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Hydrogen as a fuel for the railway sector

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Hydrogen as a fuel?

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Hydrogen is an energy vector

Producing hydrogen requires a lot more energy than is released when it is used

Shouldn't we just electrify everything?

The goal is decarbonisation – and the grid will be carbon free by 2050 – so it becomes an economic choice

Huge costs of electrification mean that H2 can be competitive on less dense routes

Efficiency is important, but really the question is "What Price Speed?"

The application of fuel cell technology to rail transport operations

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Abstract: Fuel cell technology has in recent years undergone a period of rapid development. This evolution has been driven by the requirements of developed countries to reduce the emission of greenhouse gases, with particular emphasis placed on reducing CO_2 emissions. This article discusses the possibility of using fuel cell technology for rail vehicle propulsion, with the United Kingdom chosen as a case study. A brief review of fuel cell technology and its application within the UK is presented. It is concluded that, although the technology for fuel cell power will be suitable within the next few years, its adoption by mainline UK rail operators will be delayed considerably until existing diesel vehicles have reached the end of their useful life. By this time the technology of fuel cells will be well proven within other transport markets and its transfer to rail markets will be facilitated. This will be augmented at this time by increasing diesel fuel prices. However, the adoption of fuel cell technology for light rail/tram systems does offer advantages in terms of infrastructure development and aesthetics which could make it a serious option for new and upgraded light rail/tram schemes.

Keywords: fuel cell, hydrogen economy, motive power

1 INTRODUCTION

In response to the global effort to reduce the environmental burden of CO_2 emissions, the rail industry has already anticipated changes in the relevant emissions standards. There has been a sustained improvement in diesel-powered vehicles and for electric vehicles there are continuing efforts to reduce emissions in power generation. Rail travel is considered to be an environmentally friendly form of transport, but there is considerable scope for improvement. Currently in the United Kingdom, the number of electric rail vehicles outnumbers diesel-powered vehicles by approximately 2:1. The electric vehicles are favoured in the congested South-East for commuter services, where the power is supplied via the third rail system. The high-speed East and West Coast mainlines are also electrified along most of the route, offering high-speed services to the North of England and Scotland from London. Diesel locomotives and diesel multiple units (DMUs) are used on routes with a lower density of passenger and freight traffic, where the investment required to electrify the route has proved prohibitive. The approximate energy required for rail travel is 0.8–0.9 MJ per passenger-km for a load factor of 0.5. This already compares well with the 1.4–2.8 MJ per passenger-km for road vehicles with passenger occupancy of 1.3 persons per vehicle [1]. Electrified rail propulsion offers the further advantage of reduced CO_2 emissions associated with large-scale power production. For example, France uses nuclear power with virtually zero CO_2 emissions to supply approximately 37 per cent of its total energy requirements [2]. Therefore current rail travel has a significantly lower environmental burden than other forms of transport, and future reductions in CO_2 emission can be achieved by encouraging more people to use rail as a method of transportation. In the UK the Strategic Rail Authority (SRA) aims to increase passenger usage by 50 per cent and freight tonnage by 80 per cent over the next 10 years, as set out in their ten-year plan [3].

Fuel cell development for current vehicular applications has concentrated on the private automotive industry. For example, the California fuel cell partnership [4, 5] is a unique collaboration of vehicle manufacturers, energy companies, fuel cell technology companies and government agencies. Their mission is to develop new technologies to improve the environmental sustainability of road vehicles. An initial goal is to have up to 60 vehicles in operation before the end of 2003. Similar goals have been specified for a fleet of

The MS was received on 21 October 2002 and was accepted after revision for publication on 10 March 2003.

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Fifty-five years ago, 'What Price Speed?' illustrated the price to pay in terms of efficiency for faster travel. Now Imperial College's Railway Research Group updates this seminal study and shows that the efficiency range of modern transport modes has been 'stretched' at both ends. Economic and environmental demands leading to more efficient transport have been matched by a growth in faster, more fuel hungry modes brought about by society's need for speed.

WHAT PRICE SPEED – REVISITED

THE DEVELOPMENT OF TRANSPORT

As society grows wealthier over time, people tend to travel more frequently and over greater distances. Travel demand increases by a factor of approximately 10 for each generation, but the amount of time spent travelling has remained constant at approximately one hour per day per person over the past three decades. The primary reason for this is the development of faster and faster modes of transport. Speed is a key driver for transport developments, although factors such as price, convenience, comfort and safety also play major roles.

