Accelerating towards sustainable travel

It's not (just) what you use, but the way that you use it

IMechE Automobile Division
Chairman's Address 2023

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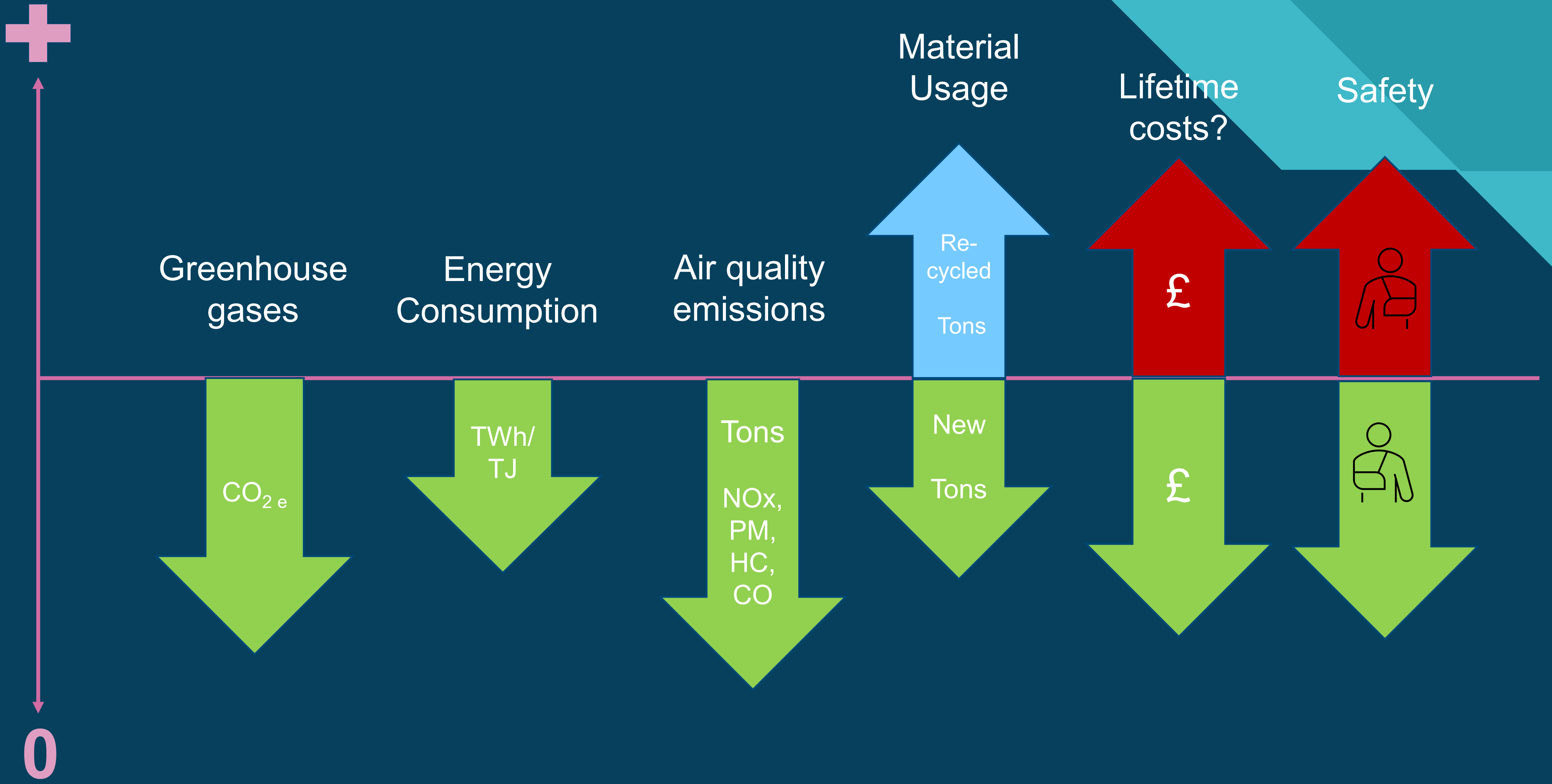
Disclaimer

- This presentation reflects some of the author’s personal observations and experiences of improving the sustainability of travel.
- The views expressed are those of the author, and not of the IMechE or other organisations.

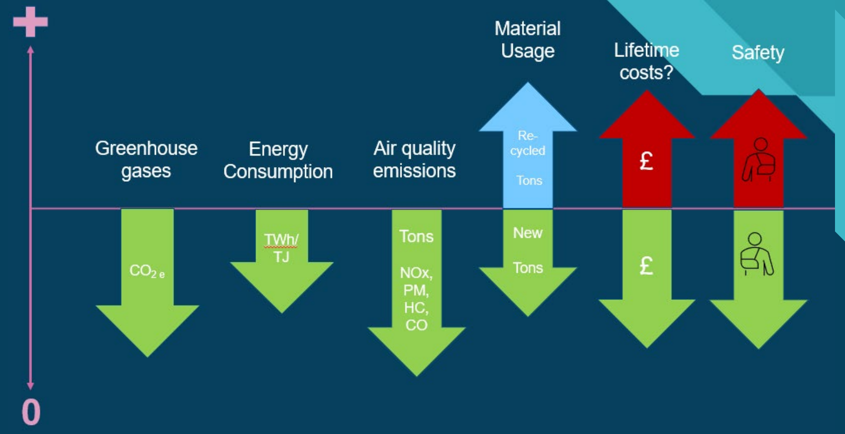
What do we actually mean by “sustainability”?



How should Chartered Engineers contribute?

Extract from the RAEng & Engineering Society Statement of Ethical Principles:

- *Hold paramount the health and safety of others, and draw attention to hazards*
- *Protect, and where possible improve, the quality of built and natural environments*
- *Maximise the public good and minimise both actual and potential adverse effects for their own and succeeding generations*
- *Take due account of the limited availability of natural resources*



Should we just travel or transport less?

- Should we feel guilty about flying, or just stop flying altogether?
    - “I believe, as transport secretary, that we can get to “guilt free” flying in this country” Rt Hon Grant Shapps, former transport minister, CoP26, November 2021

- Should we limit what cars people can drive, or when and where they can use them?

- Should we restrict internet deliveries, especially “next day” or “same day”?

?

?

?

Should we just travel or transport less?

- Perhaps we should just hold all family “gatherings” on Zoom?

?

- While some reductions in travel and transport are undoubtedly achievable, the economic and societal impacts of radical travel restrictions have been clearly demonstrated during the CoVid pandemic, and are probably not desirable as standard practice.

