The Future for Zero Emissions Transport

Winton Symposium - November 2017

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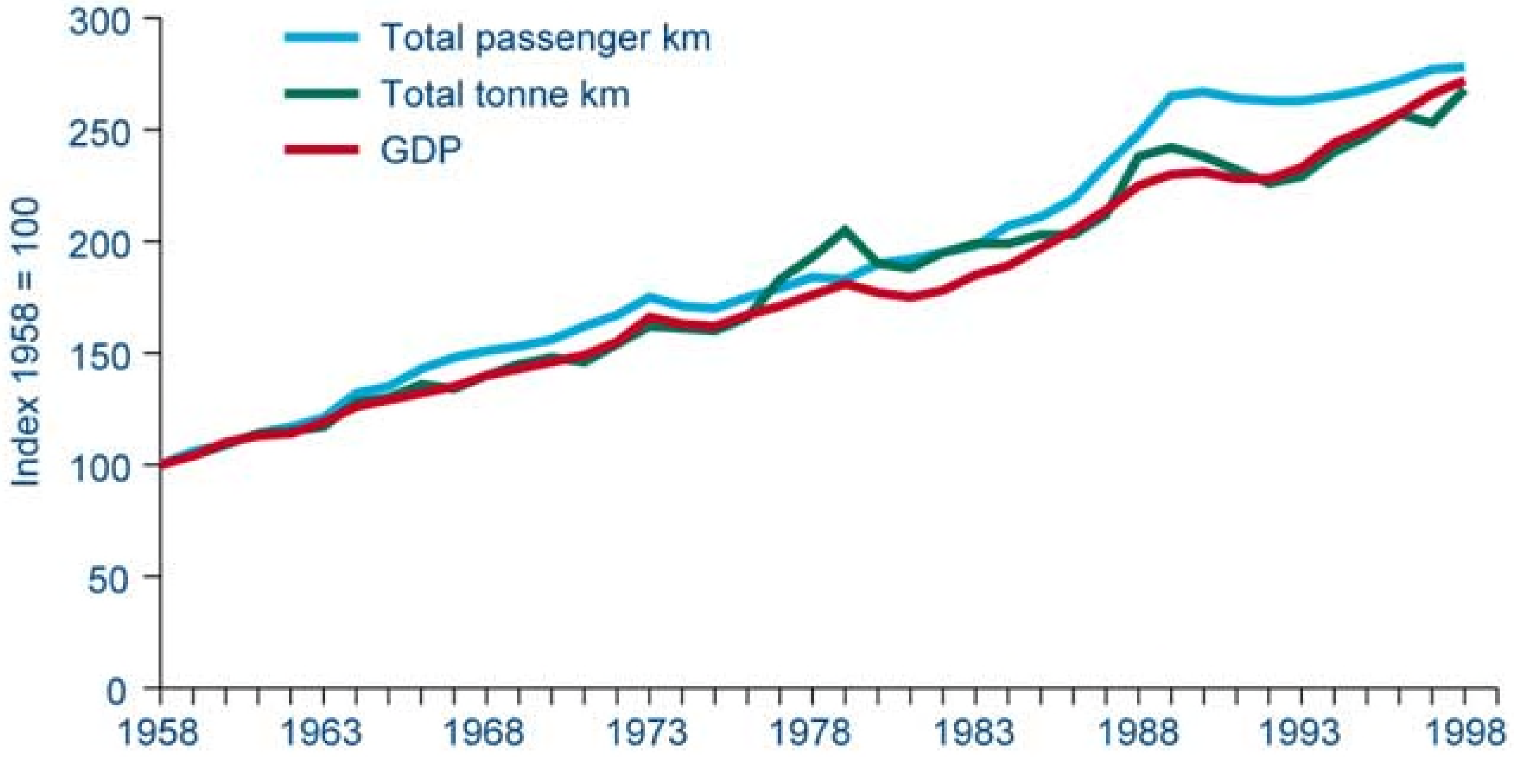
Transport is strongly linked to economic growth



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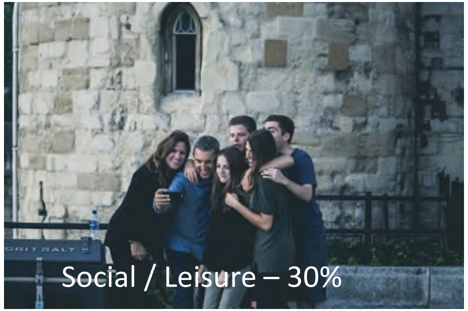
Source: DfT Transport 10 year plan 2000

It is essential to our personal and business lives

Moving People

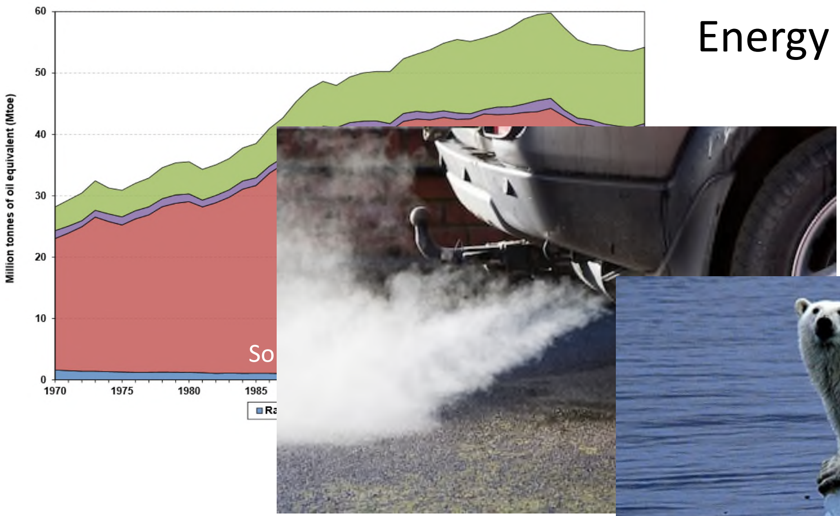


Moving Goods

Source: UK Department for Transport National Travel Survey 2014

But transport growth comes at a cost

Chart 2 **Transport energy consumption by type of transport, UK (1970 to 2014)**



Energy Demand

Air Quality

Climate Change

Congestion

Accidents

What can we do about it ?

