Powering Transport – an update for 2021

Some decarbonisation options for rail transport in Scotland

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and also

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Some history first

2019

Powering Future Transport in Scotland

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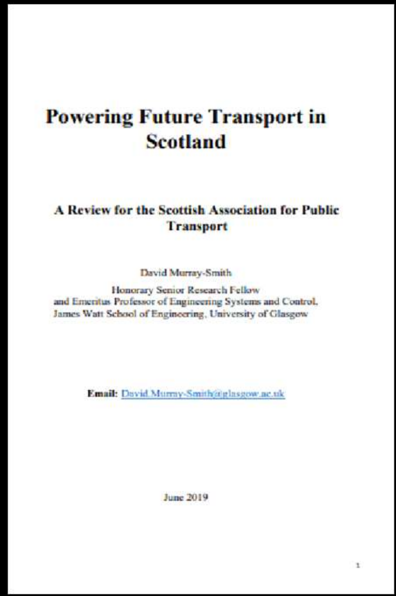

Powering Future Transport in Scotland

A Review for the Scottish Association for Public Transport

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June 2019

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That presentation and first SAPT report led on to a more detailed report later in 2019 on batteries, fuel-cells and other energy storage systems.

" .....this is a continuing process and the report requires regular updating.....".

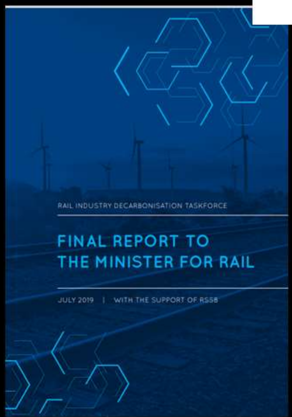
2020

Two more reports were prepared in 2020, more specifically on modelling and computer simulation of hydrogen/battery electric trains for secondary routes such as the West Highland lines. Aim: initially mainly personal - to try to understand the issues better.

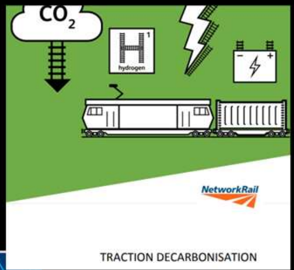
All these reports now available through the SAPT website.

What has been happening since April 2019?

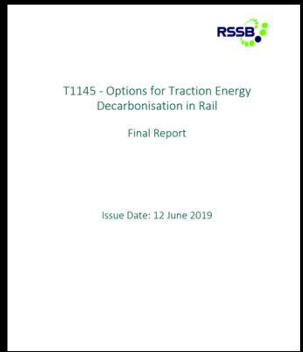
Reports etc in 2019 and 2020.



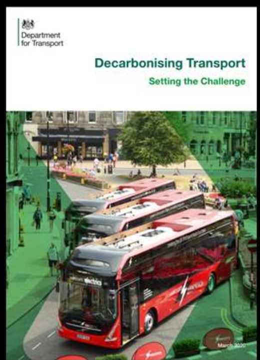
Rail Industry Decarbonisation Taskforce: Final Report July 2019



Network Rail Traction Decarbonisation Network Strategy interim business case July 2020



RSSB "Options for Traction Energy Decarbonisation in Rail", June 2019



DfT"Decarbonising Transport, setting the challenge". 2020

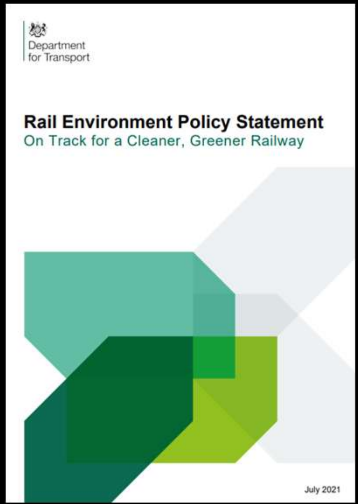
RIA "Electrification Cost Challenge" March 2019

Transport Scotland "Rail Services Decarbonisation Action Plan" 2020

Transport Scotland "National Transport Strategy: Protecting our Climate and Improvong Lives" and "National Transport Strategy: Delivery Plan 2020-2022", 2020.

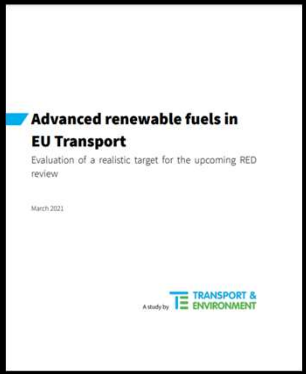
and still they keep coming....

UK Government Energy White Paper "Powering our Net Zero Future", December 2020

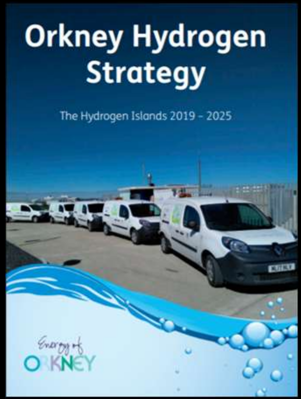


DfT "Rail Environment Policy Statement Traction : On Track for a Cleaner, Greener Railway", July 2021

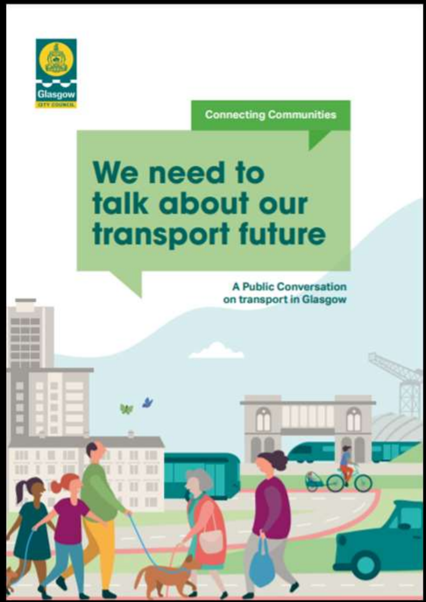
UK Government "UK Hydrogen Strategy", August 2021



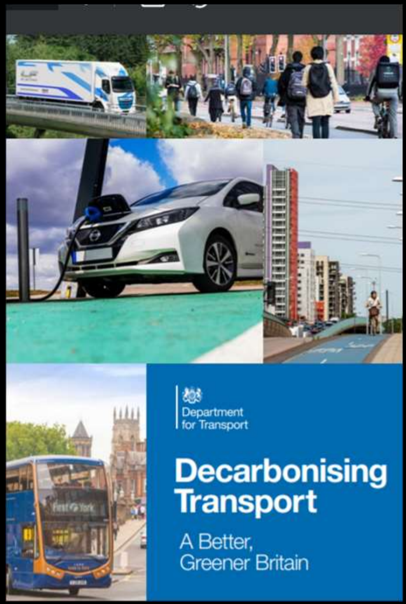
"Advanced Renewable Fuels oin EU Transport", A Study by Transport & the Environment, 2021



Orkney Islands Council "Orkney Hydrogen Strategy" 2019-2025



Glasgow City Council "We need to talk about transport future", 2021



DfT "Decarbonising Transport", July 2021

Meanwhile in the real world…

Alstom iLint hybrid hydrogen/battery mu on test in the Netherlands

Hydroflex hybrid hydrogen/battery mu by Porterbrook and Birmingham University. Now cleared for testing on network. Converted from Class 319 emu.

Alstom "Breeze" hybrid hydrogen/battery mu

The LOCATE facility at MSIP, Dundee, will support heavy duty vehicle platform testing and innovation, particularly around hydrogen fuel cell and battery-electric powertrains.

Vivarail Class 230 bemu at Bo'ness

Hydrogen/battery powertrain on bus (Arcoloa Energy)

and on the road, in the air, at sea and in the lab.

Single deck hydrogen/battery hybrid bus in Union Street, Aberdeen. Double-deck services since January 2021

MV “Ampere” – battery-powered car ferry in Norway. Image Wikipedia

“Oceanbird”: proposed wind powered cargo vessel., Sweden
Image Wallenius Marine

June 2020. EU Aviation Safety Agency announced certification of Pipistrel Velis Electro – first in world for fully electric aircraft. Image by Andrejcheck

Research developments:

- Materials for batteries and new types of battery.
- New forms of fuel cells and developments in fuel cell materials.
- Power electronics, motors and drive systems.
- Powertrain optimisation methods.
- Renewable energy systems (e.g. tidal power).
- New fuel combinations for internal combustion engines – many not zero carbon but could help get to net-zero for rail network.

and the headlines continue….

