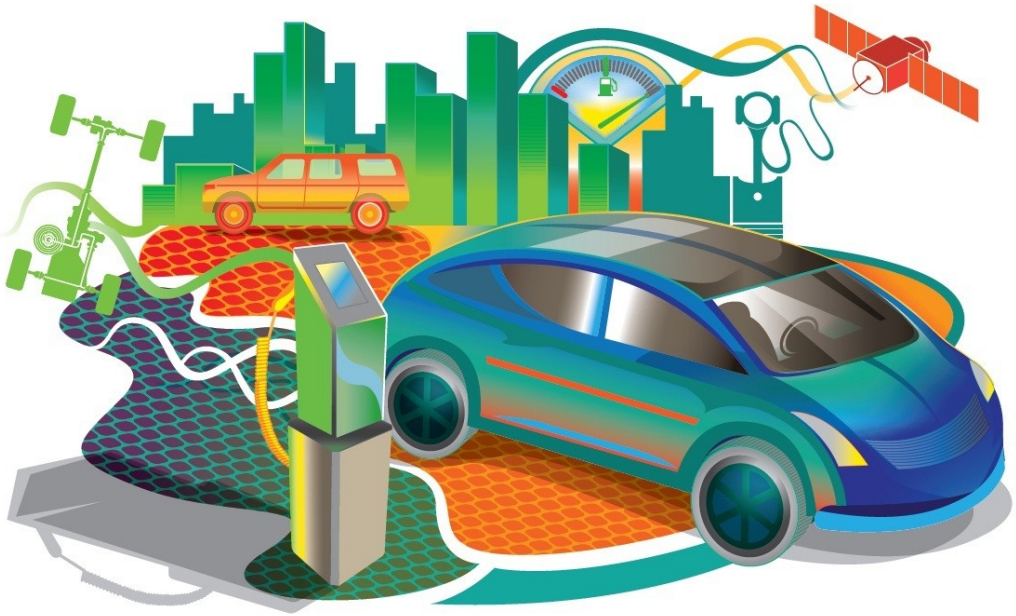
Future Low Carbon Vehicles

Prof. Neville Jackson

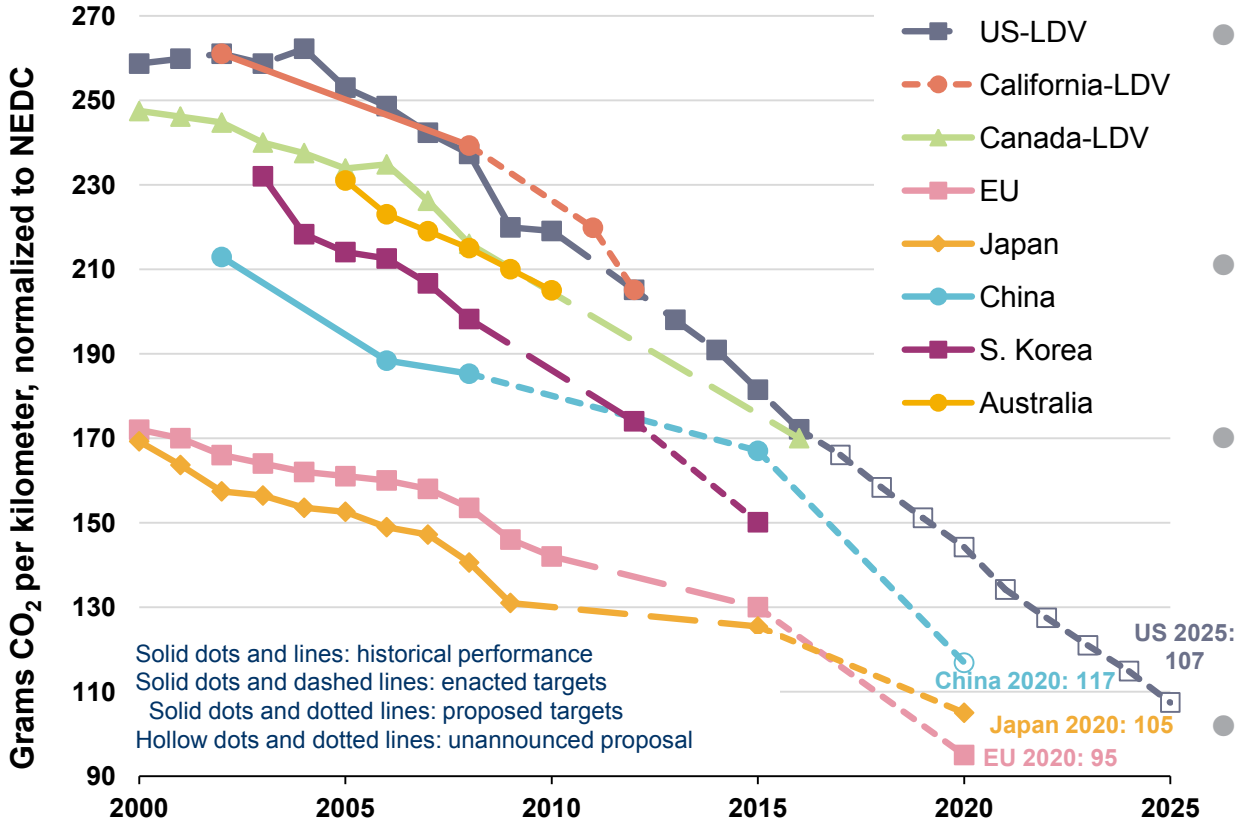
Chief Technology & Innovation Officer

Ricardo plc



The Green Charge
27 March 2012

The growth of both regulation and targets for Low Carbon Vehicles sets a major challenge for the road transport sector



- EU, USA, Canada,China Australia & Japan all have legislation/ agreements for fuel economy or CO_2
- EU Proposal for Vans
