Zero-carbon rail traction options for Far North lines

David Shirres, Editor RailEngineer

Responding to the environmental agenda

Edinburgh science festival charity bans fossil fuel sponsorship

"Public concern about issues such as climate change and the impact of business on society has never been more intense than it is today. Accordingly, sustainability has now risen to the very top of the corporate agenda."

Arthur D Little Global

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

Speech

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

Net zero carbon emissions by 2050

"It is the duty of the Secretary of State to ensure that the net UK carbon account for the year 2050 is at least 80% lower than the 1990 baseline"


Net Zero
The UK's contribution to stopping global warming

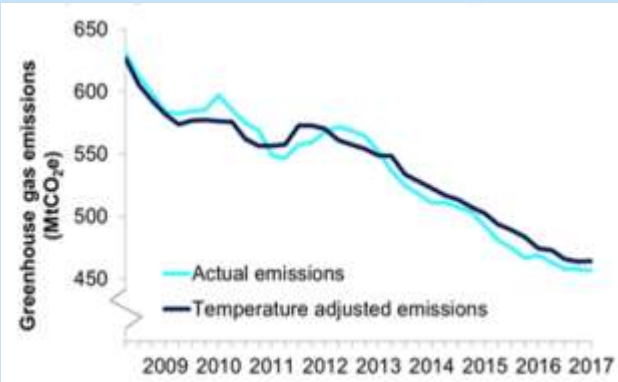
Committee on Climate Change
May 2019

A net-zero greenhouse gas target for 2050 is achievable with known technologies.

Only possible if clear, stable and well-designed policies are introduced across the economy without delay.

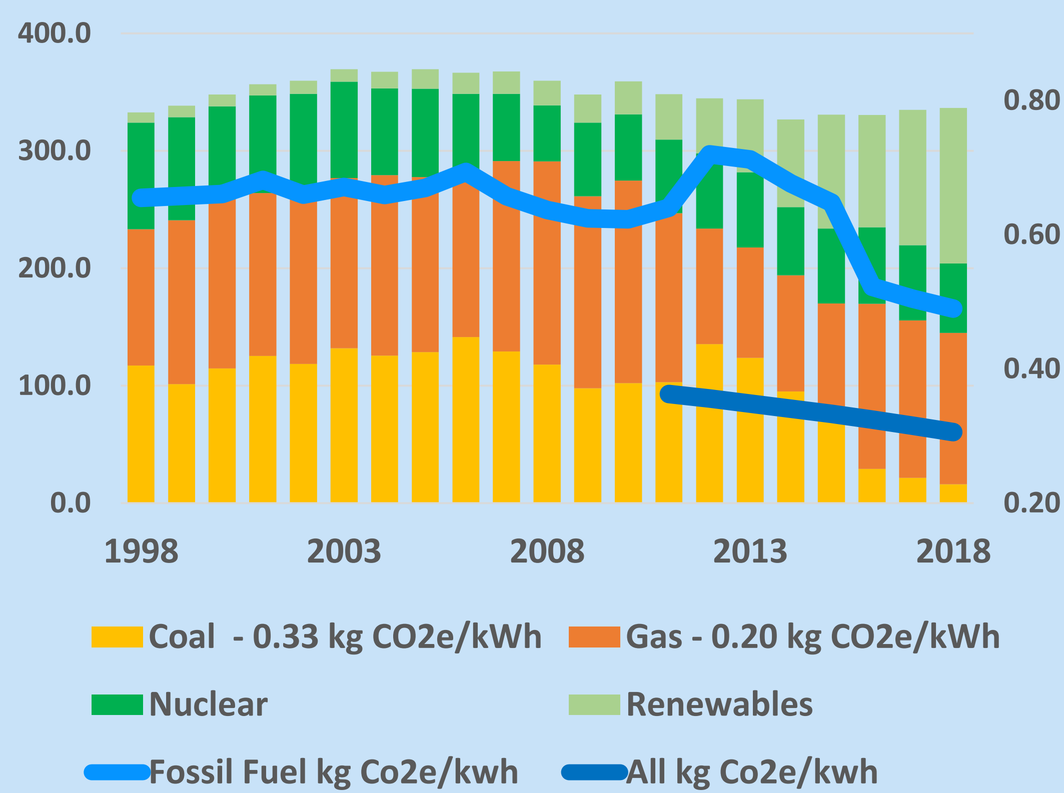
- Electrification (of road transport and heating) is a key to reducing emissions
- Rail electrification should be planned on a rolling basis to keep costs low
- This will roughly double grid demand to just under 600 TWh in 2050
- Scenarios assume that HGVs largely switch to hydrogen fuel by 2050
- "Currently the general public has a low awareness of the need to move away from natural gas heating".