"Hydrogen '158' proposed for Highlands"
Modern Railways 9th August 2021

"Can freight locos run on steam?"
Rail Freight Group Webinar Report November 18 2020

"Glasgow Central to welcome special HVO-powered locomotive tomorrow"
Glasgow Live website September 14th 2021

"Appeal to raise car tax to subsidise public transport …"
The Herald, June 2021

"British start-up attempts to bring steam power back to shipping"
Splash247.com website July 1 2020

"Greener planes of the future…. or just pretty plans?" *BBC News* website January 8 2021

"Huge tram extension planned for Edinburgh"
The Herald February 12 2021

"How will hydrogen trials in Tees Valley shape the future of transport?" *Quadrant Transport website*, August 2021

So, what are the fundamental issues?

- Emissions – and not just CO_2
- Energy storage capacity (and therefore range).
- Efficiency.
- Performance.
- Cost, capital and running costs

CO2 emissions (current)*

	Rail	Road	Air
gCO2 per pass.-km	28.4	101.6	244.1
gCO2 per tonne-km	15.6	139.8	up to 820

* Figures from European Environmental Agency

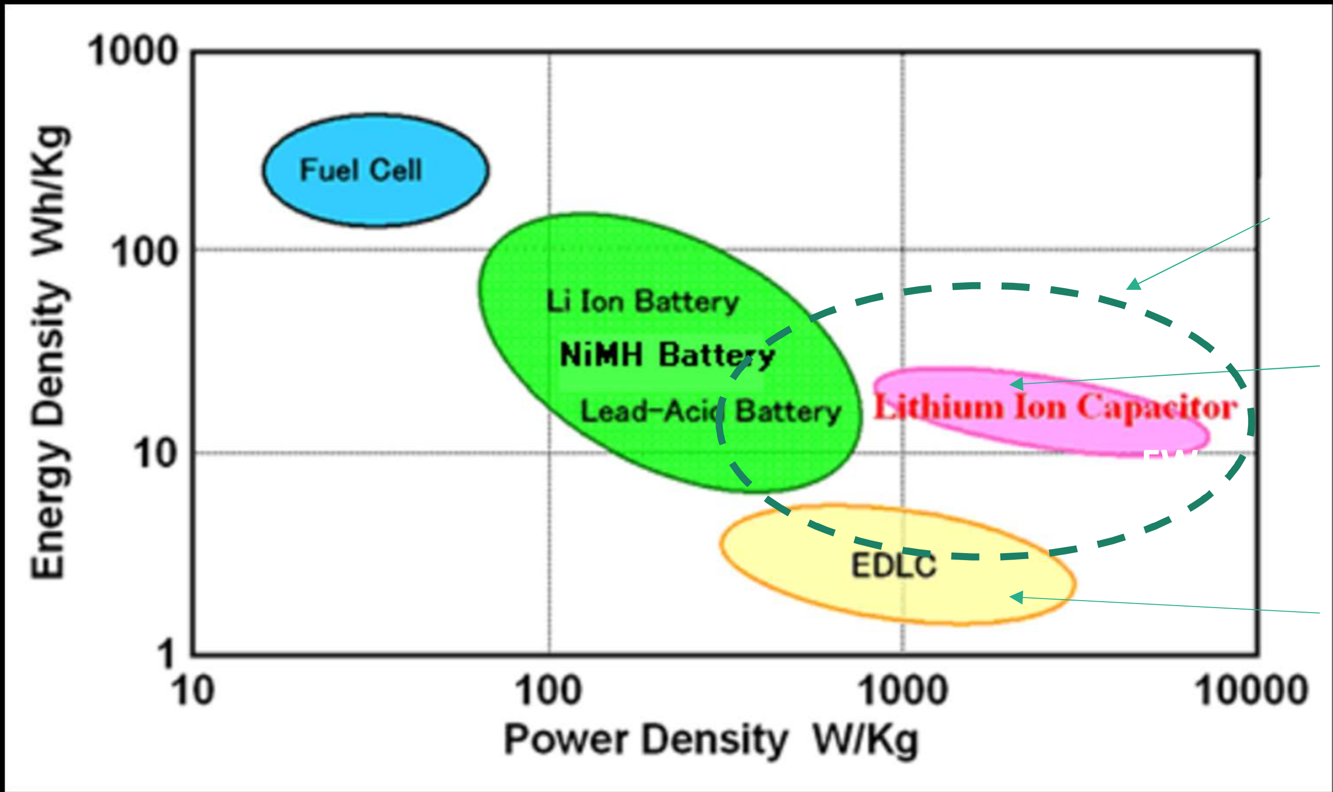
Energy density and storage issues+

Diesel	35.8 MJ/l	48.0 MJ/kg
Hydrogen at 350 bar	4.6 MJ/l	71.0 MJ/kg
Li-ion battery	2.3 MJ/l	0.9 MJ/kg

- Hydrogen takes 8 times space for diesel fuel
- Battery pack takes 16 times space for diesel fuel and introduces a lot of extra weight .

+ Figures from presentation by David Shirres 17/10/2019

Ragone diagram: concise way of expressing energy density and power density figures



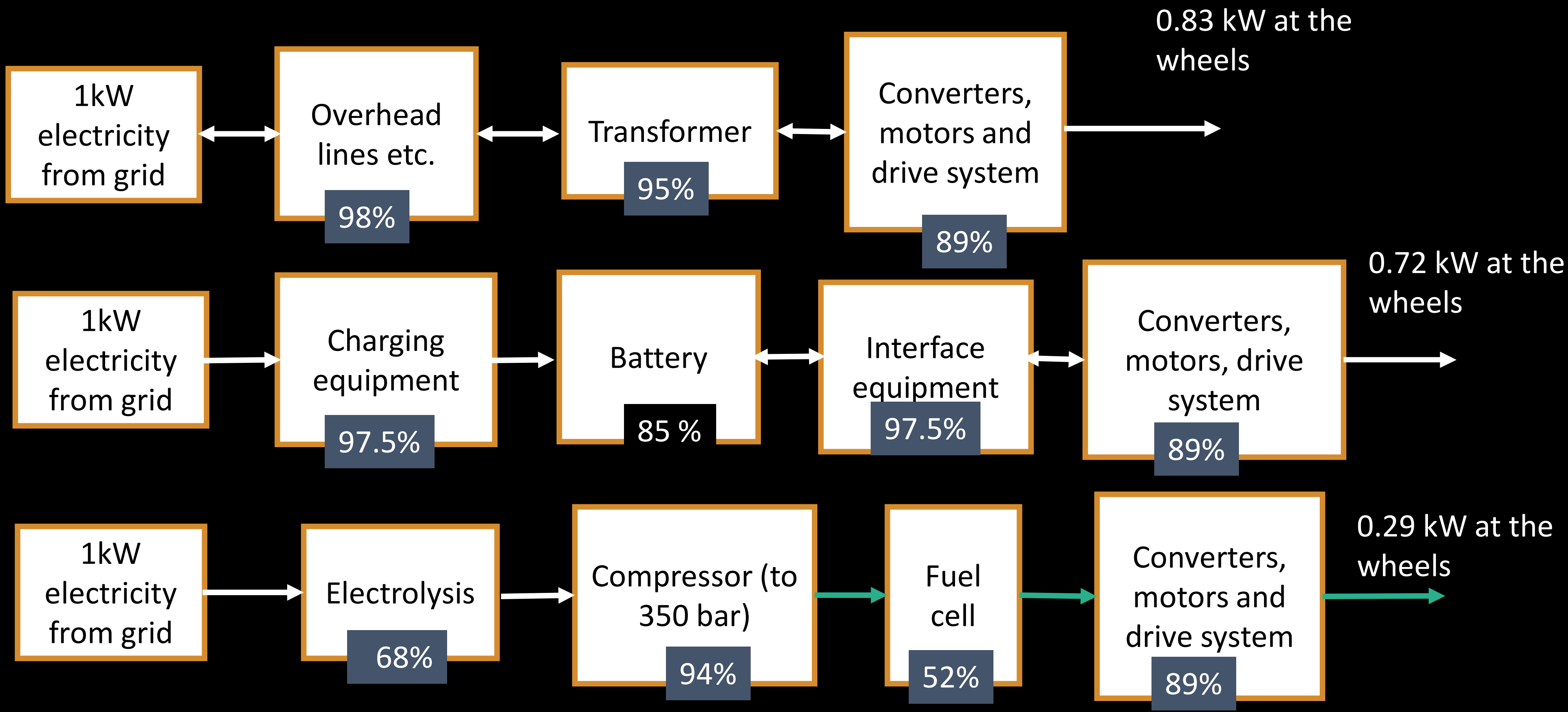
Flywheel energy storage systems

Lithiun-ion capacitor. Combines some features of Li-ion batteries with electrical double-layer capacitors

Electrical double-layer capacitor ("supercapacitor" or "ultracapacitor")

Diagram adapted from Wikipedia

Efficiency: Conventional railway electrification compared with battery and hydrogen, with indicative efficiencies.