- Travel & tourism were estimated to contribute £234Bn to the economy in 2019, 11% of GDP, providing 4.3M jobs. *

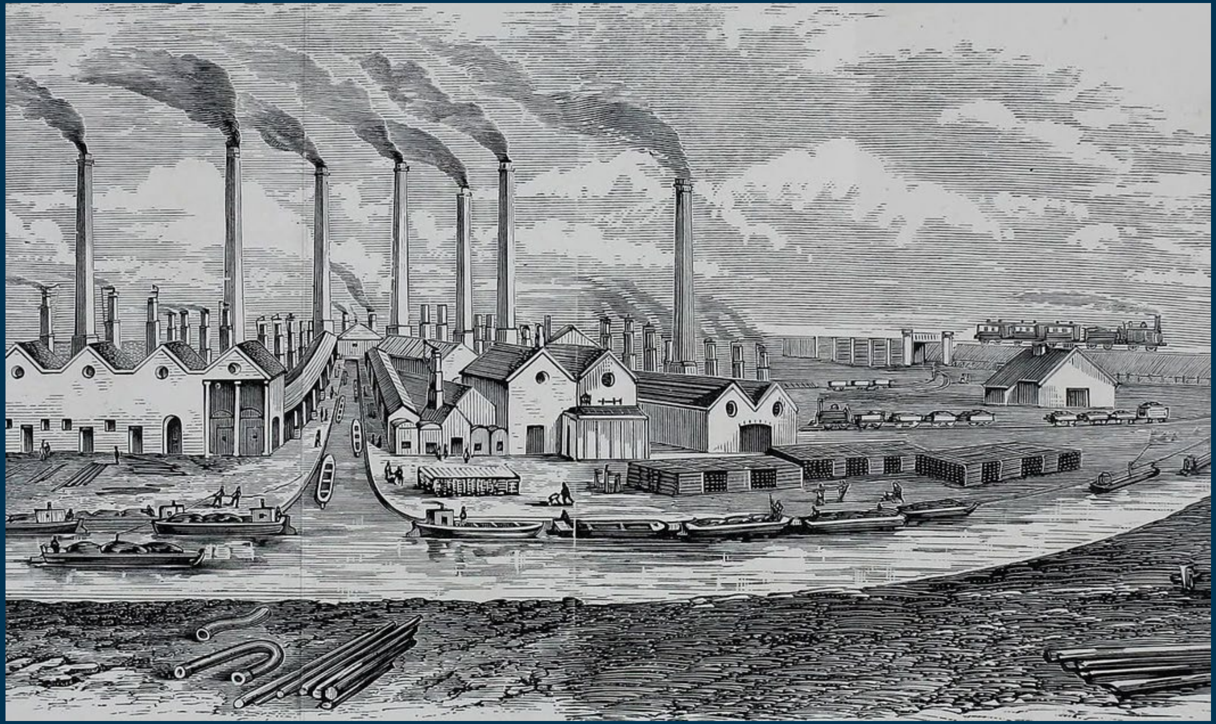
* Statista.com June 2022

Through history, Professional Engineers have greatly enhanced the Economy

By the early 19th century, the industrial output of factories powered by the steam engines developed by Boulton & Watt was exceeding the traditional transport mechanisms of the day: canals and horse & cart.

James Watt developed the idea of the *useful output* of a machine, when asked by mill and mine owners "*how many horses will one of your steam engines replace?*"
In 1782 he conducted experiments and deduced that a heavy horse could turn a 24' wheel 2.4 times per minute, with a force of 180 lbf. Thus:

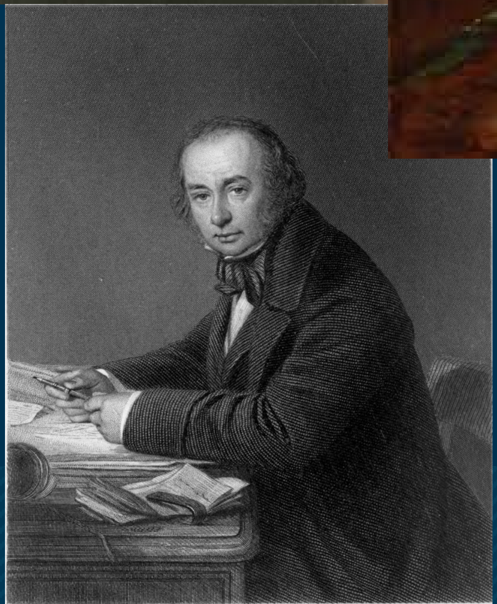
$$1\ horsepower = 180\ x\ 2.4\ x\ 24\ x\ \pi$$
$$= 32{,}572\ lbf.ft/min$$



For convenience, Watt rounded 32,572 up to 33,000 lbf.ft/min, which equals 746W, the unit used to this day.

Through history, Professional Engineers have greatly enhanced the Economy

- At the forefront of the industrial revolution, Britain had the choice: either constrain progress due to transport limitations, or develop better alternatives.
- Faced with the challenge of maintaining economic progress, the great engineers of the early 19th century, including Trevithick, Stephenson and Brunel, developed locomotives and complete railways to facilitate the movement of goods, and latterly people, across the country.
- Later came the development of steam ships to enhance international trade.
- Thus the next two centuries of fossil fuel-powered transport was born.



Professional Engineers have also Radically Improved the Environment

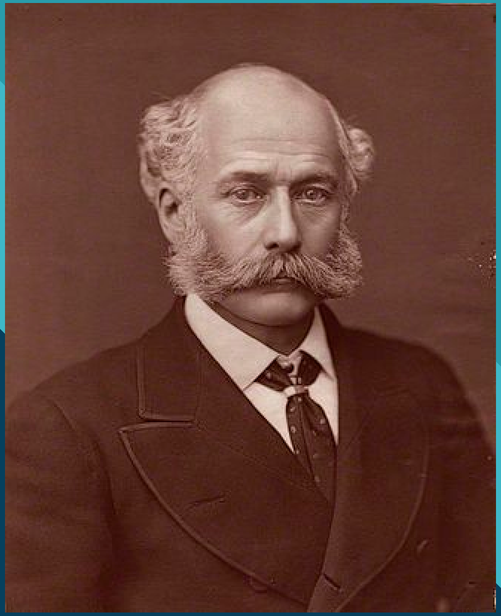
Rapid growth in towns and cities, driven by the industrial revolution, and enabled by the railways, created one of the first great environmental challenges: how to provide clean water and sanitation for the rapidly increasing, and overcrowded, population? Cholera outbreaks in London between 1831 and 1854 claimed over 32,000 lives.

The hot summer of 1858 made the problem so acute that "The Great Stink" enveloped parliament, and in 1859 Joseph Bazalgette was asked by parliament to implement a solution; but only after they had previously rejected his proposals *five* times.

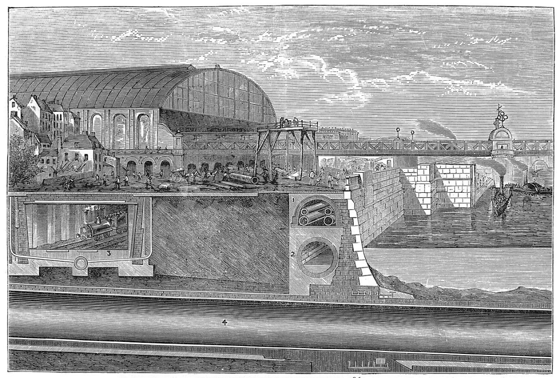
Bazalgette was a colleague and contemporary of I K Brunel, who championed his appointment to the Metropolitan Board of Works in 1856, a far-sighted decision.

