UNIVERSITY OF BIRMINGHAM | BCRRE

Birmingham Centre for Railway Research and Education

Dr Stuart Hillmansen
Senior Lecturer in BCRRE

A big thanks to the team at BCRRE
Twitter @BCRRE

Deacarbonisation and the role of Hydrogen

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

I am calling on the railway to provide a vision for how it will decarbonise"

Jo Johnson, 12 February 2018

Why we like trains

- F=Ma
- How much acceleration?
- How much Mass?
- What Force?
- How fast?
- How much Power?
- How much Energy?
- How much does the Energy cost?

Physics of traction

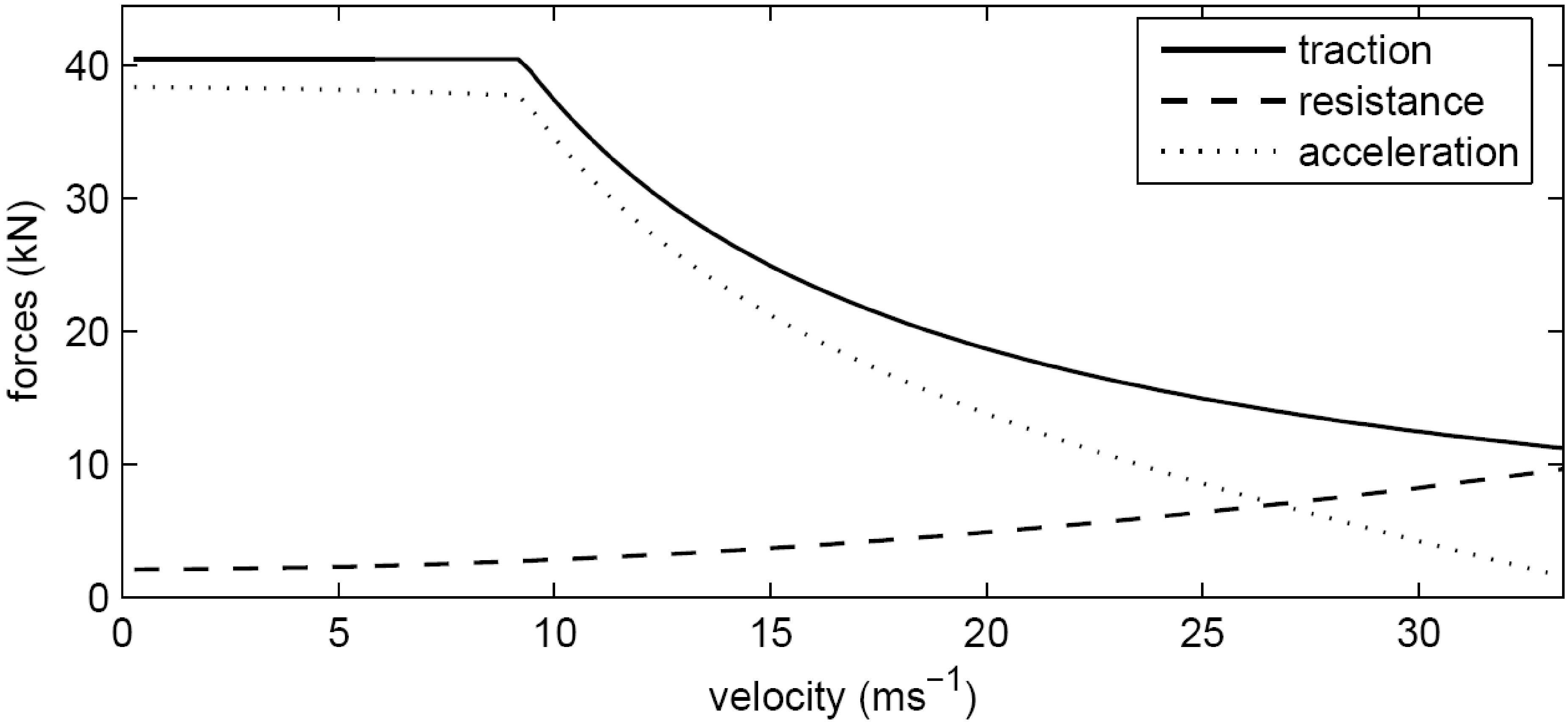
Mass* Acceleration =(Traction – Resistance – slope)

$$M\left(1+\lambda\right)\frac{\mathrm{d}^2 s}{\mathrm{d}t^2}=T-\left(c\left(\frac{\mathrm{d}s}{\mathrm{d}t}\right)^2+b\left(\frac{\mathrm{d}s}{\mathrm{d}t}\right)+a+\frac{d}{r}\right)-\left(Mg\theta\right)$$