Performance: another railway example

Efficiency

Type	Power/weight ratio	Efficiency
Class 385	12.6 kW/tonne	83%
Class 170	6.4 kW/tonne	26%
iLint	8 kW/tonne	29%

Acceleration

Type	
Class 385	zero to 60mph 40s
Class 170	zero to 60mph 100s
iLint	somewhere between diesel and electric performance

Comparison of electric stopping-train and diesel non-stop services Glasgow Queen Street to Stirling.

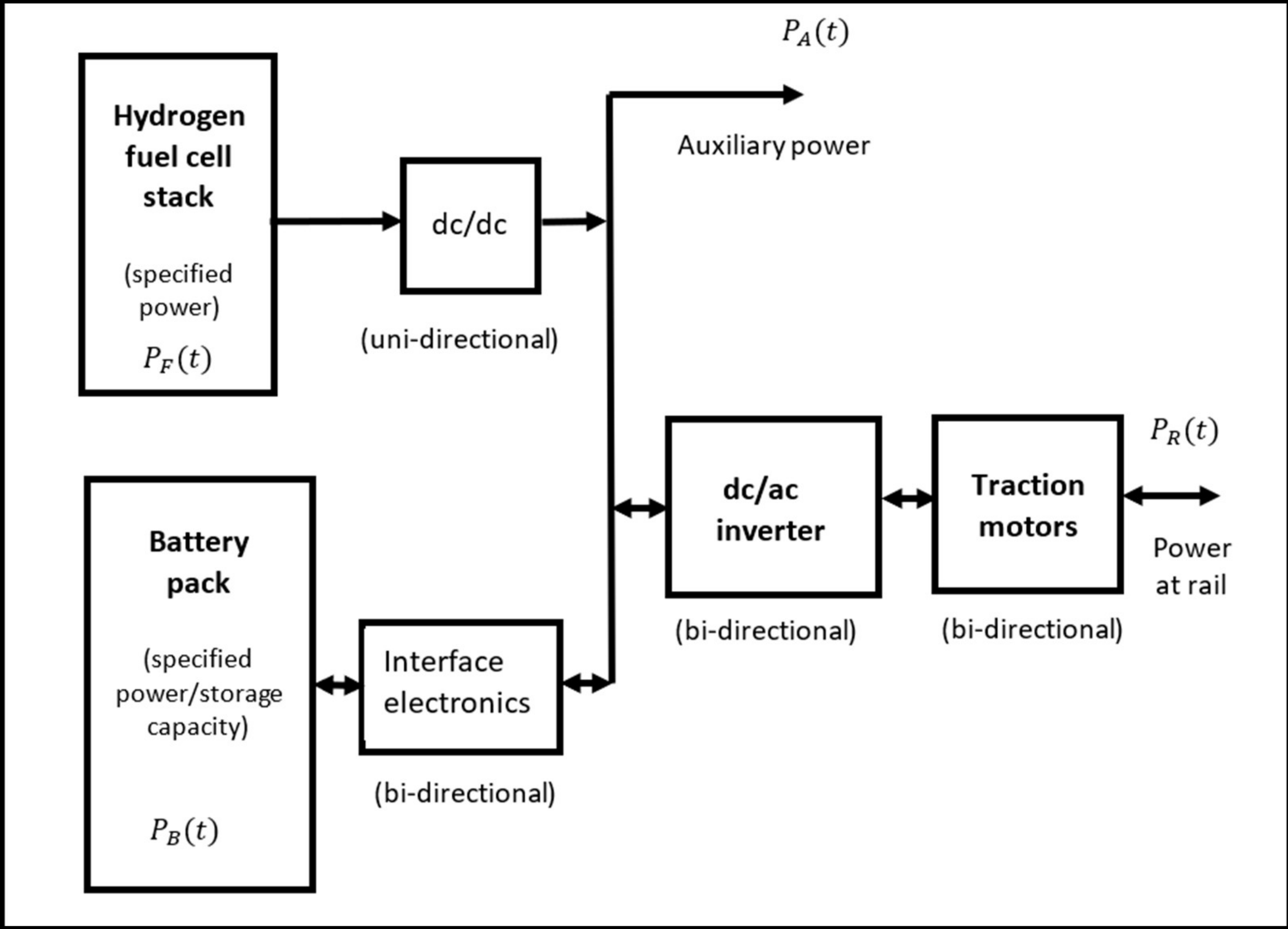
Diesel non-stop time (average of all HST + Class 170 services)	28 mins
Electric with four stops (Class 385, WTT dwell-times =3 mins 30s) mins.	33 mins

Costs

A few facts, some known unknowns and, inevitably, some unknown unknowns (e.g. when the next pandemic will arrive).

- **Electrification costs likely to be of the order of £1.0 M/single track kilometre** (at least). Possibly more to provide suitable electrical supplies away from main centres of population. Perhaps less because secondary route electrification might not be as costly as for main lines.
- Cost estimates of converted battery or hydrogen units substantially less than cost of purpose-built new units. **Conversion from existing emus or dmus is attractive option for leasing companies.** Hence involvement of Angel Trains, Porterbrook, Eversholt Rail etc in battery and hydrogen demonstrators.
- Running cost estimates (per vehicle mile): **new hydrogen unit almost twice cost of emu and new battery-electric unit about 25% more than emu at current prices.**

Typical hydrogen/ battery electric powertrain



My starting point....

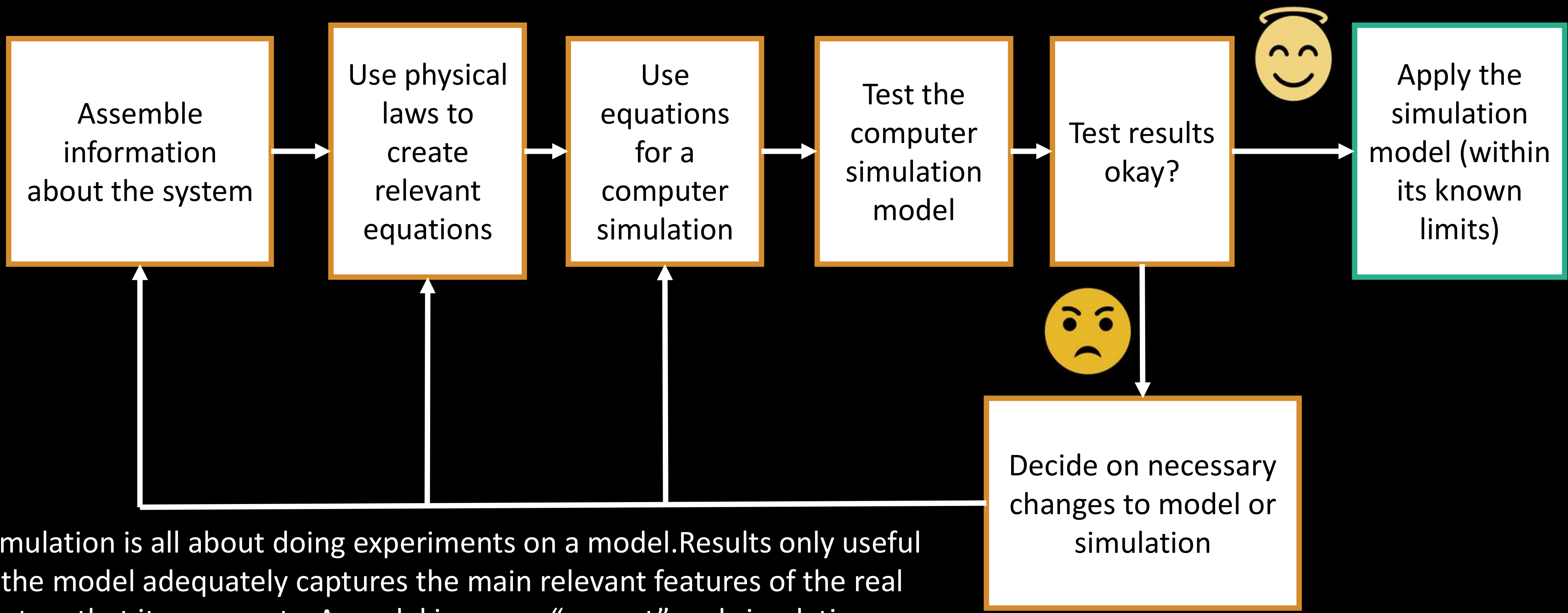
I have for long believed best way to find out whether you understand something is to try to create a mathematical model.