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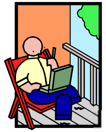
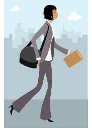
Manage Demand

Travel Less

Use best transport mode



Manage transport network


Improve Technology

Reduce vehicle mass and drag

Improve powertrain

Reduce carbon in fuel

Ultimately we can only get to zero emissions by addressing fuel

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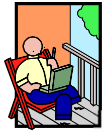
Manage Demand

- **Travel Less**

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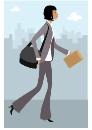


- **Manage transport network**


Improve Technology

- **Reduce vehicle mass and drag**

- **Improve powertrain**

- **Reduce carbon in fuel**

To get to zero carbon, zero emissions, we need zero carbon fuel

- Liquid fuels – bioethanol and biodiesel
  - First generation not energy efficient and competed with food crops. Second generation will be better, but limited availability due to land use.
  - Still produce NOx, PM etc when burned

- Hydrogen
  - Currently mostly made from natural gas
  - Renewable hydrogen (electrolysis or biodigester) possible but conversion losses are high

- Electricity
  - Varies in CO_2 intensity by source
  - Increased nuclear, solar, hydro and wind
  - “Greening the grid” in progress in most countries

Electricity (& hydrogen) are only as clean as the process to make them

Lifecycle CO2 by generation type:

• Nuclear and wind	5g/kWh
• Photo voltaic (depending on sunshine)	30-60g/kWh
• Gas circa	500g/kWh.
• Target with sequestration	250g/kWh
• Coal	1000g/kWh
• with gasification	800g/kWh
• Target with sequestration	100g/kWh

Different grid mix used according to time of day and season

- UK summer
  - 7am – 4pm: 480g/kWh, 42GW
  - 11pm – 4am: 340g/kWh, 28GW
  - Mean 460g/kWh
- UK winter mean >600g/kWh

NATIONAL AVERAGE GRID MIX

Sweden	<20g/kWh
France	88g/kWh
Japan	365g/kWh
EU average	366g/kWh
UK	557g/kWh
USA	611g/kWh
India	805 g/kWh
China	868 g/kWh
Poland (Coal)	1000g/kWh

Most nations pushing for 20-30% renewables by 2020 – 2030, reducing carbon intensity by further 15-28%

Source: "Carbon Footprint of Electricity Generation" – Parliamentary Office of Science and Technology 2006, CARMA database 2007 data

