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Drive trains and fuels for road transport

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186 Countries have set long term GHG targets – COP21 delivers further -0.9°C in global warming – but how to adopt in transport?

Global warming predicted to be

- 3.6°C by 2100 prior to COP21
- 2.7°C with COP21 commitments (-0.9°C)

- **Europe:**
  - 40% reduction in GHG by 2030 (1990 base)
  - 89-95% reduction in GHG by 2050 (1990 base)
- **USA:**
  - 26-28% reduction in GHG by 2025 (2005 base)
  - 83% reduction in GHG by 2050 (2005 base)
- **China:**
  - CO_2 to peak by 2030
  - “best efforts” to peak earlier
  - 20% of energy from low-carbon sources by 2030
  - CO_2/GDP reduced by 60-65% by 2030 (ref 2005)

- **What are the implications for road transport GHG emissions regulations?**
  - How can we balance the costs and benefits across all energy consumers?
  - Who should pay for these reductions and what is affordable?

Source: United Nations Framework Convention on Climate Change

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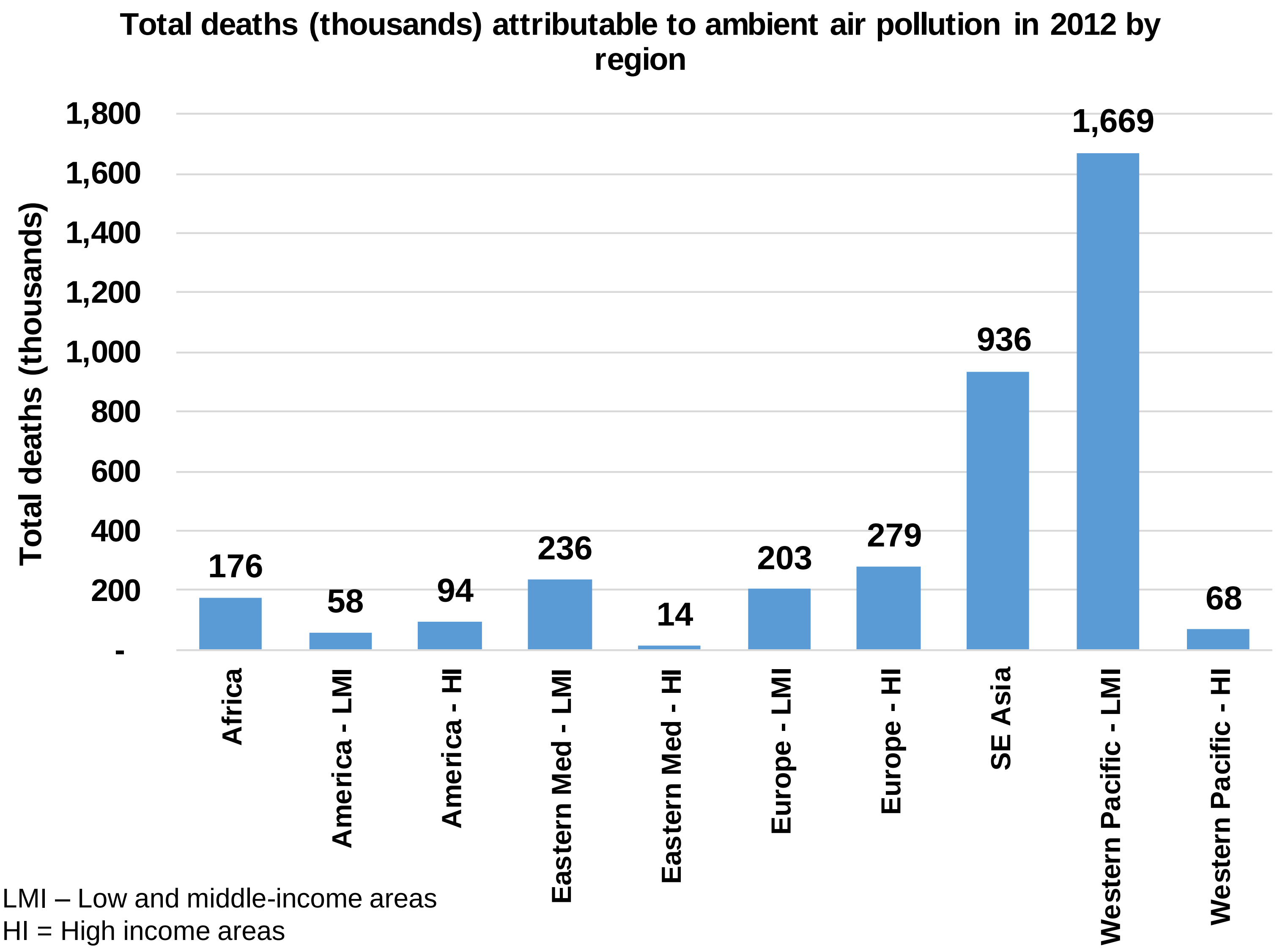
Poor air quality rated as world's largest single environmental health risk – impact highest in Asia but significant in EU/USA

- **In 2012, 7 million people died as a result of air pollution exposure** – one in eight of all deaths worldwide
- **3.7 million people died due to exposure to outdoor (ambient) air pollution**
  - This compares with 1.3 million global road accident fatalities
- **Air pollution is now the world's largest single environmental health risk**