In this case the modelling involves two separate but linked systems:

a) the train

and b) the drive system – electric or battery or bi-mode or hydrogen hybrid or flywheel hybrid or whatever.

The modelling process.



Simulation is all about doing experiments on a model.Results only useful if the model adequately captures the main relevant features of the real System that it represents. A model is never "correct" and simulation models must always be tested before they are applied.

The first steps…

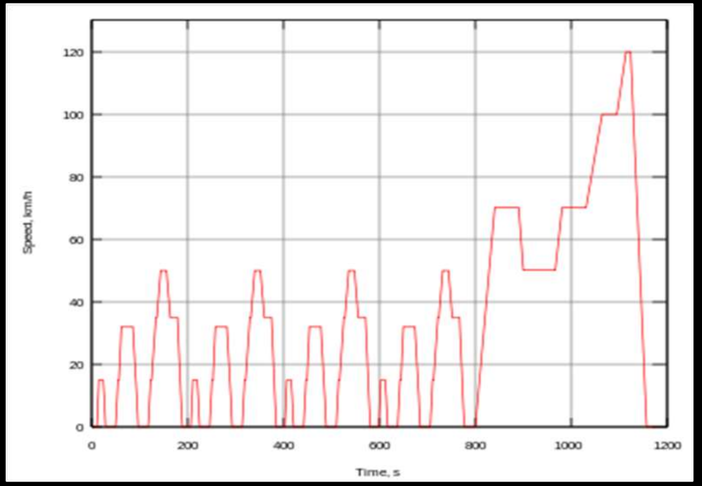
Decide on the requirements:

What performance is needed? At least equivalent to performance of existing diesel multiple units on relevant routes? Perhaps better?

Create a reference ("drive cycle") for performance comparisons

For automotive applications several different drive cycles are widely used.

Typically involve speed versus time record based on straight-line segments. Often Involve a repeated urban cycle and an extra-urban section.



For railway applications:

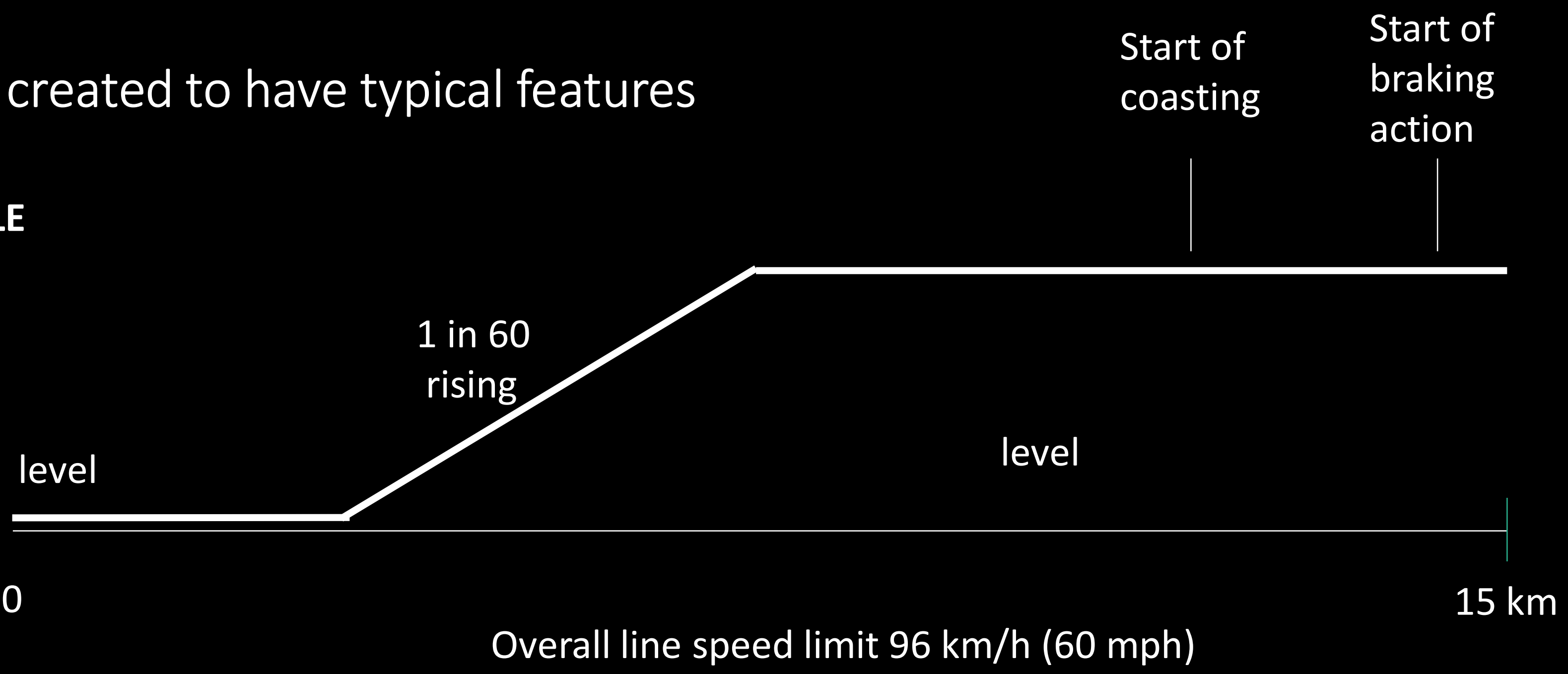
Gradient profile and speed restrictions are important and must choose appropriate route characteristics:

a) real route

or

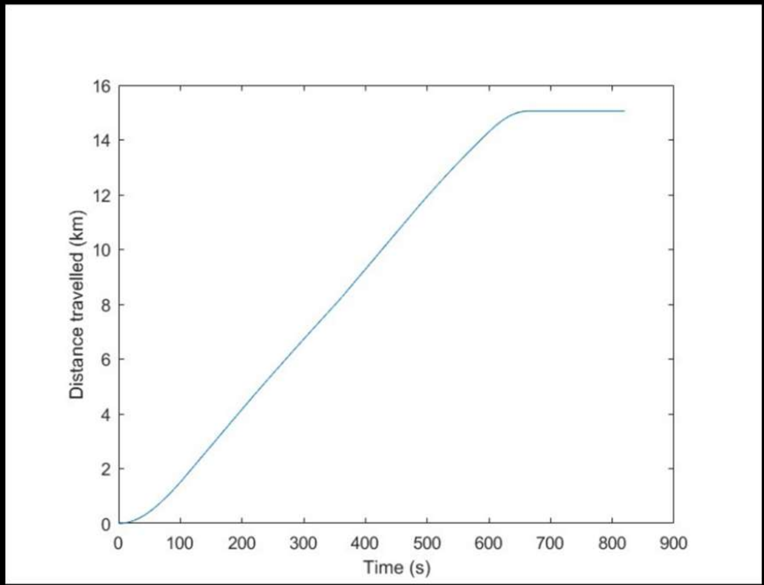
b) a route created to have typical features

