Transport in Scotland: Some Options for the Future

SAPT

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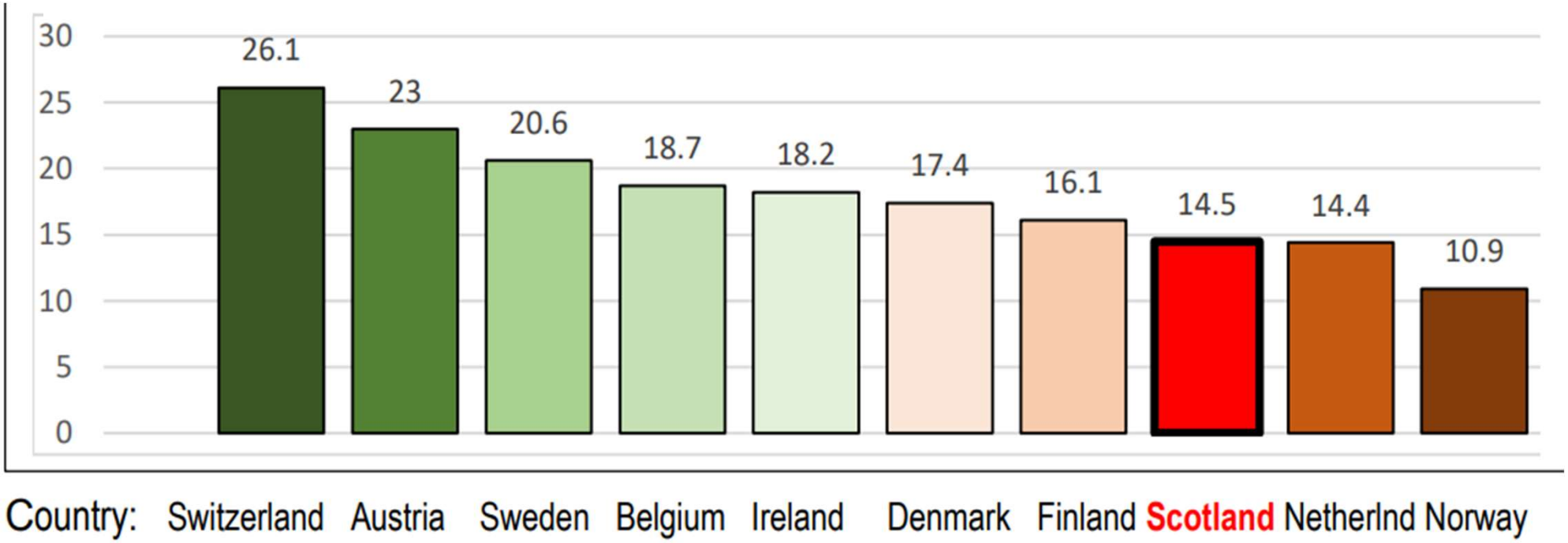
This is an updated version of a presentation entitled “Powering Future Transport in Scotland” given at an SAPT meeting and discussed in more detail in a report for SAPT produced in 2019.

Issues affecting transport in Scotland

- **Devolved government**
  - Transport Scotland - not UK DfT so strategy different
  - Significant transport investments since devolution
- **Geographical and economic issues:**
  - Renewable energy - onshore and offshore wind, wave power, potential for tidal power etc.
  - Very uneven population distribution.
  - Island communities – ferry/air links essential
- **Transport largest contributor to greenhouse gas emissions** in 2019-20

Usage of public transport

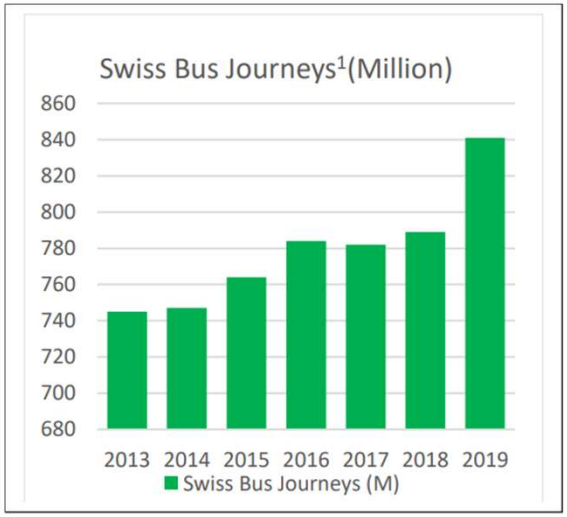
International comparisons - % of journeys by public transport

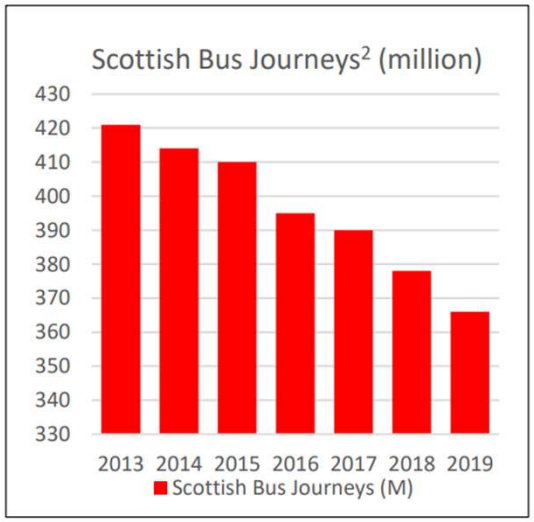


Source: Report by SAPT in 2022 on international comparisons of transport in Scotland with other small European nations

Some trends…..
2002-2018

Trends in Bus Journeys in Switzerland and Scotland 2013 - 2019





- **Car use down by 13% (miles per person per year)*. But increasing car use in rural areas and more second cars.**
- **Bus miles per person down by 19% * (e.g.** First Bus - 40% reduction in 10 years) **and average speeds falling.**
- **Rail miles per person up by 41 %***

***DfT figures (for England)**

Scottish Government Decarbonisation Targets (2019)

- **Reduce all carbon emissions to net-zero and eliminate fossil-fuelled vehicles by 2045.**

- **End sales of new fossil-fuelled cars and vans by 2030.**
- **End sales of new fossil-fuelled buses by 2025.**
- **End sales of new fossil fuel-powered trucks by 2035.**
- **Reduce private car kms by 20% by 2030 compared with 2019**
- **Introduce low-emission zones in the major cities (Glasgow, Edinburgh, Aberdeen, Dundee)**

- **Eliminate diesel trains on ScotRail services by 2035.**
- **End sale of fossil-fuelled ships from early to mid-2030s.**
- **Support development of zero-carbon options for aviation.**

Developments, problems and uncertainties

- **Developments** in power sources and storage (e.g. batteries, double-layer capacitors, hydrogen fuel cells etc.). Uncertainties continue (e.g. lithium and precious metals supplies). Much research and development work needed.
- **Movement** to electric or hybrid cars and vans. Issues include concerns over range and charge point availability, reliability, life-time costs and electrical distribution system infrastructure. How can the electrical supply network cope?
- **Rail electrification** – progress in Scotland better than in rest of UK. But are the plans ambitious enough? Some secondary routes show poor business cases for electrification. What should be done there? What about freight?