Electricity CO_2/kWh improving with use of nuclear, gas, solar and wind

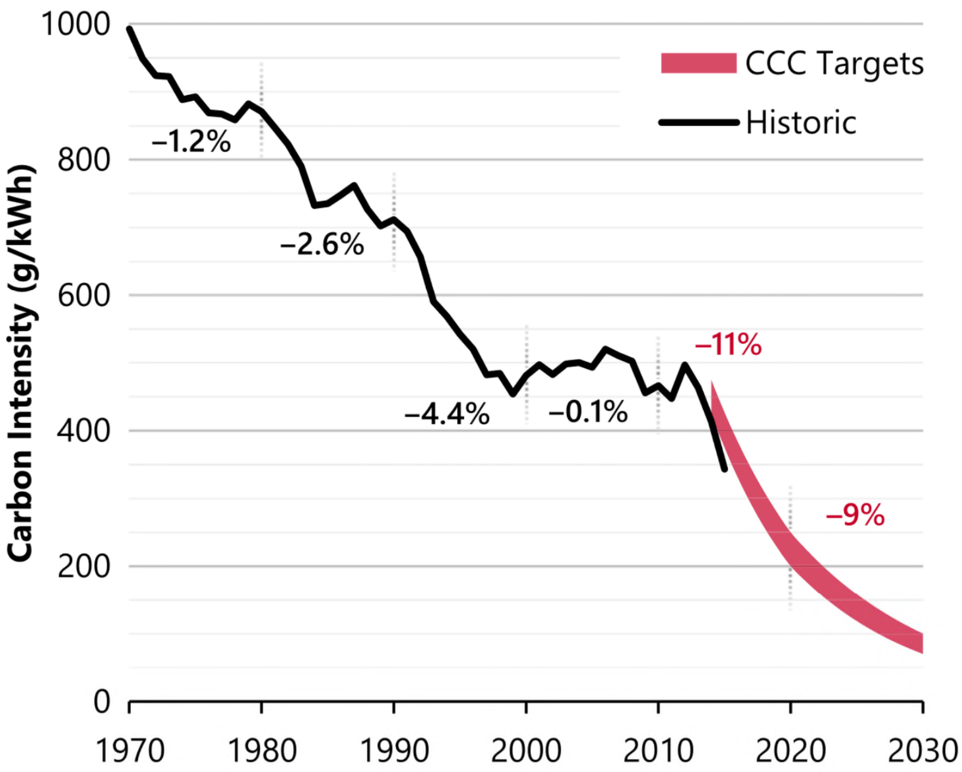
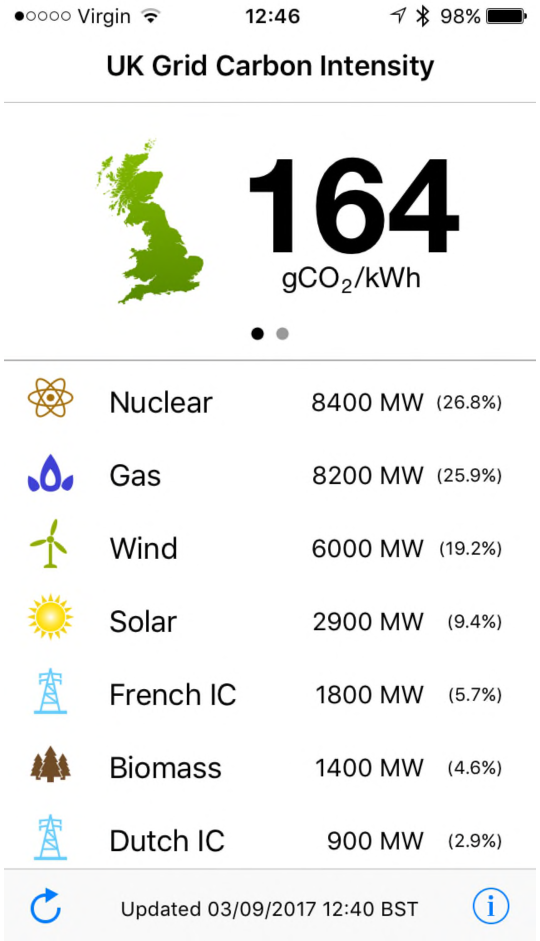
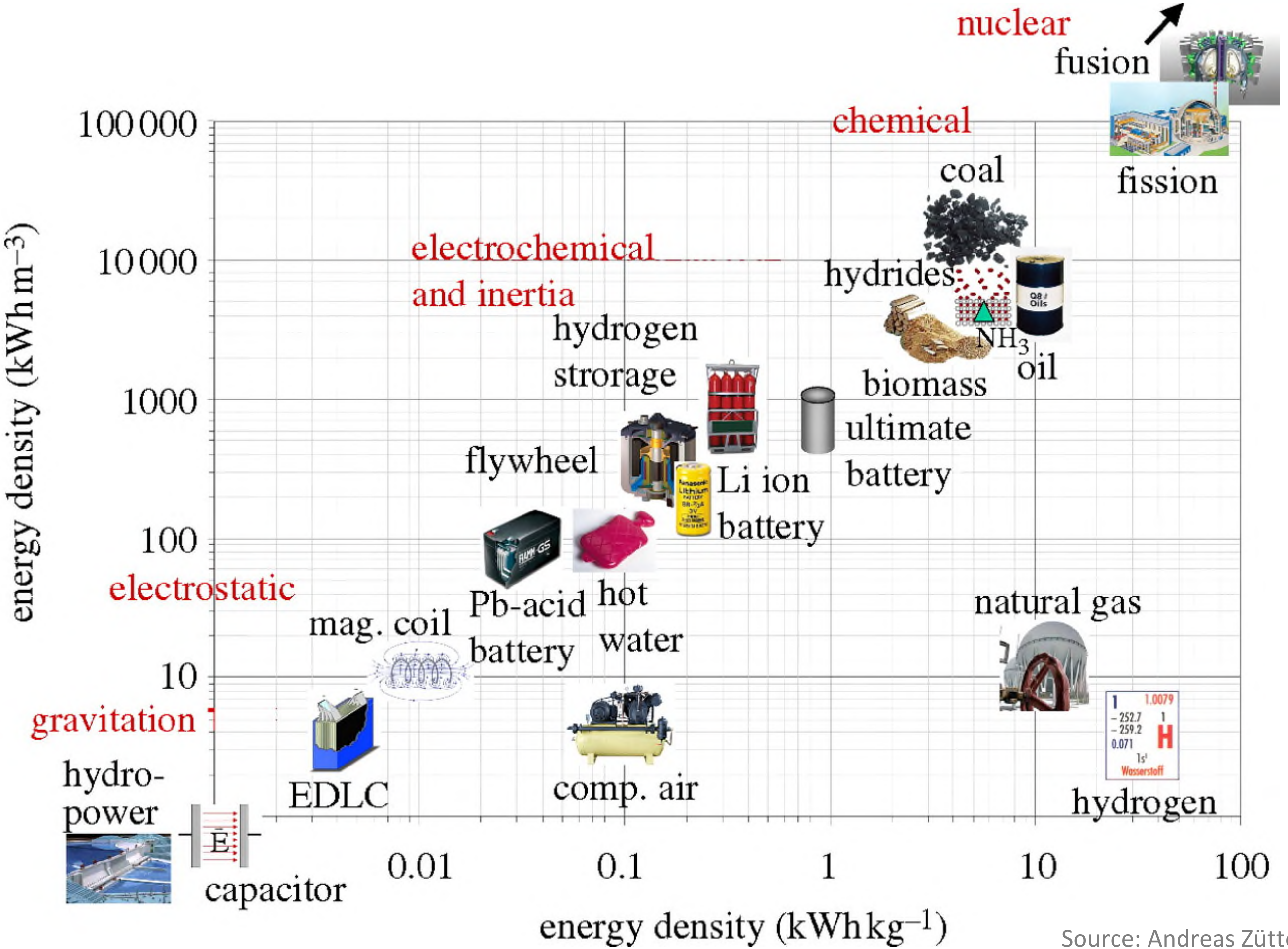


Fig. 1. The historic and required future carbon content of British electricity, highlighting the average year-on-year change during each decade. Data from (CCC, 2015a; MacLeay et al., 2016).