  - 175 g/km from 2014-16
  - 147 g/km by 2020
- USA has set target of
  - 35.5 mpg by 2016
  - 54.5 mpg by 2025
  - Implemented over whole of USA by EPA
- Challenging Targets:
  - EU 3.9% pa to 2020
  - US 4.7% pa to 2025

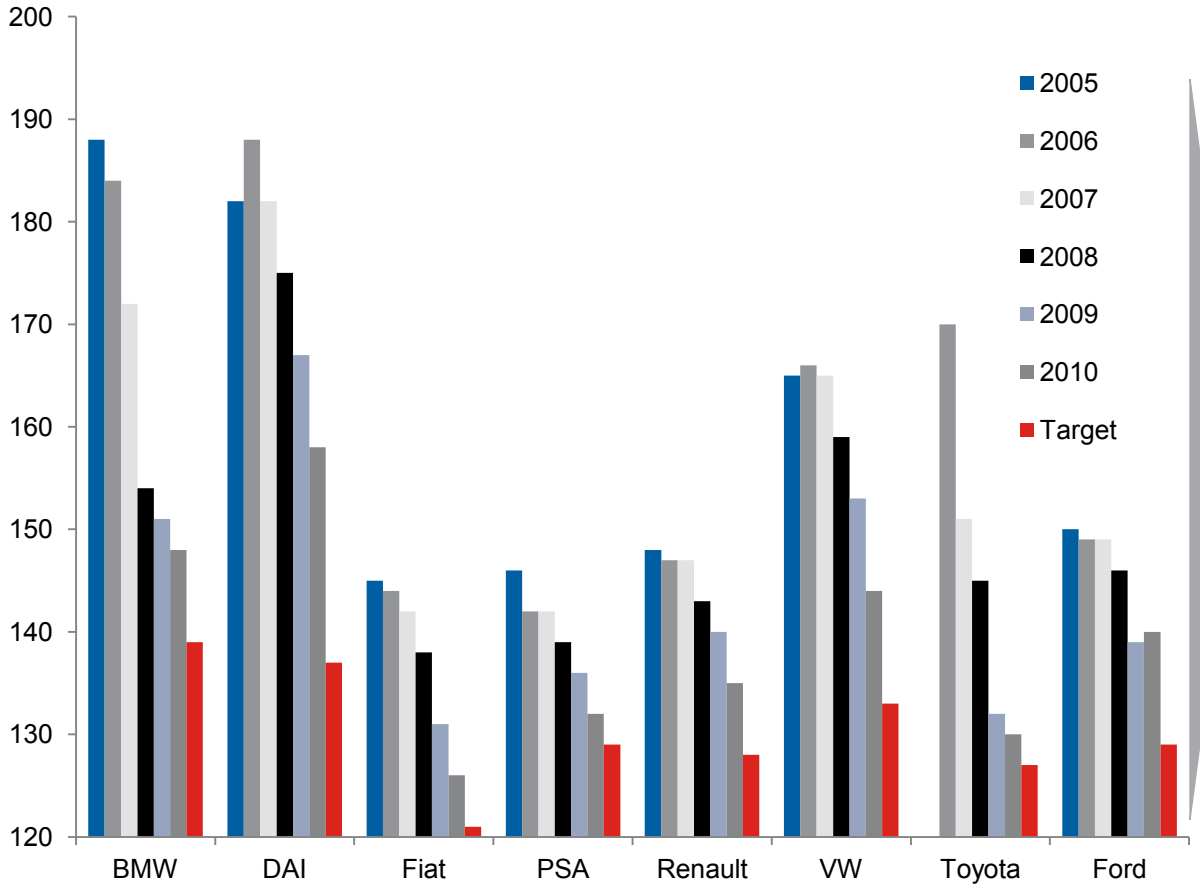
[1] China's target reflects gasoline fleet scenario. If including other fuel types, the target will be lower.
[2] US and Canada light-duty vehicles include light-commercial vehicles.