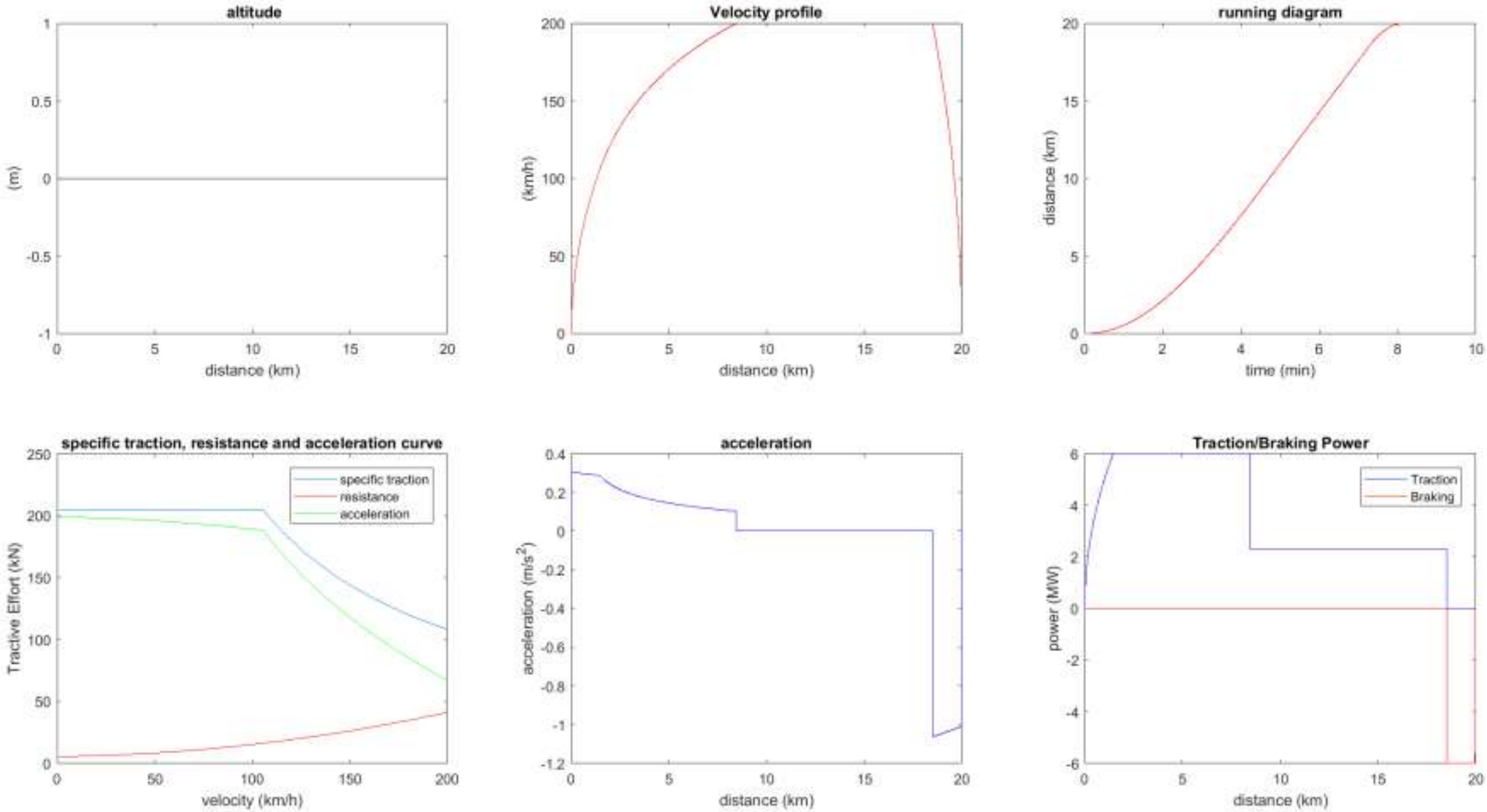
A spectrum of challenges

- Low Power, modest speed
- High Power, high speed

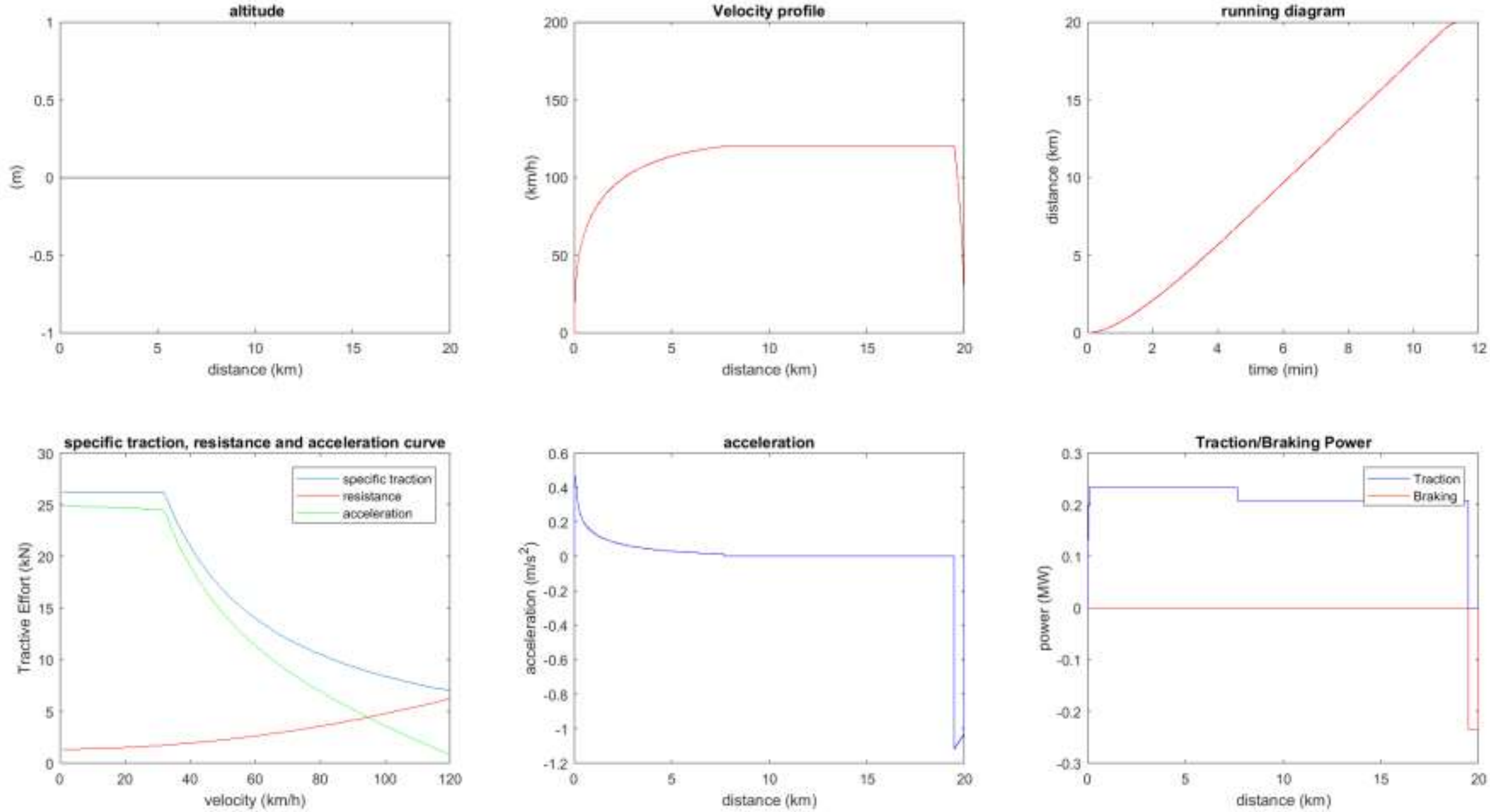
Tractive and resistive forces



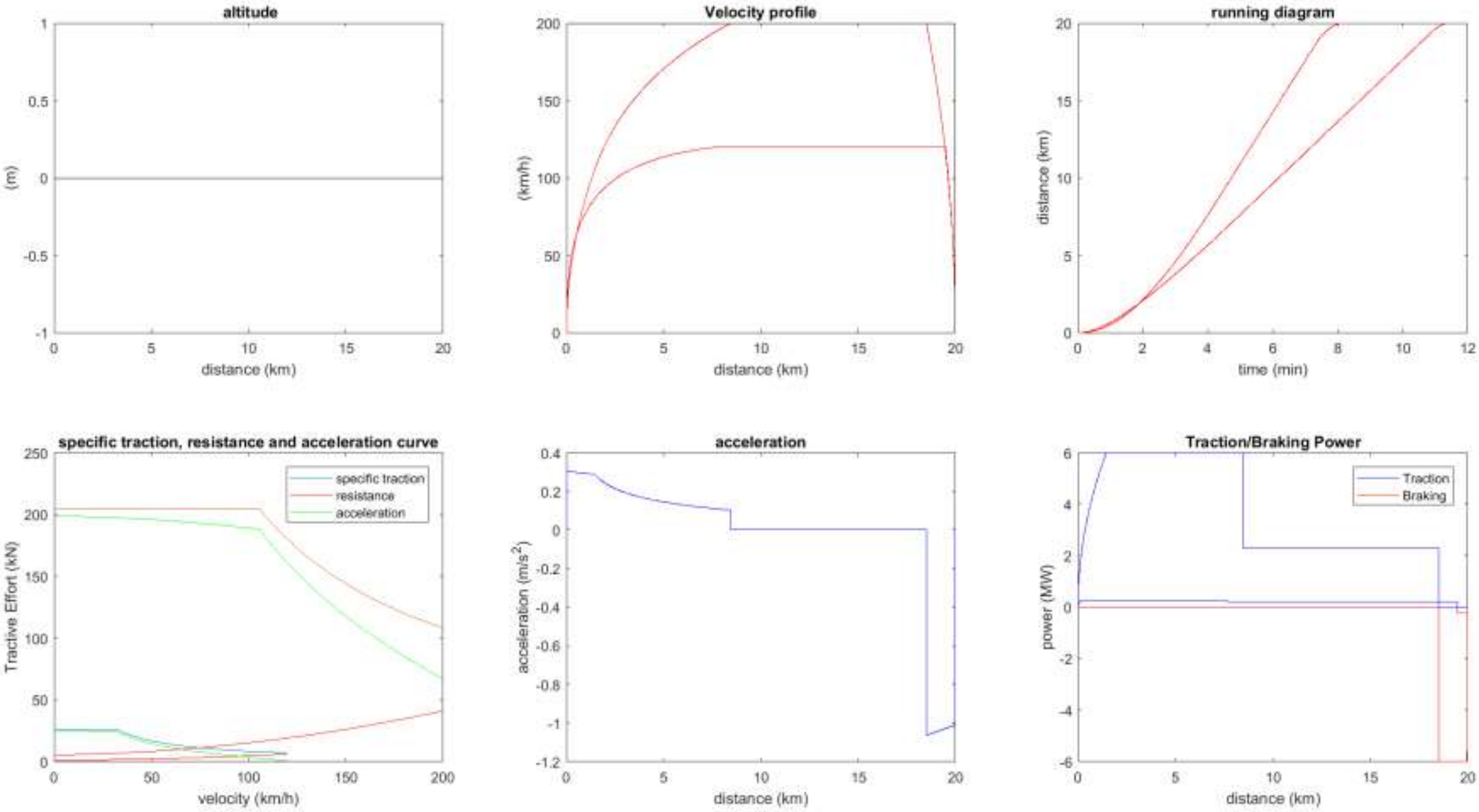
Class 390 performance analysis



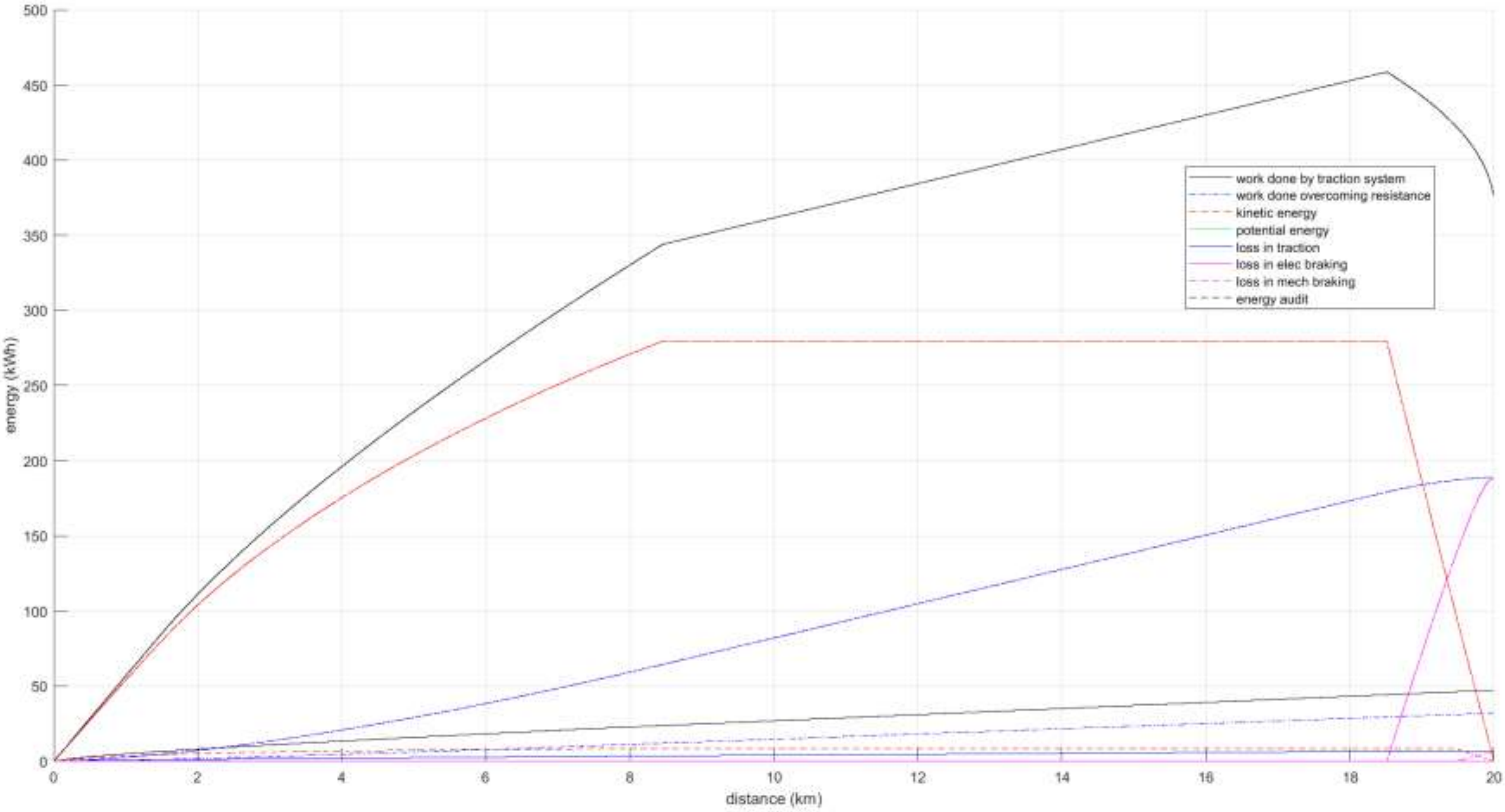
Class 14x performance analysis



Comparison of trains at the extremes of performance



Energy analysis comparison



Regen metrics

Power to be absorbed is approximately the rated traction power.

Energy is related to Kinetic Energy

Class 390 would need at least 300 kWh battery pack. It would need to absorb about 6 MW.

- There is no battery with these specs – so you would end up with a battery probably with ~2 MWh – this would be 20-40 tonnes

Class 14x would need about 8 kWh. It would need to absorb about 300 kW.

- There is no battery with these specs – so you would end up with a battery probably with ~100 kWh – this would be 2-4 tonnes

Metric for hybridisation and discontinuous electrification

Distance where the work done overcoming the resistance to motion at line speed is equal to the Kinetic Energy.

At distances of this and probably 1 or 2 times greater it is beneficial to have regen.

For a class 14x this is approx 5 km

For a class 390 this is approx 25 km

Discontinuous electrification

Need to consider:

Small gaps (neutral sections) – coasting

Medium gaps (~hundreds of metres) – coasting with some energy storage

Slightly bigger medium gaps (~few kms) – energy storage

Very big gaps (10-100 kms) – bi-Mode hydrogen or diesel

Energy Storage Capability (in MJ/kg) for bi-mode (3.6 MJ = 1 kWh)

Hydrogen	142 MJ/kg (HHV)
Compressed natural gas (CNG):	50 MJ/kg
Petrol:	44 MJ/kg
Diesel fuel:	39-42 MJ/kg
Ethanol:	30 MJ/kg
Coal:	29 MJ/kg
Ammonia	18.6 MJ/kg