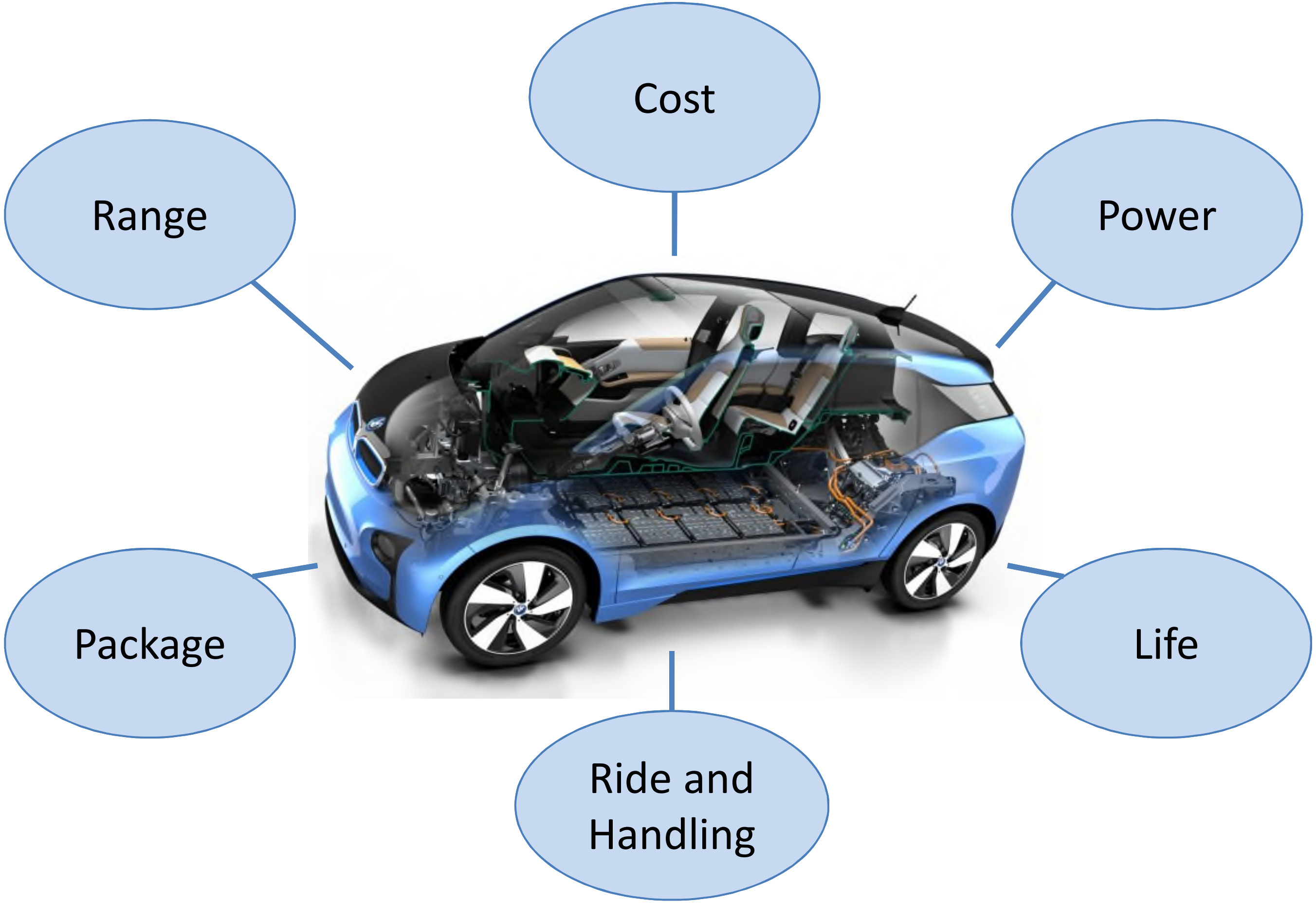


To use electricity we need to store it on-board the vehicle



Source: Andreas Züttel et al. Phil. Trans. R. Soc. A 2010;368:3329-3342

Battery is the defining component of an electrified vehicle



Degrees of Electrification

	Engine	Motor	"Battery"
Conventional	100kW Full transient	Starter motor Stop/start	12V 3kW, 1kWh
Mild Hybrid	90-100kW Full transient	3-13kW Torque boost / re-gen	12-48V 5-15kW, 1kWh
Full Hybrid	60-80kW Less transient	20-40kW Limited EV mode	100-300V 20-40kW, 2kWh
PHEV	40-60kW Less transient	40-60kW Stronger EV mode	300-600V 40-60kW, 5-20kWh
REEV	30-50kW No transient	100kW Full EV mode	300-600V 100kW, 10-30kWh
EV	No Engine	100kW Full EV mode	300-600V 100kW, 20-60kWh