'WHAT PRICE SPEED?'

Transport now consumes a large and increasing proportion of our energy budget. Efficient energy use is therefore of considerable importance, but a method of comparison over a wide range of speeds and different vehicle types is by no means obvious. In a classic paper written just over 50 years ago, Gabrielli and von Kármán suggested using specific traction force (or conversely specific resistance) to make such comparisons. The central question of their paper was 'What Price Speed?'. A further examination of this revealed that any form of transport is an economic balance between the cost of the transport and the value of the time that goods or people are incapacitated for during transit. As Gabrielli and von Kármán also predicted travel trends 50 years into the future, it is now opportune to revisit and update their work.

SPECIFIC TRACTIVE FORCE

For any vehicle type, motion is achieved through the action of a tractive force, which is the ratio of power (*P*) divided by velocity (*V*). If this ratio is further divided by the weight (*W*) then the non-dimensional specific tractive force ($\mathcal{E}$) is obtained ($\mathcal{E}=P/WV$). This can also be interpreted as the specific resistance, akin to a coefficient of friction. The lower the value, the more 'efficient' the transport mode.

Gabrielli and von Kármán assembled a collection of data for installed power, maximum velocity and gross weight for a wide variety of transport modes. Their original data, transformed to SI units, is shown in Figure 1, in which $\mathcal{E}$ is plotted as a function of speed. Broadly speaking, sea, land and air transport are divided into bands of $\mathcal{E}$ from 0.001 to 0.01, between 0.01 and 0.1 and greater than 0.1 respectively. The bulk of the data lies above a line of gradient 1, identified as the Gabrielli-Kármán (GK) line, which represents 'best performance'. The only exceptions below the line are varieties of railway vehicles which operate using a convoy system, for which the resistive force does not increase appreciably with the length of the train (see Figure 1).

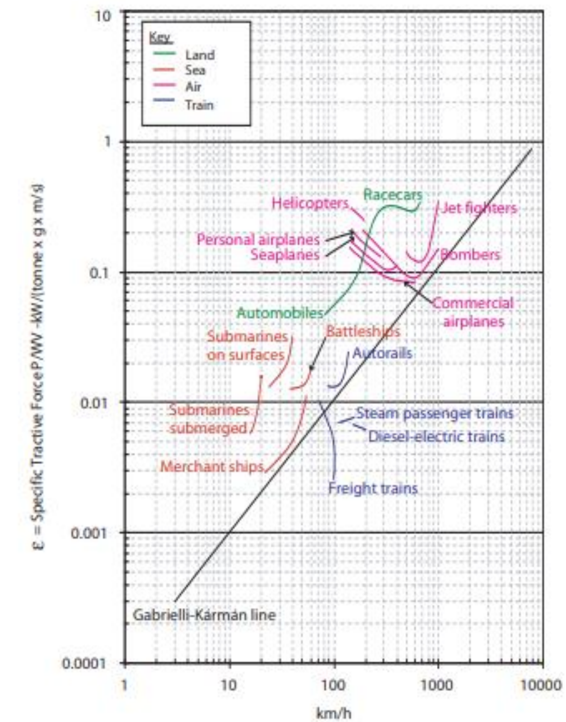


Figure 1
Specific resistance for various transport modes before 1950. The Gabrielli-Kármán (GK) line represents best performance.