LMI – Low and middle-income areas
HI = High income areas

Source: World Health Organisation

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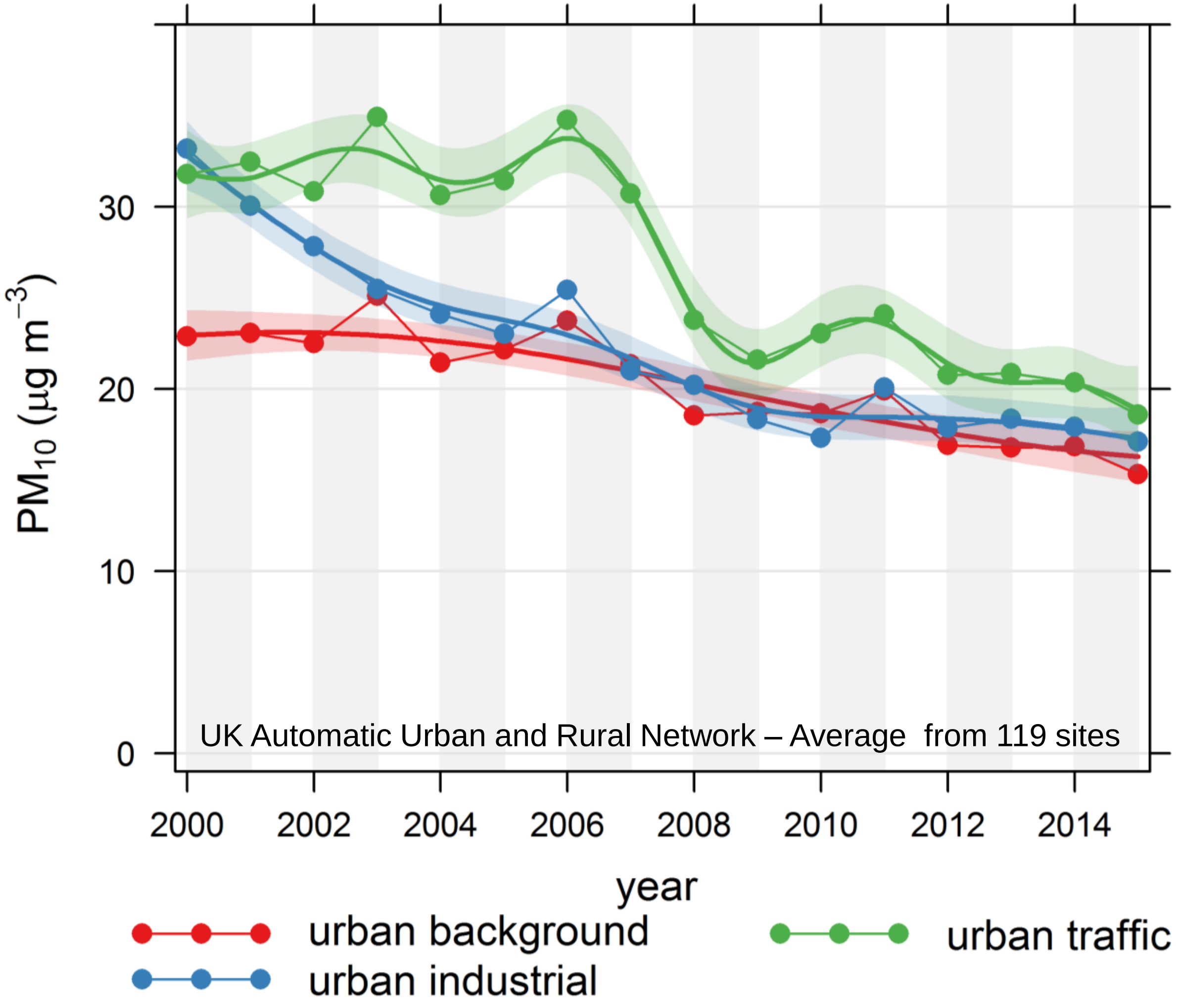
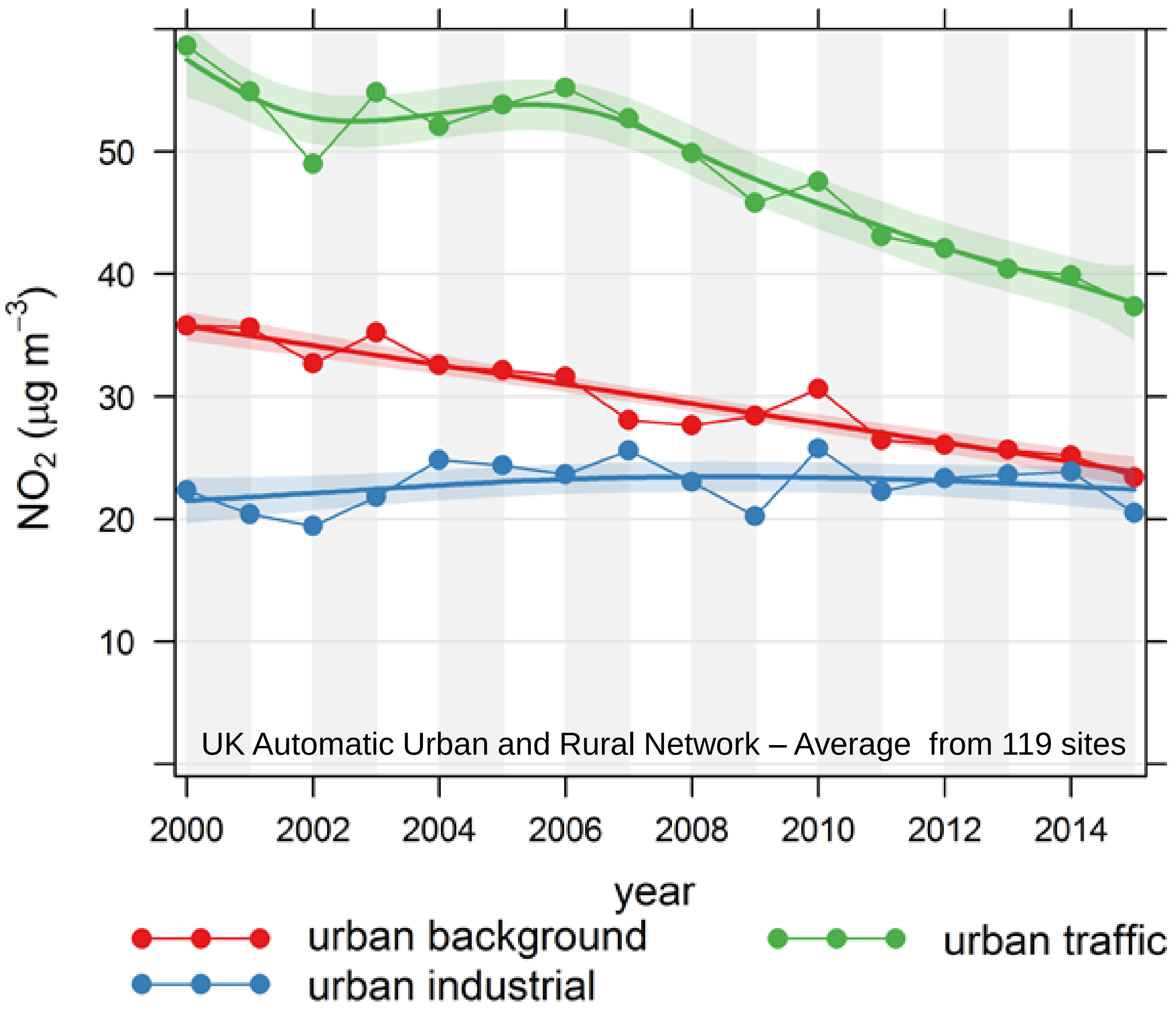
Roadside NO_2 has been falling, but levels are still higher than those permitted by AQ legislation – Urban PM_{10} now close to background





Source: RAC Foundation "Road transport & Air Pollution – Where are we now" - Ricardo Energy & Environment

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Traffic congestion, pollution, parking, air quality, safety and affordability are all driving demand for radical interventions

(London Smog 1952)

- UK, London congestion charge & ULEZ, restrictions on diesels, alternative fuelled taxis and buses.
- Germany’s Bundesrat resolution to ban the internal combustion engine starting in 2030
  - Hamburg plans 40% of city car free by 2034.
  - Vauban (Freiburg) has banned cars, residents rent a €20,000 parking space on the city outskirts
- Finland, Helsinki overhauling public transport via smartphones; car ownership pointless by 2025.
- France, Paris plans to ban diesel vehicles by 2020
- Amsterdam is to ban city centre cars on Saturdays, to reduce motor traffic and pollution.