Where are we heading in Scotland?

Where **should we** be heading?

So, what are the fundamental issues in powering transport?

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

CO_2 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

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

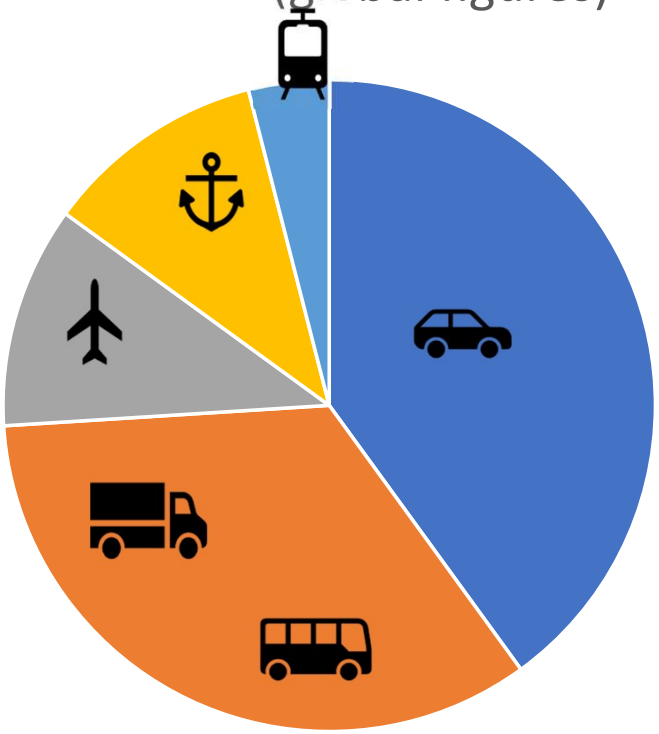
+ Figures from presentation by David Shirres 17/10/2019

About comparing modes of transport

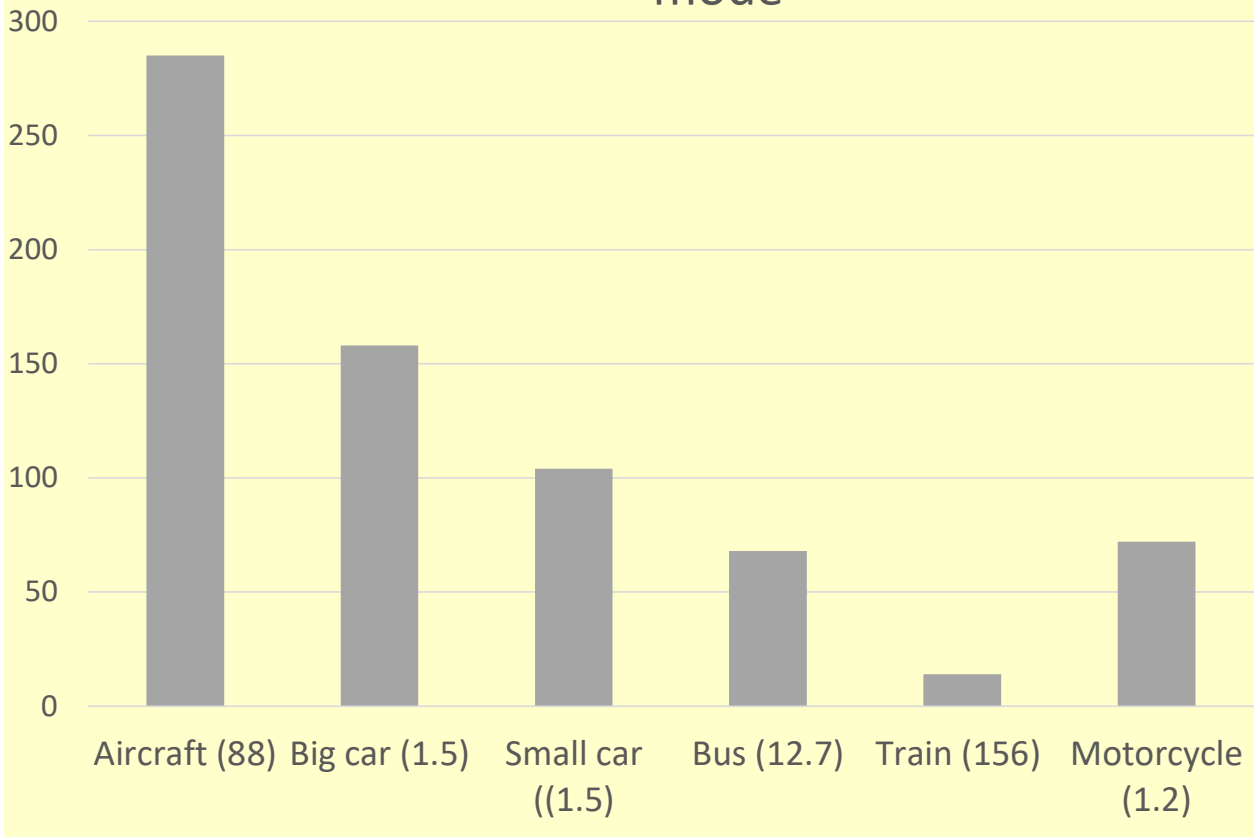
- Different vehicles: different energy measures
  e.g. Cars and other road vehicles: litres/100km;
  Electric trains: kWh/seat-km.
  or for comparisons of transport modes can use gCO2/passenger km
  e.g. Comparing diesel and electric trains - grams of CO2/seat-km
  or grams of CO2/passenger-km