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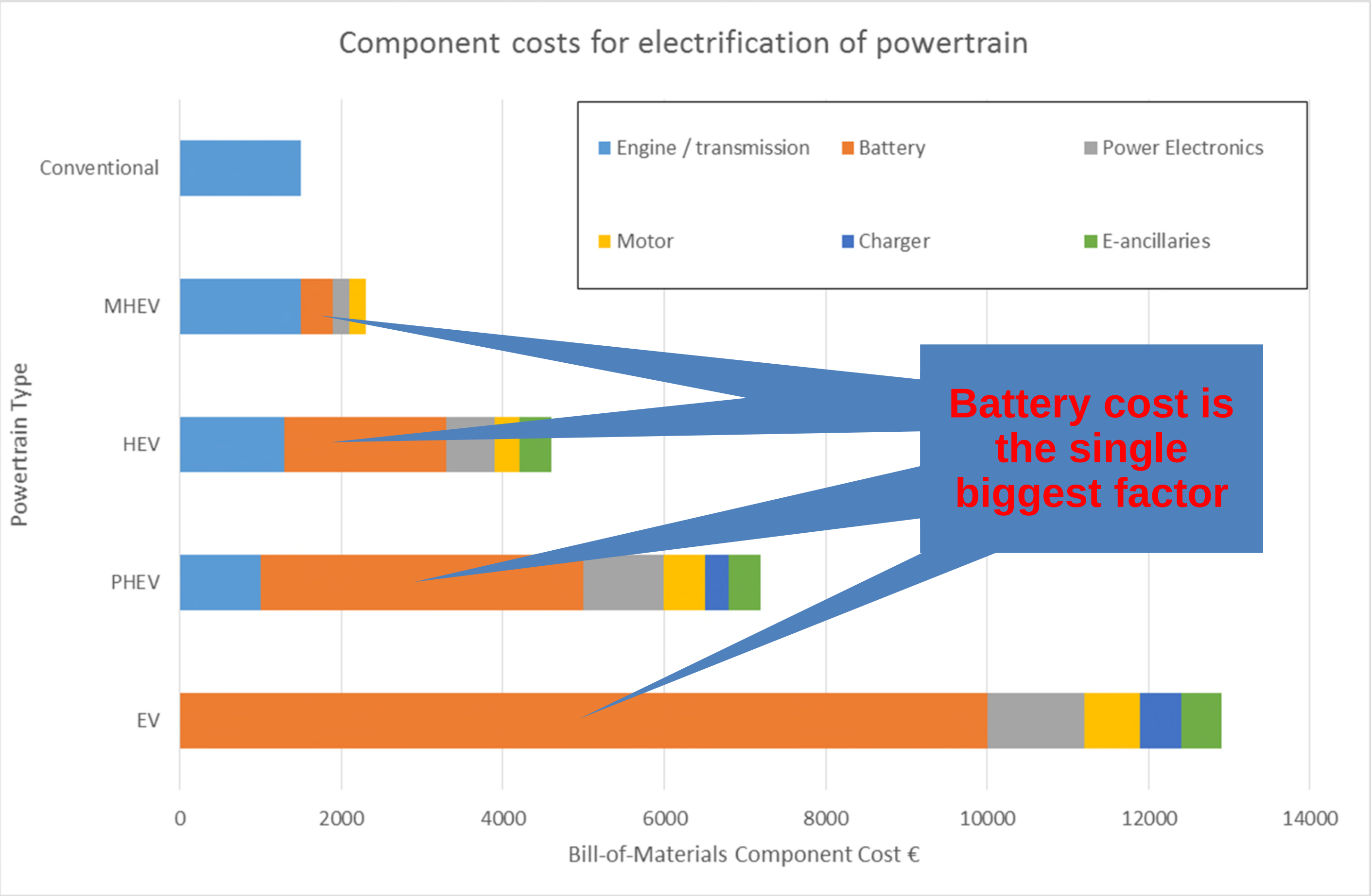
Biggest challenge for mass market uptake is cost