Source: Media reports

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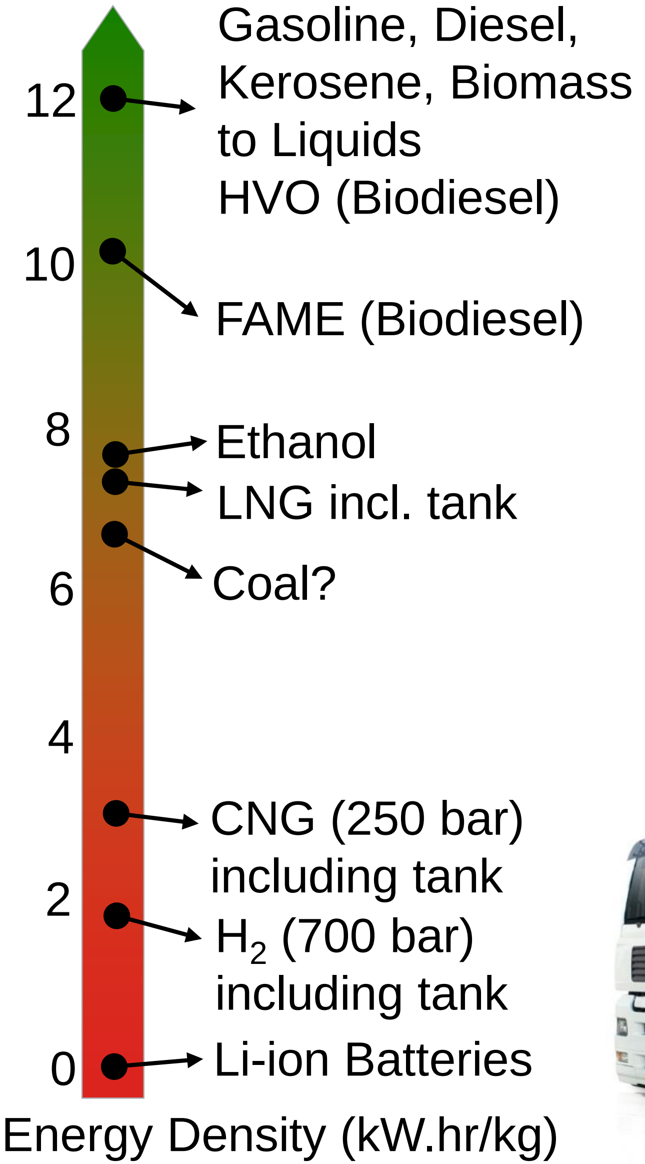
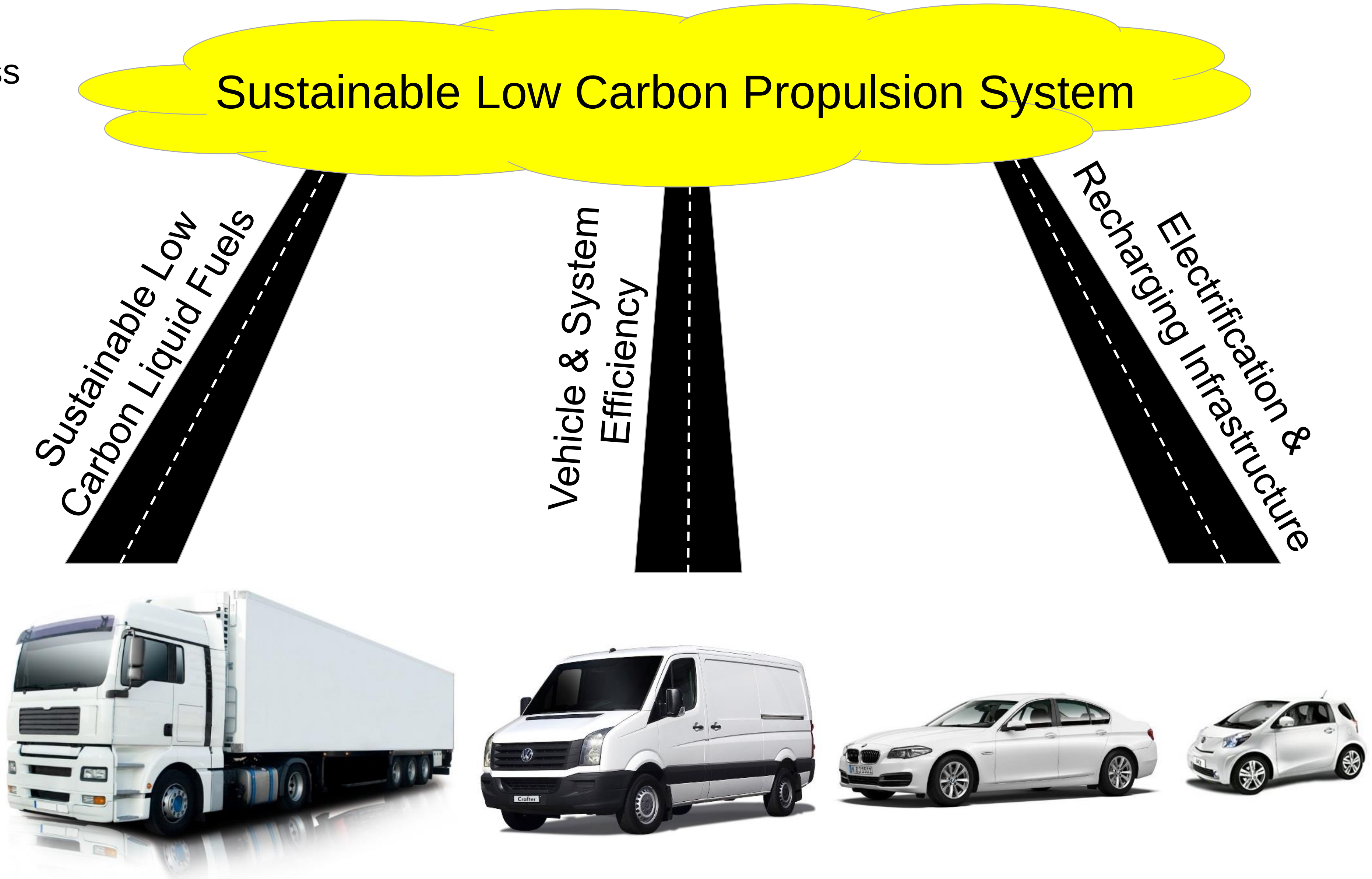
Electrification is only one part of the future transport solution – we will still require low carbon liquid fuels for many decades…





Source: Ricardo

Is this really the answer for heavy duty applications?