Biomass:	15 MJ/kg
Domestic waste:	9 MJ/kg
Liquid petroleum gas (LPG):	45-50 MJ/kg
Steel flywheel:	0.014 MJ/kg
Battery:	0.01-0.56 MJ/kg

Summary

Very high speed and long distant trains are best powered using electrification

Modest speed and routes where there is a mix of electrification could be bi-mode hydrogen

Hydrogen is not the solution for all types of railway – but can form an important part in a decarbonised railway

Fuel cell trains

- Overview of Hydrail at UoB
- Introduction to the principles of Fuel Cell power units

- Why hydrogen?
  - Zero emissions at point of use
  - Better range than batteries
  - Easy of refuelling
  - Sources of hydrogen
  - Effectively an electric train
  - FC products now reaching maturity and lower costs

Our contribution to research in Hyrdail:
15 leading research publications (since 2003)

The application of fuel cell technology to rail transport operations

S Hillmansen
Department of Mechanical Engineering, Imperial College of Science, Technology and Medicine, Exhibition Road, London SW7 2BX, UK

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

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

IET Electrical Systems in Transportation
Research Article

IET Journals
The Institution of Engineering and Technology

Conceptual propulsion system design for a hydrogen-powered regional train

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www.ietdl.org

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Abstract: Many railway vehicles use diesel as their energy source but exhaust emissions and concerns about economical fuel supply demand alternatives. Railway electrification is not cost effective for some routes, particularly low-traffic density regional lines. The journey of a regional diesel–electric train is simulated over the