- Both US and EU regulations allow credits for “eco-innovations” that result in real world fuel consumption/CO_2 reductions but without regulated drive cycle benefits

Sources: http://www.nhtsa.gov/staticfiles/rulemaking/pdf/cafe/Oct2010_Summary_Report.pdf www.theicct.org/info/documents/PVstds_update_apr2010.pdf;

Progress has been made against EU emissions legislation, but OEMs still have a lot to do in a comparatively short time

Progress against 2015 130g CO_2 / km target



Source: Bernstein & Ricardo analysis

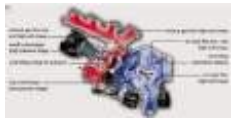
Comments

- OEMs have an average annual CO_2 reduction of ~3% since 2005
  - Toyota and BMW lead with 6.5% and 4.7%
  - Ford and Renault are laggards with 1.4% and 1.8%
- Market still has average of ~6.6% to go to hit targets
  - PSA & Toyota have ~2%
  - Daimler has 15%
- 130 g/km compliance phased in for each OEM:
  - 65% of vehicles in 2012
  - 75% in 2013
  - 80% in 2014
  - 100% in 2015

Vehicle OEM's have implemented a wide range of measures to reduce CO_2 emissions - with scope for further improvements

OEM Approaches to CO_2 Reduction

Base Engine Updates
Combustion + Air System Match
Minor Friction Improvements

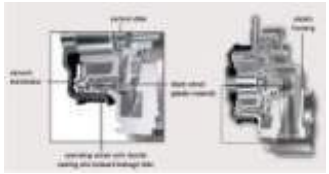



Calibration for CO_2
Often with some compromise to NVH

Downspeeding
Longer Final Drive Ratio




Thermal Management e.g.
Map Controlled Coolant Temp
Switchable Piston Cooling
Variable Speed Water Pump



Downsizing
e.g new Ford EcoBoost:
Same power, lower friction

Reduced Rolling Resistance Tyres

Energy Management
e.g. Smart Alternator,
Adaptive PAS


Stop-Start

Auto Start-Stop

Aero Improvements
e.g ride height,
reduced/active grill

Vehicle Weight Reduction

Source: Ricardo Research

Advanced combustion engines & electrification of the powertrain are key elements of the automotive future

SHORT TERM: ~2015

- Boosting & downsizing
  - Turbocharging
  - Supercharging
- Low speed torque enhancements
- Friction reduction
- Advanced thermal systems
- Stop/Start & low cost Micro Hybrid technology
- Niche Hybrid, PHEV's and Electric Vehicles

MEDIUM TERM: ~2025

- Extreme downsizing with 2 & 3 cylinder engines
- Combined turbo/ supercharging systems
- Advance 48 volt micro hybrid systems dominate
- PHEV's in premium & performance products
- EV's for city vehicles
- High Efficiency Lean Stratified Gasoline
- Advanced low carbon fuel formulations