Source: recombu.com:Sweden is testing electric roads for trucks

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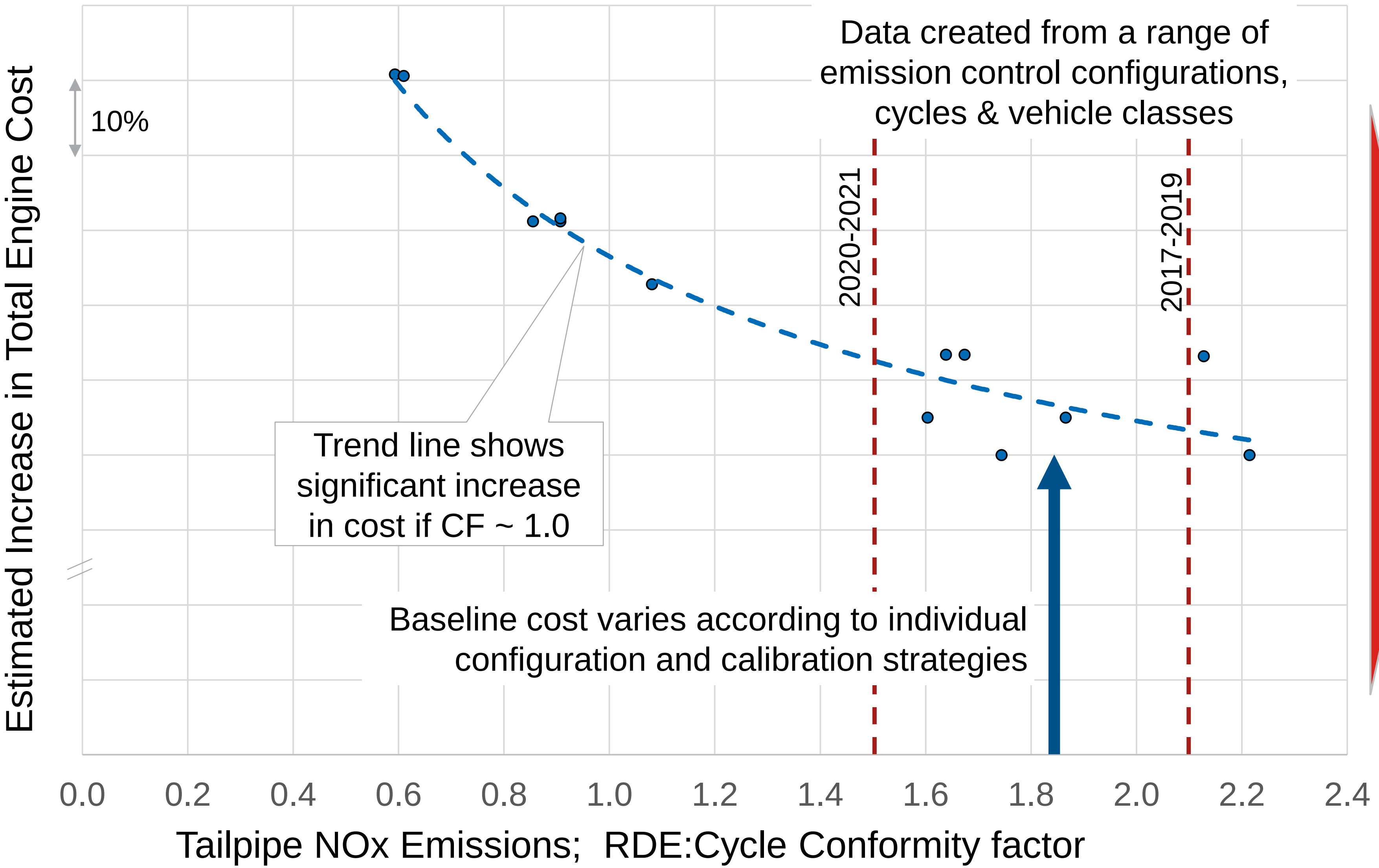
Estimated extra costs of compliance with Euro 6c (RDE) will add significant costs – pass car diesels limited to LCV's and large cars



Source: Ricardo data & analysis

Future Diesel Engines will be very clean but:

- Aftertreatment complexity will add ~€500-1000 to production cost
- Diesel engines for small cars will be unaffordable
- Diesels limited to Light Commercial and large car/long distance applications where the costs are more affordable

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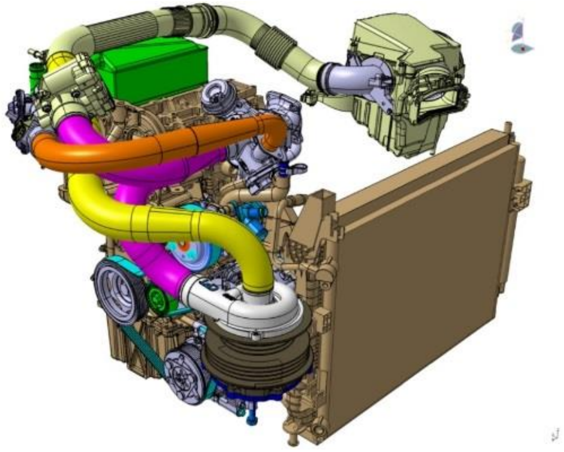
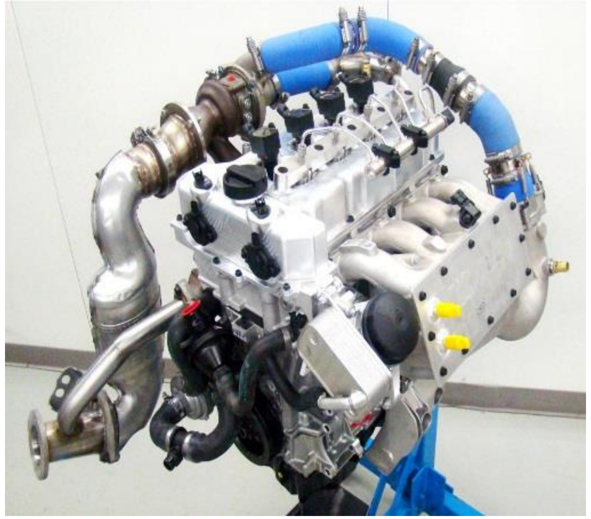
Future gasoline engines technologies – sophisticated highly downsized miller cycle &/or various levels of electrification to enhance functionality