"The Silent Highwayman"
Death rows the Thames.
"Punch" July 1858

Professional Engineers have also Radically Improved the Environment

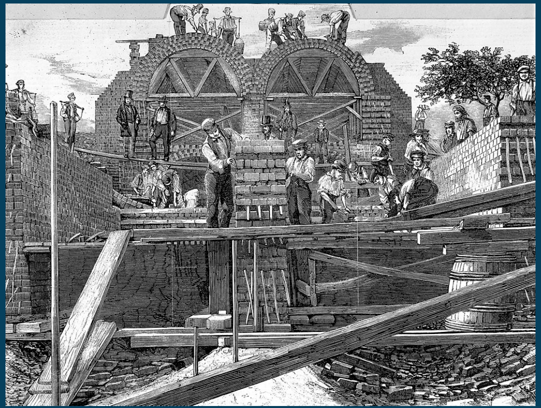


- Bazalgette took a systemic approach, embracing both the macro design of nearly 1200 miles of sewers, pumping stations, and the Thames embankments to house them and deepen and speed up the river flow.
- He also developed details such as novel testing and quality control methods for the Portland cement used in construction, and personally signed off *every* connection to his new system.
- Bazalgette's sewer system remains in use today, catering for nearly double the population for which it was designed. It was estimated to have increased life expectancy in London by 20 *years*.



SECTION OF THE THAMES EMBANKMENT, 1867.
Showing (1) The Subway. (2) The Low-Level Sewer. (3) The Metropolitan District Railway. (4) The Pneumatic Railway.

Bazalgette did *not* tell Londoners to use the bathroom less!



Environmental Engineering was highly regarded….

Joseph Bazalgette was knighted in 1875, and in 1883 was elected President of the Institution of Civil Engineers.

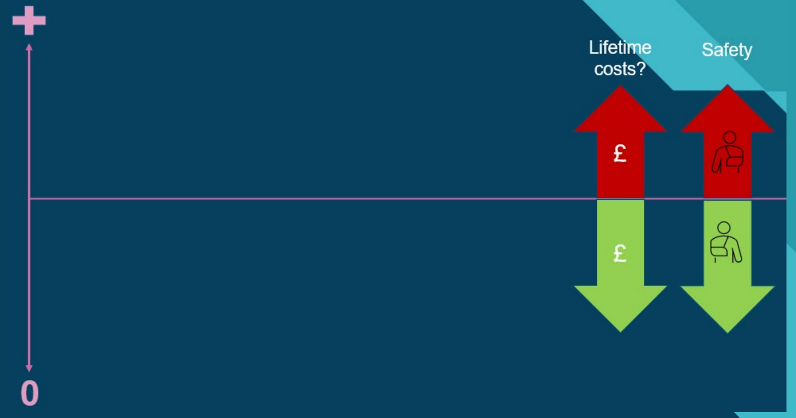
He has a memorial on Victoria Embankment.

His salary in the 1860's was £2,000 p.a., the equivalent of around £270,000 today!

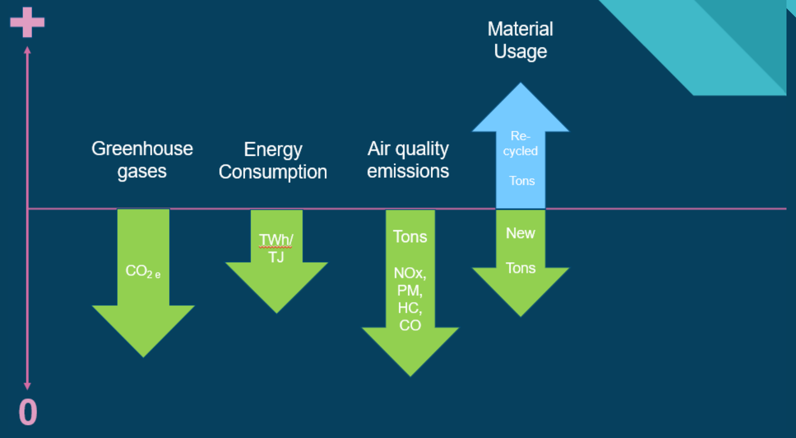
The first ship built to transfer waste sludge from the East London outlets to the North Sea was called the SS Bazalgette….

As with our 19th Century Forebears, Engineers in the 21st Century face huge challenges, and immense opportunities

Sustaining, and further improving, the economic and safety performance of our current transport systems.



While simultaneously minimising the GHG, energy, AQ emissions and material usage of these systems.



For the best outcomes, a systemic approach is needed

Ideally we should consider:

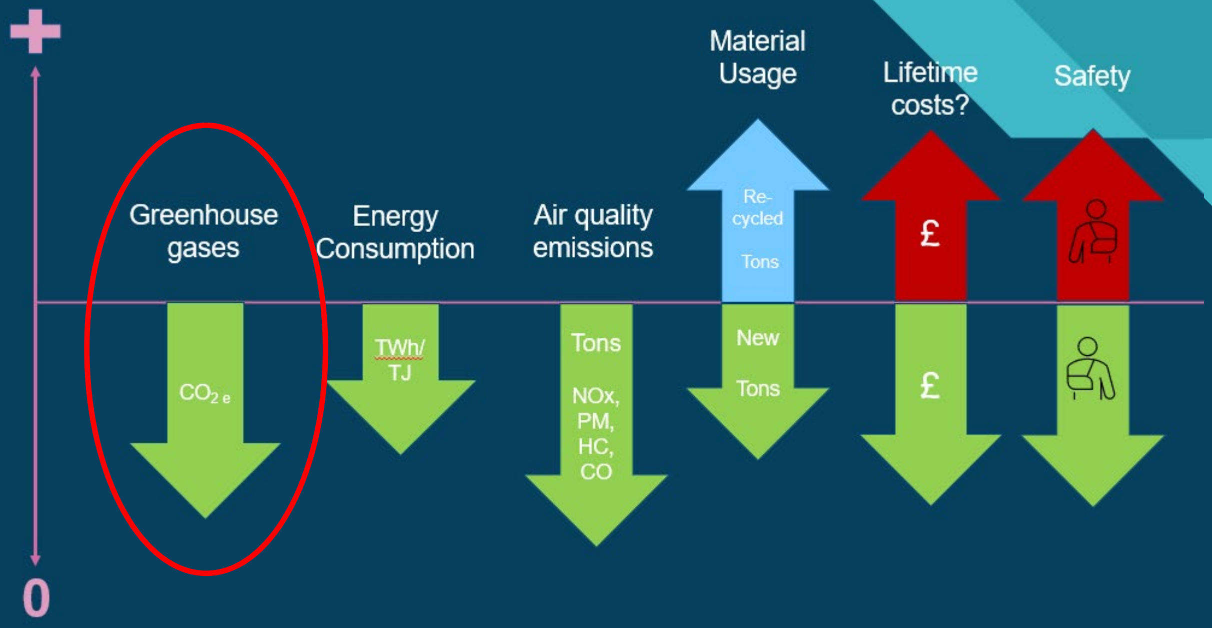
- The efficiency of the vehicles themselves, (preferably on a lifecycle basis, although there is as yet no consistent approach to this).
- The energy supply on a complete “well to tank” basis.
- The “useful work” of that vehicle, in terms of what it is actually delivering, as originally pioneered by James Watt.