- Load factors important
  Widely-used load factors are (for UK): car – 30%, urban bus – 20%,
  intercity coach – 60%, intercity rail – 40%, other rail – 30%,
  domestic airlines – 70%

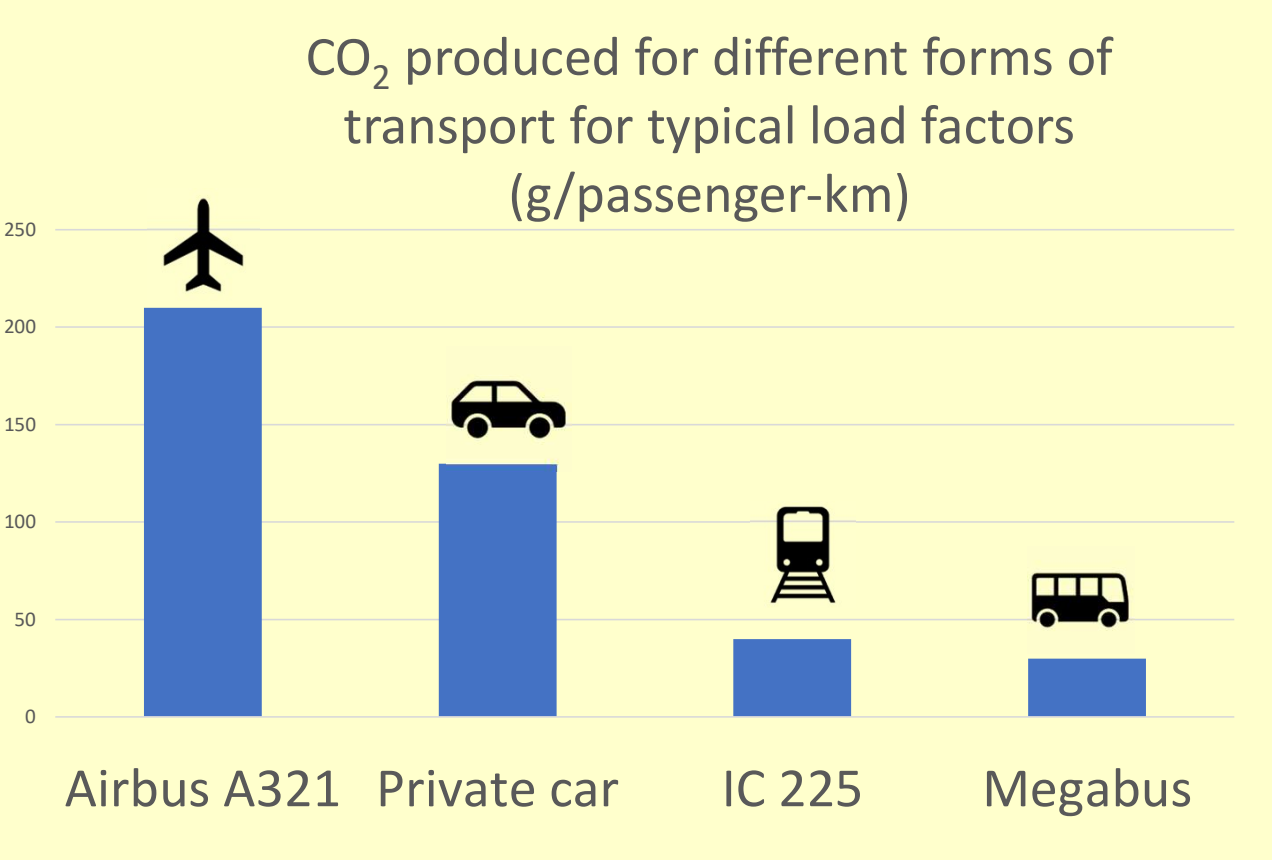
Greenhouse gas emissions for transport sector (global figures)



Global carbon dioxide emissions (gCO2/passenger-km), showing also average (UK) passenger numbers for each mode



Comparing different modes on longer routes (e.g. Edinburgh – London)



Figures from 2017/18: electrified rail services now show even lower figures due to increased use of renewable sources

"Air pollution wipes at least year and a half from life expectancy" *Herald (13 M*arch 2019)

Other emissions

- Oxides of nitrogen (NO_x): Adverse health effects but threshold set at 40 $\mu g/m^3$ (annual mean).

- Particulate matter (PM): Measures based on particle size – tyres and brake pads mainly.
- PM10 - 10 micrometres (μm). Threshold - annual mean 18 $\mu g/m^3$
- PM2.5 – 2.5 μm. **No safe level** but accepted threshold is mean of 10 $\mu g/m^3$

- Oxides of sulphur (SO_x): Important in shipping; not so significant elsewhere.

- **NOx and PMs** - **no threshold levels below which there are no adverse health effects**. PM2.5 especially damaging.

- **All transport sector emissions down from 1990**, apart from international aviation and shipping where levels have risen for some emissions.

Example: Bearsden Cross emissions

Designated Air Quality Management Area by EDC since 2011. Figures 1 Jan. to 28 Feb. 2019 show daytime means of NO_2 and $PM_{2.5}$ both above thresholds. $PM_{2.5}$ value exceeded threshold 160 times in those two months for 0700-1900.*

*My thanks to Professor Michael Hitchman (University of Strathclyde) for providing this information. (Photograph: David Murray-Smith)

“Electric cars spark fear for whether national grid can meet extra demand”
Times 20th August 2018

The electrical supply system

“Market failures could see Britain suffering five-day power cuts”
Engineering and Technology, April 2019

- Electrical supply system in Scotland – already less fossil fuel generation; less nuclear; more renewables than England and Wales.
- System more distributed - issues of control and stability; problems of “black start”.
- What are the likely effects of more electric transport? Extra demand estimates from battery charging range from 10% to 40%. How do we provide that? What pricing systems are appropriate?
- Need more investment in generation and distribution systems.

Developments in battery technology

- Mostly lithium-ion batteries - developments are improving range, reducing charge times, reducing fire risks etc.
- Other developments - lithium-metal batteries, flow batteries, lithium sulphur batteries etc. Improved power-electronics for regenerative braking.

- Issues of overall energy efficiency and long-term, availability of materials, environmental effects of mining, processing and end-of-life disposal.
- Increasing life expectancy and range – but uncertainties continue.