E-Boost and 48 Volt Micro Hybrid

- Aggressively downsized gasoline engine (50%)
- E-Boosting for transient response
- 10-15kW BSG:
  - Kinetic energy recovery & improved driveability
- Route to ~ 70 g/km CO_2 in C class vehicle



High Efficiency

- High Dilution (EGR/Lean) combustion system
- 40% Brake thermal efficiency
- Central DI and highly developed combustion system
- 25+ Bar BMEP (depending on fuel octane)
- 275 g/kWh @2000rpm 2bar BMEP

Source: Ricardo data & analysis

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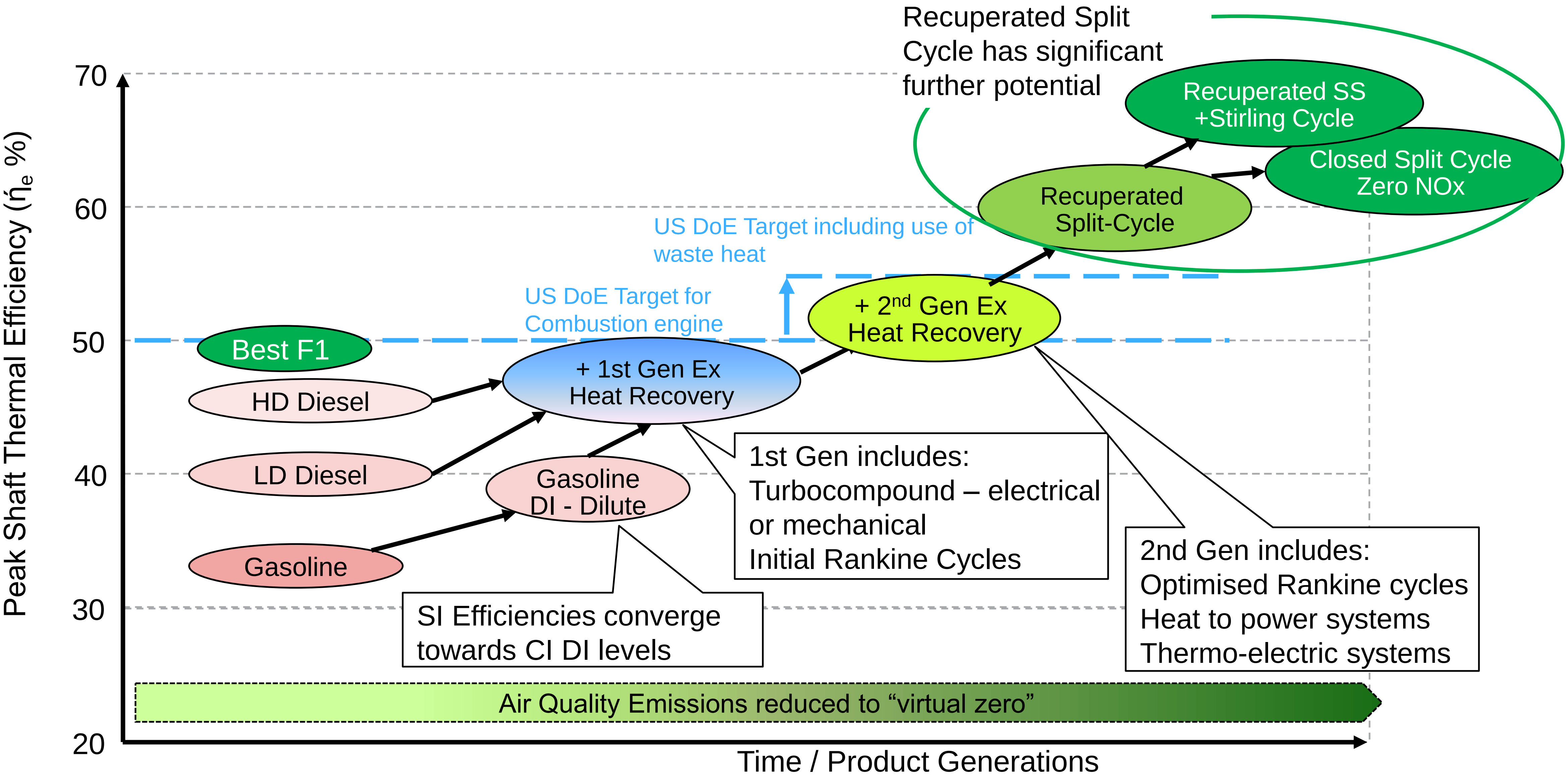
ICE thermal efficiency remains a significant area for research ~60% may be possible for future heavy duty products