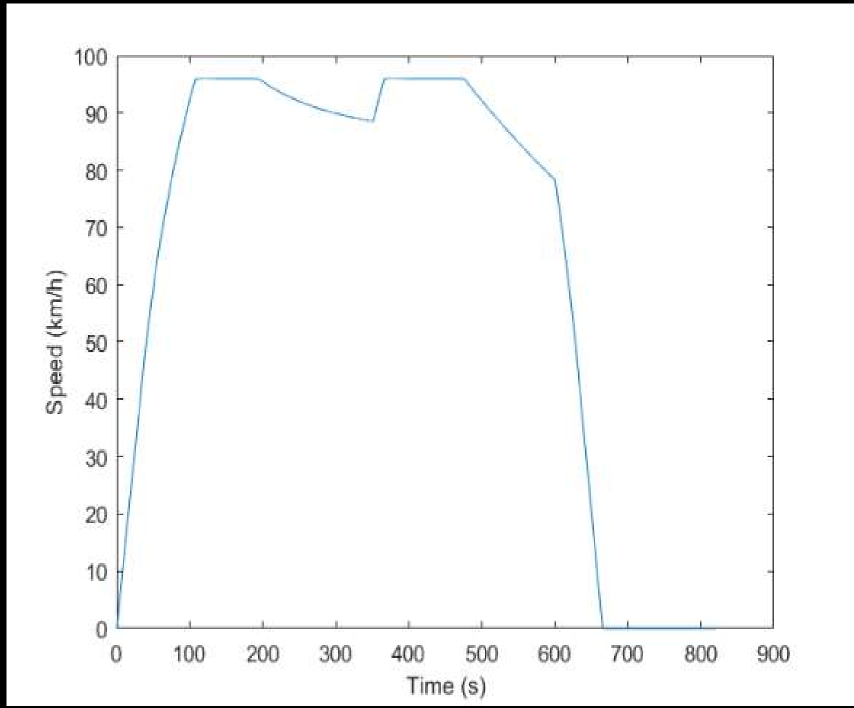
SIMPLE EXAMPLE



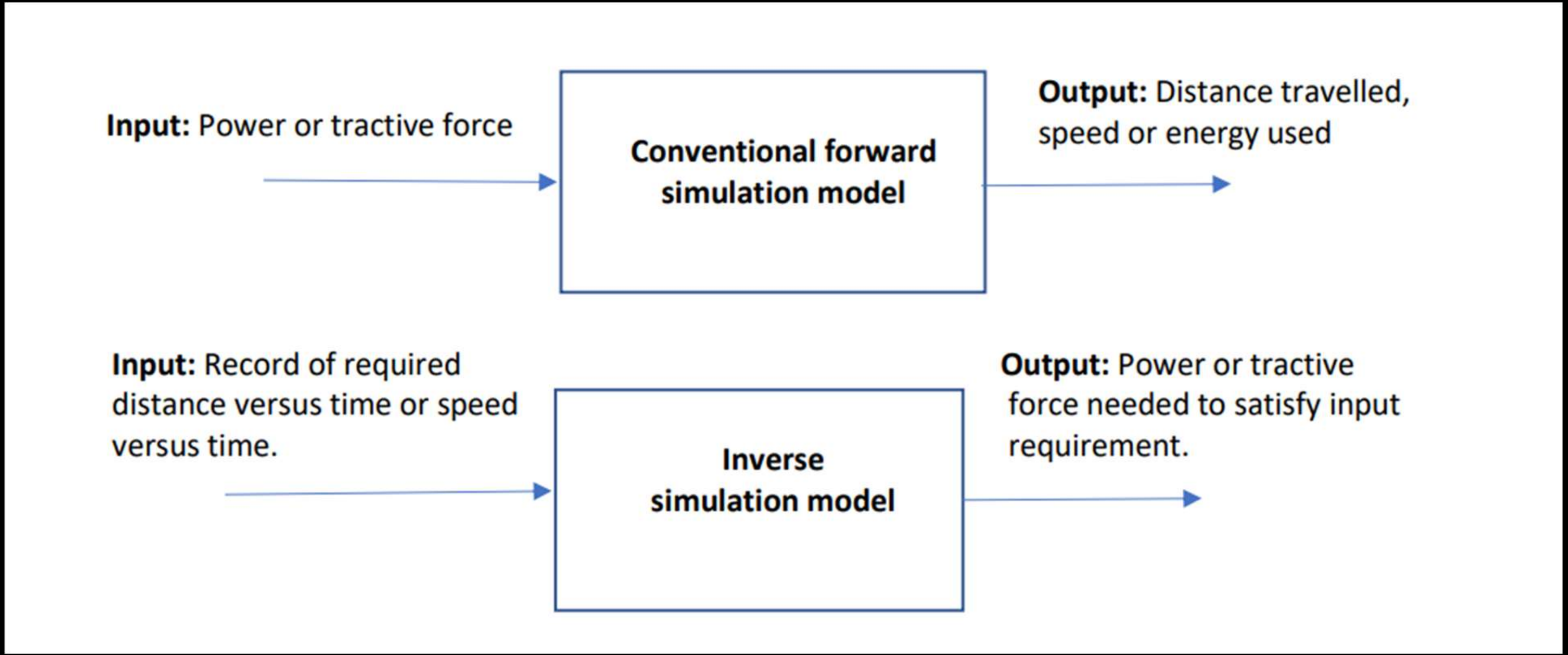
Several other route descriptions considered, including some with descending gradient sections and intermediate speed restrictions.

Simulated speed and distance profiles for Class 159/1 dmu on the defined 15 km route.