42 % reduction so far – mainly by greening the grid



	1990-2017 % change
Energy supply (including power sector)	57%
Industrial process	49%
Business	41%
Transport	1%
Residential	18%
Public	41%

UK Electricity Generation (TWh) 1998-2018



Predicted CO2 kg/ kWh	
2019	0.285
2040	0.050

Rail electrification's carbon credentials

2016/17	Rail passenger vehicles	
	Electric	Diesel
Fleet energy usage	3,534 m kWh	501 m litres
Fleet emissions (m tonnes CO2e)	1,004	1,361
Fleet size	10,794	3,871
tonnes per vehicle	93	352
2040 (with same fleet size and Government predictions for reduced grid emissions)		
Fleet emissions (m tonnes CO2e)	176	1,338
tonnes per vehicle	16	346

Hydrogen trains are effectively electric trains if hydrogen is produced by electrolysis

First hydrogen passenger train

Alstom's iLint entered passenger service in Lower Saxony in 2018,

- Maximum speed of 140 km/hr
- 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 – a 7.9 kW / tonne power to weight ratio
- Energy savings from regenerative braking up to 25%
- 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.

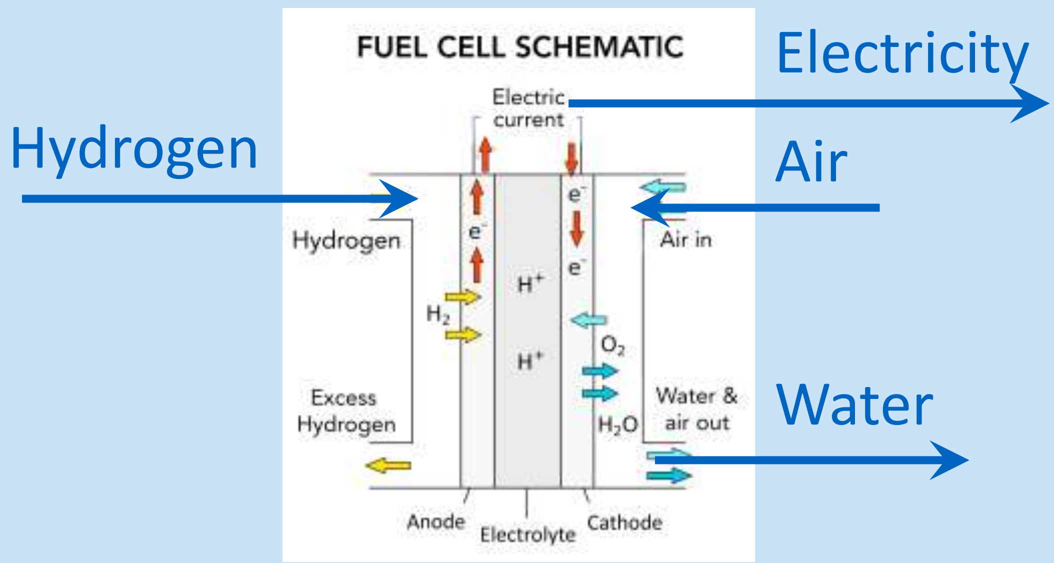
Only possible due to rapid advances in fuel cell technology

Fuel Cell development	2001	2011
Power (kW)	25	33
Power density (W/kg)	86	440
Power density (L/kg)	68	264
Efficiency %	38 - 45	48 – 55