British route Birmingham Moor Street to Stratford-upon-Avon and return to establish a benchmark for the conceptual design of a hydrogen-powered and hydrogen-hybrid vehicle. A fuel cell power plant, compressed hydrogen at 350 and 700 bar, and metal-hydride storage are evaluated. All equipment required for the propulsion can be accommodated within the space of the original diesel–electric train, while not compromising passenger-carrying capacity if 700 bar hydrogen tanks are employed. The hydrogen trains are designed to meet the benchmark journey time of 94 min and the operating range of a day without refuelling. An energy consumption reduction of 34% with the hydrogen-powered vehicle and a decrease of 55% with the hydrogen-hybrid train are achieved compared with the original diesel–electric. The well-to-wheel carbon dioxide emissions are lower for the conceptual trains: 55% decrease for the hydrogen-powered and 72% reduction for the hydrogen-hybrid assuming that the hydrogen is produced from natural gas.

1 Introduction

2 Benchmark simulation

$$F = ma \quad (1)$$

$$F = m(1 + \lambda)a \quad (2)$$

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Appalachian State University

Search: Search

International Hydrail Conference 2016

Mon, 07/04/2016 - Tue, 07/05/2016 | Birmingham, UK

The Eleventh International Hydrail Conference was hosted by the University of Birmingham Centre for Railway Research and Education in Birmingham, UK on 4-5 July 2016, and conferees were also ecouraged to attend the Institution of Mechanical Engineers' Railway Challenge competition on Sunday 3 July 2016.Date/Time: Monday, 4 July 2016 (09:00) - Tuesday, 5 July 2016 (17:30)HYDROGEN RAIL NEWS UPDATE: BMVI STUDY EXAMINES THE ECONOMIC, LEGAL AND TECHNICAL PREREQUISITES FOR THE DEPLOYMENT OF FUEL...

