Powering Future Transport in Scotland

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Headlines: Fact or Fiction?

“Air pollution ‘wipes at least year and a half’ from life expectancy”
Herald (13th *M*arch 2019)

“Britain falls behind on electric cars”
Times (20th January 2019)

Electric car surge will risk power blackouts
Times (2nd October 2018)

“Self driving cars may be closer than they appear”
ww.goldmansachs.com/insights (June 2018)S

“Driverless cars create ‘robot-fuelled gridlock’”
Herald (2nd Feb 2019)

Problems, uncertainties and developments

- **Demanding targets for emissions**
- **Growth of plug-in hybrid/battery electric cars**
- **Uncertainties about autonomous vehicles and user preferences.**
- **Rail electrification uncertainties – slower progress than other European countries**
- **Developments in energy sources – batteries, hydrogen fuel-cells etc**
- **Potential problems for electrical supplies**

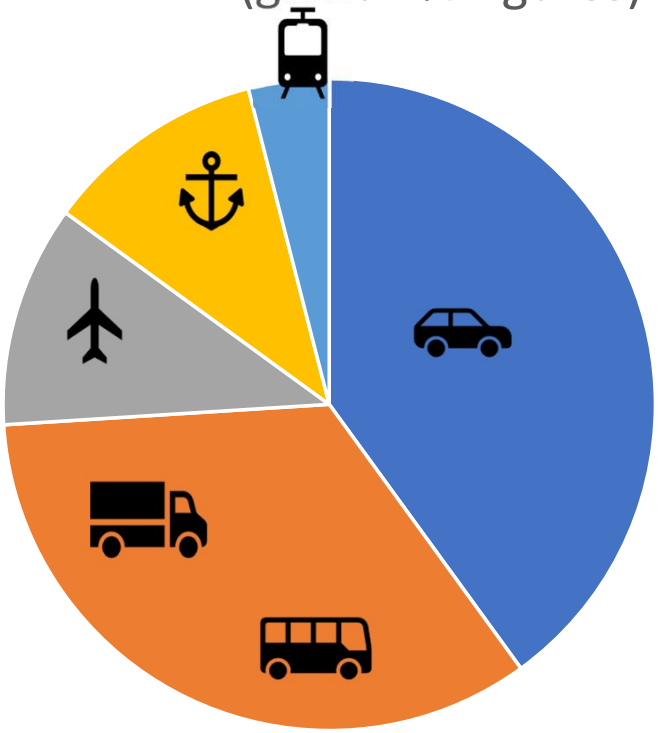
Where are we heading in Scotland?
Where **should we** be heading?