- R & D in other areas such as “structural” batteries using carbon-fibre materials – vehicle structure is the battery.

Developments in hydrogen fuel cells

"Full steam ahead for hydrogen trains"
Times 7th January 2019

"Hydrogen-powered planes to clean up skies"
Times 6th November 2018"

Hydrogen fuel-cell technology: r & d and full-scale trials for transport using fuel-cell/battery combination. e.g. Bus trials: Aberdeen; HGVs (Tesla and Hyundai); ferries for Norway and Orkney.

- Fuel-cells in Alstom *Coradia iLint* trains in Germany (Lower Saxony).
- Porterbrook/University of Birmingham hydrogen/battery train under test.
- Various other developments in hydrogen trains reported, but still doubts over costs.
- "Enable H2" aircraft project: Cranfield University, GKN Aerospace etc.

Hydrogen in action: some examples in the UK

Single deck hydrogen/battery hybrid bus in Aberdeen in 2019. (Photograph: D. Murray-Smith).

Porterbrook/University of Birmingham hydrogen/battery hybrid conversion at Glasgow Central station for COP26. (Photograph: D. Murray-Smith).

Some options for Scotland

Buses

Battery-electric bus outside Glasgow Queen Street station. (Photograph: David Murray-Smith)

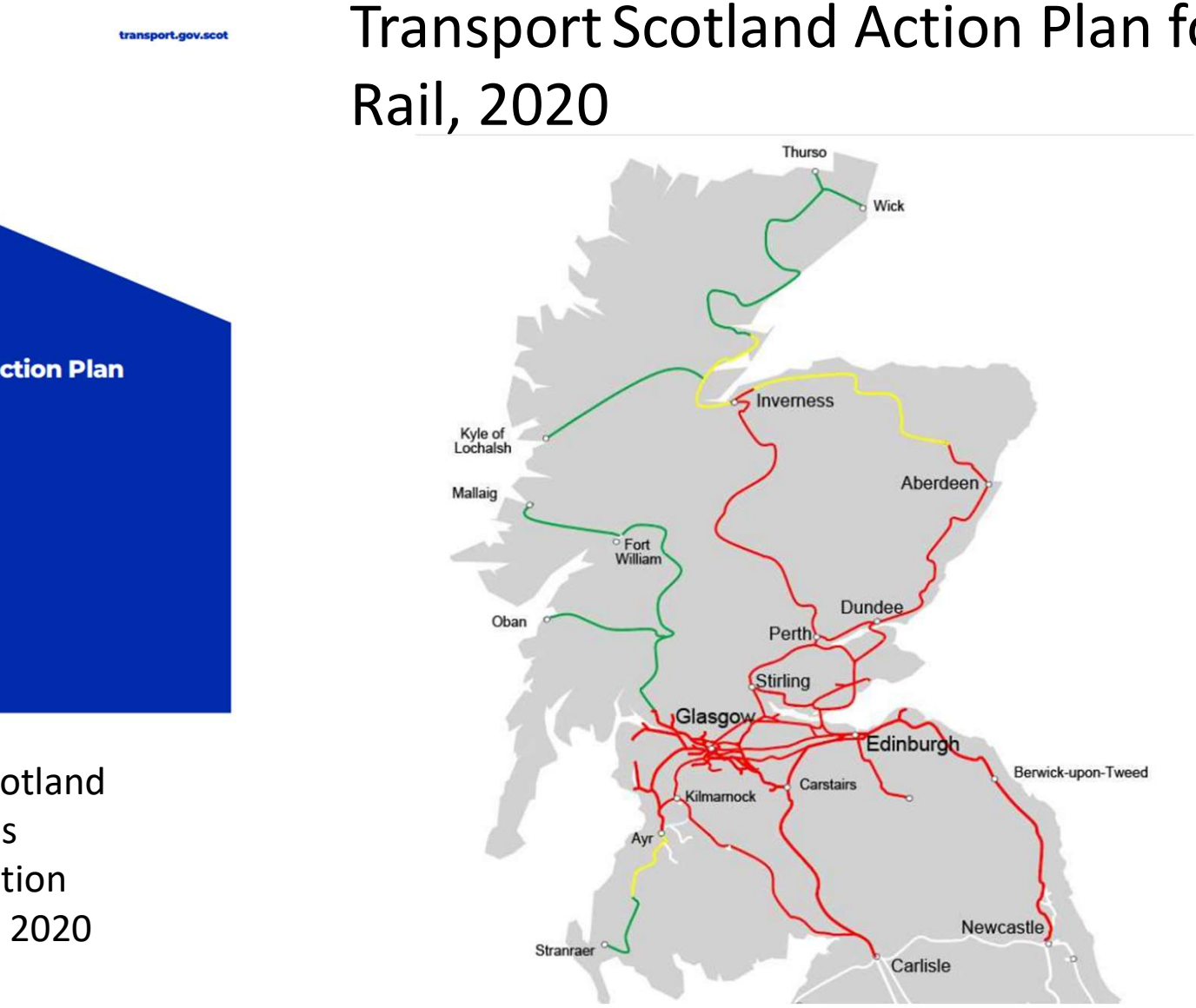
Introduction of LEZs in main cities and government support for operators means new battery-electric buses on local and some longer-distance services in Scotland.

Problems:

High bus traffic levels on many city-centre streets with many competing operators (e.g. 60 in Strathclyde area). Alternatives: franchising? public ownership?