Source: Ricardo Analysis, Mercedes HPP

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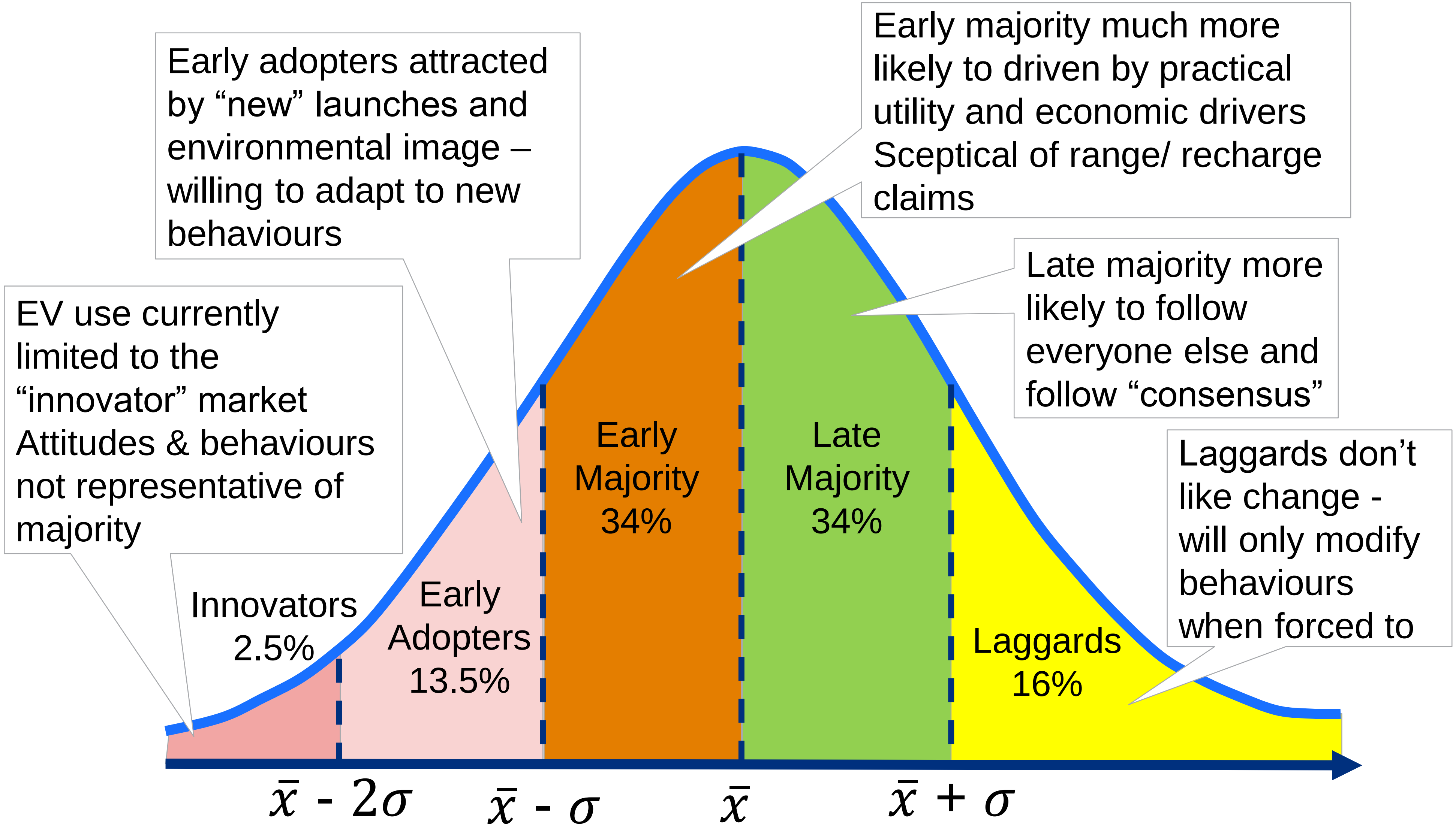
To accelerate EV/PHEV penetration and move beyond the innovator/early adopter market, focus on "User Centric" attributes and requirements



Reaching the early and late majority market:

- Focus on "User Centric" approach
- A more attractive EV/PHEV experience for consumers:
  - Ease of charging – wireless?
  - Improving charge availability?
  - More connected?
  - Preferential usage – HOV lanes/ Parking etc.
  - New ownership models?

Source: Ricardo analysis

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New EV’s - with ranges < 200 miles by 2018 – Implications for mass market battery supply, recharging and life cycle/environmental impacts

OEM	Model	Production	Range (miles)
Chevrolet	Bolt	2016	**238**
Hyundai	Ioniq	2017	110
Ford	Focus	2017	110
Fisker	E-Motion	2017	**400**
Renault	Zoe	2017	186
Tesla	Model 3	2017-8	**200**
Audi	etron SUV	2018	**310**
Aston Martin	Rapid E	2018	**200**
Jaguar	I-Pace EV	2018	**220**
Faraday Future	FF91	2018	**378**
Tesla	Roadster	2019	**400**
Tesla	Model S	2019	**500**
Mercedes	Generation EQ	2019	**300**
Volvo	full size	2019	**200**
Audi	A9 etron	by 2020	**300**
Nissan	Leaf	by 2020	**200**
Porsche	Mission E	by 2020	**310**
VW	I.D. Concept	by 2020	**240**
BMW	i5 SUV	2021	**300**

Source: carwow, inside evs, web




Are Electric Vehicles really “zero” emissions?

- To reach 2030 targets, EU will need equivalent of 12x Li-ion Battery Gigafactories to make cells & packs
- Need to focus on total environmental impacts
  - Life Cycle Analysis – embedded CO_2 etc.
  - Material & waste from battery manufacture

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Long distance battery electric travel will remain a logistical challenge for many decades – ICE/BEV re-fuelling/charging not comparable

- UK M25 Cobham Service Station
  - M25 - 150,000 vehicles/day
  - 24 fuel dispensers
  - 3,400 vehicles a day
    - (140 vehicles/hour)
  - Power Transfer
    - ~ 600 megawatts peak ~ 50 MW average

- UK M40 Tesla Supercharger Station
  - M40 - 65,000 vehicles/day
  - 6 chargers
  - 144 vehicles a day (max)
    - (6 vehicles/hour – assuming 80% charge)
  - Power Transfer (120 kW/station)
    - ~ 1 megawatt peak

Source: Shell Cobham UK, Tesla

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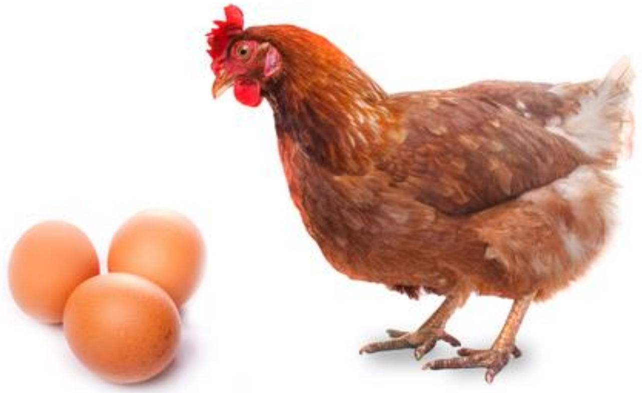
Auto Industry concerned that Infrastructure will limit market penetration – Supply/Network operators currently unconvinced about early action



- To achieve EV market uptake, need **longer range** and improved **charging** facilities
- Local urban/city **networks** are **insufficiently sized** to support even low uptake of EV's and Plug-in vehicles
- Average electricity demand will only increase gradually but **"peak" demand will be an issue** (EV owners all charge at same time)

- Network Operators believe that **power demand** for xEV's will be **insignificant** before 2030
- There is **no business case for recharging facilities**, particularly fast charge – all will need high subsidies
- Local network issues will be resolved by **demand control** and **strategic positioning** of recharge facilities

Source: Ricardo Analysis, UK OLEV, Role of the power sector for Electromobility - Iberdrola