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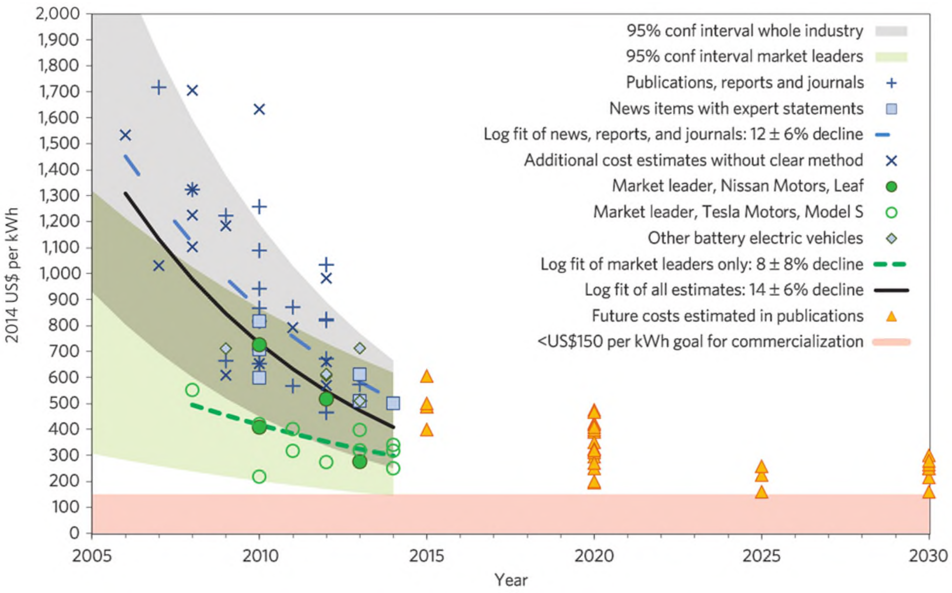
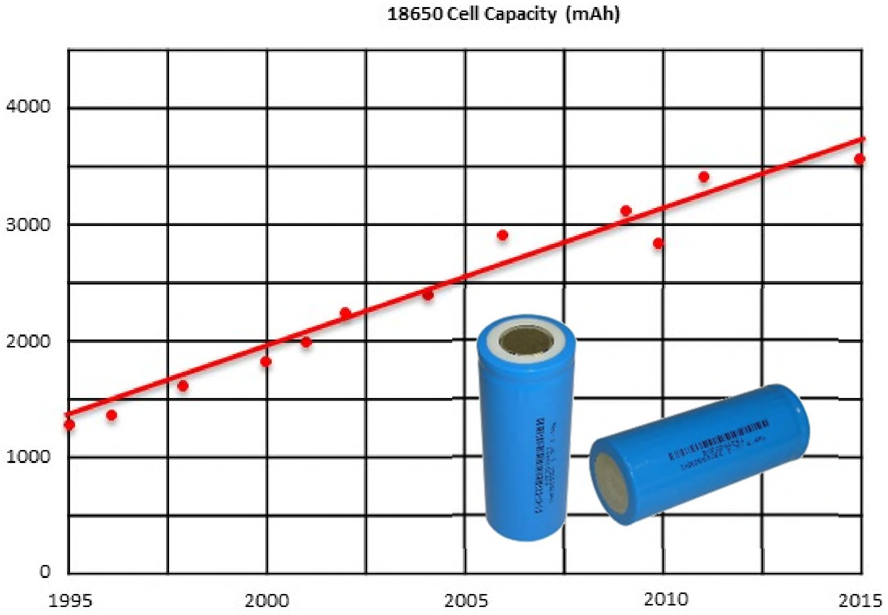
Lithium Ion batteries are improving rapidly

- Costs have fallen dramatically due to technology, production volume and market dynamics
- Pack cost fallen from $1,000/kWh to <$250/kWh in less than 8 years