Traditionally a large amount of engineering effort and investment has gone into the first topic, as does a large amount of public debate, with much less attention focused on the other topics.

Assessing useful work, in terms of useful passenger or freight carrying, can change perspectives.

GHG emissions in terms of *useful work*, in passenger-km

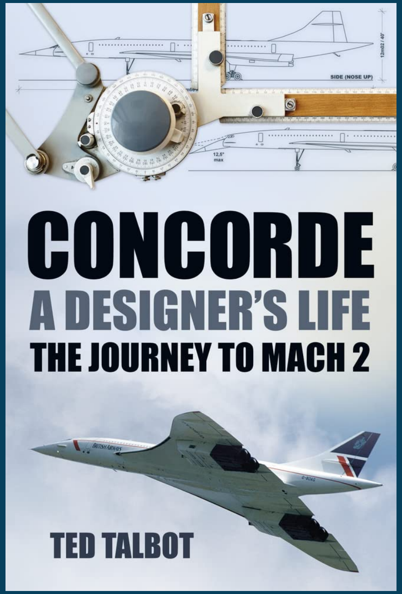
- *“Maximise the public good and minimise both actual and potential adverse effects for their own and succeeding generations”*

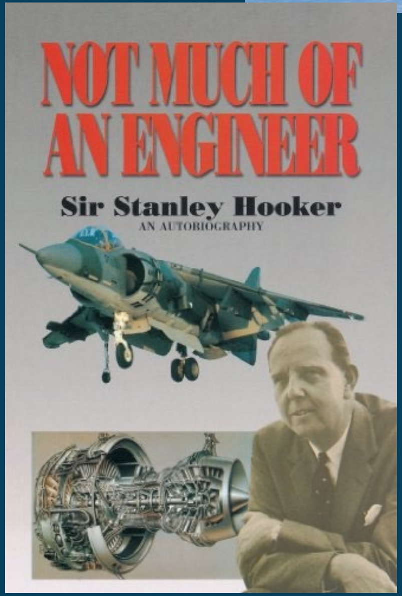


- CO_2e values for fuels are sourced from BEIS 2021 company reporting figures, Scope 1 (TTW) + Scope 3 (WTT).

A Radical Example: Concorde

- Engine efficiency at Mach 2 cruise = 43%, the highest of any thermal machine at the time, enabled by >80:1 overall compression ratio, and only recently bettered.
- Fuel burn rate at Mach 2 = 25,600L/hr.
- Kerosene = 3.08kg CO_2e/L^* = 78,850 kg/hr
- Cruise speed = 2160 km/h
- Passengers = 100
- Specific CO_2e = **365g**/pax-km
- Approximately 24 pMPG





*BEIS 2021 Reporting figures, Scope 1 (TTW) + Scope 3 (WTT), aviation kerosene includes CH_4 + N_2O effects

General Passenger Aviation

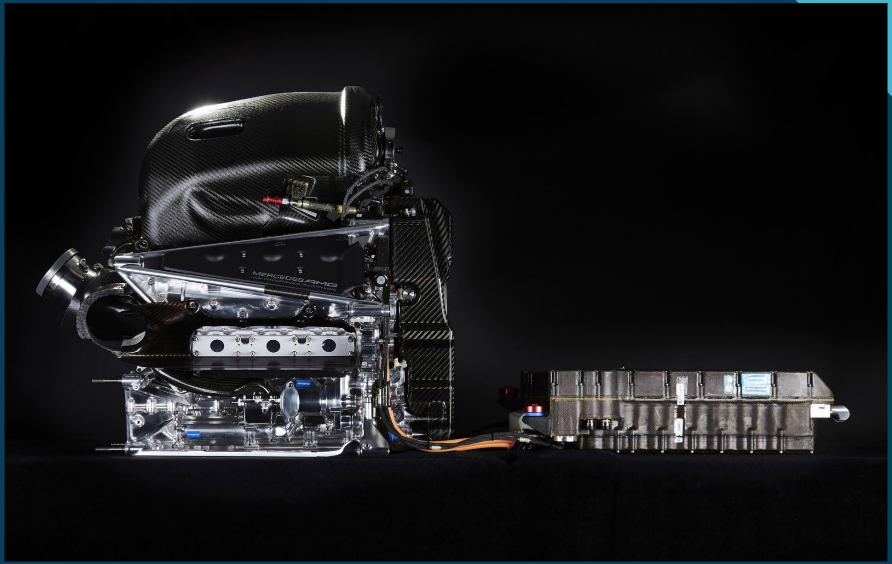
- The International Council on Clean Transportation (ICCT) published detailed research on global flying emissions in 2019*
- More than 20 different global sectors were analysed, with average of **88gCO_2e**/pax-km, although short-haul flights <500km can be up to **155g**/pax-km
- Modern aircraft are extremely efficient in cruise if full, typically from around **62**g/pax-km on a 787, to only **46**g/pax-km in a 737-Max200.
- Enabled by latest high bypass turbofans with compression ratios c. 50:1, and extremely low air resistance (c. 23% of sea level)
- Sir Frank Whittle was correct nearly 100 years ago!

- Globally the best airline is Ryanair, which averages **75**g/pax-km overall (source: MSCI), due to modern, very efficient aircraft, and 96% passenger loading. EasyJet **82**g/pax-km.
- Ryanair is also the lowest cost operator in p/pax-km.

- https://theicct.org/publication/co2-emissions-from-commercial-aviation-2018/

Another Radical Example: Formula 1

- The Mercedes-AMG F1 powerplant is believed to be the most efficient on the grid, although others use similar technology. Very high compression ratio with lean burn (as gas turbines), plus exhaust heat recovery via MGU-H.
- Total powertrain quoted at 52% thermal efficiency at end of 2021 season[1]. Improved from 44% when launched in 2014, an 18% improvement in efficiency.
- Maximum fuel mass 110kg or approx. 150L, giving CO_2e of 415kg, over maximum race distance of 305km.
- Despite world-leading powertrain efficiency, with only one driver, this equates to specific CO_2e of c. **1,360** g/pax-km !!
- Renewable e-fuels planned for introduction in 2026 should reduce this greatly.