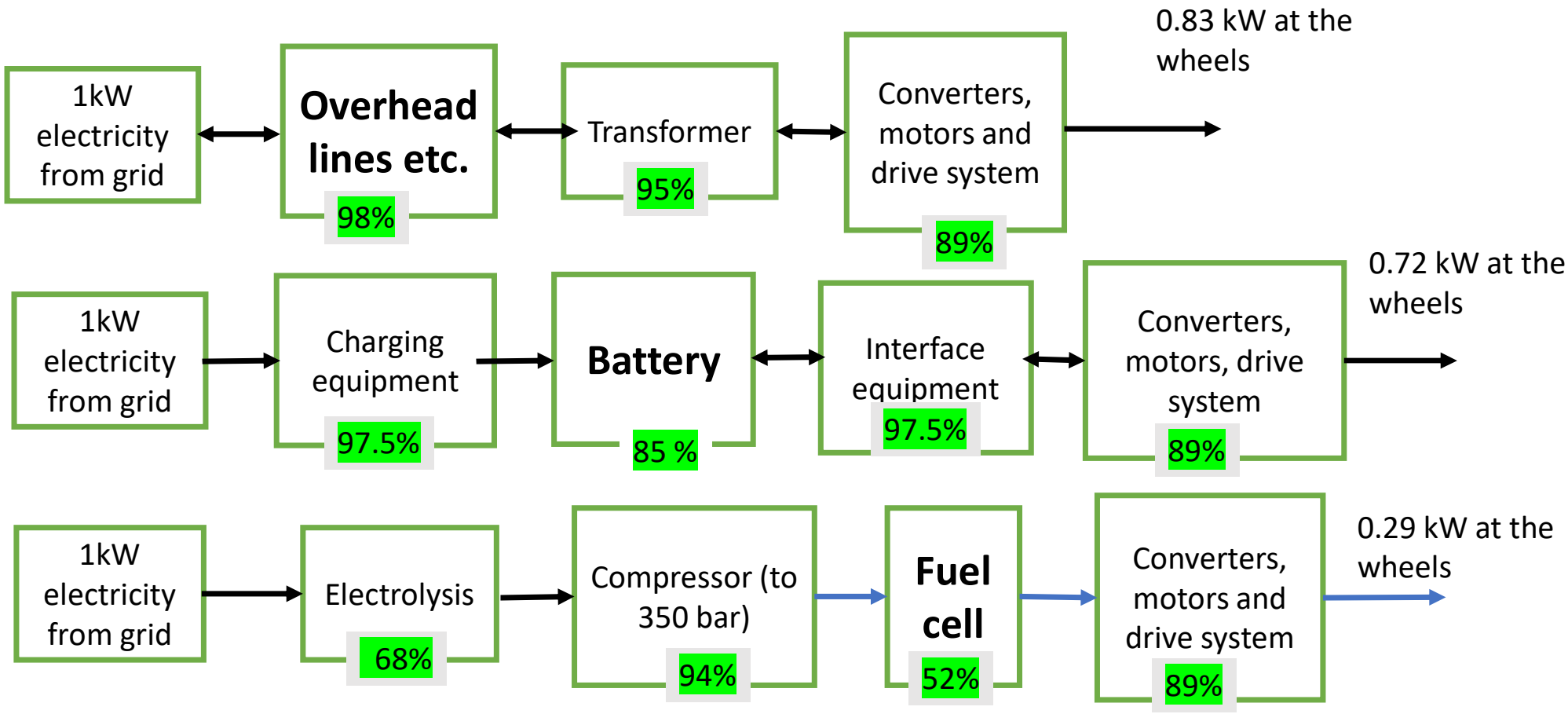
Little co-ordination with other modes (e.g. subway or rail in Glasgow and trams in Edinburgh)

Transport Scotland Action Plan for Rail, 2020



Transport Scotland "Rail Services Decarbonisation Action Plan" 2020

Efficiencies: Conventional railway electrification compared with battery and hydrogen, with indicative efficiency values.



First choice: electrification…..for better, faster services and decarbonisation

Class 170 diesel multiple unit on Glasgow-Perth train running “under the wires”. Eliminating diesel passenger trains is central for rail decarbonisation.

Class 385 electric multiple unit arriving at Glasgow Queen Street Station. Extending electric services to all of Scotland’s main cities forms part of the plan.

Photographs: David Murray-Smith

Longer secondary routes

Options: **use batteries----------** Limited range before recharge needed

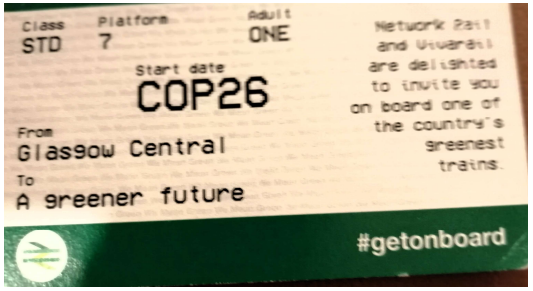
electrify---------- High initial cost, but discontinuous electrification with on-train batteries for bi-mode operation?

use hydrogen/battery hybrids---------- Increased range but lower efficiency and costs. Appropriate for freight?

use diesel fuel substitutess ---------- Biofuels and synthetic fuels. Low capital cost for conversion. Long-term viability? Freight?

Battery trains…

Vivarail battery powered Class 230 unit on Bo'ness and Kinneil Railway for demonstration trips. October 2018

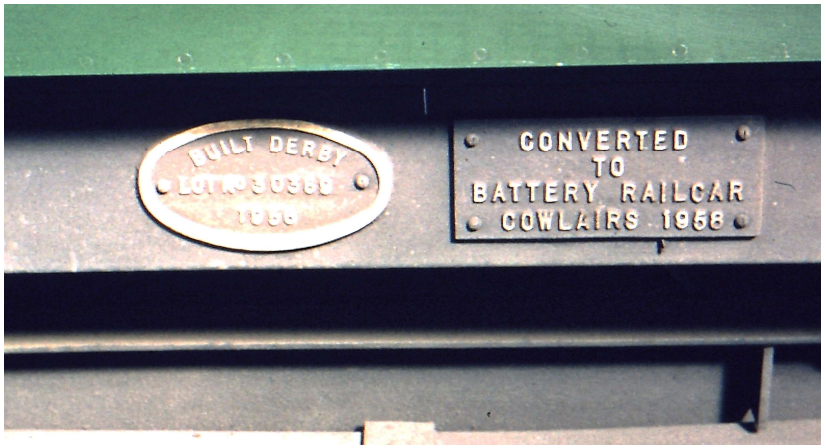


Vivarail unit (on left) at Glasgow Central station for COP26. Since demise of Vivarail now intended for use on W. Ealing to Greenford branch (GWR).

(Photographs: David Murray-Smith)

…an old idea revived!

First day of battery railcar service on Aberdeen – Ballater line (April 1958).



Joint venture - Scottish Area Board of BTC, NSHEB, Bruce Peebles Ltd and Chloride Batteries Ltd.

Photographs: David Murray-Smith

Heavy rail, light-rail transit (LRT), tramways and tram-train systems

Suburban trains, metros, trams, LRT and tram-trains: energy-efficient for mass urban transportation - use 2/3 less energy than equivalent rubber-tyred vehicles such as buses.