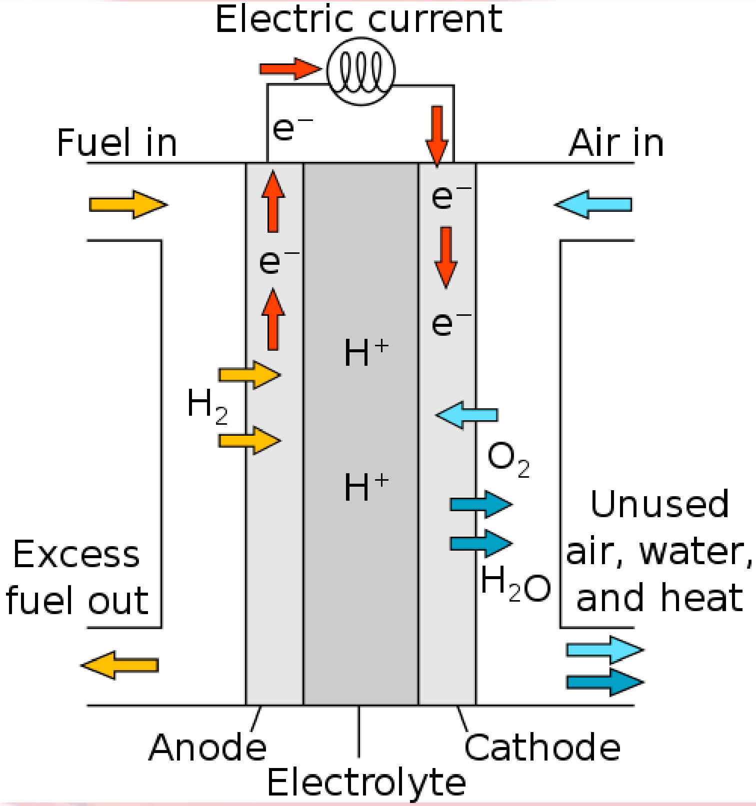
Seventh International Hydrail Conference

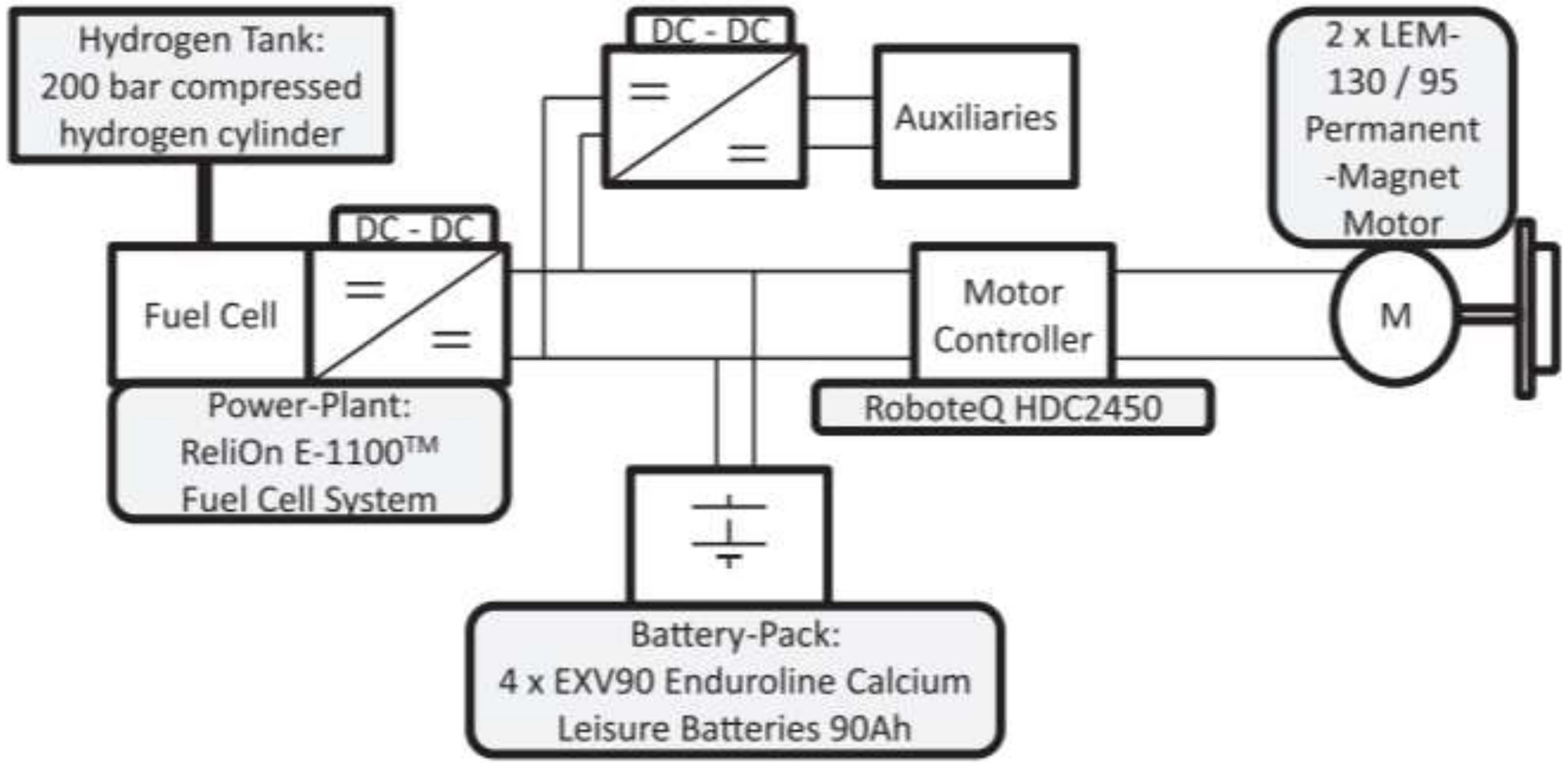
Tue, 07/03/2012 - Wed, 07/04/2012 | University of Birmingham, UK

Download Speaker Presentations The 7th International Hydrail Conference was hosted by the Birmingham Centre for Railway Research and Education in the Gisbert Kapp Building on the Edgbaston Campus of the University of Birmingham. The conference featured presentations by experts in a wide range of fields related to the development, deployment, and use of hydrogen and fuel cells in railway transportation. Highlights of the conference included a keynote presentation from the Chief Scientific...