1. MercedesAMGF1.com

Private Cars

National Travel Survey Car Occupancy = 1.6 Average

- Toyota Yaris Hybrid: WLTP = 102g/km CO_2 = **131**g/km CO_2e WTW. Specific CO_2e = **82**g/pax-km

- Ford Puma 1.0 MHEV: WLTP = 122g/km CO_2 = **156**g/km CO_2e WTW. Specific CO_2e = **98**g/pax-km.

- Range Rover Evoque 2.0D MHEV: WLTP = 171g/km CO_2 = **206**g/km CO_2e WTW. Specific CO_2e = **129**g/pax-km

How about Buses?

Occupancy figures from NTS 2021, quoting 2018-19, pre-pandemic.

- A combination of mass, aerodynamics and duty-cycle tends to make buses inefficient as vehicles, and therefore also good candidates for alternative powertrains.
- Testing* shows conventional EU V diesel buses ranging from c. 1550-1795g/km CO_2e WTW for double-deckers, and c. 1360-1485 for singles. Mass and duty cycle make hybridisation effective, with TfL and others observing c. 30% CO_2 reductions.
- Bus occupancy varies enormously with location and time of day, running at maximum capacity at peak times in major cities, but often close to empty in less populous areas, or off-peak and late night.

* Testing of EU V buses over MLTB cycle 2010-2013, & Braunschweig cycle 2017 (SAE).

How about buses?

Occupancy figures from NTS 2021, quoting 2018-19, pre-pandemic.

- London dominates bus usage, with over half of all journeys completed nationally, and average occupancy of 20 , giving WTW CO_2e of **68-90g**/pax-km. (cf. general aviation)
- England, excluding London, only averages 10.1 (**135-178**g/pax-km), Wales 8.5 (**160-211**) and Scotland only 7.5 (**181-239**).
- Hence on a national basis, standard diesel buses do not show significant CO_2e benefits vs. efficient petrol or diesel passenger cars (**98-129g/pax-km**).
- Hybrid diesel buses, with c. 30% lower fuel consumption & hence CO_2e, (estimated **95-125g**/pax-km nationally), will match cars.
- Due to higher occupancy, London buses are much better on average than cars, but an efficient hybrid car will still give similar results (**82g**)

Britain's Best-Selling Bus

- The Ford Transit minibus is easily Britain's best-selling bus, with Q2 2022 sales over three times next competitor (SMMT).

- 2.0L diesel 170PS: WLTP CO_2 **231** /km = **286** g/km CO_2e WTW
- NTS does not quote average occupancy for minibuses.
- If full, 16 passengers, specific CO_2e = **18g**/pax-km.
- At half load, specific CO_2e = **36g**/pax-km.
- Even at half load, this matches national rail (**35g**/pax-km) as the lowest CO_2e mode of transport on a specific basis.

How do Zero-Emission Vehicles Compare?

BEIS 2020 Grid Average CO_2e = 262g/kWh. Occupancy 1.6

- Vauxhall Corsa-E: WLTP = 157Wh/km = 41gCO_2e/km
  - Specific CO_2e = **26g**/pax-km

- Kia Niro : WLTP = 165 Wh/km = 43gCO_2e/km
  - Specific CO_2e = **27g**/pax-km

- Tesla Model Y: WLTP = 170Wh/km = 45gCO_2e/km
  - Specific CO_2e = **28g**/pax-km

Electric Buses

- ADL/BYD are currently the best-selling electric bus manufacturer, with around 66% of sales to date. Typical in-service energy consumption for the ADL200e single-decker is around 1.2kWh/km, 1.5kWh/km for the ADL400e double-decker.
- Based on the national average occupancy of 10.1, and the 2020 BEIS grid factor, this yields a specific CO_2e of **31-39g**/pax-km.
- London will be **16-20g/**pax-km CO_2e.

- As expected, electric buses have significantly lower CO_2e per passenger-km than diesels, but nationally still only approximately equate to electric cars.
- In busy urban environments such as London, with high passenger loading, electric buses will be the best performing transport mode, beating national rail in terms of passenger-specific CO_2e.

But.....

- Real world usage data for the new E-Transit is as yet scarce, but using Ford’s prediction of “worst case” real range to be 100 miles or 160km, gives a consumption of c. 460 Wh/km.
- At a vehicle level, with current grid, this represents a vehicle CO_2e of 121g/km.
- With 16 passengers, this would give a specific CO_2e of only **7.5g**/pax-km, and at half load **15g**/pax-km.
- Low-carbon “Backbone of Britain”?

Other Transport Modes

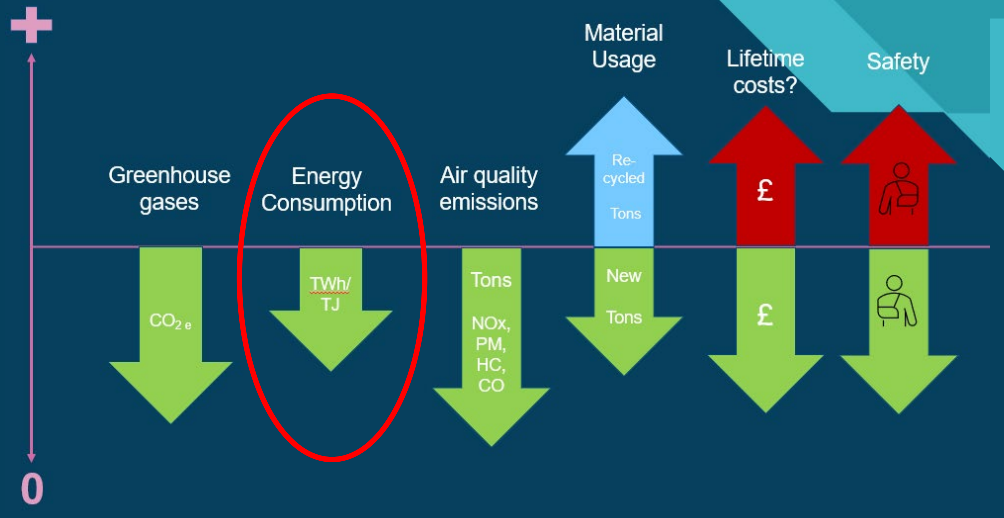
DfT ENV 0701 2021 or other as noted

Transport Mode	CO_2e g per pax-km
National Rail[1,2]	35
London Underground[3]	44
Coach	54
Motorbike	233
Taxi	298

1. ORR figures for 2018-19, ORR Statistical Release Nov 2020.
2. Electric vehicle ave = 358g/km, diesel vehicle ave = 1400g/km
3. TfL June 2020 data for 2018/19

Energy Consumption

- Even if vehicles are "zero emissions" (locally), as engineers we should remain focused on energy efficiency.
- *"Take due account of the limited availability of natural resources"*



