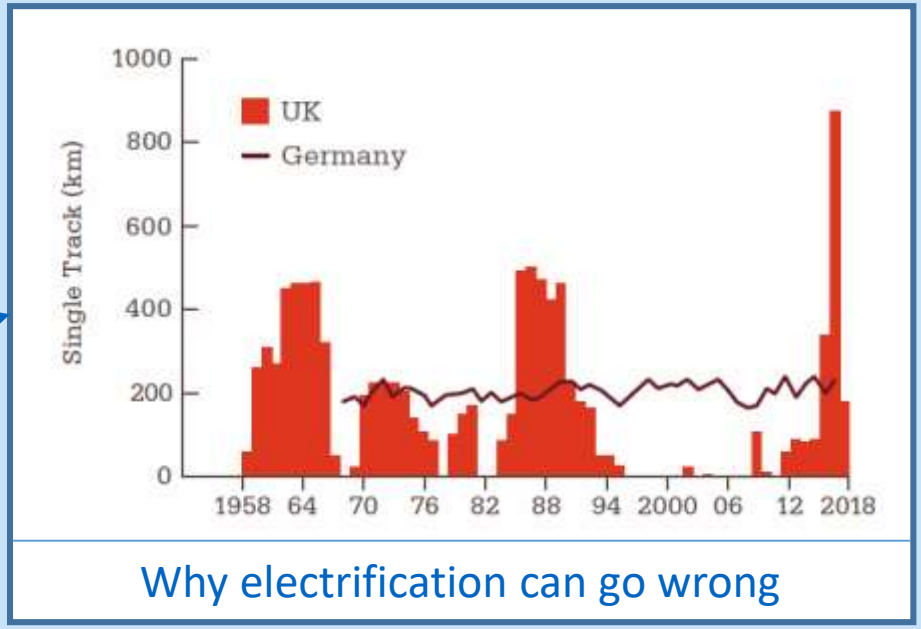


Hydrogen is not an alternative to electrification



"That the UK Government rethinks the cancellation of electrification programmes and moves forward with a more innovative, and long-term approach, electrification rolling programme"

"There is a concern that hydrogen trains will be used by funders as a reason to avoid future electrification. Fuel cell traction should be viewed as an option only where long-term technical, environmental and/or economic factors make electrification a poor option"



Why electrification can go wrong

So is Hydrogen the answer? Yes in some cases

YES for non electrified medium-speed, medium - range services

- Mature technology – carrying passengers in Germany
- Offers DMU performance, efficiency and range
- Slightly more efficient that diesels
- Long term stability of fuel costs
- Synergies with renewable energy supply and hydrogen road vehicles
- Zero local emissions, zero CO2 from green hydrogen

NO for high speed, high acceleration, long range services

- Limited range due to low energy density of hydrogen
- Unsuitable for freight services
- Not a bi-mode diesel module replacement
- Poor overall efficiency - almost three times the energy consumption of an electric train
- Electric trains are more powerful

Not a replacement for electrification but it may be for short and middle distance diesel trains that comprise 2,500 rail vehicles (17% of UK passenger fleet)

Hydrogen trains should be part of the future but they are not -