LONG TERM: ~2050

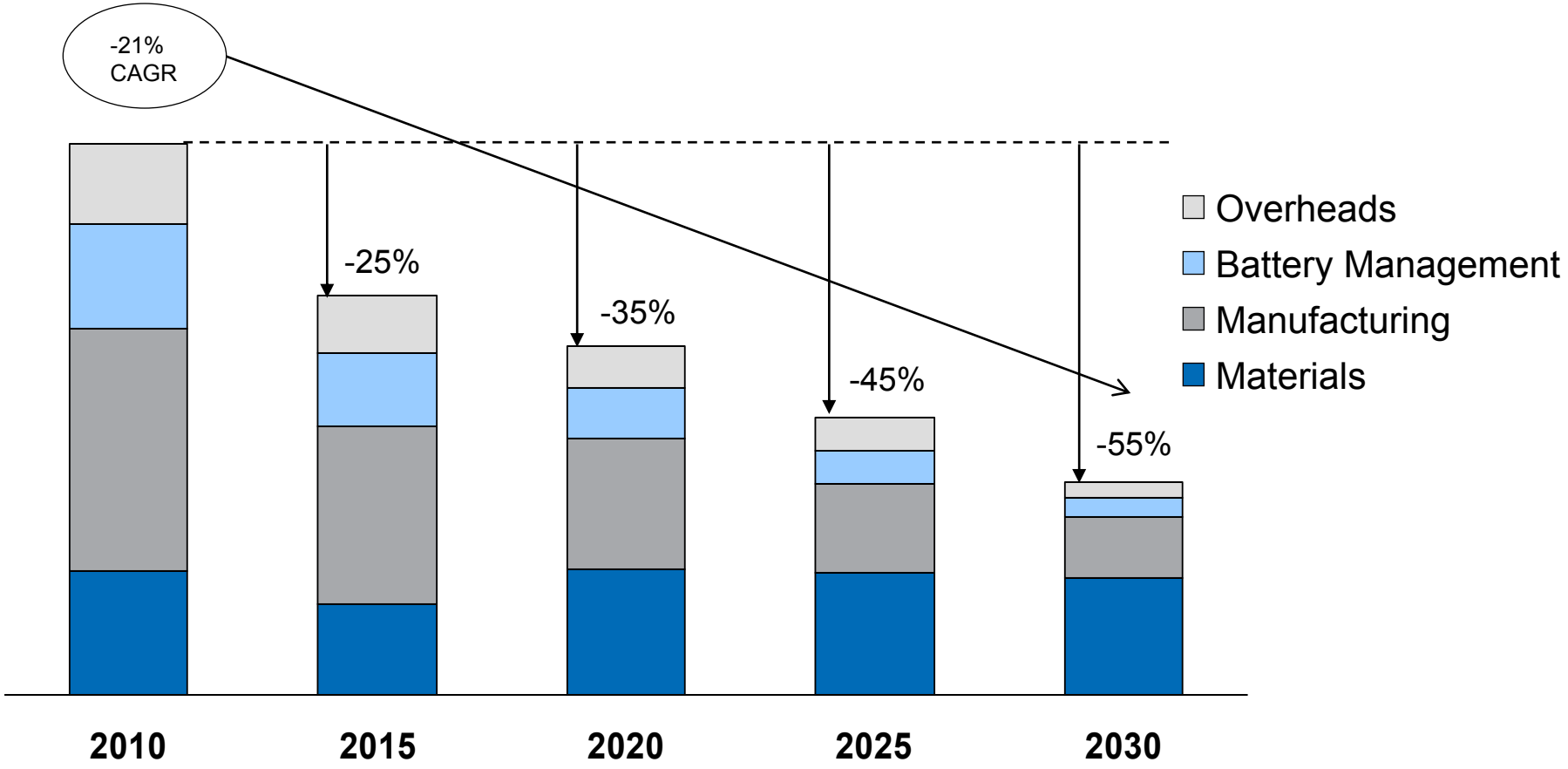
- Plug-in/Hybrid electric systems dominate
  - Very high specific power ICE's
- Range of application specific low carbon fuels
- Exhaust & Coolant energy recovery
- Advanced thermodynamic Cycles
  - Split Cycle?
  - Heat Pumps?