MODERN VEHICLES

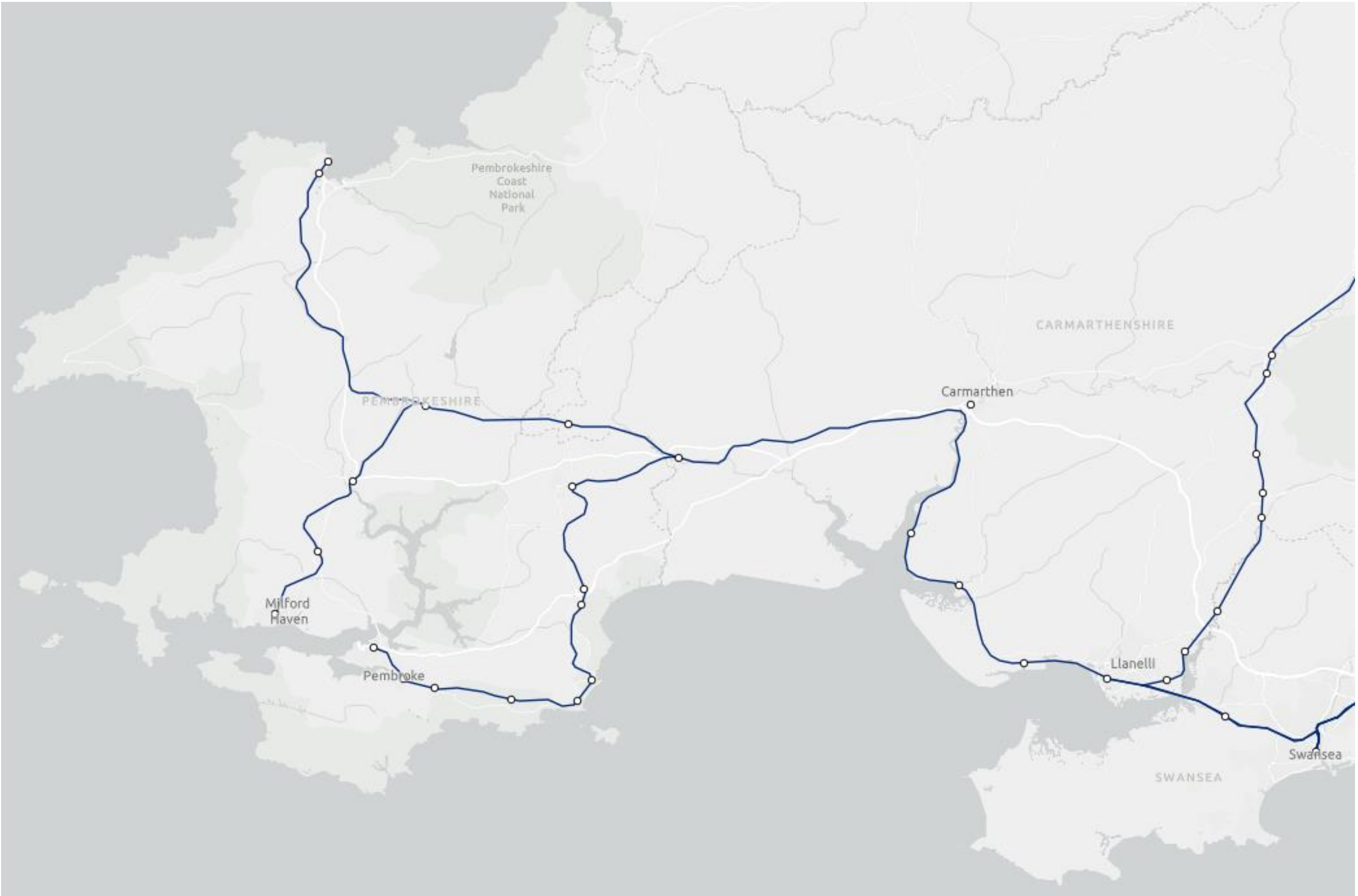
The Railway Research Group at Imperial College, London has recently updated this with information about modern vehicles (with the exception of military vehicles) as shown in Figure 2. At first sight, the fruits of 55 years endeavour seem slight, but the representations are on logarithmic scales, so careful interpretation is needed. Increases in speed will push data to the right, whilst higher speeds need more installed power, which pushes data upwards. On sea, land and air, the best performance has now moved below the original GK line (movement emphasised by arrows on Figure 2), illustrating considerable performance improvement in all kinds of transport. For each of the various transport modes, a line is drawn to represent the lower boundary of existing vehicles. In general, existing technology is capable of producing a vehicle that resides to the left and above the boundary, but some sort of technological advancement is required for a new vehicle to surpass the line and add a data point to the lower-right. A look at the improvements for each mode of transport follows.