Emissions

- Diesel train emissions do not meet strict Euro 6 road vehicle standard for emissions per kWh
- Until recently this was acceptable as more energy efficient trains have lower emissions per passenger kilometre than road vehicles
- As cities such as Glasgow and Edinburgh introduce Ultra Low Emission Zones, it will become increasingly unacceptable for rail vehicles to have lower per kWh emissions standard

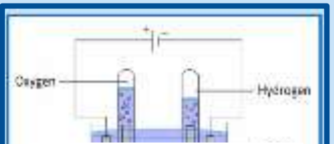
The rail industry has to respond to this concern for which Hydrogen trains are a solution

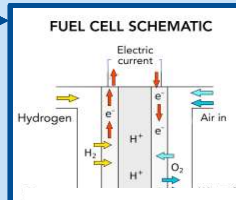


Indicative well-to-wheel efficiency comparisons

Hydrogen - on site production from renewable energy

Electricity from grid 3.4 kW → Electrolysis → Compress to 350 bar → Fuel Cell → Converter and Drive → Wheel 1.0 kW





Efficiency	Electrolysis	Compress to 350 bar	Fuel Cell	Converter and Drive	Overall
Efficiency	68%	94%	52%	89%	29%

Diesel

Diesel 3.7 kW → Engine → Transmission → Final Drive → Wheel 1.0 kW

Efficiency	Engine	Transmission	Final Drive	Overall
Efficiency	38%	78%	94%	27%

Electrification from renewable energy

Electricity from grid 1.2 kW → OLE Transmission → Transformer → Converter and Drive → Wheel 1.0 kW

Efficiency	OLE Transmission	Transformer	Converter and Drive	Overall
Efficiency	98%	95%	89%	83%

Energy density

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**
Automotive battery pack	1.0	10.8
Automotive battery pack 2035 (1)	3.6 ??	43.2 ??

1. Technology roadmap for electrical energy storage produced by the UK Advanced Propulsion Centre

Battery trains – extending electric traction


FEATURED RAIL NEWS

Hitachi plans to run ScotRail Class 385 EMUs beyond the wires

BY DAVID SHIRRES BSC CENG MIMECHE DEM

1 28TH MARCH 2019

Hitachi are in discussions with the Scottish Government to run a Class 385 variant with underfloor batteries that could either be charged whilst under the wires or whilst stationary at the end of the route.

MUST READ

CAF wins DLR train order

The 5 bidders for HS2 train

- 20 to 60 miles beyond the wires according to number of batteries fitted, the more batteries the more complex the required train modification
- Significantly reduced maximum speed and acceleration under battery power
- Batteries changed from overhead line supply

Battery trains – Vivarail

- Has a 200 kWh battery which gives a range of 60 miles
- Sufficient for a return trip between Thurso and Wick
- Has an automatic fast charging system

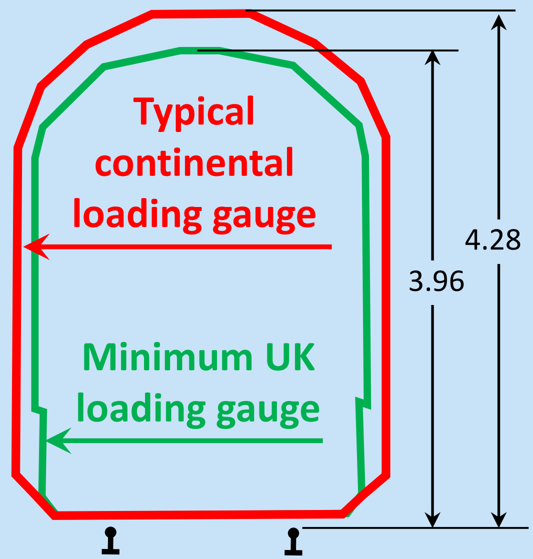
Vivarail class 230 battery railcar under trial on the Bo'ness and Kinneil Railway on 11th October 2018

Automatic Fast charging system

- Uses short section 3rd and 4th rail
- Train has carbon ceramic shoegear to withstand heat generated
- High charging current from a bank of lead acid batteries which are trickle charged and so do not require heavy current supply