Energy Consumption

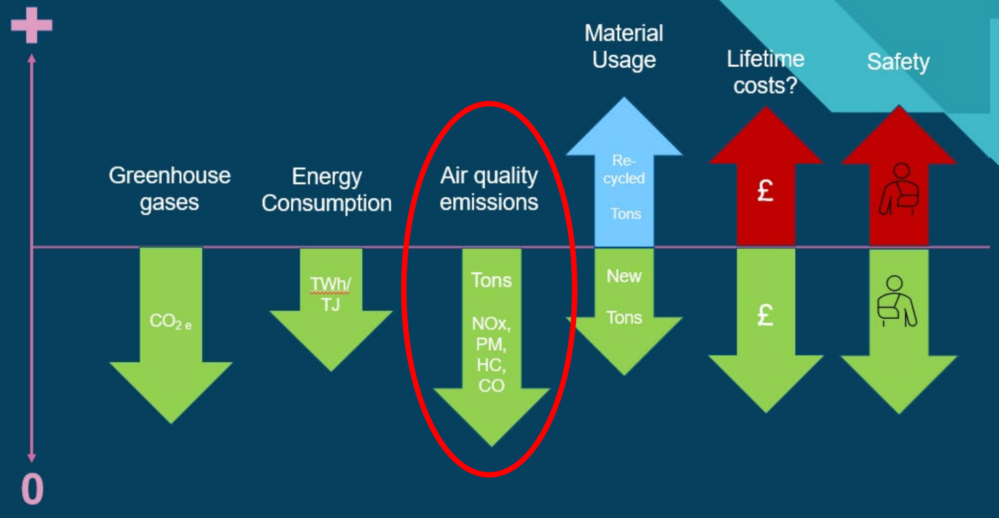
Overall system efficiency strongly favours electrification.

Vehicle Type	Energy per Pax-km (Wh)
Electric minibus, 50% full	58
Medium electric car	100
Electric bus (national)	129
Medium fuel-cell car (veh level)	175[1]
Medium fuel-cell car (grid level)	292[2]
Medium petrol car	333[3]

1. Toyota Mirai WLTP H_2 consumption TEL/TEH ave. = 0.84kg/100km, H_2 = 33.3kWh/kg.
2. Assumes green H_2 generated from electrolysis using grid electricity at 60% efficiency.
3. Ford Puma MHEV WLTP WTW

Air Quality

- Air quality emissions are currently a key concern for road transport, especially in urban areas.
- For passenger transport, cars & buses dominate.
- *“Protect, and where possible improve, the quality of built and natural environments”*



NO_x Emission Comparison

- Petrol-engined cars consistently have lower NOx emissions, although EU6/VI RDE regulations have significantly lowered diesel NOx levels, and narrowed the gap.

Transport Mode	NOx g/km (vehicle)	NOx g/km (passenger)[7]
EU V diesel bus	10[1]	1.0
EU5 diesel car	0.8[2]	0.5
EU5 petrol car	0.2[3]	0.125
EU VI diesel bus	1.0[4]	0.1
EU6 diesel car	0.125[5]	0.075
EU6 petrol car	0.09[6]	0.056

1. MLTB/Braunschweig testing
2. ICCT Average RDE test result 2014
3. Emission Analytics average RDE result 2013
4. Zemo PEMS test data 2021
5. Euro 6d final RDE limit with 1.5 CF
6. Euro 6d final RDE limit with 1.5 CF
7. Bus national occupancy = 10.1, cars = 1.6

Other Emission Sources are Increasingly Significant

- Legal NOx limit for new gas boilers is 56mg/kWh. OFGEM average gas consumption = 12,500kWh. Cf. 13,300 km average car mileage. NOx emissions lower per “passenger” (resident), but 100% urban.

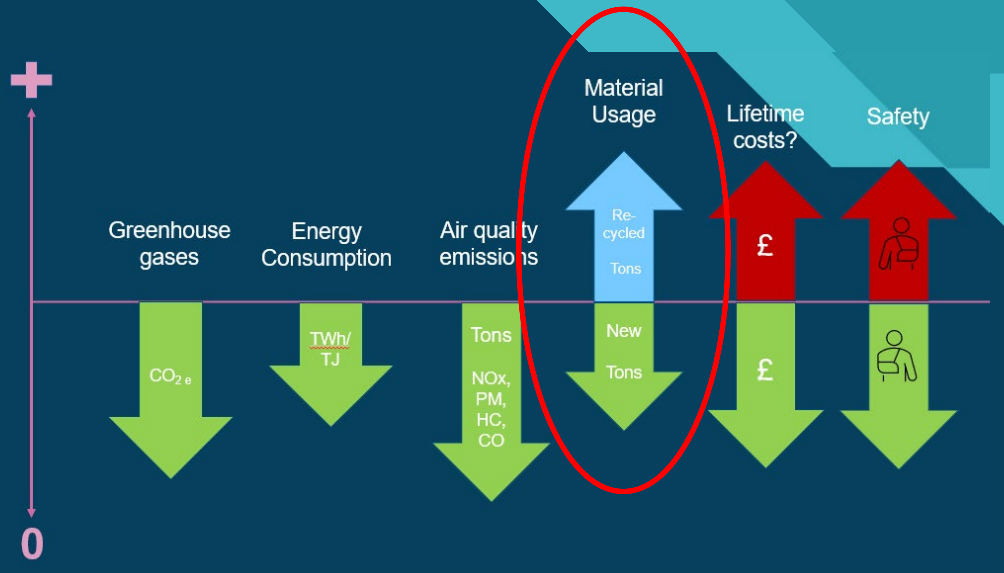
- Cigarette smoke averages around 14mg/cigarette[1]. EU6/VI diesels with DPFs consistently deliver <1mg/km PM, so one cigarette = c. 15km total diesel exhaust. Approximately 50% is exhaled[2], so *exhaled* PM from a 10-a-day smoker is 2-3x greater than average daily PM from one EU6 diesel.

- Wood burning stoves are good for GHG, but very poor for PM. Current soot limit = 2g/kg wood burned, c. 10g per evening. Equivalent of c. **10,000km** EU6/VI diesel emissions!