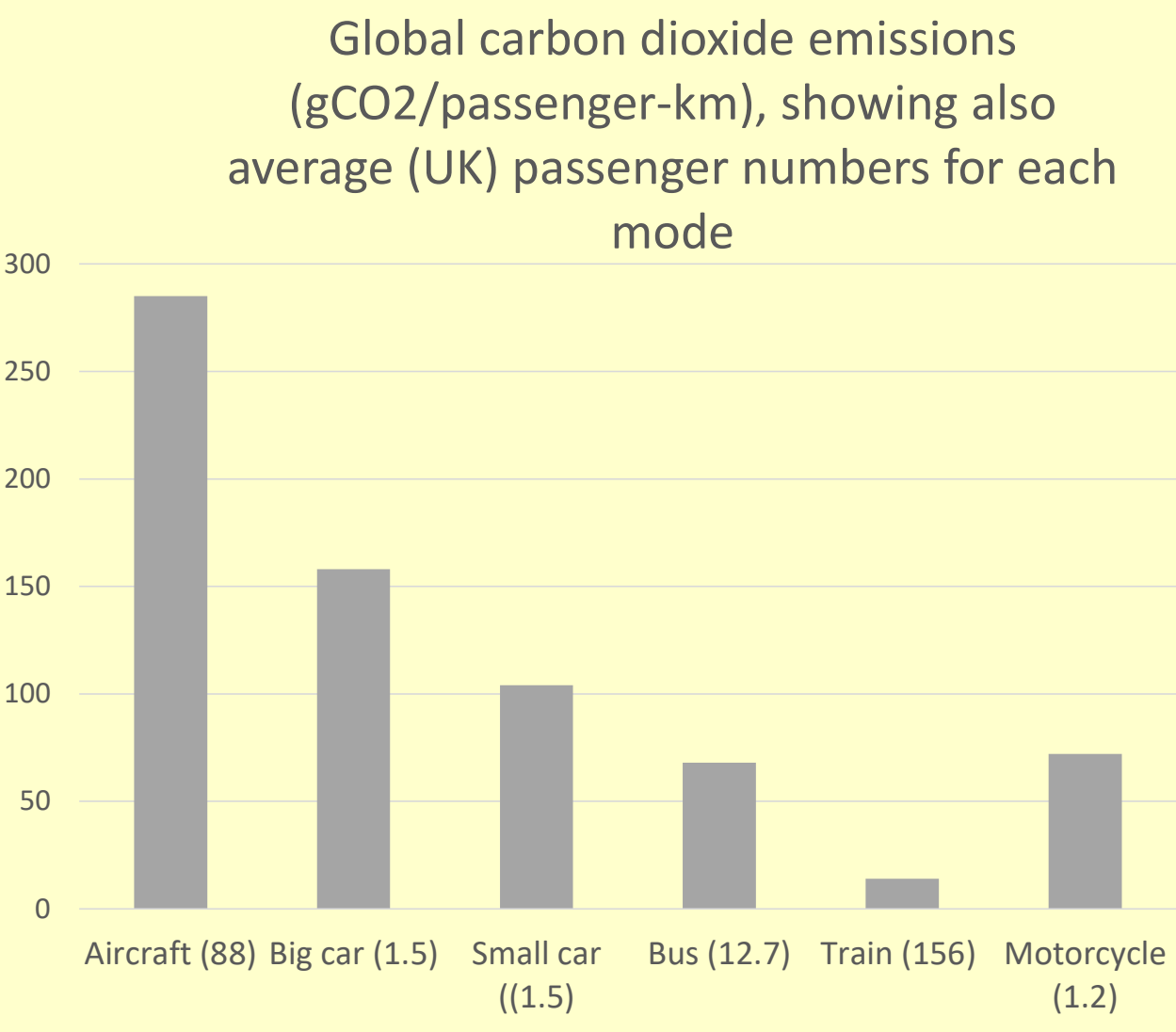
Transport in Scotland

- Geographical issues:
  - Uneven population.
  - Rapid population growth in some areas
    - e.g. Edinburgh, Aberdeen, Perth and Kinross.
  - Island communities – ferry/air links essential

- Devolved government
  - Transport Scotland - not UK DfT
  - Distinctive transport strategy?
  - Significant transport investments since devolution

Greenhouse gas emissions for transport sector (global % figures)





Some government targets

- Scottish target: end to sales of new diesel and petrol cars by 2032.
- UK government target: phase out conventional petrol and diesel engines from 2040.
- Low emission zones to be introduced in some cities in Scotland from 2020.

- UK Department for Transport suggests (2018) diesel-only trains be eliminated by 2040.

About comparing modes of transport

- Different vehicle types: different measures of energy

  e.g. Cars: litres of fuel/km or litres/100km;

  Aircraft, buses and diesel trains: litres/100 seat-km

  Electric trains: kWh/seat-km.