Increasing Importance of Electrification

Source: Ricardo Technology Roadmaps, Ricardo Analysis

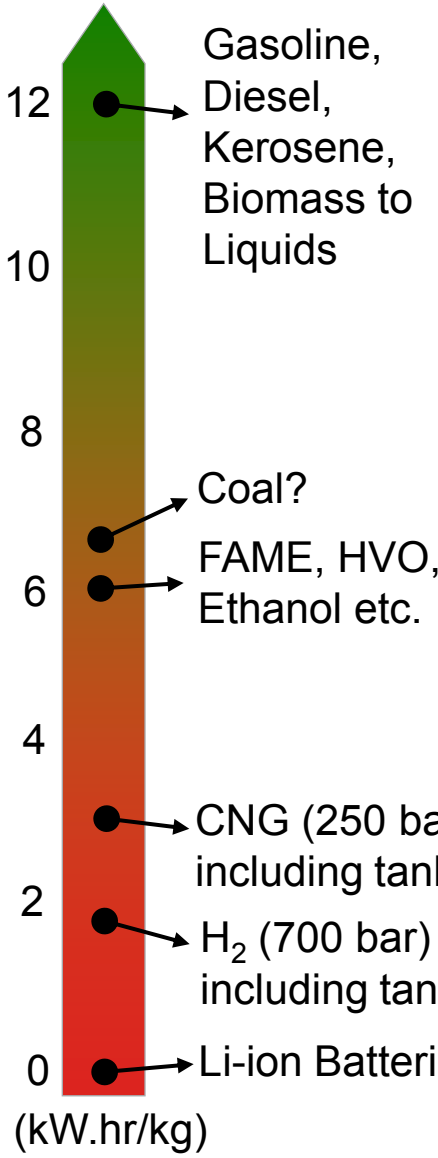
Battery packs are the key cost factor for xEVs, while costs will reduce they remain the biggest hurdle to mass adoption

Energy Battery Pack Cost Forecasts – based on 20kWh High Energy pack provides ~ 150 km urban range



Source: Ricardo Analysis and Modelling

Long haul/ heavy duty applications will require low carbon liquid fuels – light duty applications more suited to batteries



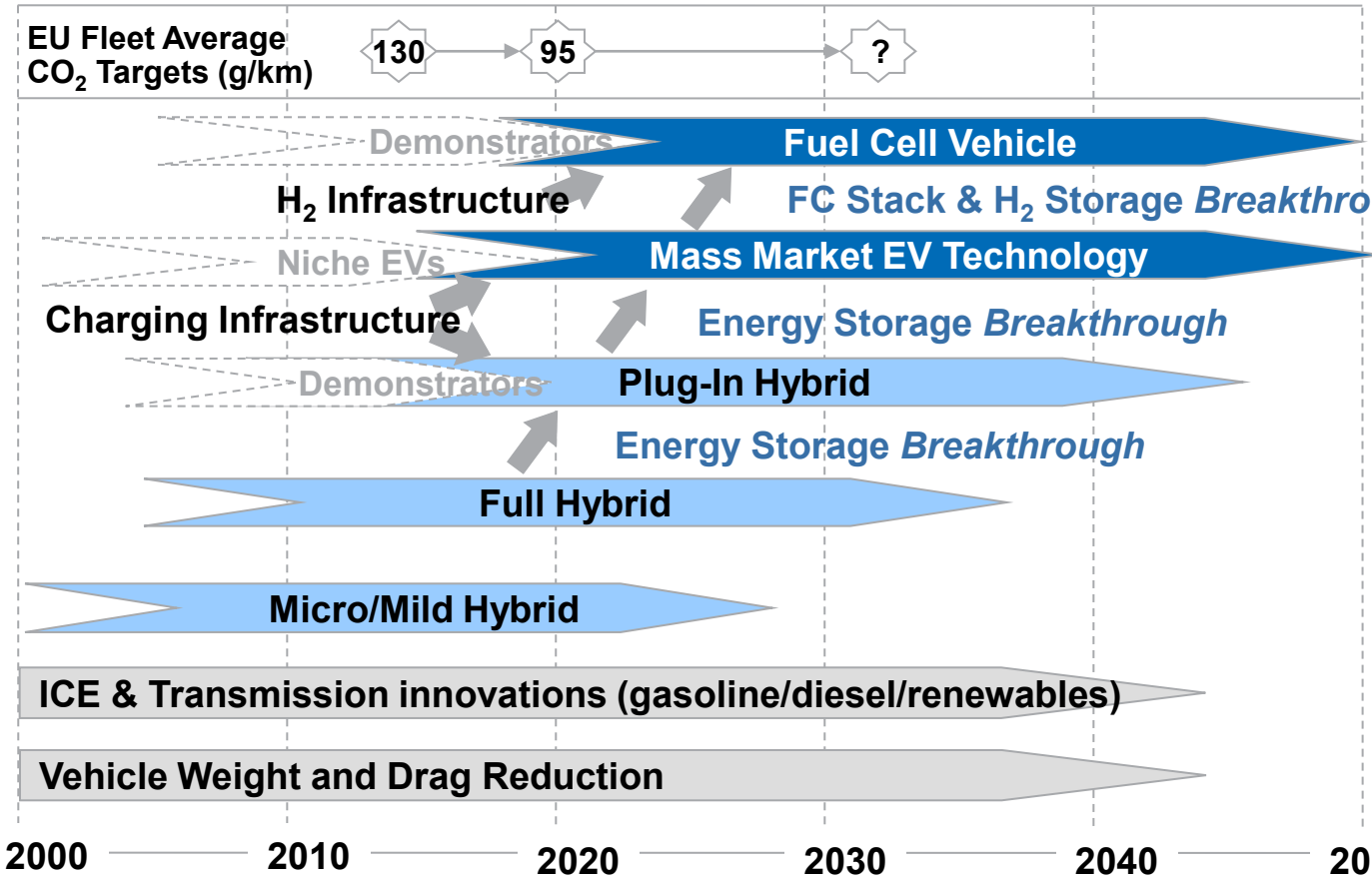
State of the Art Li-ion battery for 500 mile range 40 ton HGV would weigh 23 tons*