AIR TRANSPORT

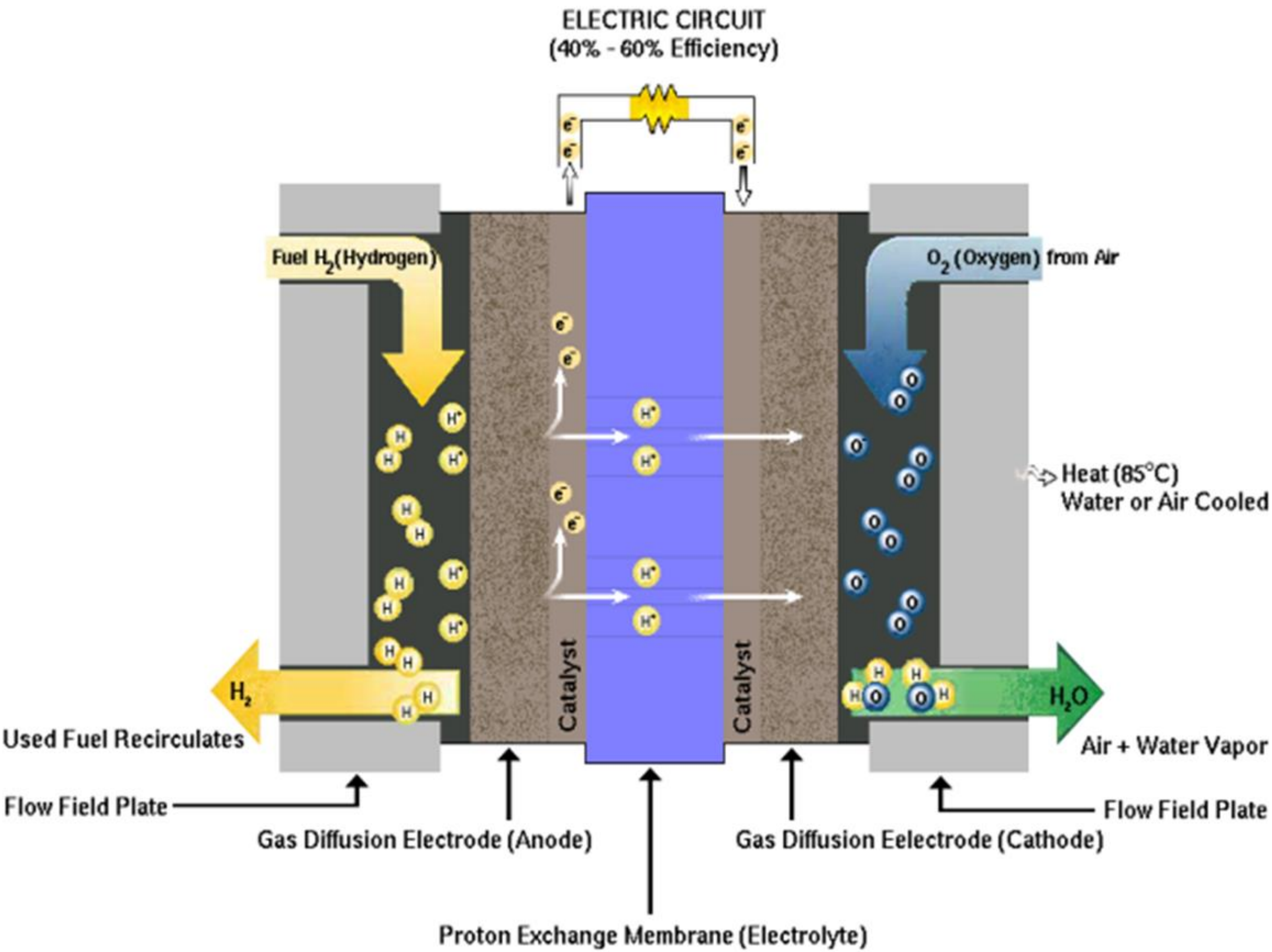
The jet engine has been one of the most significant developments in aircraft propulsion. Combined with a huge increase in the size of aeroplanes, it has enabled a huge growth (and democratisation through lower fares) of air transport to occur over the last 55 years. The Boeing 747-400 ER, with a maximum cruising speed of approximately 1020 km/h and a maximum seating capacity of 524, is an example of a modern plane below the original GK line. Its four engines produce a combined power of about 78 MW at cruise. By comparison, 55 years ago a trans-continental train would have operated at 100 km/h with about 1 MW of steam power.

Developments in material technology have enabled power to weight ratios to increase, through weight reduction in power plants, structure and internal fittings. Together with improvements in combustion technology, the changes have resulted in a huge increase in the operational range of commercial planes. The longest single-leg flight now available is from Singapore to New York, a great-circle distance of 15,323 km

Last in the queue for electrification?