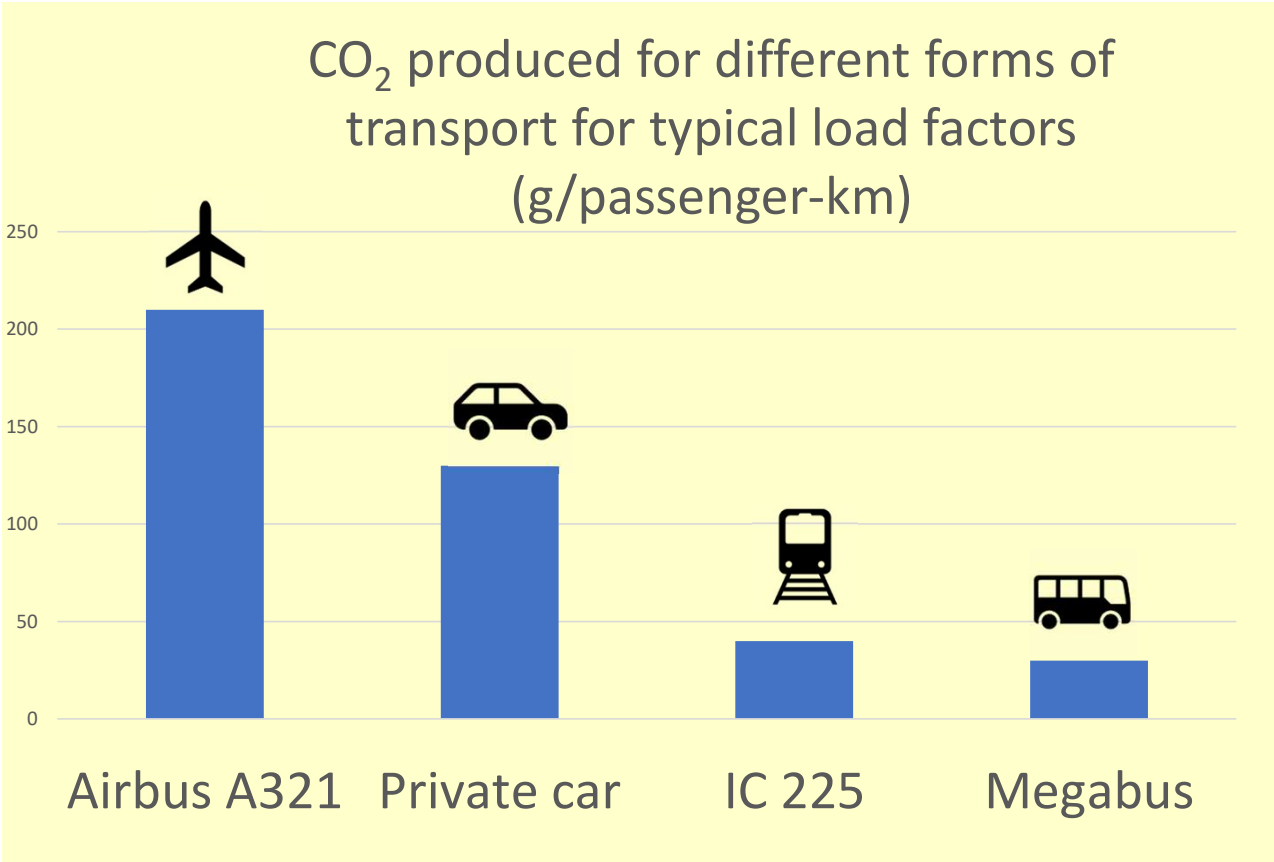
  Comparing diesel and electric trains - grams of CO_2/seat-km (g CO_2/seat-km)

- Load factors often important

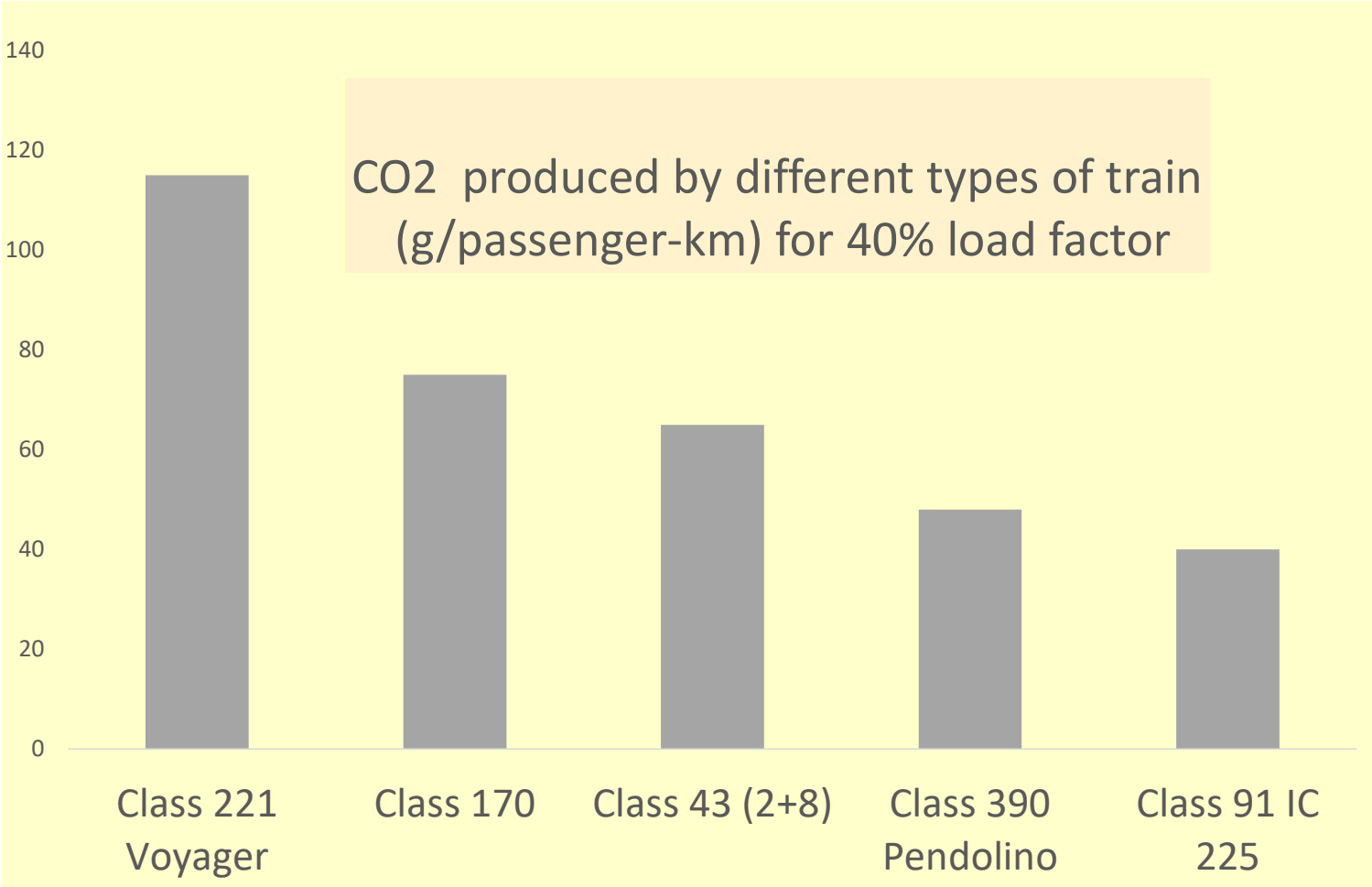
  e.g. For comparisons of transport modes can use gCO_2/passenger km