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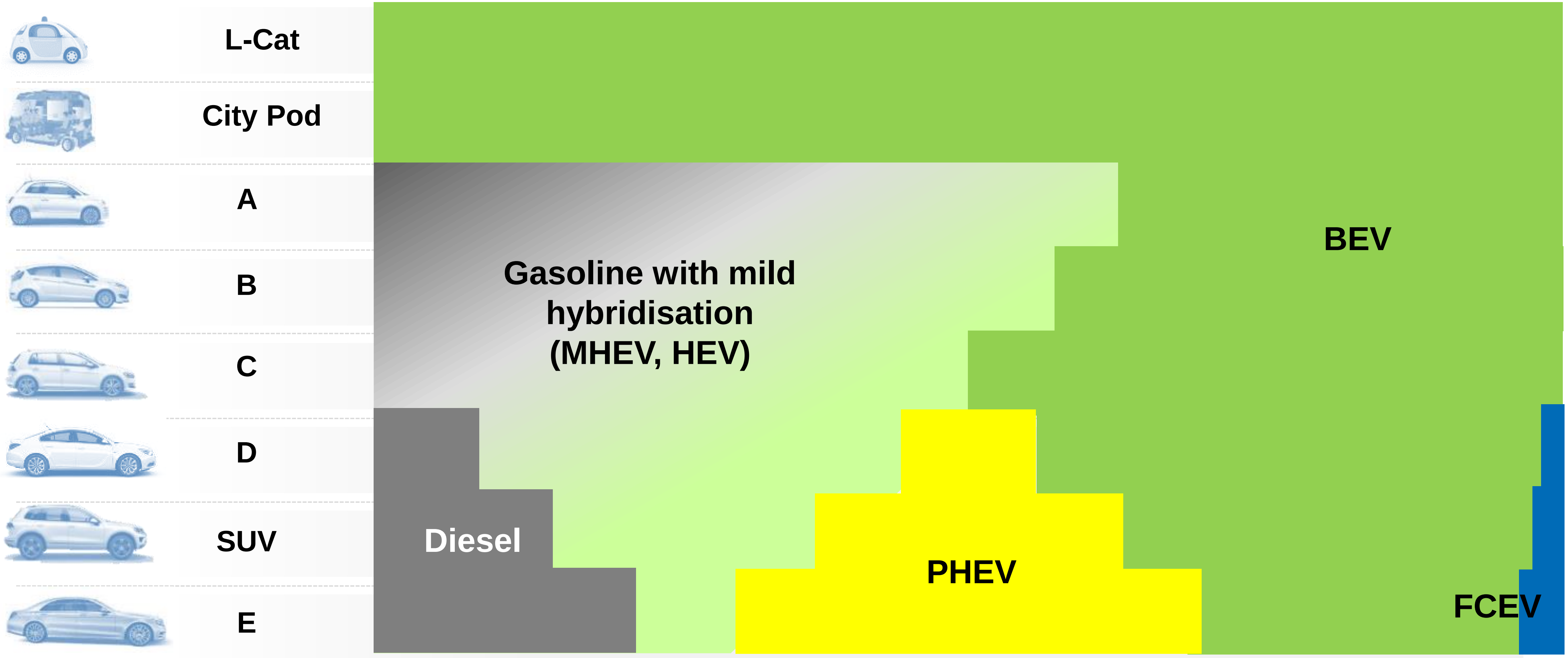
Ricardo view of the 2030 passenger vehicle electrified powertrain mix - penetration rates by powertrain type will vary by segment

Powertrain mix 2030 – developed markets – *high level of charging infrastructure*

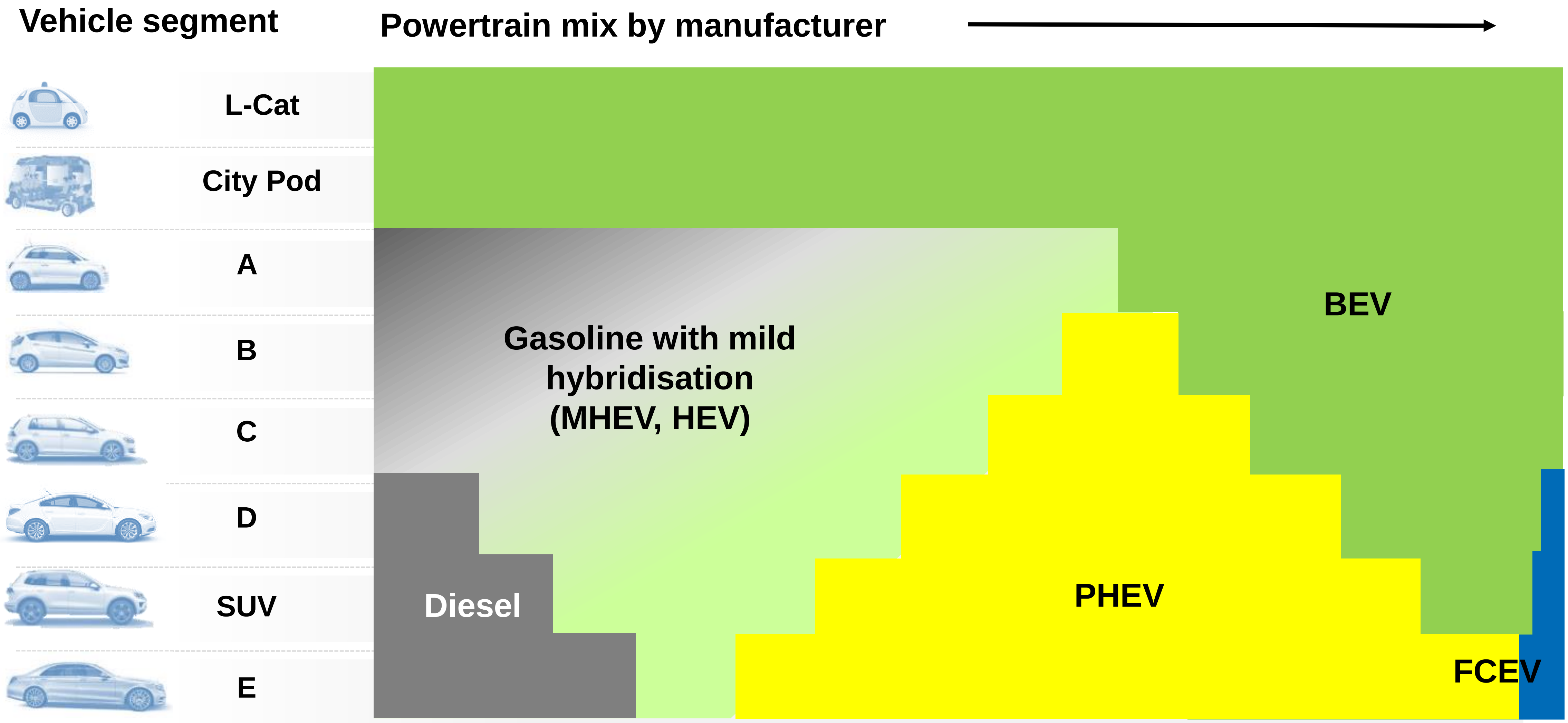
Vehicle segment **Powertrain mix by manufacturer**