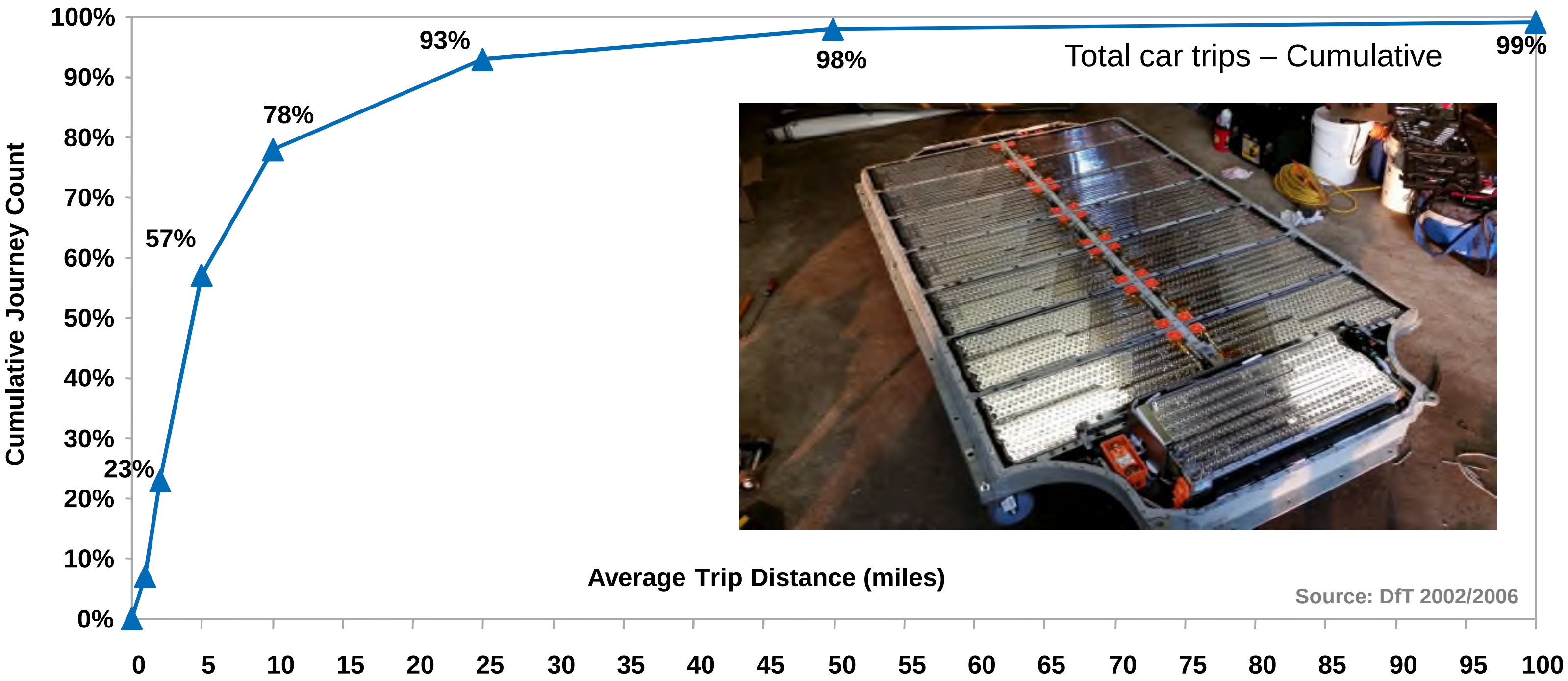


Nykvist et al 2014



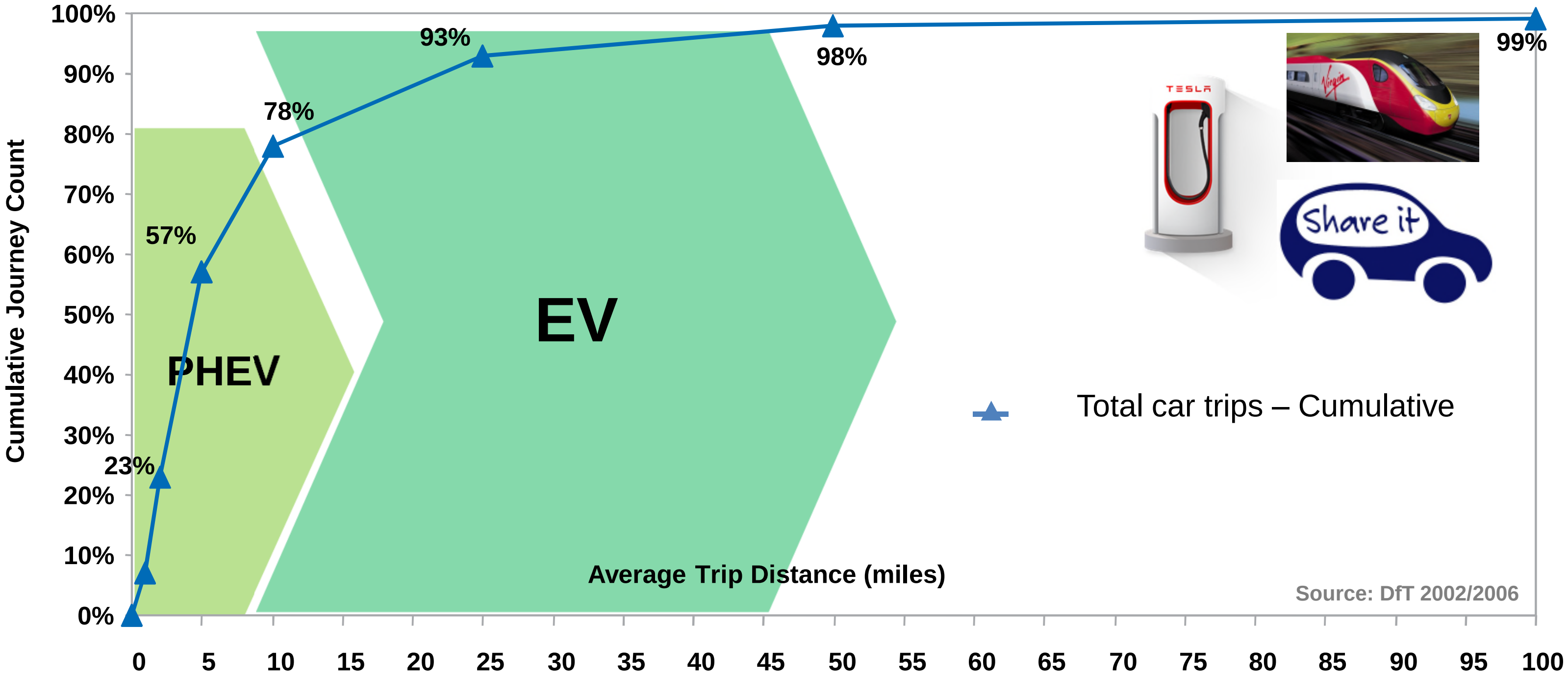
- Volumetric energy density is increasing due to better materials and cell structure
- Doubled in 15 years
- Requires continuous chemistry and materials innovation to continue

And consumer behaviour is adapting to daily refuelling



- 98% of UK journeys are <50 miles one way (similar in EU and US)
- >90% are less than 25 miles Average total daily distance is 24 miles
- 200+ mile battery costs £10,000 more and weighs 350kg more than 100+ mile battery – and pays back for just 2% of typical journeys

And consumer behaviour is adapting to daily refuelling



- For PHEV, the battery should be large enough for typical daily mileage
  - As small as possible for cost and packaging => 20-40 miles
- For EV, 100 miles (real world) covers 98% of usage.
- Fast charge, car-share or alternative mode for remaining 2% of journeys

Where could batteries be in 20 years ?

Cost

Now $130/kWh (cell)
$280/kWh (pack)

2035 $50/kWh (cell)
$100/kWh (pack)

Energy Density

Now 700Wh/l,
250Wh/kg (cell)

2035 1400Wh/l,
500Wh/kg (cell)

Power Density

Now 3 kW/kg (pack)

2035 12 kW/kg (pack)

Safety

2035 eliminate thermal runaway at pack level to reduce pack complexity

1st Life

Now 8 years (pack)

2035 15 years (pack)

Temperature

Now -20° to +60°C (cell)

2035 -40° to +80°C (cell)

Predictability

2035 full predictive models for performance and aging of battery

Recyclability

Now 10-50% (pack)

2035 95% (pack)