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

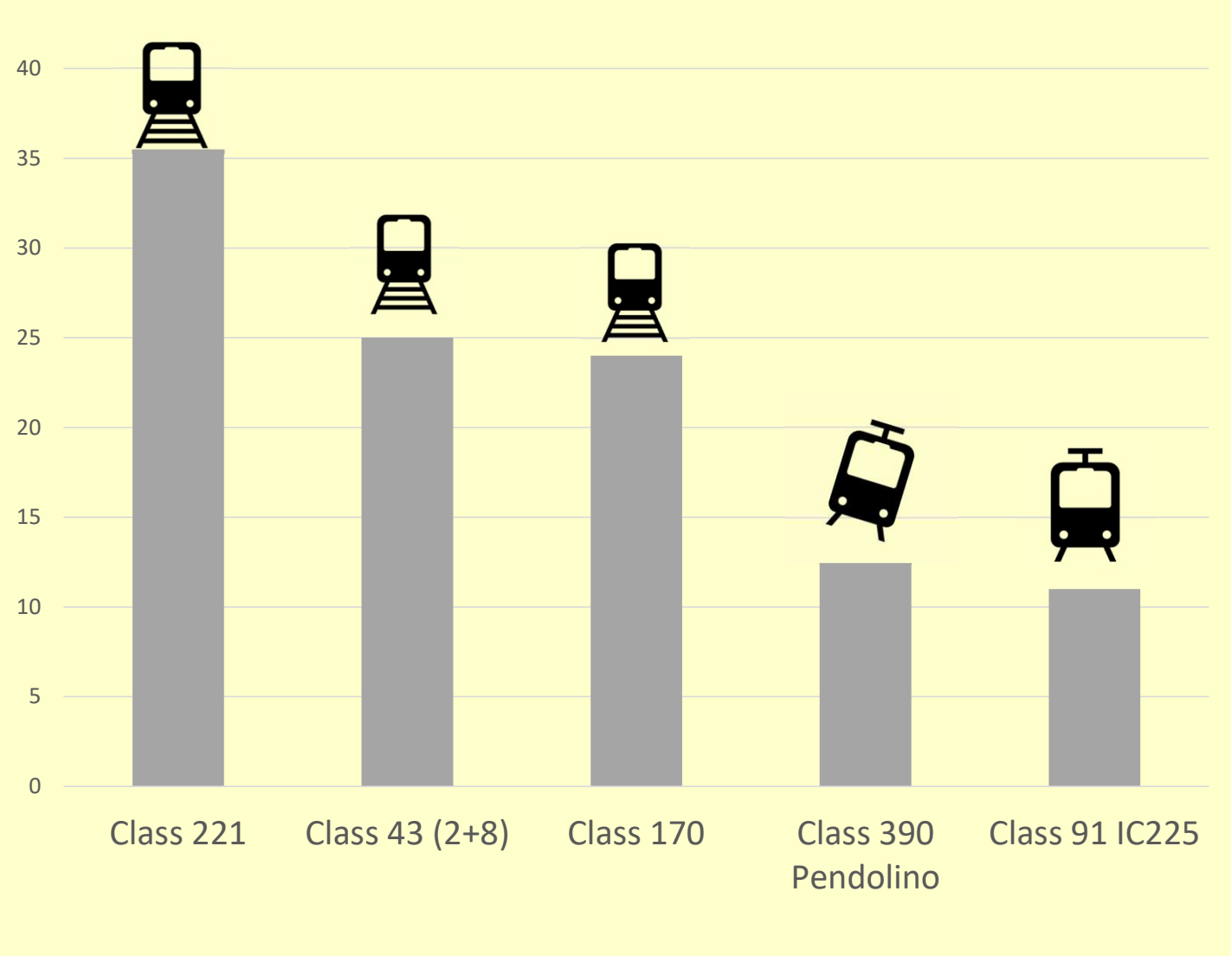
Comparing different modes on longer routes (e.g. Edinburgh – London)