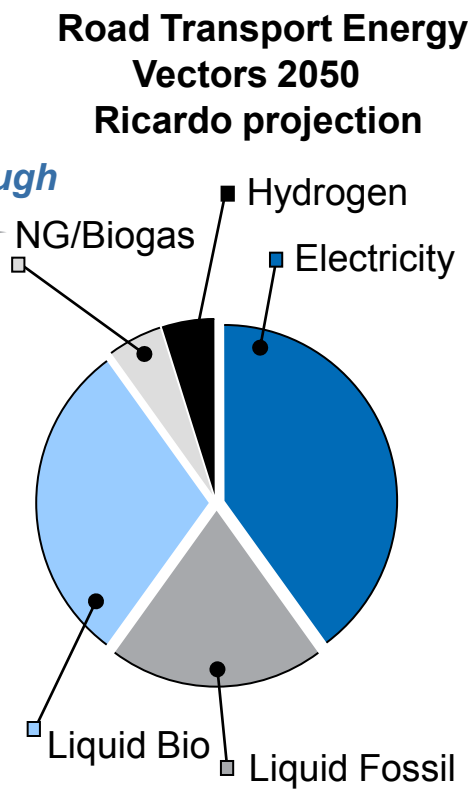
Long Distance/Heavy Duty — Short Distance/Light Duty

Low Carbon Liquid Fuels	Liq Fuel/Battery Hybrid	Battery Electric
Long distance/ heavy duty vehicles need space/weight efficient energy storage	Use of both liquid fuel and grid re-charged battery offers more flexibility and utility	EV's suited to short distance/light duty applications to minimise cost
Technology/Cost & Availability →		← Technology/Cost Innovations

Source: Ricardo research & US DoE*

"Consensus" mass market roadmap developed by Ricardo for UK Auto Council shows a range of technologies will be required to meet regulatory targets