Practical Work – Institution of Mechanical Engineers: Railway Challenge

PEM Fuel Cell




Hydrogen Tank:
200 bar compressed
hydrogen cylinder
DC - DC
Auxiliaries
2 x LEM-
130 / 95
Permanent
-Magnet
Motor
DC - DC
Fuel Cell
Motor
Controller
M
RoboteQ HDC2450
Power-Plant:
ReliOn E-1100TM
Fuel Cell System
Battery-Pack:
4 x EXV90 Enduroline Calcium
Leisure Batteries 90Ah

Industry funded activity

- UK industry - RSSB – Powertrain challenge (finished 2016)


Future Railway Powertrain Challenge

Fuel Cell Electric Multiple Unit (FCEMU) Project

FCEMU Project - Phase 1 Report - Issue 1

University of Birmingham, Hitachi Rail,

Fuel Cell Systems Limited

HITACHI
Inspire the Next

FUEL CELL SYSTEMS

Primary Author: Stephen Kent

Contributors: Dimantha Gunawardana, Tom Chicken & Rob Ellis

Issue Date: June 2016

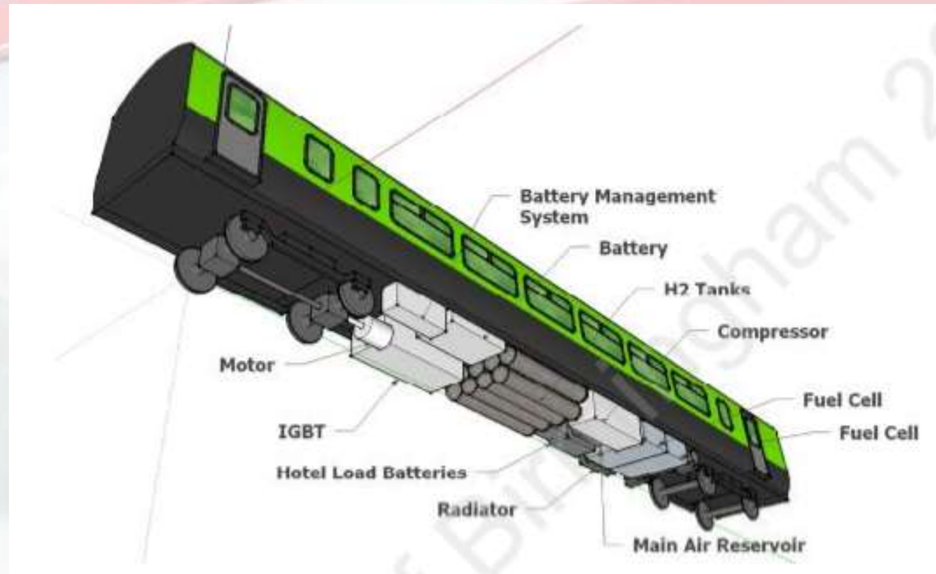
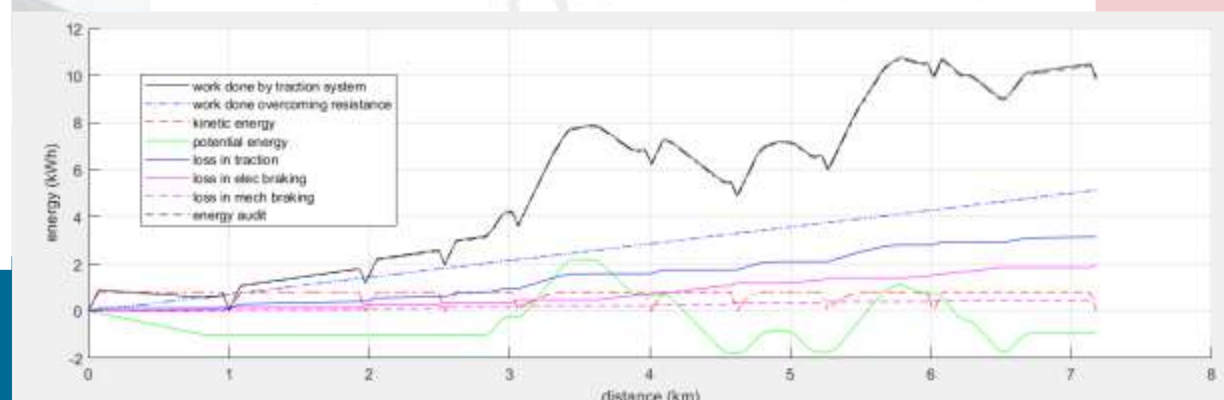


Figure 10 – Concept Design for Class 156 FCEMU (FCSL, 2016)