Trains: comparing different types



Trains: comparisons based on g CO2/seat-km



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

Other emissions

- Oxides of nitrogen (NO_x): Acceptable level - annual mean of 40 $\mu g/m^3$

- Particulate matter PM): Measures based on size of particles.
- PM10 - 10 micrometres (μm). Acceptable annual mean 18 $\mu g/m^3$
- PM2.5 – 2.5 micrometres. Acceptable annual mean of 10 $\mu g/m^3$

- Oxides of sulphur (SO_x): Important in shipping; no longer so significant in other sectors

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

- All transport sectors contributing less since 1990, apart from international aviation and shipping where levels have risen for some emissions.

Example: Bearsden Cross, East Dunbartonshire

Glasgow suburb typical of routes into major cities: Designated an Air Quality Management Area by East Dunbartonshire Council since 2011. Figures for 1st 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 two months for day-time periods (0700-1900).*

*My thanks to Professor Michael Hitchman (University of Strathclyde) for providing this information.

Notes on atmospheric pollutants for different transport sectors

- Emissions in Europe from **transport** declining despite increase in activity but transport responsible for over half of all NOx emissions.

- **PM figures** include tyre-wear, brake-wear and road surface particles.

- In Europe **ships** account for 25 % and 13 % of all NO_x and SO_x emissions, respectively.

- NO_x emissions from international aviation increasing (+142 %) since 1990.

- For **rail** NOx and particulates most significant in station areas etc. Particulates are special problem in diesel engine transient conditions (e.g. starting and accelerating).

“Airlines fall short in race to lower carbon emissions”
Engineering & Technology, April 2019

Emissions from internal air services

- CO_2 emissions for typical turbo-prop aircraft (Bombardier Q400 or ATR 72) for 200 km flight = approx. 150 g/passenger-km

- CO_2 emissions for Airbus A321 for London-Edinburgh/Glasgow flights = approx. 210 g/passenger-km

Emissions of NOx important for short-haul routes as well as for international flights (but not growing as fast).

Emissions from ferries

- Emissions issues: NO_x, particulates and SO_x. Typical car - 101 g of SOx annually (for 15000km), but large marine diesel generates 5,200 tonnes of SOx per year.

- Ships now use low sulphur fuel in North Sea and other European waters (1.5% sulphur in 2007; 1% in 2010; 0.1% in 2015).

- Car ferries - more NOx and particulates than vehicles for same distance by road. Reducing speed 10 per cent cuts emissions least 19 per cent.

- Standards agreed by IMO in 2008 estimated to save up to 26,000 lives per year in the EU in 2020.

- Liquified natural gas and biofuels could reduce toxic emissions.

"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 undergoing big changes.
- Less fossil fuel generation; less nuclear; more renewables; system more distributed - issues of control and stability; problems of "black start".
- Need more investment in generation and storage to keep system balanced.
- What are the likely effects of more electric transport? Estimates of extra demand from battery charging range 10% to 40%. How?

The impact of electric vehicles

- Home charging – stronger local networks (and domestic supplies?) plus developments such as “lamp-post” or inductive charging facilities in street.
- Fast charging for batteries - significant investment in infrastructure.
- “Intelligent systems” approach (e.g. trials with TfL buses, UPS fleets in London – battery energy pumped back into grid at times).