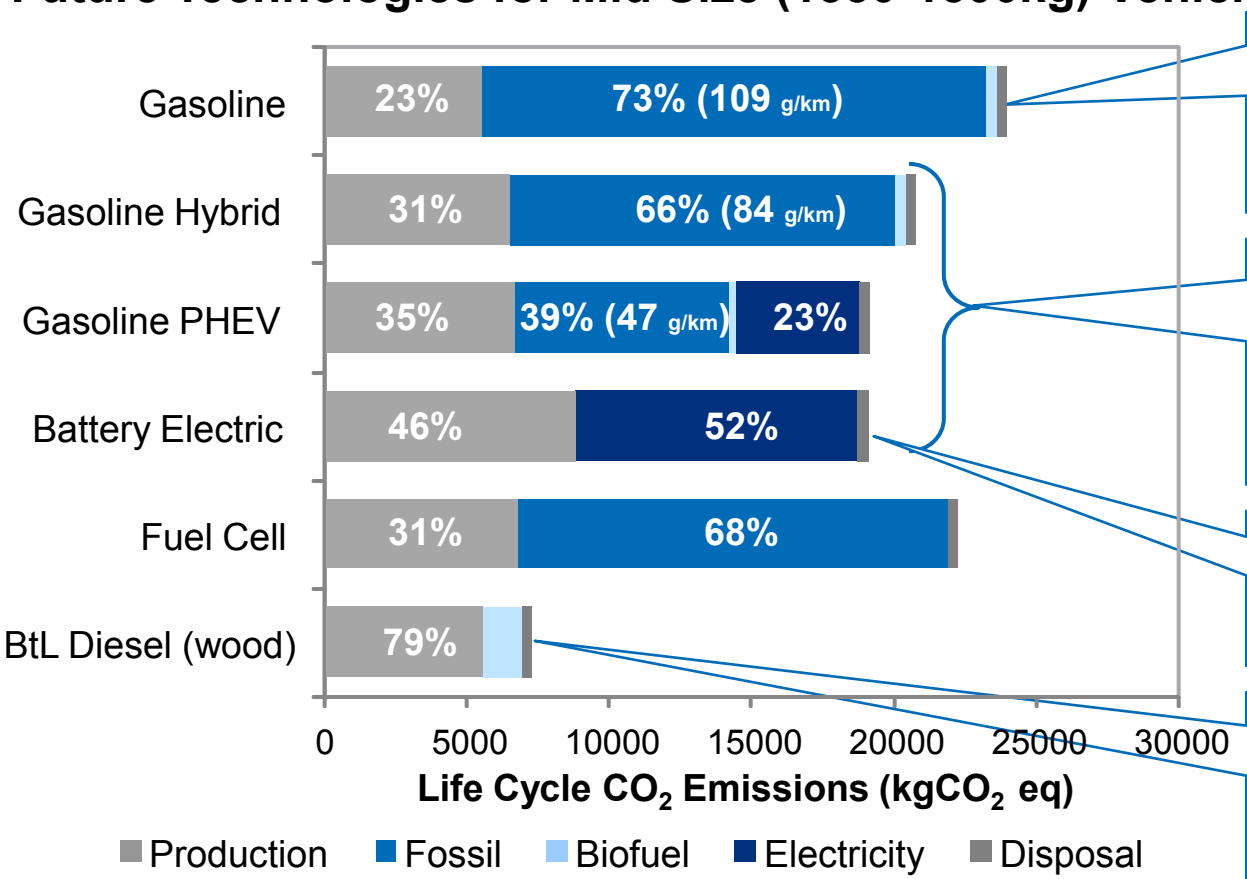
Regulation Basis:

Tailpipe CO_2 or Vehicle fuel efficiency	WTW CO_2 & efficiency	Life Cycle Analysis

Source: Ultra Low Carbon Vehicles in the UK – BERR/DfT; Ricardo roadmaps and technology planning; Shell Energy Scenarios to 2050 (2008)

A move to a Life-Cycle CO_2 measure may impact choice of future technology. Higher embedded emissions for hybrids and EVs

Future Technologies for Mid Size (1350-1500kg) Vehicle



Improvements in ICE powertrains will be very effective in reducing life cycle CO_2 emissions

Embedded CO_2 for electrified vehicles higher than conventional due to advanced battery packs, electronic motors and power electronics

For an EV, nearly half the life cycle CO_2 could result from production

Biomass to Liquid based on Fischer Tropsch process & farmed wood ~ very low in-use emissions

Assumptions:

Vehicle specifications based on roadmap projections for 2015. Assumed lifetime mileage 150,000 km. Gasoline fuel E10. Diesel fuel B7 Fischer-Tropsch diesel from farmed wood (WTW = 6 gCO2eq/MJ via UK RED), Hydrogen carbon intensity 99.7 gCO_2e/MJ (from Natural Gas Steam Reforming), Electricity carbon intensity assumed to be 594 gCO_2/kWh.

Hybrid Bat. 1.8 kW.hr NiMH, 56 kW Motor, EV Bat. 32 kW.hr Li-ion ~ 150 km range, PHEV Bat. 5 kW.hr ~ 20 km range, FCEV Bat. 1.8 kW.hr

Source: Ricardo report for LowCVP, "Preparing for a life cycle CO2 measure" (RD.11/124801.5), plus additional Ricardo analysis