1. US CDC Journal of Tobacco Control 2004. 2. Journal of Aerosol & Air Quality Research, 2012.

Material Usage

- Mass, and specific mass, of vehicles, is a key consideration in transport sustainability.
- *“Take due account of the limited availability of natural resources”*

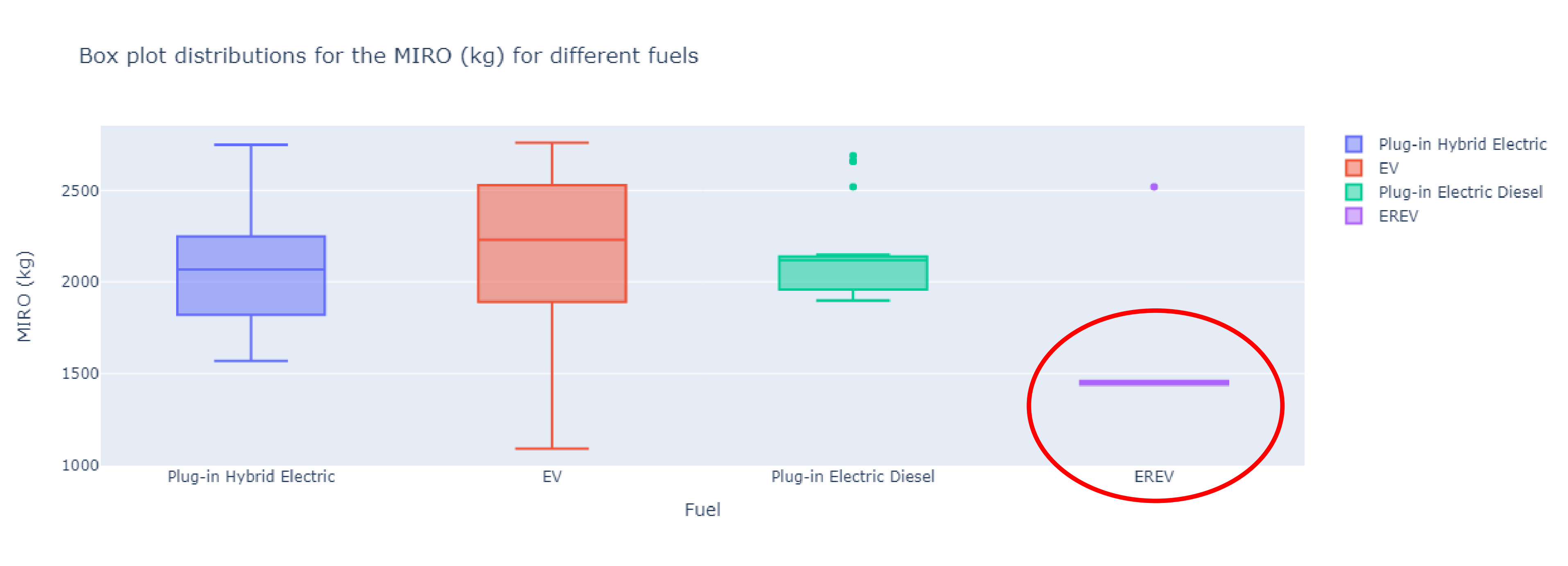


Battery Mass of EVs is Significant!

- Original 1958 Mini = 580kg
- 2019 iPace 92 kWh *Battery Pack* = 610kg


Current EVs have high mass

- Mass distribution of all plug-in vehicles sold in UK to September 2021*
- Average BEV c. 2200kg. c. 440kg/passenger as designed, 1375kg/pax at average occupancy.
- BMW i3 is notable outlier with 22kWh battery & lightweight architecture.



* DfT data analysed by Zemo Partnership

Compare to 20 Years Ago…

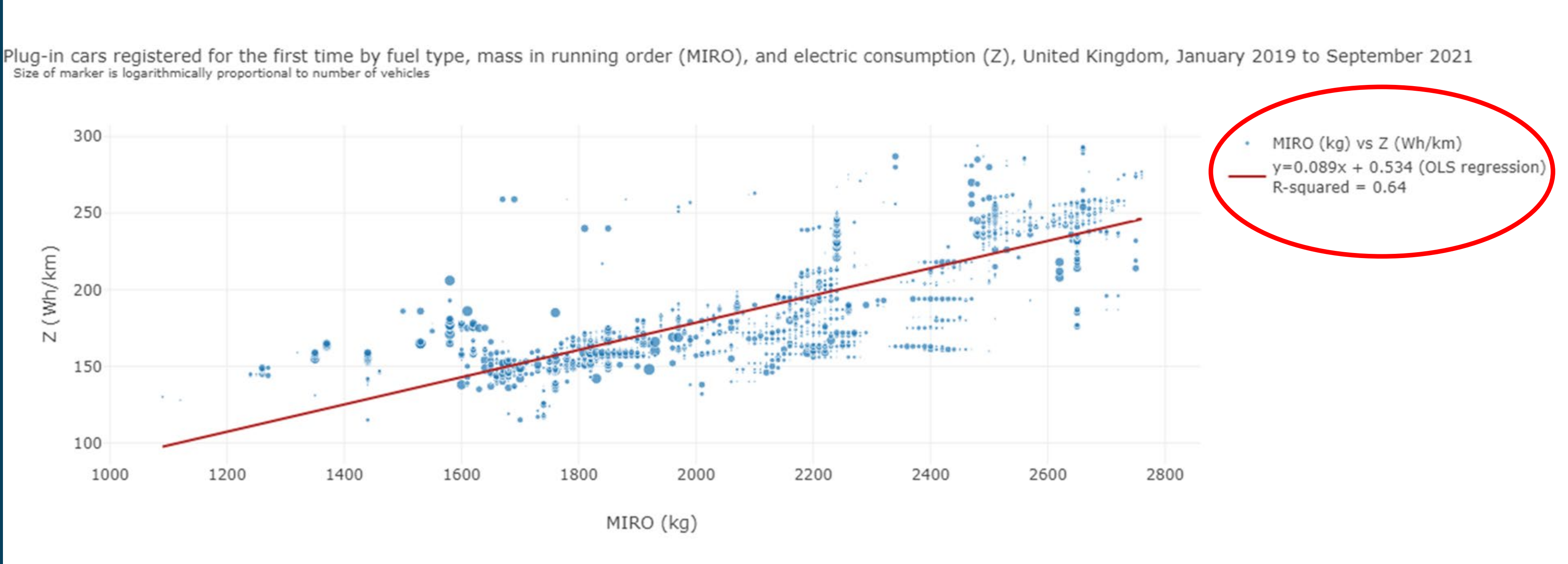
- Ford launched the original Focus in 1999. Led by Richard Parry-Jones and Tony Pixton, it redefined the C-segment.

- Marketed as "the least dense car in its class". Most interior space for lowest mass – an excellent metric.

- Typical weight for petrol-engine versions was 1070-1130kg.

- Current EVs are effectively <u>double</u> that mass ☹

Greater Mass = Greater Energy



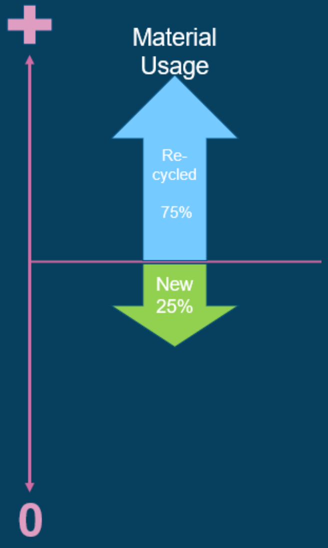
- Analysis of WLTP energy consumption for all plug-in vehicles sold in Britain through to September 2021*.
- Gradient = 89 Wh/km/tonne.
- WLTP energy @ average mass = c. 200Wh/km.
- 100kg mass saving on 35M cars = c. 4.1 TWh/year, or c. 1.2 MT CO_2e.