Fuel Cell Principles



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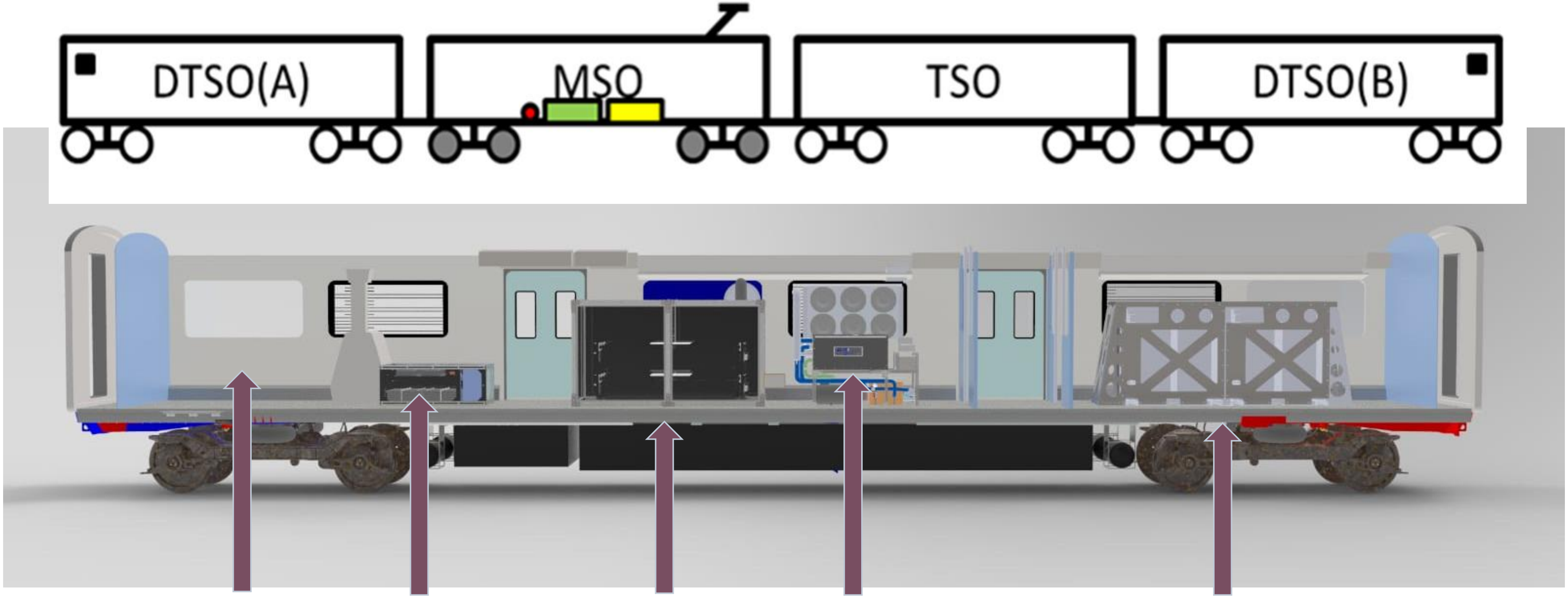
Introducing HydroFLEX

The UK’s first (full-size) hydrogen powered train

How does HydroFLEX work?

Internal layout



The MSO vehicle needed its seats and interior fittings removed to house the HydroFLEX system components

How does HydroFLEX work?

Hydrogen fuel tanks

Carbon Fibre wrapped aluminium tanks

- 350 bar maximum working pressure
- Stores ~5 kg of Hydrogen each (x 4)
- Can run the fuel cell for ~ 4 hours
- Designed to EC79 standards
- Technology developed from Automotive sector

How does HydroFLEX work?

Li-Ion battery packs (84kWh)