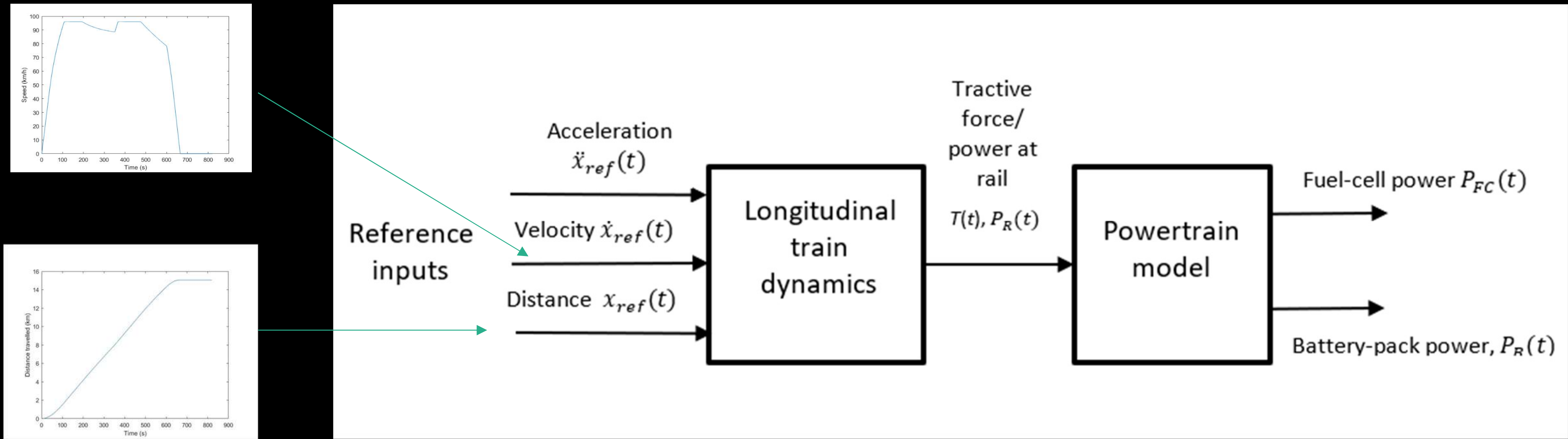




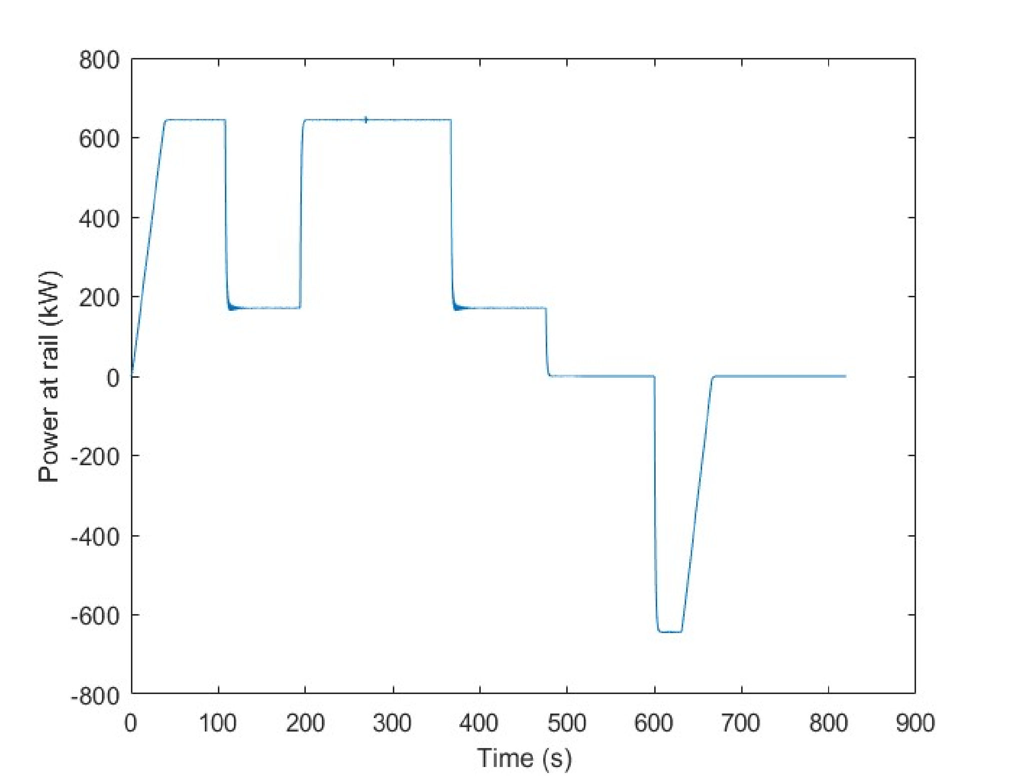
Forward and inverse simulation methods

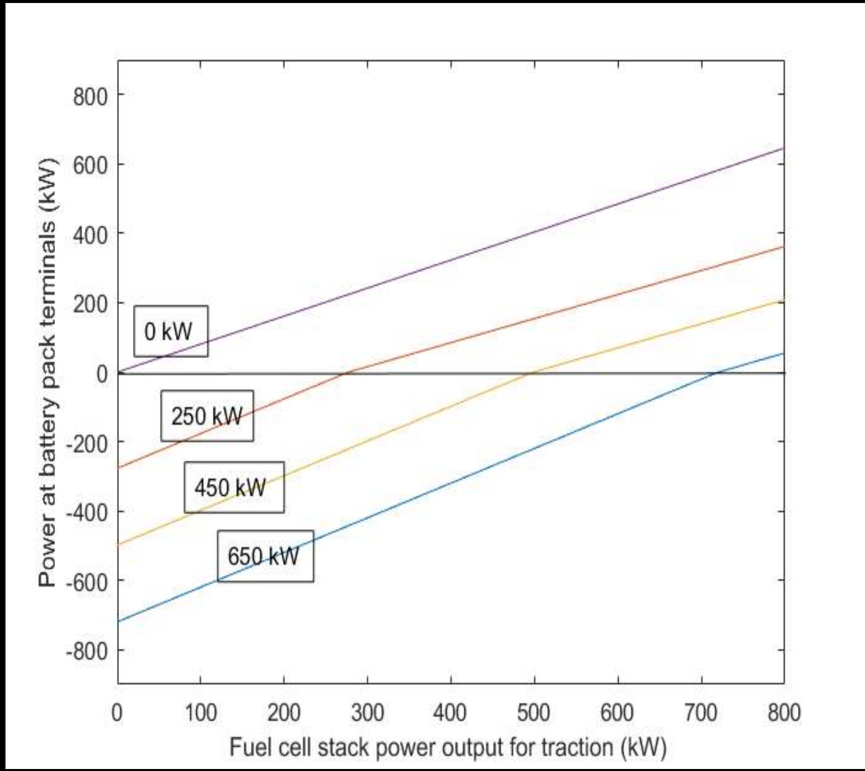


One inverse simulation approach

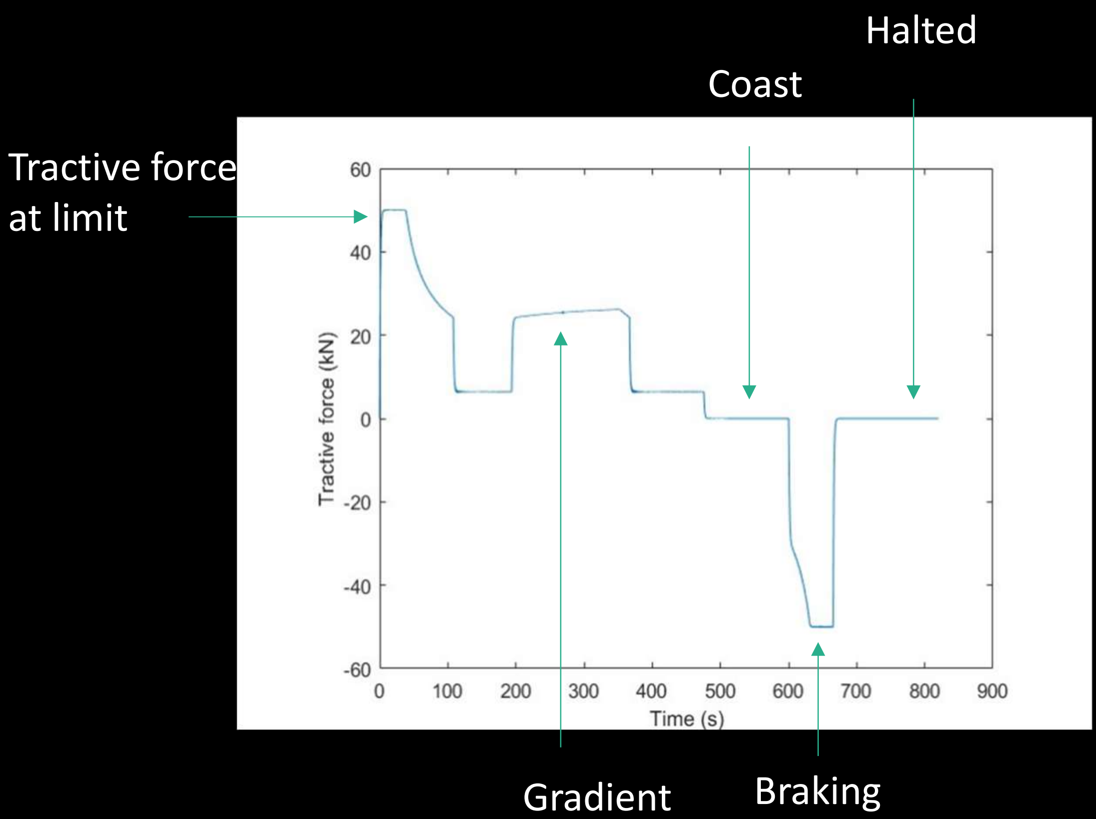


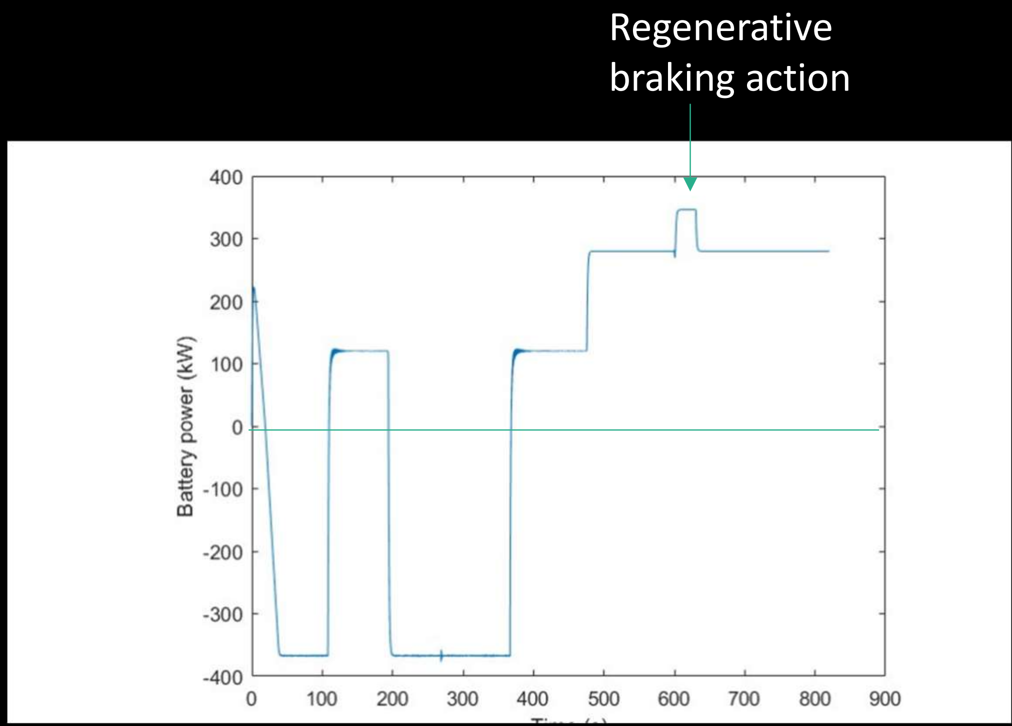
Typical results for hydrogen/battery electric hybrid three-coach simulation