* DfT data analysed by Zemo Partnership

Weight Can be a Virtuous Circle

- 2013 Range Rover was launched with an all-aluminium monocoque body, replacing the prior body-on-frame.
    - Land Rover claimed a total weight saving of 400kg vs. the outgoing model:
    - Bonded aluminium body
    - Engine downsized V8->V6 at c/o performance.
    - Fuel tank reduced from 90->80L but with better range, due to improved fuel economy.

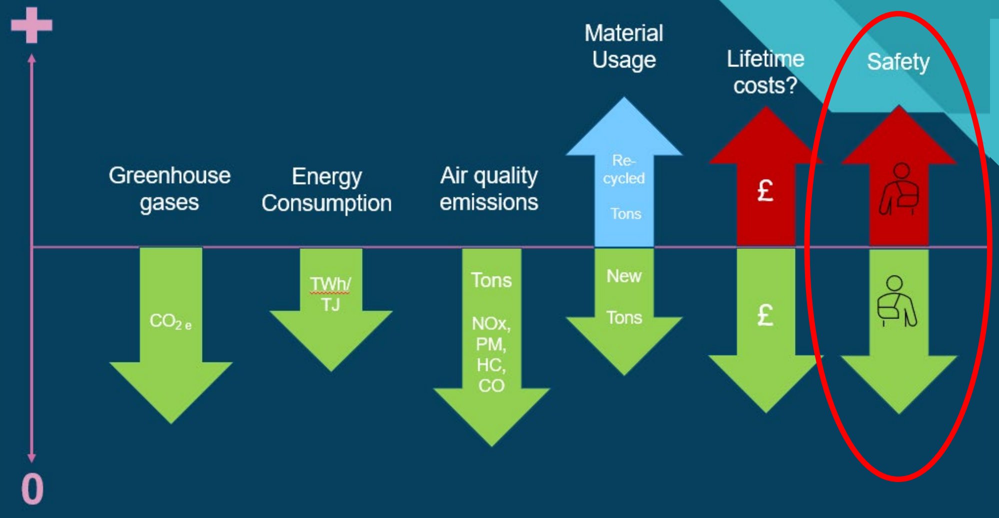
- JLR estimate 75% aluminium content is recycled, plus lower GHG in manufacturing process vs. steel.



- Euro NCAP safety improved from 4 to 5 star.
- Parallels for EVs?
- "*Just add lightness*" – Colin Chapman

Safety

- *"Hold paramount the health and safety of others, and draw attention to hazards"*



Safety Statistics
Adapted from DfT RAS 0201   2021

Overall road traffic safety has been a huge success story over last decade, with total casualties down 37% from 2011->2021, but varies widely by mode.

Transport Mode	Casualties per Bn-person-miles	Change 2021 vs. 2011 (%)
Bus & coach passengers	82	-71
Car Occupants	199	-43
Pedestrians	1282*	-36
Pedal Cycles	3920	-14
Motorcycles	6259	-21

* Pedestrian rate calculated from casualties per million population (RAS 102) x average annual walking distance (Sustrans)

Alternative Transport Solutions Need Careful Consideration

- Encouraging users from buses or cars into higher-casualty modes such as pedal cycles or electric motorcycles, e-bikes or e-scooters could have major casualty impacts unless mitigated.

- Motorcycles have over 30x the casualty rate of cars, and over 75x vs. buses.

- Even a few % shift from buses & cars into electric two-wheelers without mitigating measures could double accident rates.

- “Environmental health” is very important & necessary, but must not over-rule near-term individual safety.

Conclusions

- Transport has been an essential part of society and the economy for c. 200 years, and seems likely to remain so, although some reduction opportunities such as remote working and virtual meetings clearly exist.

- Improving transport sustainability is a multi-dimensional challenge, probably greater than any previously undertaken, but well-aligned to Professional Engineering principles, and very much in keeping with historic achievements.

- The "useful work" of any transport vehicle must be considered, along with the efficiency of both the vehicle and the total energy system, not just the "tailpipe".

Conclusions

- Professional Engineers should work to improve the sustainability of all transport modes, and avoid picking winners & losers, or “halo & horns”:

  - Commercial aviation, conventional cars & buses all have similar GHG emissions, in the range 68-240g/pax-km.

  - National rail is extremely efficient in GHG terms, but is matched by electric cars, and diesel traction has 4x GHG of electric traction. Need OLE!

  - Cars generally outperform buses on air quality emissions, although EUVI has significantly narrowed the gap. Other pollution sources for both NOx and PM are rapidly exceeding the contribution of road transport.

Conclusions

- Electrification generally offers the most efficient overall system solution, with GHG emissions steadily reducing as the grid improves. It is technically effective and relatively economic in lighter vehicles, but more difficult in larger ones, where alternative solutions may prevail.

- Distributed charging of EVs via local PV generation at home, workplace or educational establishment can offer extremely cost-effective (6p/kWh or 2p/mile)* and near-zero GHG transport.

- Renewable fuels, especially “drop in”, as planned for Formula 1, have potential applications in many sectors, and should be considered more widely.

* Typical domestic 4kW solar PV system cost c. £6,000, and will produce approximately 100,000kWh over 25 years.

Conclusions

- Even in light vehicles, the mass of batteries, and the vehicle structures required to house them, are a key issue for both energy and material consumption. Urgent action is required in both fields to address this growing issue.

- Raw material supply and consumption, and need for battery recycling on an industrial scale, within the next 10-15 years, may rapidly become the "great stink" of our generation. Do we have "budding Bazalgettes" up for the challenge?

- As was the case in Bazalgette's day, Engineers should be confident in "speaking truth to power" – politicians are not always correct!

Thank You

Official DfT Statistics

Table ENV0701			
Emissions from journeys across the United Kingdom, by mode, 2021			
Summary table			
Transport Mode	Direct Emissions Factor (TTW) g/km	Indirect Emissions Factor (WTT) g/km	Total WTW g/km
London Underground	0.028	0.005	0.033
Coach	0.027	0.006	0.033
National Rail	0.036	0.007	0.043
Average Electric Car	0.000	0.043	0.043
Average Plug-in Hybrid Car	0.045	0.033	0.078
Small Hybrid Car	0.066	0.018	0.084
Average Hybrid Car	0.075	0.020	0.095
London Bus	0.078	0.019	0.097
Average Diesel Car	0.106	0.026	0.132
Average Petrol Car	0.110	0.031	0.140
Motorbike	0.114	0.032	0.146
Local Bus (not London)	0.118	0.029	0.147
Plane	0.131	0.027	0.158
Regular Taxi	0.150	0.037	0.186

Thank You