Li-Ion battery pack – supplied by Denchi

12 modules in series to form each battery at ~625V

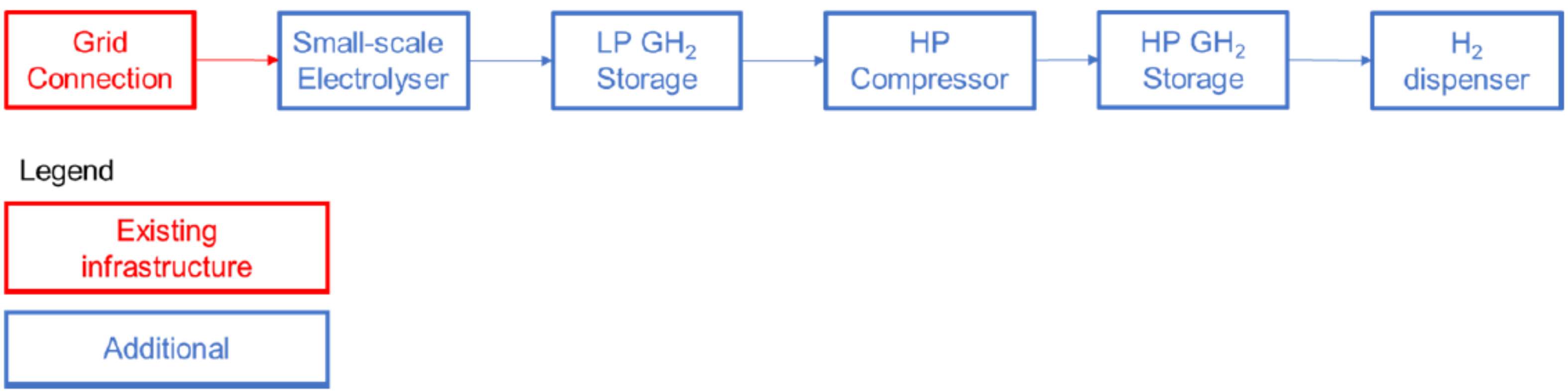
2 batteries in parallel giving additional current & capacity

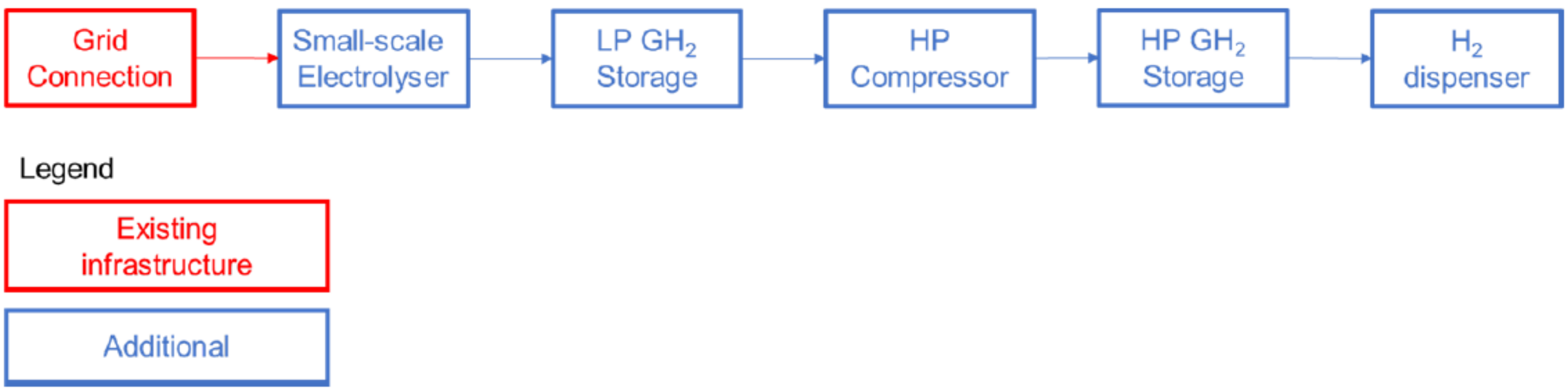
How does HydroFLEX work?

100kW hydrogen fuel cell

Ballard 100 kW fuel cell

- Takes in Hydrogen at 8-10 Bar
- Balance of plant
- Air handling
- Cooling
- DC to DC converter
- Controlled with CAN bus and hardware signals using bespoke BCRRE developed software


Grid Connection
Small-scale Electrolyser
LP GH_2 Storage
HP Compressor
HP GH_2 Storage
H_2 dispenser
Legend
Existing infrastructure
Additional


Grid Connection
Small-scale Electrolyser
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HP GH_2 Storage
H_2 dispenser
Legend
Existing infrastructure
Additional

The future

Hydrogen fuel cell technology is ready today for rail applications – both freight and passenger

On lightly used lines it is the obvious choice to achieve decarbonisation

It will be economic when compared to electrification

Expect to see trails in the coming months and years – with small fleets very soon.

Hydrogen is not a replacement for electrification – but is complimentary

Thank you

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