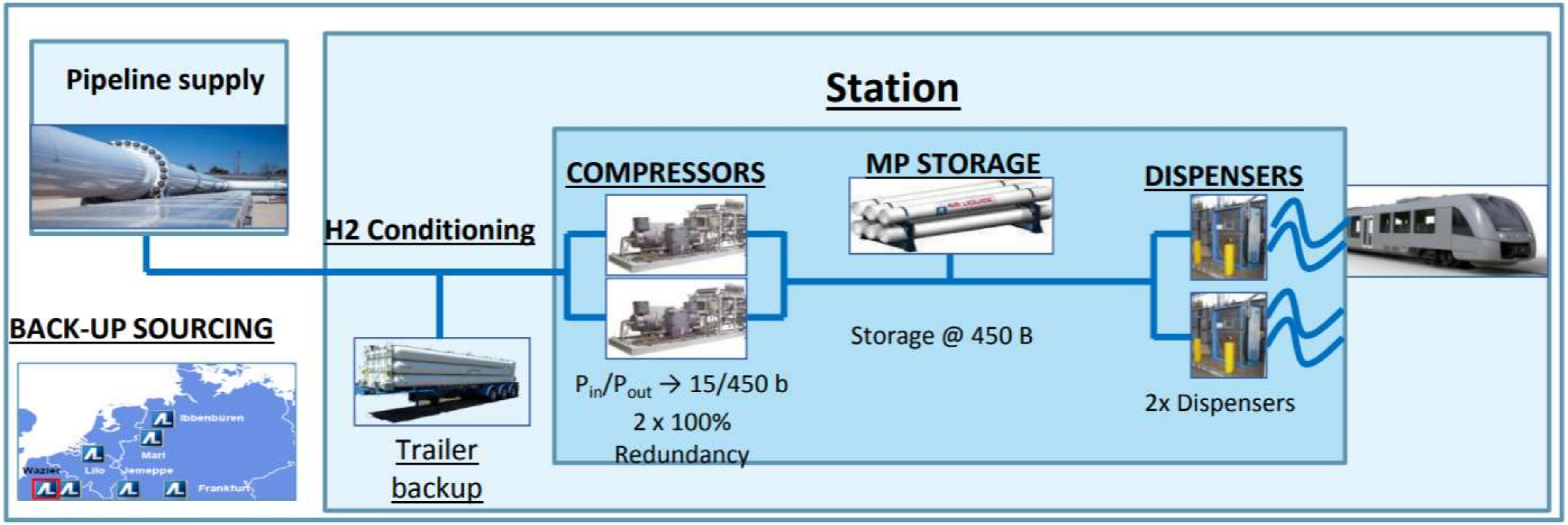
Hydrogen Storage Technologies

- Types:-
  - Liquid Storage
  - Cryo Storage
  - Metal Hydrides
  - Compressed Gas
    - 700 Bar
    - 350 Bar

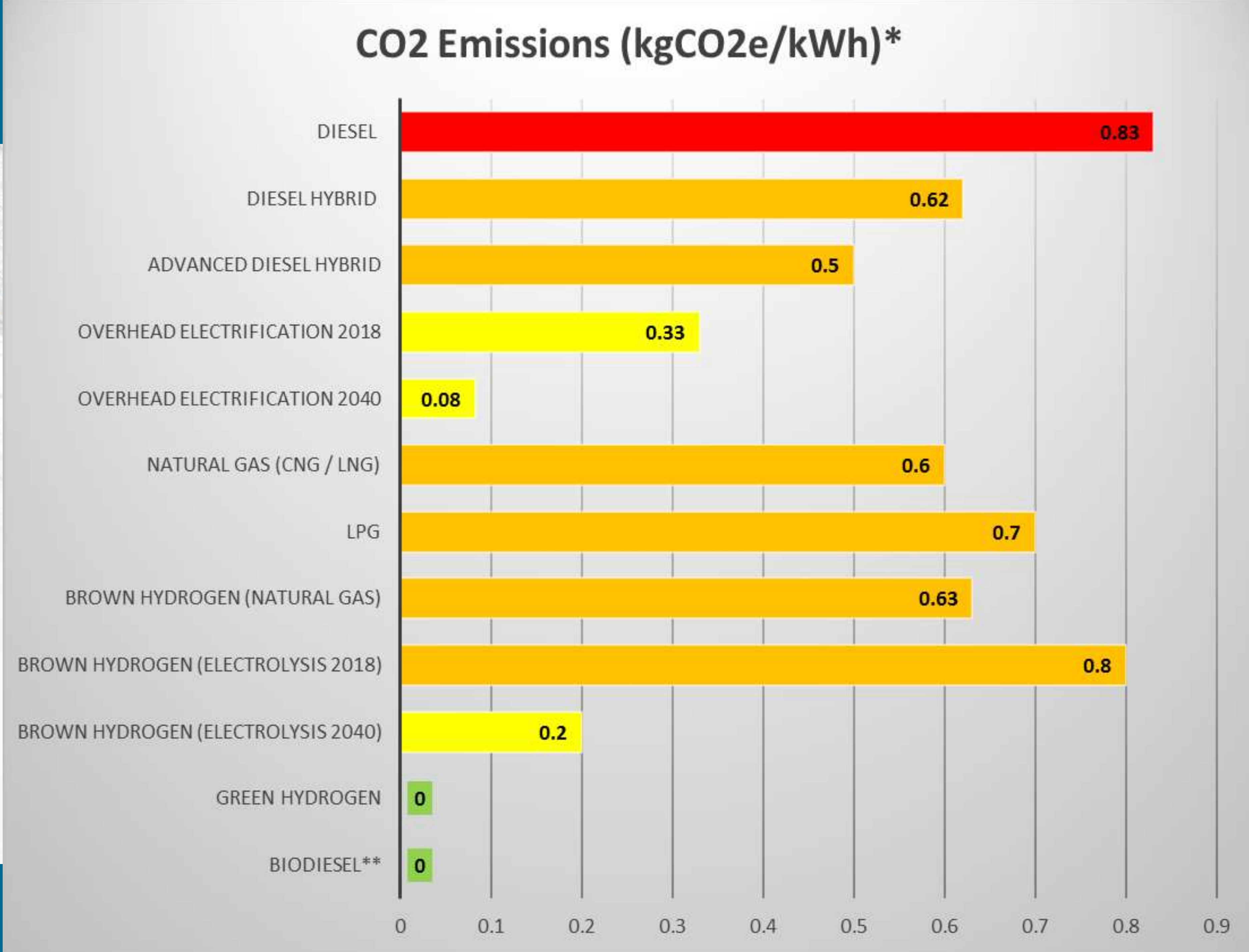
Hydrogen Supplies

- Natural Gas
  - Steam Reforming
  - Fracking
- Electrolysis
  - From The Grid
  - From Renewable Sources
- Algae + Biomass

Pipeline connection offers highest H2 supply reliability



- https://hydrail.appstate.edu/sites/hydrail.appstate.edu/files/12_raphelis.pdf


CO2 Emissions (kgCO2e/kWh)*
DIESEL
DIESEL HYBRID
ADVANCED DIESEL HYBRID
OVERHEAD ELECTRIFICATION 2018
OVERHEAD ELECTRIFICATION 2040
NATURAL GAS (CNG / LNG)
LPG
BROWN HYDROGEN (NATURAL GAS)
BROWN HYDROGEN (ELECTROLYSIS 2018)
BROWN HYDROGEN (ELECTROLYSIS 2040)
GREEN HYDROGEN
BIODIESEL**
0.83
0.62
0.5
0.33
0.08
0.6
0.7
0.63
0.8
0.2
0
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9