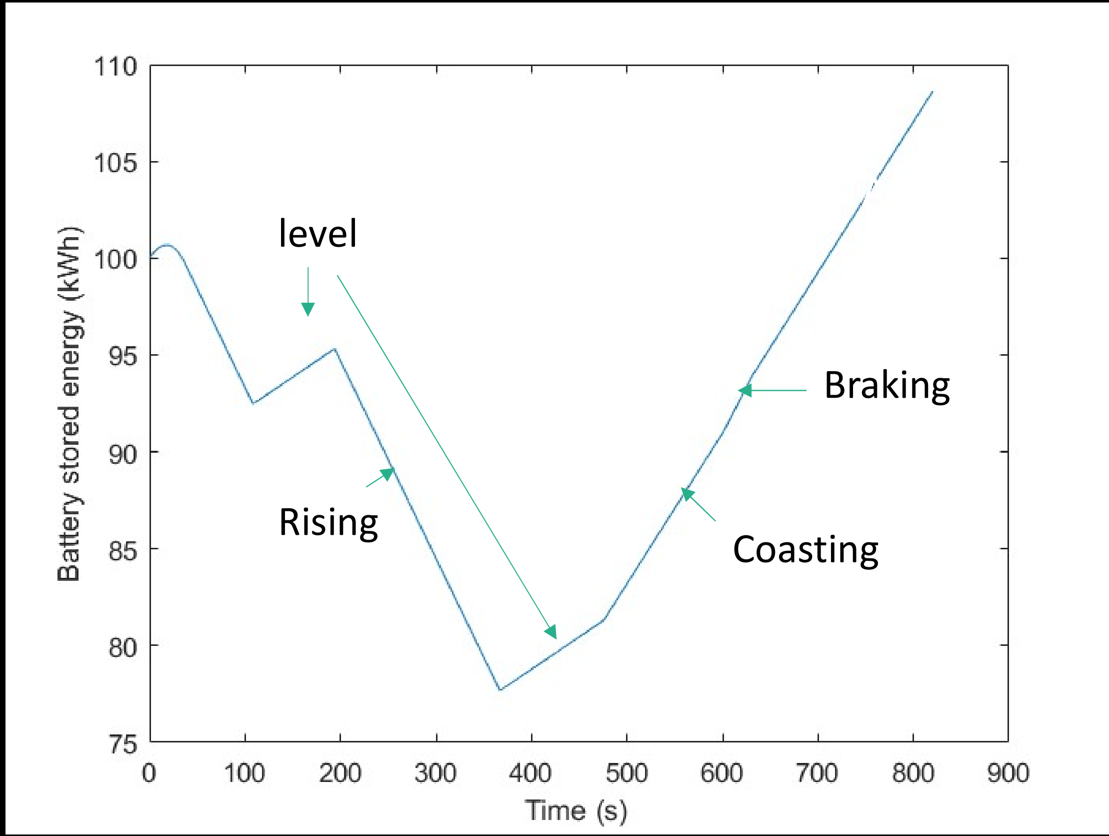
Tractive force and battery power results



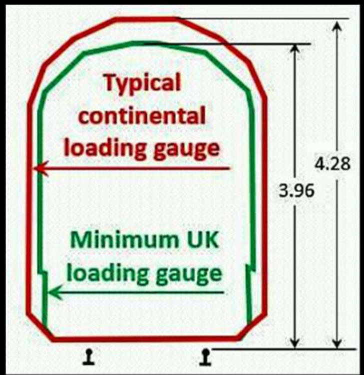


Battery stored energy

- Battery starts discharging soon after start and then charges during level section before further discharge on the gradient. Battery charges on level section, while train is coasting, braking and at rest.
- Battery state of charge must remain within specified limits to maximize battery life.
- Battery power during charge and discharge must also remain within certain specified limits.

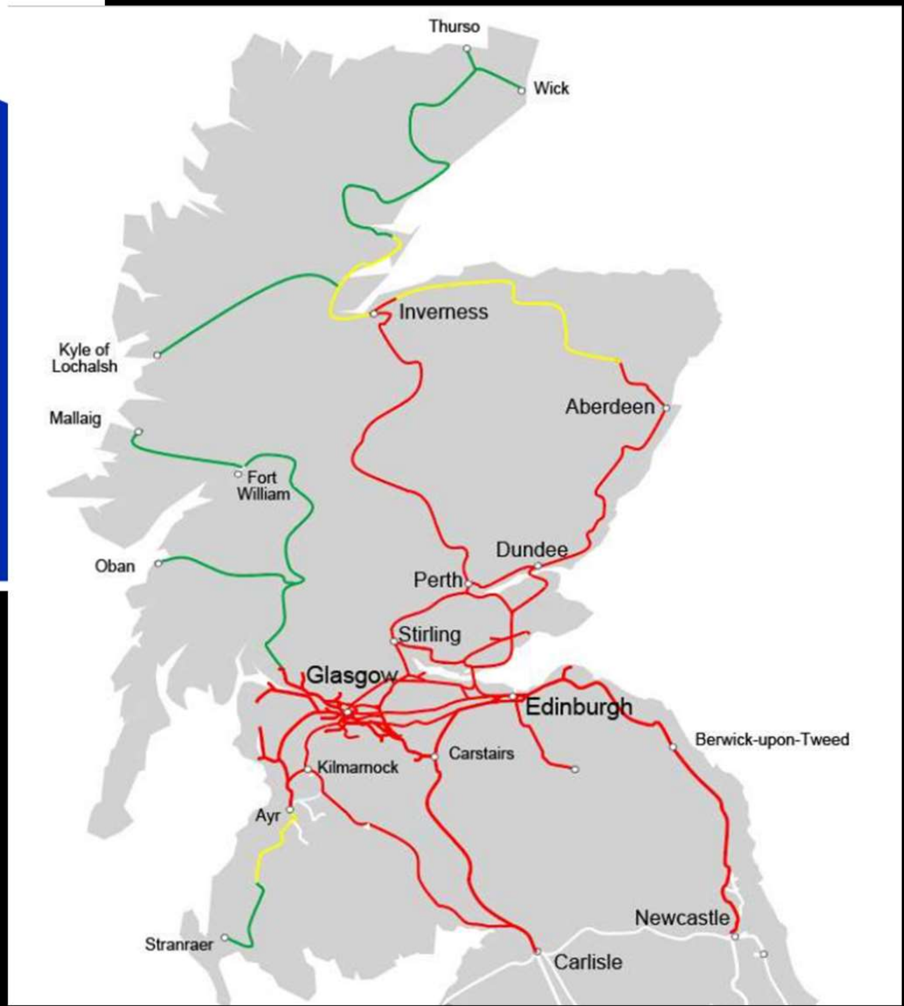


Points emphasised in my 2020 reports



- Hydrogen fuel cells show sluggish response to power level changes and their efficiency depends on operating condition.
- Control strategies should involve slow rates of change of fuel-cell stack operation with fast changes and peak loads met by the battery pack.
- Matching 3-coach dmu performance on the 29.6km climb from Spean Bridge to Corrour needs 3 traction motors rated at 250kW, fuel cell stack of 500kW max. output and battery pack of 375kW max. power with 210 kWh storage capacity (with stored energy never falling below 30% of max.). **For comparison now known that iLint has 400kW fuel cell stack and 450 kW battery pack with storage capacity of 175 kWh. Gives max power for iLint of 850 kW compared with 875 kW on the proposed WH unit and 175 kWh stored energy compared with 210 kWh on my proposed WH unit.**
- **BUT** rough calculations suggest hard to fit storage tanks and other hardware within UK loading gauge without using passenger space. Hydrogen (at 350 bar) takes up 8 times space of diesel fuel and batteries occupy 16 times space of diesel fuel for same stored energy.