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Big contrasts between cities like Los Angeles where the car has largely remained “king” and Vienna (seen here on right) where so many forms of public transport are available everywhere, including trams, buses, metro and suburban trains.

Photograph: David Murray-Smith

Better transport interchanges….and better ticketing systems

Partick Interchange in Glasgow:
ScotRail trains, SPT subway,
bus operators and a taxi rank
all offering **easy transfer between transport modes**.
The station has ticket offices, escalators
Lifts and bicycle storage.

What is missing is a properly **integrated fares and ticketing system**

Glasgow City Region Plan: “ClydeMetro”

Concept proposed by SAPT many years ago, with landmark seminar in 2016

Endorsed by Glasgow Connectivity Commission in 2018

Now main project in Scottish Government’s Strategic Projects Review (2022)

Some benefits:

- **Extend rail network (as light rail) into growth corridors, eg Clyde Waterfront developments**
- **Link Glasgow Airport to city centre, business areas and the ScotRail network**
- **Reduce car traffic and thus CO_2 and other emissions**
- **Improve environment in city centre through reductions in car and bus traffic**

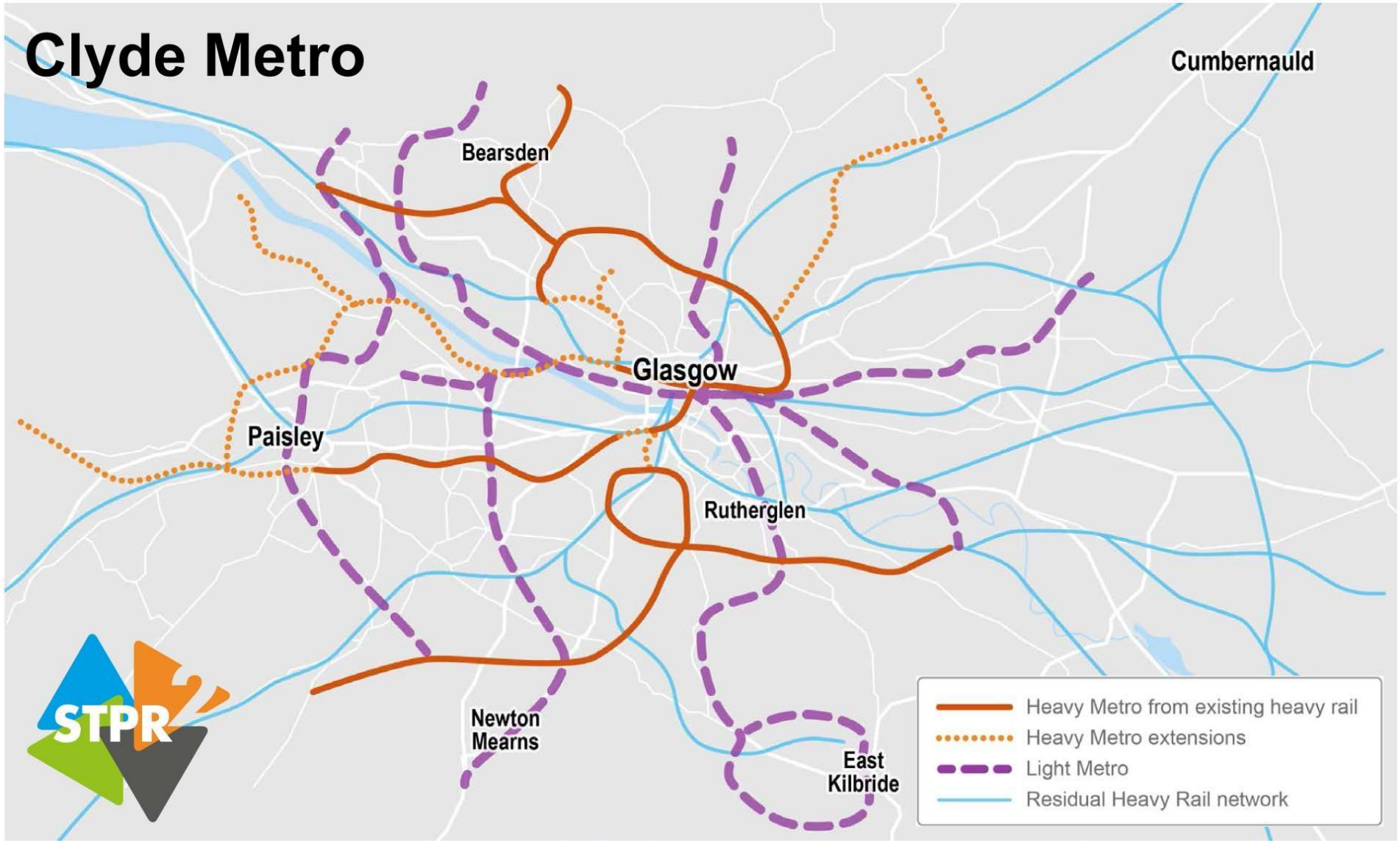


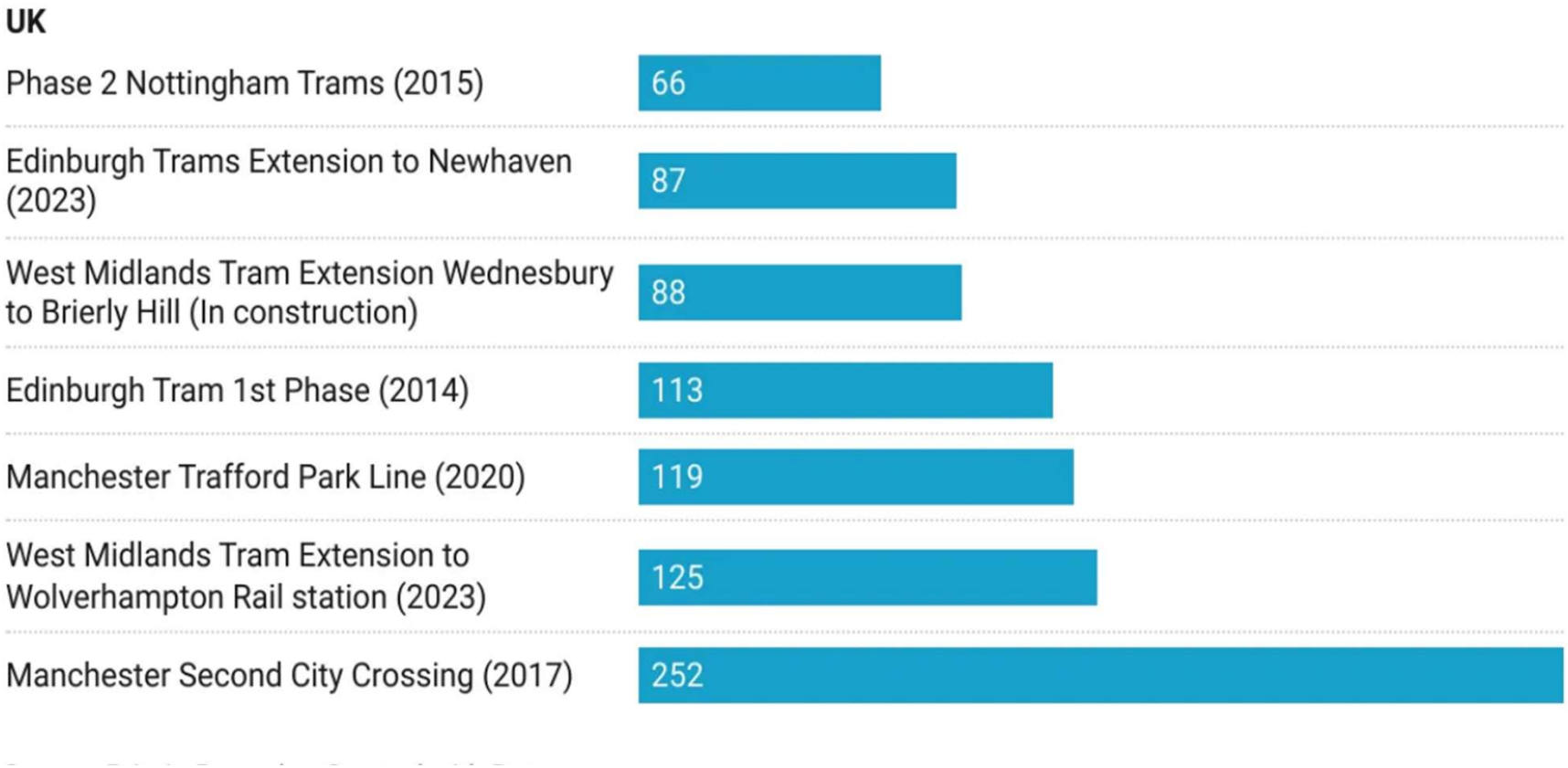
Diagram published by Transport Scotland in Scottish Transport Projects Review (2022) showing possible Clyde Metro routes

SAPT ideas for ClydeMetro

Line 1 to Airport and Paisley

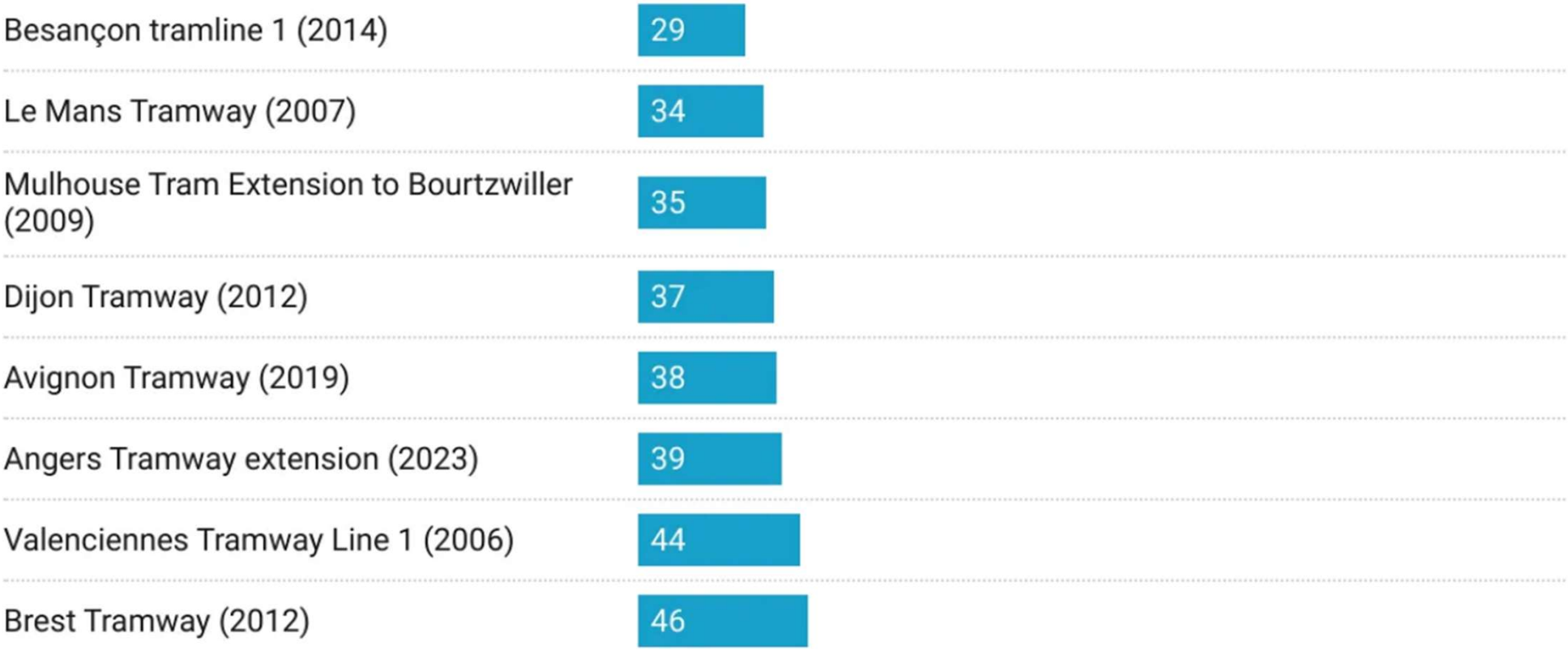
Light rail/tramway project costs in UK

Cost per mile of new lines adjusted to 2023 Pounds (millions)



Source: Britain Remade report August 2023

Similar costs in France - again adjusted to 2023 Pounds (millions)



Source: Britain Remade report August 2023

Existing old infrastructure: Ready for re-use?