Conclusion

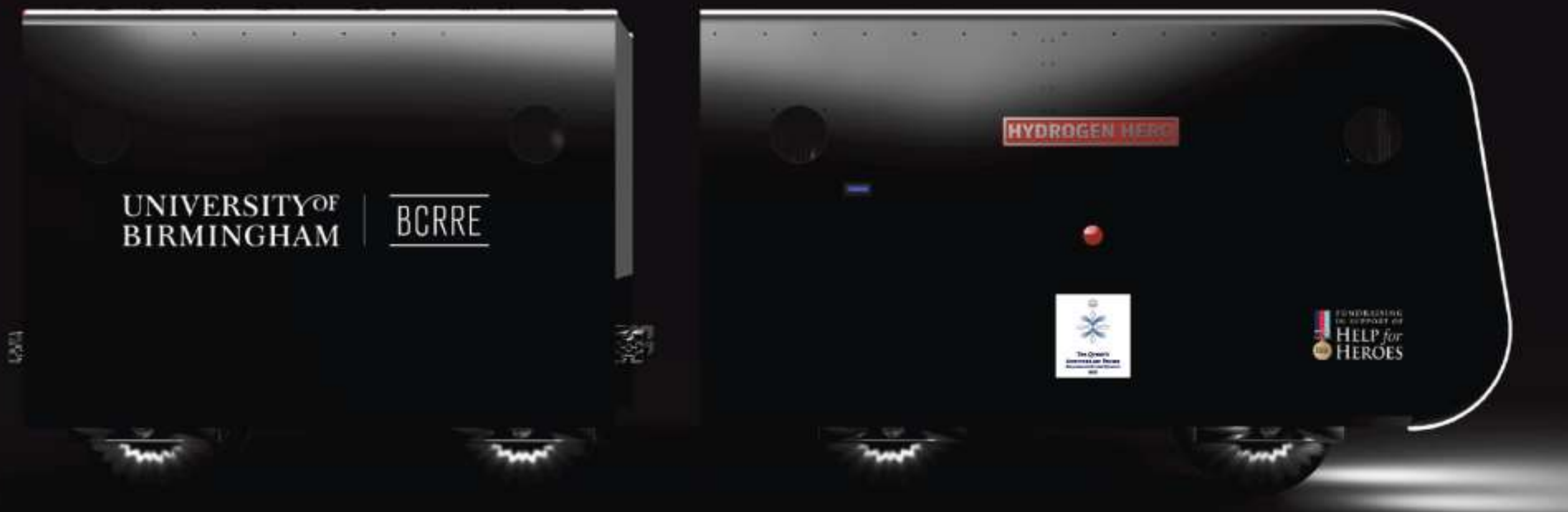
- Route to decarbonisation is complex.
- Electrified railways are dependent on the on-going effort to decarbonise grid electricity.
- Hydrogen Bi-mode and energy storage are a good option of achieving the benefits of electrification away from the wires.

- Hydrogen is being seriously considered – watch this space!

But!!!

- Where does the hydrogen come from – better to use electricity directly?
- Aren't batteries getting better – well yes but unlikely to compete in the long term.

- High pressure.
- Explosive.
- Flammable.



HYDROGEN HERO

- Our students are brought up on hydrogen – they would have big safety concerns about using a liquid fossil fuel.

Network | NEWS FROM INNOTRANS

BCRRE and Porterbrook plan UK's first hydrogen train

Andrew Roden
Contributing Writer
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PORTERBROOK and the Birmingham Centre for Railway Research and Education (BCRRE) signed a memorandum of understanding at InnoTrans in Berlin on September 19 to develop the UK's first standard gauge hydrogen-powered train.

Porterbrook will supply a Class 319 electric multiple unit to BCRRE for conversion. The deal will allow both organisations to demonstrate how hydrogen-powered trains could be deployed across the UK rail network.

Development has recently started, and the train - to be known as HydroFlex - will begin testing and embarking on demonstration runs in summer 2019. The train will be able to operate on 25kV AC overhead and 750V DC third-rail routes, while the addition of a hydrogen fuel cell will enable it to operate in self-powered mode without the need for diesel engines.

A team from BCCRE recently demonstrated *Hydrogen Hero*, a narrow-gauge fuel cell-powered train, at the Rail Live event in June this year (*RAIL* 856).

Present at the signing was Secretary of State for Transport Chris Grayling, who joined discussions afterwards on the potential to 'decarbonise' the railway in terms of emissions at source.

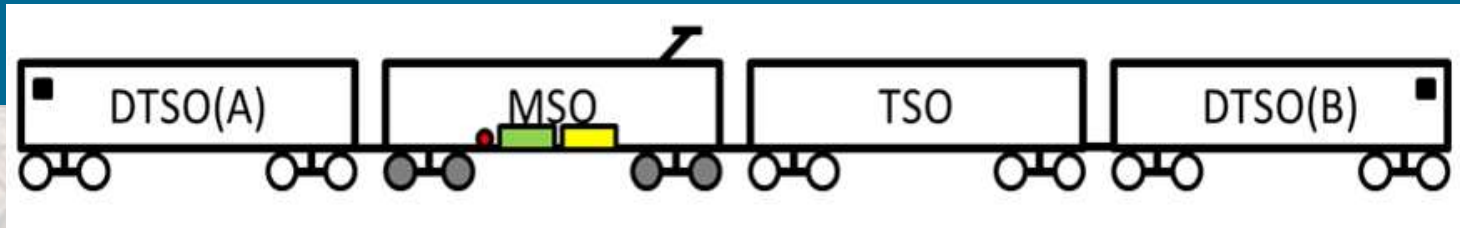
"This exciting partnership between Porterbrook and the University of Birmingham is a great example of how forward-thinking businesses and our world-class universities can work together to deliver innovation that matters. I look forward to seeing the HydroFlex train coming to the UK railway in the very near future," he said.

Porterbrook Chief Executive Mary Grant said: "I am delighted that BCRRE has chosen to work with Porterbrook on this exciting fuel-cell project. The HydroFlex will not only showcase rail innovation, it will also demonstrate how the private sector railway can effectively partner with educational bodies to jointly deliver real benefits to passengers, train operators and the communities our railways serve."

BCRRE Senior Lecturer in Railway Systems Dr Stuart Hillmansen added: "Hydrogen-powered trains offer a cleaner alternative to current diesel trains, and this project demonstrates the opportunities and value of innovation in the rail industry."

@AndyRoden1

An artist's impression of the HydroFlex train. PORTERBROOK.


DTSO(A)
MSO
TSO
DTSO(B)


DTSO(A)
MSO
TSO
DTSO(B)


HYDRO
FLEX
porterbrook
in partnership with
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Zero emissions for a greener railway