2020 key events



The Class 314 Project

Arcola Energy
ARUP
Abbott Risk Consulting
AEGIS Certification Services

Angel Trains (since May 2021)

Hydrogen Accelerator Group

- Early in 2020 Transport Scotland and Scottish Enterprise announced financial support for development of hydrogen fuel-cell/battery electric multiple unit for trials in Scotland.
- In December 2020 contract for conversion of a Class 314 emu awarded to a consortium led by Arcola Energy (hydrogen fuel cell integration specialists).
.
- Conversion being done at Bo'ness & Kinneil Railway workshops.Links with Michelin Innovation Parc project in Dundee where Arcola Energy are establishing a design and manufacturing base
- Hydrogen Accelerator Group based at St Andrews University is involved in project management.
- Project forms part of a broader move to strengthen relevant industrial and business supply chains in Scotland and promote new industrial/academic collaborations in rail and energy sectors.
- Some personal involvement since 1st January 2021 when I was approached by Dr Ben Todd who expressed interest in my earlier reports. Now formal agreement in place with Glasgow University for support (in kind) from Arcola Energy for MEng student project.

- Configured for initial trials on the Bo'ness to Manuel route – to be showcased during COP 26 with demos of live running planned for March 2022.

- Hydrogen storage tanks and powertrain components all housed beneath floor using proven Arcola A-train technology

- Mainline approval to be sought at later date.

Images: Arcola Energy

- My personal contacts mainly with Peter Fisher who is a Senior Systems Engineer with Arcola.

- Arcola Energy interested primarily in performance prediction and design issues with the Class 314 project. My interests broader, mainly in applying simulation methods to design issues for trains on secondary routes, allowing for practical constraints. Our interests and activities largely complementary.

Summary of collaborative work since January 2021

Comparing our simulation methods and modelling assumptions. Establishing common ground.

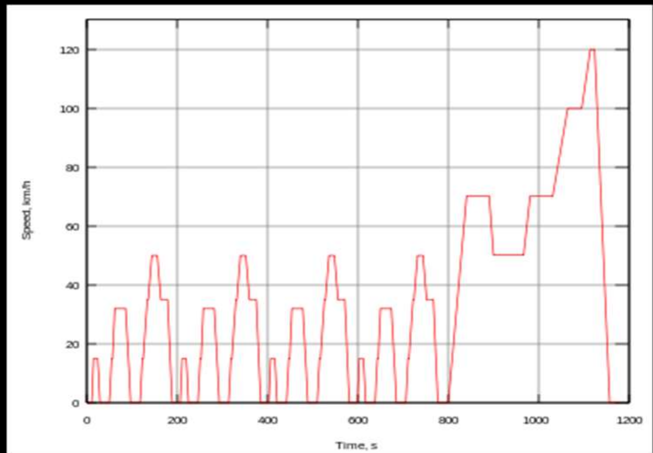
Comparing results for specific routes (e.g Bo'ness to Manuel). Comparing use of reference from GPS data and data generated from a dmu simulation involving conventional route information.

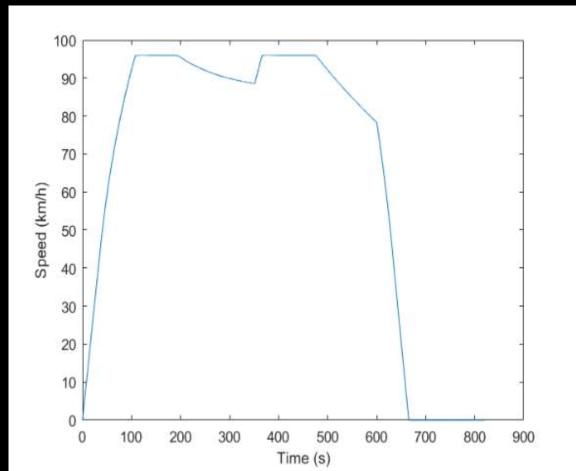
Investigating effects of model parameter variations, train length, loading etc.

Comparing driving patterns. "Drive cycles" traditionally used for road vehicle powertrain studies not so suitable for trains which have much more kinetic energy.

e.g. Speed versus time plot for typical rail journey. Straight line approximations produce unrealistic transients in terms of power and tractive force.

- In April 2021 Peter Fischer of Arcola and I were invited to provide an article entitled "The Highlands Hybrid" for a new magazine *Electric and Hybrid Rail Technology* which appeared in July 2021.





Summary of rail de-carbonisation options

- Rail can contribute to greenhouse gas reduction by: **taking traffic from road and air** (through high speed **and** high acceleration) and **reducing own emissions.**
- **Main emphasis on conventional electrification of mainline railways.**
- **Battery trains** useful for short routes and **mainly as transitional technology** for discontinuous electrification schemes.
- **Hydrogen/battery hybrids** are an **option** for rural services **on longer routes**. New build or converted from existing dmu or emu types? Hilly routes need large batteries but this involves extra weight. Problems for longer routes in terms of space for hydrogen storage tanks. Complex design optimisations and trade-offs.
- **Many uncertainties remain** and much research worldwide is relevant. More focus on rail needed, including modelling and simulation, hardware-in-the-loop investigations (e.g. using LOCATE facilities at MSIP) and work based around test vehicles such as the converted Class 314. However, we must avoid **"paralysis by analysis",** so results from such trials must feed back into the modelling work.
- Still **no practical alternative to diesel for freight services** and for sleeper services on routes that are not electrified (e.g. on WH lines). Research on new fuels important.

This week's example…..

DB Cargo UK launch of HVO100 and HVO50 products

HVO – Hydrotreated Vegetable Oil

HVO produced from 100% renewable sources including waste materials.

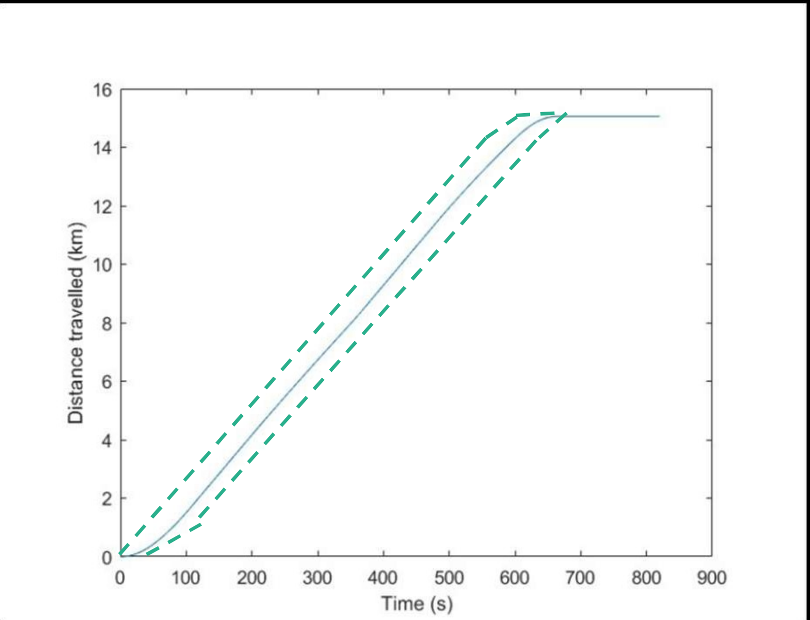
HVO100

Reduces carbon dioxide emissions by up to 90%
Reduces particulate emissions by up to 30%
Reduces carbon monoxide emissions by up to 25%
Reduces NOx emissions by up to 10%

Photograph: David Murray-Smith, Glasgow Central, 15th September 2021

What direction now for me?

Continuing collaboration with University colleagues and Arcola engineers on hydrogen/battery-electric hybrids, powertrain modelling etc.



Try looking at **requirements in terms of performance bands** rather than individual curves. e.g. for fixed distance, journey time specified to within ±30 s while adhering to all limits and using references generated from physics-based models.

How good is the model? Testing and validation of train performance simulations.

Improved modelling of braking systems.

Energy management and powertrain control systems.

Conclusions from 2019 presentation still valid

▶SAPT should engage with other similar organisations and press to:

- Ensure transport modes are compared objectively (through appropriate energy and atmospheric pollution measures).
- Encourage developments in renewable energy and energy storage facilities for areas in Scotland far from main population centres.
- Support r & d activities in new areas of technology (including batteries, fuel cells etc) for transport applications of all kinds.
- Support objective research on benefits of automation within all transport modes.

We should also:

- Press strongly for an integrated transport strategy and public transport system that is first choice for most journeys for most people.
- Support proposals for rail infrastructure improvements (e.g. further electrification)to make inter-city train journey times in Scotland substantially less than time by car.
- Press for joined-up approach to development of our transport and electrical power generation and distribution systems.
- Press for new metro, light rail and tramway systems in Scottish cities.
- Support objective evaluation of battery and hydrogen powered trains on secondary routes in Scotland, including comparisons with conventional or discontinuous electrification.