Glasgow has much unused railway infrastructure such as the St.Enoch railway bridge over the Clyde which is now used only for a few empty train movements from Corkerhill to Eastfield depot or Queen St. station.

There are also many disused railway tunnels – such as under London Road at Parkhead and under Great Western Road between Kelvinbridge and Botanic Gardens

Where do I fit in?

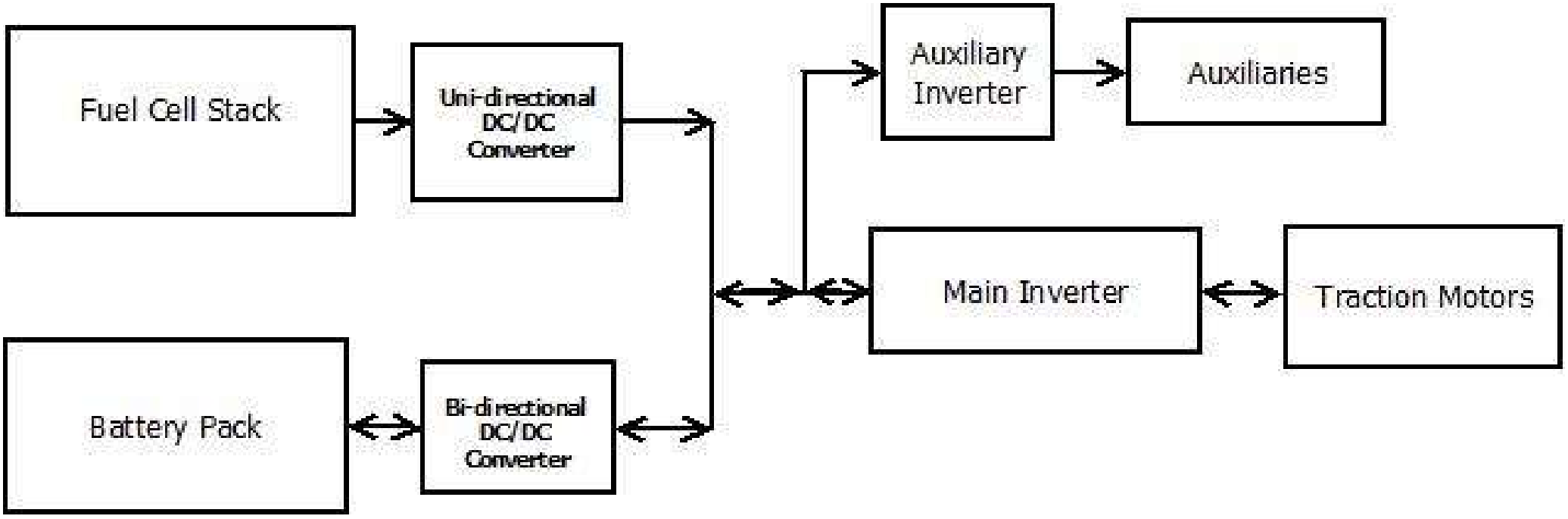
Applying system modelling, computer simulation and control system design methods to transport issues.
Example: simulations of hydrogen fuel-cell/battery electric trains for use on secondary routes.

Scottish hydrogen/battery-electric hybrid train converted from emu at Bo'ness, involving Hydrogen Acccelerator Group at St Andrews University and industry consortium led by Arcola Energy Systems Ltd.

(Photographs: David Murray-Smith, November 2021).

Acknowledgements to GU colleagues – Dr Euan McGookin, Dr Douglas Thomson and Adam McGirr (research student) who have collaborated with me on this project and to Scott Prentice of ScotRail and also to Arcola Energy Systems Ltd for data.

Hydrogen/battery electric powertrain for railway applications



The route considered, West Highland line Glasgow-Fort William

- Distance = 74 miles (119 km)
- Current journey time = 3hr 45min
- Typical train: diesel multiple unit, 2, 3 or 4 coaches.
- Current number of trains per day each way = 4
- Plenty of scope for regenerative braking – thus energy saving.
- Also locomotive-hauled freight and sleeper trains

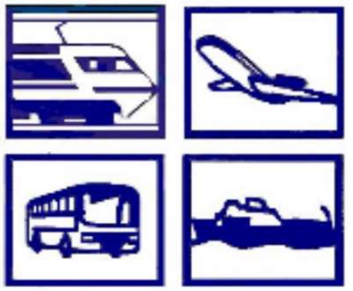
Initial simulation studies: some results

- Hydrogen fuel cells: efficiency depends on operating condition, also sluggish response to power level changes.
- Control strategy: slow changes in fuel-cells; fast changes and peak loads from batteries.
- Matching 3-coach dmu performance for 29.6km from Spean Bridge to Corrour needs: three 250kW traction motors , 500 kW fuel cell stack, 375 kW battery pack with 210 kWh storage capacity.
- Calculations suggest storage tanks cannot then be fitted in without using passenger space. Hydrogen (at 350 bar) takes up 8 times and batteries 16 times space of diesel fuel for same stored energy.
- New-build best approach? Or look again at battery options and forget hydrogen?

Challenges

- Achieving modal shift – 60% of carbon targets require behavioural changes – requires carrot + stick approach? Public transport must become more affordable and reliable. Mainly carrot at first but sticks essential too.
- Investment – rolling programmes rather than stop/go for bus, rail and ferry procurement. Need more research and development on batteries, fuel cells etc.
- Systems approach to electrical power - must allow for transport demands.
- Uncertainties in technology, skills and business models.
- Problems with short-term political agendas.
- Uncertainties in transport demand following the pandemic.
- Global demand for materials and a competitive global market.
- **COST**

Actions required from organisations such as SAPT and Transform Scotland:



SAPT

- Press strongly for an **integrated public transport strategy** and a system that is the first choice for most journeys.
- Press for **a more joined-up approach to electrical power systems, hydrogen infrastructure and transport**.
- Press for **major rail improvements** (e.g. further electrification), making inter-city journeys in Scotland faster and more pleasant than by car.
- Press for **better connections with other modes** for better travel times for passengers (also for parcels and freight).
- Support use of **electrically powered** buses and light rail systems in major cities and development of low-emission road and rail vehicles for freight.

transform scotland