- So perhaps electric vehicles not all bad news? Could be part of solution with “smart” charging and new tariffs.

- Current EV users: “early adopters” - relatively well-off, less risk averse.
- Future road and fuel tax policies? Depreciation rates? Longer term incentives?
- Highest level of electric vehicles in Norway, but with major incentives. Norway investing in public transport (e.g. new rail infrastructure programmes etc).

Developments in battery technology

- Most batteries for transport applications are lithium-ion batteries and developments giving improved range, reduced charge times etc.
- Other developments are under way in lithium-metal batteries, flow batteries, lithium sulphur batteries etc - capacity and charge time better.

- Concerns about total energy efficiency and other issues (e.g. long-term availability of materials, environmental effects of mining, processing and end-of-life disposal).
- Increasing life expectancy – but continuing uncertainties.

- R & D on “structural” batteries using carbon-fibre materials – vehicle structure becomes the battery.

"Electrical container ships are a hard sail"
IEEE Spectrrum, March 2019

Road, light-rail, marine and aircraft applications of batteries

- Buses (e.g. Vienna, Milan), light goods vehicles – often hybrid systems.
- Some tramway systems experimenting with hybrids involving batteries. Others e.g. Doha, Qatar (opened in 2018) and Busan, South Korea (demonstrator line) involve battery traction only.
- Small ships and inter-island ferries (e.g. in Orkney and Norway).
- Electrically-powered aircraft for short flights? Aviation share of greenhouse gas emissions to reach about one quarter of total by 2050? Structural batteries?

Battery-electric trains: old and new

First day of battery railcar service on Aberdeen – Ballater line (April 1958). In service until branch closed in 1966.
Joint venture involving Scottish Area Board of BTC, NSHEB, Bruce Peebles Ltd and Chloride Batteries Ltd. Later used by Railway Technical Centre Derby. Now on Deeside Railway at Crathes.

"Aberdeen to Ballater by BMU: Notes on the Battery Railcar Experiment"
David Murray-Smith, Available on Railscot website (2018).
https://www.railscot.co.uk/articles/

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

"Battery electric train demonstration", David Murray-Smith, SAPT Newsletter, 2018/4, December 2018
http://sapt.org.uk/Newsletter2018-4.pdf

Vivarail battery-powered Class 230 unit

Some features of the Vivarail Class 230

- Various hybrid versions available –diesel, electric, battery, hydrogen.
- Docking system for battery charge at each end of route.
- Modular design - fast change of batteries or change to different type of power source.

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, other European cities; HGVs (Tesla and Hyundai); ferries for Norway and Orkney.

- Fuel-cells in Alstom *Coradia Lint* trains in Germany (Lower Saxony).
- Vivarail announces fuel-cell version of Class 230 (early 2019).
- Alstom/Eversholt Rail to convert Class 321 emu (the “Breeze”).
- “Enable H2” aircraft project: Cranfield University, GKN Aerospace etc.

Potential limiting factors for hydrogen

- Most hydrogen produced today is for use in chemical processes through steam reforming of natural gas. Electrolysis potentially important and use growing. New interest in use of waste and discarded plastics.
- Recent IMechE report against general use of hydrogen for railways. More useful for lines with no business case for electrification. Case different if local hydrogen source (e.g. electrolysis from renewables) for buses, trains, ferries and other local needs.
- Best for areas with renewables surplus and poor transmission links (e.g. islands)?
- Recent study of the single-track Trondheim-Bodø line in north Norway – case for electrification poor and hydrogen fuel-cell locomotives better?

Developments in energy recovery systems

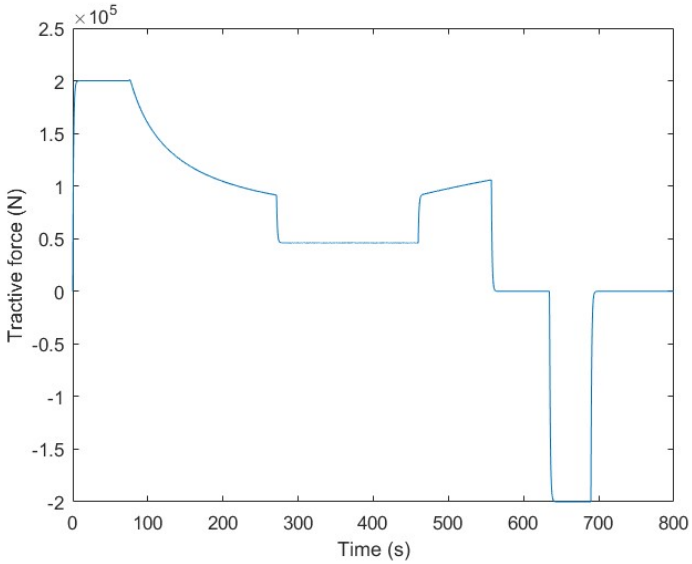
Idea is to make more use of energy currently dissipated in braking. Various approaches possible:

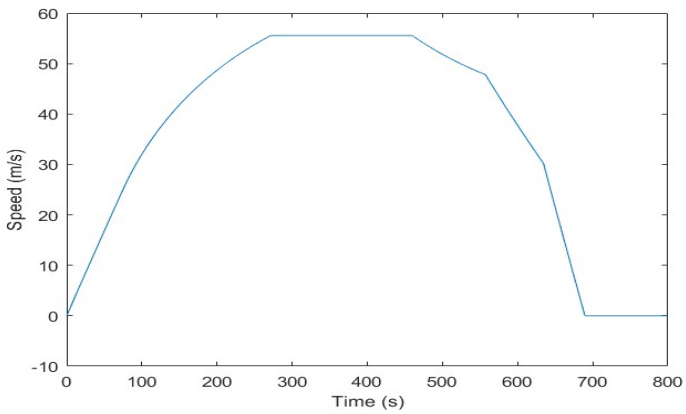
1. Mechanical systems based on flywheels (e.g. Parry "People Mover" approach).

2. Hydraulic systems (e.g. Artemis approach).

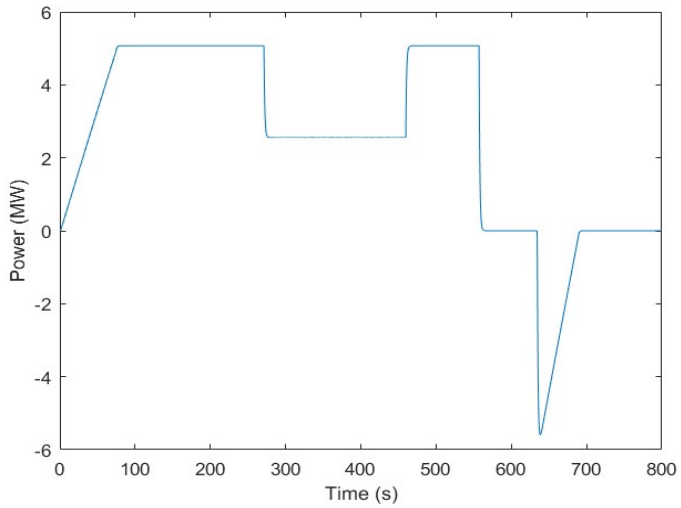
3. Electrical methods based on batteries or supercapacitors.

What are the possible benefits?





Computer-based study using inverse simulation methods:
Pendolino 9-car set



Mechanical stored-energy systems

Flywheel technology: old and new

BR Class 70 electric locomotive, built 1942. Image Ben Brooksbank,
CC BY-SA 2.0, https://commons.wikimedia.org/w/index.php?curid=15078547

Class 139 unit, (2009) (Parry People Movers) LPG+flywheel

BR Class 71 E5001. Image by Phil ScottBCC BY-SA 3.0,
https://commons.wikimedia.org/w/index.php?curid=338137

Example of hydraulic energy storage

Artemis Intelligent Power Digital Displacement® pump technology: trials in Scotland, with train accelerated from rest using energy stored from braking. Could avoid using diesel engines in station areas?

Second application area:

Hydraulic units powering cooling fans and generating electricity in dmu trains use about 15% of fuel. Digital pump technology could give savings. Reports of trials on a ScotRail Class 170 unit suggest savings of 1.5 million litres of fuel/year for ScotRail Class 170 fleet

Artemis Intelligent Power test vehicle at Bo 'ness, October 2018

Supercapacitor applications: not just energy recovery

A “capabus” in Kai Tak, Hong Kong

https://commons.wikimedia.org/w/index.php?curid=76944179

Wuhan supercapacitor trams. CRRC designed fleet of 21 four-section trams with Siemens traction and braking equipment. Capacity: 400 passengers. Range: 3-4 km after each charge. Charge time: 10-30s.