Alstom's UK Breeze proposal – January 2019

- In January, Alstom unveiled their UK hydrogen train design, a conversion of a redundant electric multiple unit
- Range of 1,000 km
- Top speed of 140 km/h
- Trains could be running in 2022
- Fleet operation needed to justify investment in hydrogen infrastructure
- Unlike Germany, hydrogen tanks are within motor coach taking up 25 % of the space of a 3-car train
- A purpose-built UK hydrogen train may not require internal hydrogen tanks



Performance comparisons

	Passenger multiple unit trains		
	Hydrogen	**Electric**	**Diesel**
Power/range constraints	Low energy density of hydrogen	Range – none Power – 7.5 MW per pantograph	Diesel engine & tank
Typical kW/t	8 kW/t (iLint)	12.6 kW/t (class 385)	6.4 kW/t (class 170)
Efficiency (1)	29%	83%	27%
Regenerative braking	Yes	Yes	No
CO2e	Depends how electricity is generated		2.6 kg per litre
Emissions	Only emission is water	None at point of use	NoX, particulates etc
Energy vector	Yes	No	No
Infrastructure required	Hydrogen distribution, storage and supply	OLE and power supply	Diesel storage and fuelling points

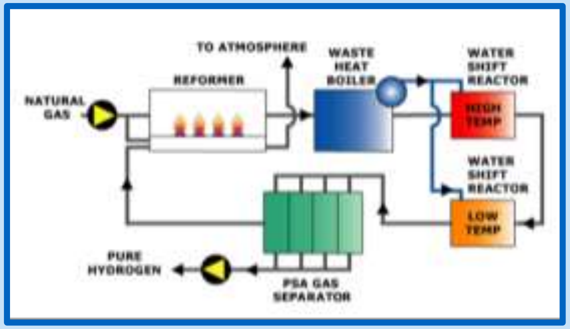
1. Does not consider efficiency of generating plant

Hydrogen production

Currently annual production 50 millions tonnes for ammonia production or petroleum refining by two main methods:

Steam reforming - extracts hydrogen from organic feedstock, usually Methane

$$CH_4+2H_2O=CO_2+4H_2$$



Percentage produced = 96%

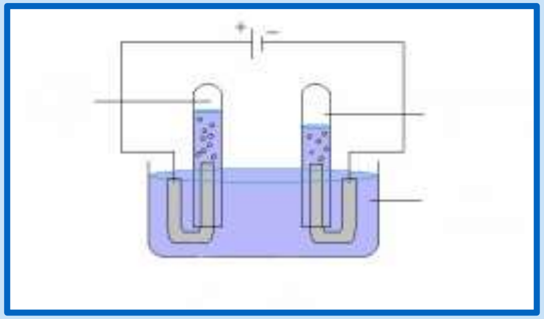
Cost = £2.6 per kg H_2

CO2e = 57 grams/MJ

CO2e diesel = 74 grams/MJ

Electrolysis -DC current splits water molecules into Hydrogen and Oxygen

$$2H_2O=O_2+2H_2$$



Percentage produced = 4%

Cost = £3.8 per kg H_2

Zero CO2e if produced from renewable electricity

Offshore wind power developments

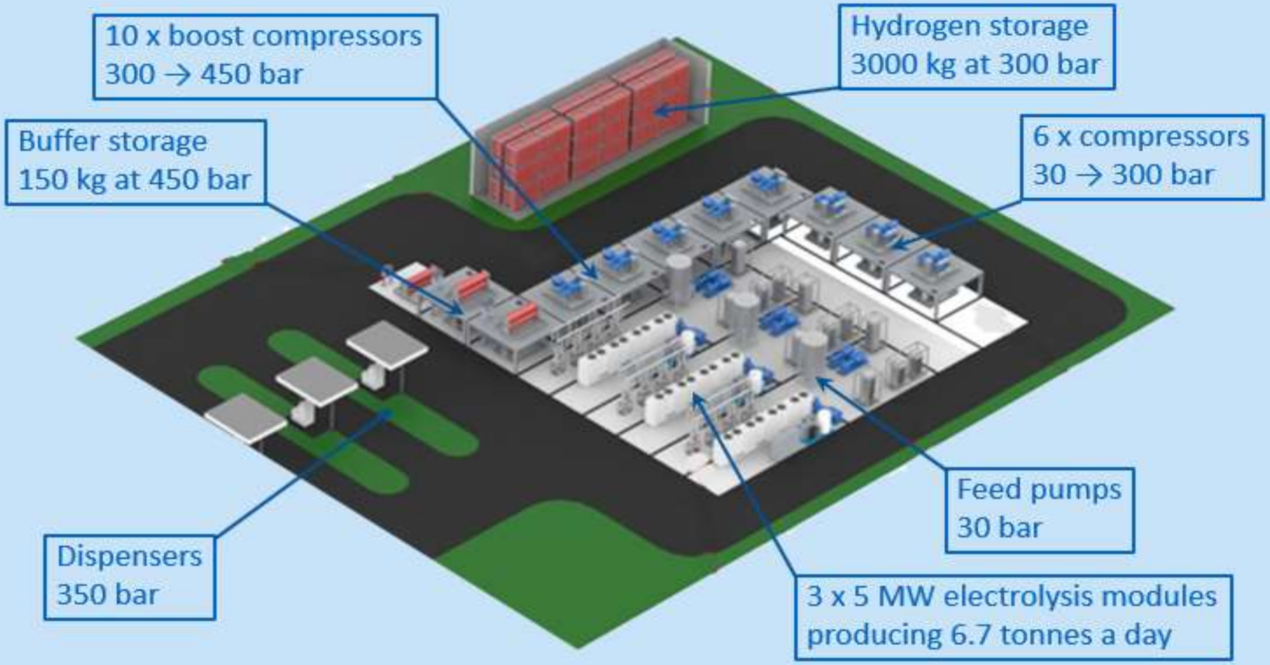
- Huge investment in off-shore turbines and specialist ships for maintenance and installation
- 154-metre turbines 7MW now being installed up to 100 km from the shore
- One control room for 7,500 Siemens turbines worldwide.
- With remote condition monitoring, very few visits to turbines, are required

- Wind is now the cheapest form of utility-scale power generation
- In past six years, costs reduced from £200 to £52 / MWh
- A trend that is likely to continue

Hydrogen supply

- Resilient supply essential
- Reforming cheaper than electrolysis but not low carbon. It also requires a large plant which may be some distance from a depot
- Hydrogen trains are only zero carbon if produced by electrolysis from renewables

A 15 MW plant could supply 30 trains or 300 buses



Hydrogen supply

With a range of 1,000 km, hydrogen trains on rural Scottish routes could be fuelled from hydrogen plants in Glasgow and Inverness

Synergies

- Hydrogen trains must not be considered in isolation
- The 2050 net-zero emissions target requires increasing use of hydrogen for road transport and to replace natural gas for heating
- Hydrogen production also provides the energy storage that is needed for the required expansion of wind power

UK’s 19 hydrogen fuelling stations (Jan 2018)

The first hydrogen trains were bought by Lower Saxony which has an installed wind power capacity of 7,800 MW

Aberdeen’s 10 hydrogen buses

Zero-carbon rail traction for far north

- With its low rolling resistance and electrified intensively used routes, rail is well placed to deliver carbon reductions to meet the 2050 net-zero target.
- If electrification is not appropriate for rural routes with infrequent services the only zero-carbon options are:

For journeys of up to 50 miles (say, Wick to Thurso 21 miles)

A battery train such as Vivarail

But - the provision of a tiny bespoke fleet may not be most cost effective option

Far North zero-carbon rail traction options

For journeys over 50 miles

Hydrogen trains

- A mature technology carrying passengers in Germany
- Offers DMU performance, efficiency and range
- Long term stability of fuel costs
- Synergies with renewable energy and hydrogen road vehicles
- Also offers zero harmful emissions

Note elsewhere hydrogen trains are not suitable for high speed, long range or commuter services

- Limited range due to low energy density of hydrogen
- Insufficient power to provide the speed and acceleration offered by electric trains
- Poor efficiency - Almost three times the energy consumption of an electric train