Source: Ricardo analysis

Ricardo view of the 2030 passenger vehicle electrified powertrain mix - penetration rates by powertrain type will vary by segment

Powertrain mix 2030 – developed markets – *Limited charging infrastructure*



Source: Ricardo analysis

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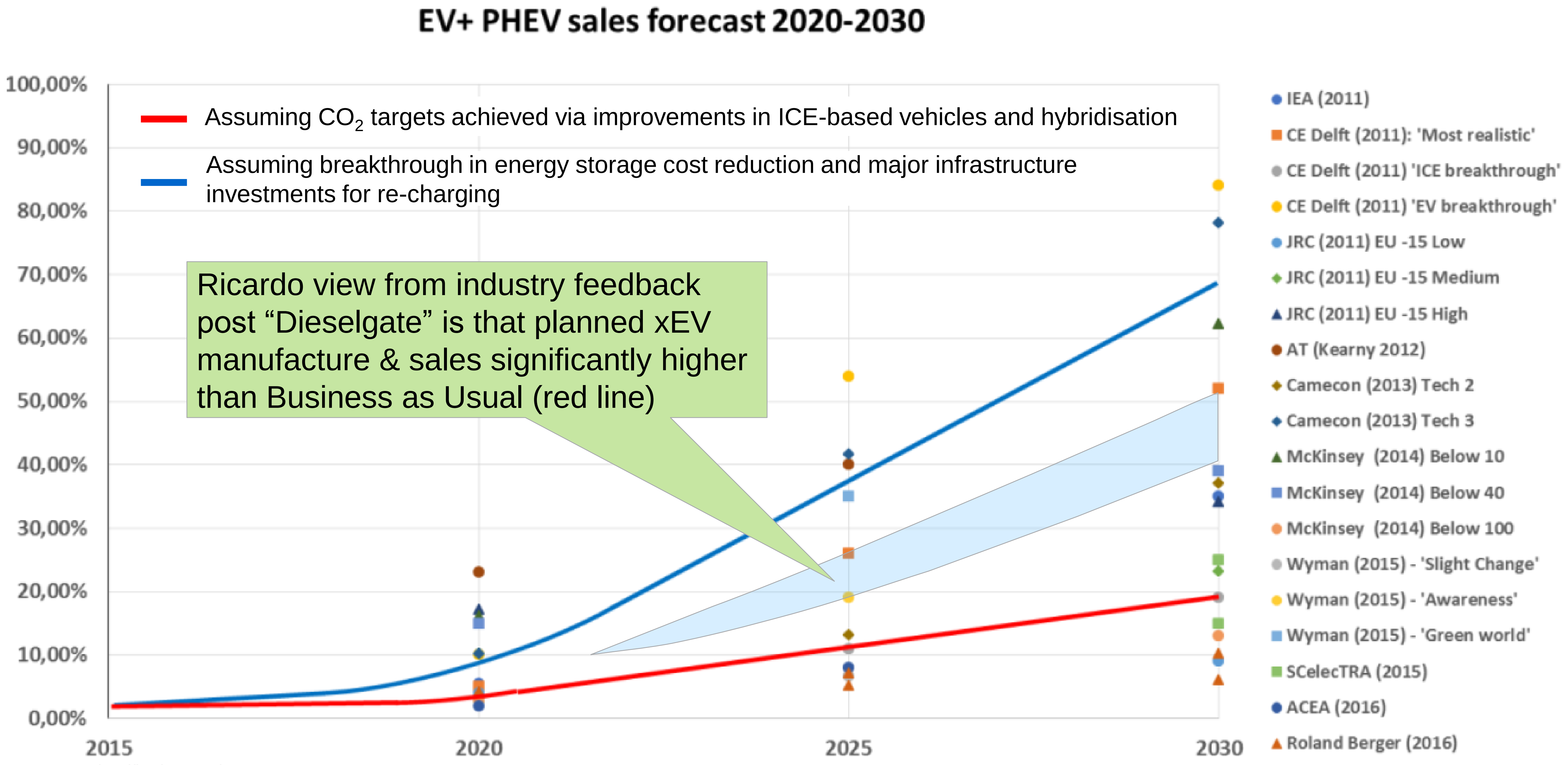
2017 ERTRAC Electrification roadmap – business as usual forecast <20% by 2030 but >60% if target cost reductions achieved - little agreement for published sales forecasts



Source: ERTRAC Electrification Roadmap

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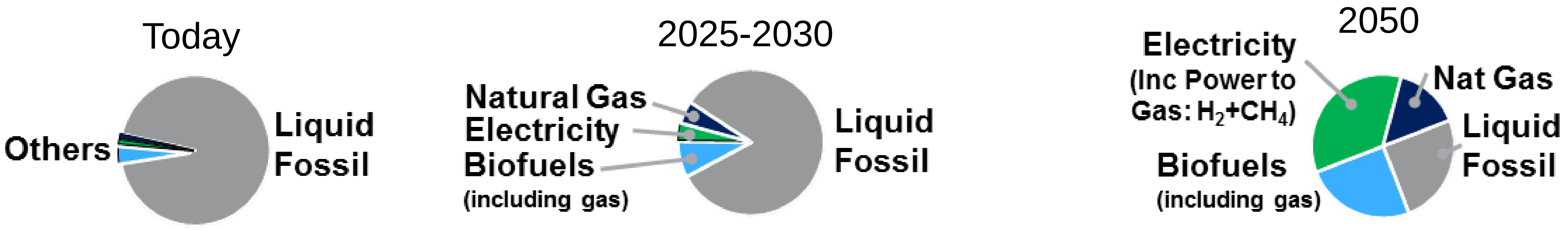
Electricity for road transport will slowly increase - fossil fuels likely to dominate in foreseeable future – EU passcar diesels will halve by 2025



- Whilst liquid fossil fuels dominate at present, electricity & alternatives more significant by 2025
- EU pass car diesel share likely to reduce from ~50% to ~25% by 2025 – mainly large car/SUV
- Natural gas growth dependent on price relative to diesel - potential “clean” fuel for city buses/taxis
- Biofuel (drop-in) likely to increase but limited by feedstock and waste conversion costs
- Hydrogen:
  - Engineering & vehicle cost challenges will be overcome but renewable H_2 supply not certain
  - “Hydrogen will always be the fuel of the future”

Source: Automotive Council, ERTRAC, E4tech, Element Energy, Ricardo analysis

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