Source: Changjiang Weekly 06/15/2016 05:06:01

Supercapacitors and batteries compared

- Battery can store more energy for given weight and volume (i.e. better energy density – up to about 25 times for given weight)
- Supercapacitor charged very quickly and discharged in a controlled fashion.
- Battery system- overall energy efficiency 75-90%; supercapacitor efficiency- typically more than 95%
- Number of charges and discharges over lifetime almost unlimited for supercapacitor.
- Battery life 5-10 years; supercapacitor life 10-15 years.
- Supercapacitor costs significantly more than equivalent battery but difference becoming smaller.

Tram, LRT and tram-train systems

- Trams: mix of street running and sections of reserved track.
- LRT – essentially trams but with most of route on reserved track.
- Tram – trains: tram/LRT vehicles which are equipped to use conventional railway lines as well as run on streets (e.g. Sheffield – Rotherham, planned system in Cardiff).

Trams and LRT: energy-efficient for mass urban transportation - use 2/3 less energy than the equivalent rubber-tyred vehicle.

Scene near Hauptbahnhof, Berlin (D. Murray-Smith)

Los Angeles County light rail Gold Line (Wikipedia)

"Taxis without drivers – or steering wheels"
IEEE Spectrum , Jan.2019

Autonomous/automatic transport systems

- Not yet clear how autonomous vehicle developments will affect car ownership. Purchase and maintenance costs higher than for today's cars.
- Will "on-call" autonomous vehicle services prove popular? Some changes in patterns of car usage already apparent.

However we should also be looking carefully at autonomous operation for other modes:

- Fully automatic train operation has been very successful in many urban rail systems (e.g. Lille, KL, Copenhagen). Will reach Glasgow subway soon.
- Autonomous trams on test in Potsdam (Siemens *Combino* 400) and in St Petersburg (PK Transportyne Systemy + Cognitive Technologies)
- Driverless 160km/hour trains for New Airport line in Beijing – opening September 2019.
- Automatic train control being applied to part of Thameslink route (St Pancras Intl. to Blackfriars) to increase service frequency – what about Kelvinhaugh Junction – Partick- Hyndland?

Examples of relevant energy research in Scotland

- University of Edinburgh: Institute of Energy Systems.

  Examples: a) Adaptation and resilience in energy systems

  b) Electro-mechanical modelling of tidal turbines

- University of Strathclyde: Department of Electronic and Electrical Engineering.

  Examples: a) Future power networks and smart grids

  b) Wind and marine energy systems

- University of Glasgow: School of Engineering, Research Division for Systems Power and Energy.

  Examples: a) Power electronics and drive systems

  b) Simulation of energy systems

Some interesting recent developments

- *Clean Air Strategy* (UK Government, January 14 2019) - rail contribute just 4% of NOx and 1% of particulate emissions nationally. Problems mostly in station areas. Calls for alternative fuels for routes where diesel trains run.
- On 7 February 2019 DfT launched "Call for Evidence" to help shape future of light rail - part of UK Government drive for carbon-free urban mobility. Part of "Future of Mobility" strategy. Deadline for submissions of 19 May 2019.
- 14th March 2019: announcement of approval for Edinburgh tram extension.
- Hitachi (*Scotsman* 25th March 2019) announces plans for addition of batteries to Class 385 units to allow use to destinations currently beyond the electrified network in Scotland (e.g. Perth, East Kilbride). "*Scottish passengers would be among the first in the world to ride on battery-powered trains under plans unveiled by Japanese firm Hitachi*" Ballater BMU in 1958? Robert Davidson's *Galvani* trial on the E&G in 1842?

Conclusions (1)

SAPT should continue to engage with other organisations and pressure groups to:

- Ensure transport modes compared objectively (e.g. appropriate energy and atmospheric pollution measures).
- Encourage developments in renewable energy and energy storage for islands and other areas far from main population centres.
- Encourage critical assessments of r & d activities and review achievements in new areas of technology (batteries, hydrogen fuel cells etc) for transport applications of all kinds.
- Support objective research on potential impact of autonomous vehicles and examine benefits of automation within other transport modes

We should:

Conclusions (2)

- Press strongly for integrated transport strategy and public transport system that is first choice for most journeys for most people.
- Support more r. & d. on “smart” electrical grid systems and effects of renewables and e.v. charging on system capacity and stability.
- Press for joined-up approach to transport and electrical power systems.
- Press for rail infrastructure improvements (e.g. further electrification) to make inter-city train journey times in Scotland substantially less than time by car for same journeys.
- Support evaluations of battery and hydrogen powered trains on appropriate routes in Scotland.
- Press for new metro, light rail and tramway systems in Scottish cities.