Battery electric for Planes, Trucks and Automobiles

- 100 kW peak
- 4 kW average
- 100 kWh / 300 miles

- 900 kg battery

- 400 kW peak
- 100 kW average
- 1000 kWh / 500 miles

- 9,000 kg battery

- 100 MW peak
- 70 MW average
- 430 MWh / 6000 miles

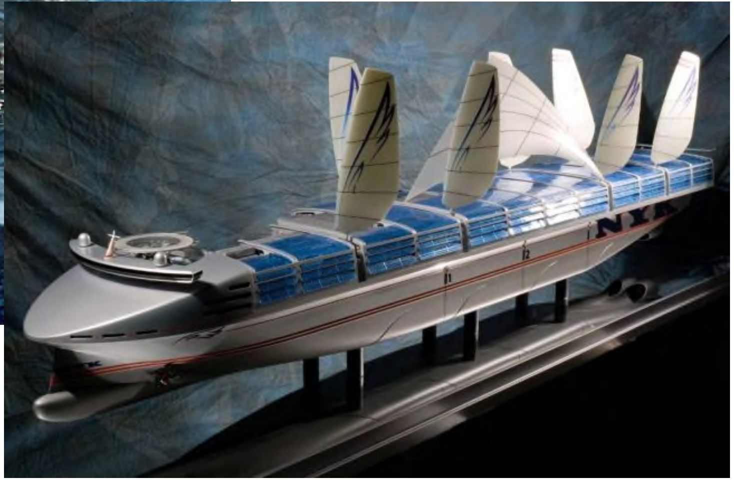
- Not a battery !

Zero emissions for trucks

Zero emissions marine

Cutty Sark - sail

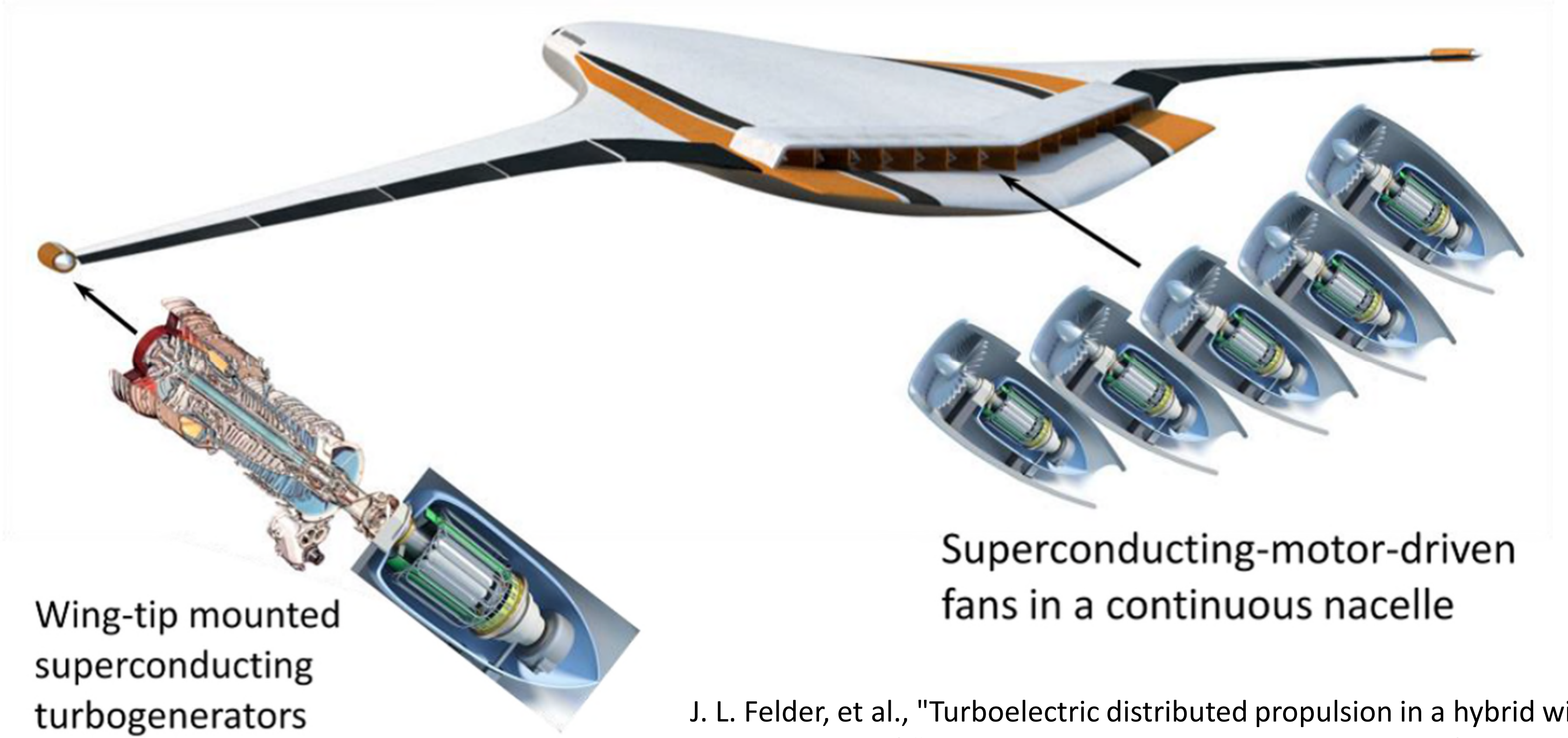
USS George Washington
nuclear



NYK Future ship concept
sail and fuel cell

Zero emissions for aviation ?

Aviation biofuel would require 1-2M km^2 land use to replace current demand



J. L. Felder, et al., "Turboelectric distributed propulsion in a hybrid wing body aircraft", Proc. Int. Symp. Air Breath. Engines Conf., pp. 1-20, 2011.

Thank you

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