Low Carbon Technology Options and their Likely Future in Transport

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low carbon vehicle partnership

Strategies and Opportunities to Invest in Low Carbon Automotive

Plaisterers' Hall, One London Wall , EC2Y 5JU

Summary – 4 key messages:

- **Technology will play a key part in meeting global targets and regulations;**
  - There is no "silver bullet"
  - Most attractive technologies are improved combustion engines, increasing hybridisation & light weighting
- **Technologies to improve fuel efficiency increasingly application specific;**
  - Urban/City vehicles demand different technologies to Intercity vehicles
  - Electric vehicles expensive but likely to form growing "niche" market
- **Improving fuel efficiency can add significant production cost to vehicles;**
  - Most cost effective technologies are generally improved combustion engines
  - However, increased function/utility/driveability could command higher price
- **Major drive to co-ordinate and focus UK initiatives in Low Carbon vehicles;**
  - UK is a leading manufacturer of high tech combustion engines
  - Connecting innovators with manufacturing community
  - Improved "signposting" of key technology requirements & R&D focus

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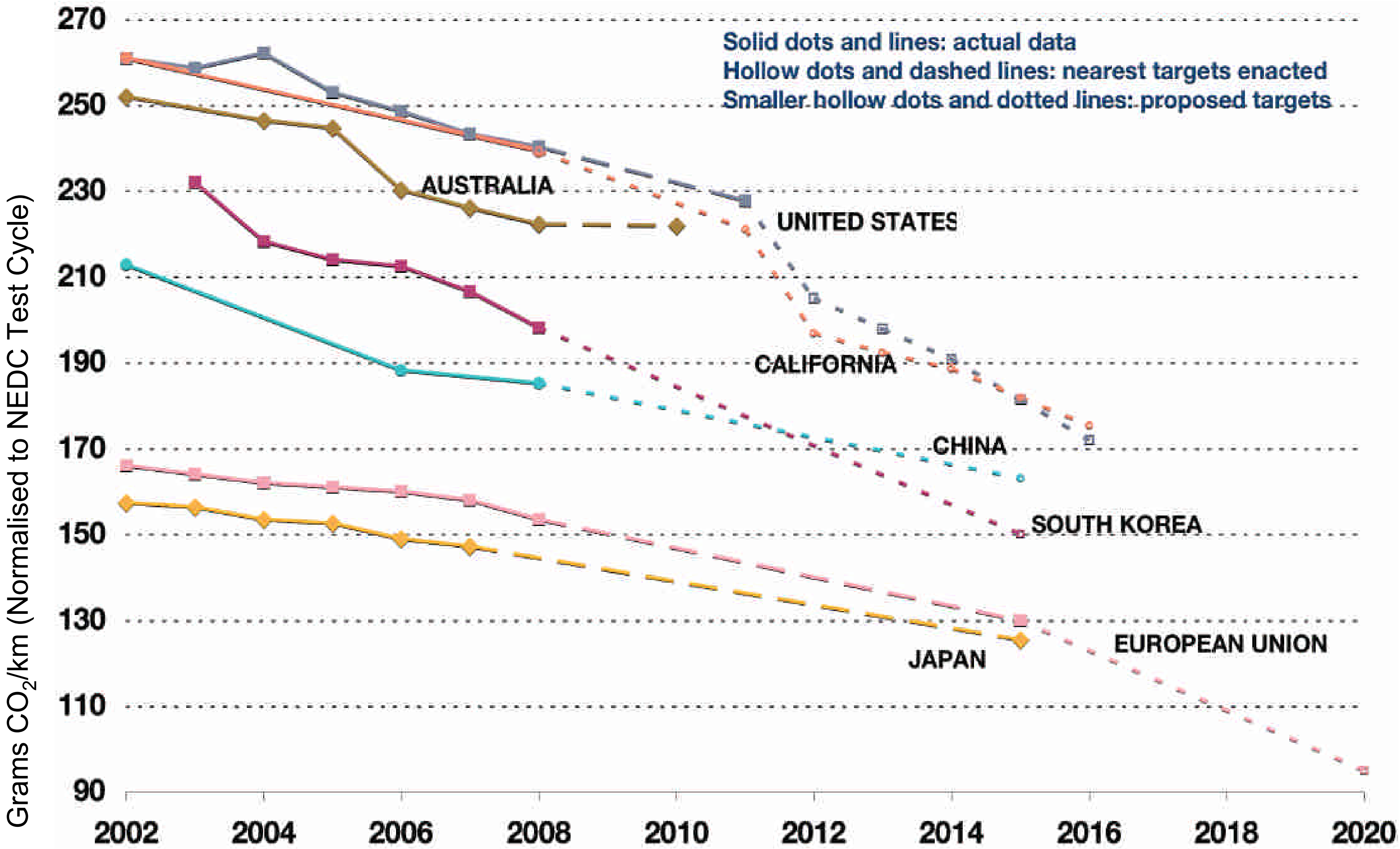
The growth of both regulation and targets for Low Carbon Vehicles sets a major challenge for the road transport sector



Source: Passenger Vehicle Greenhouse Gas and Fuel Economy Standards Nov 09 - ICCT

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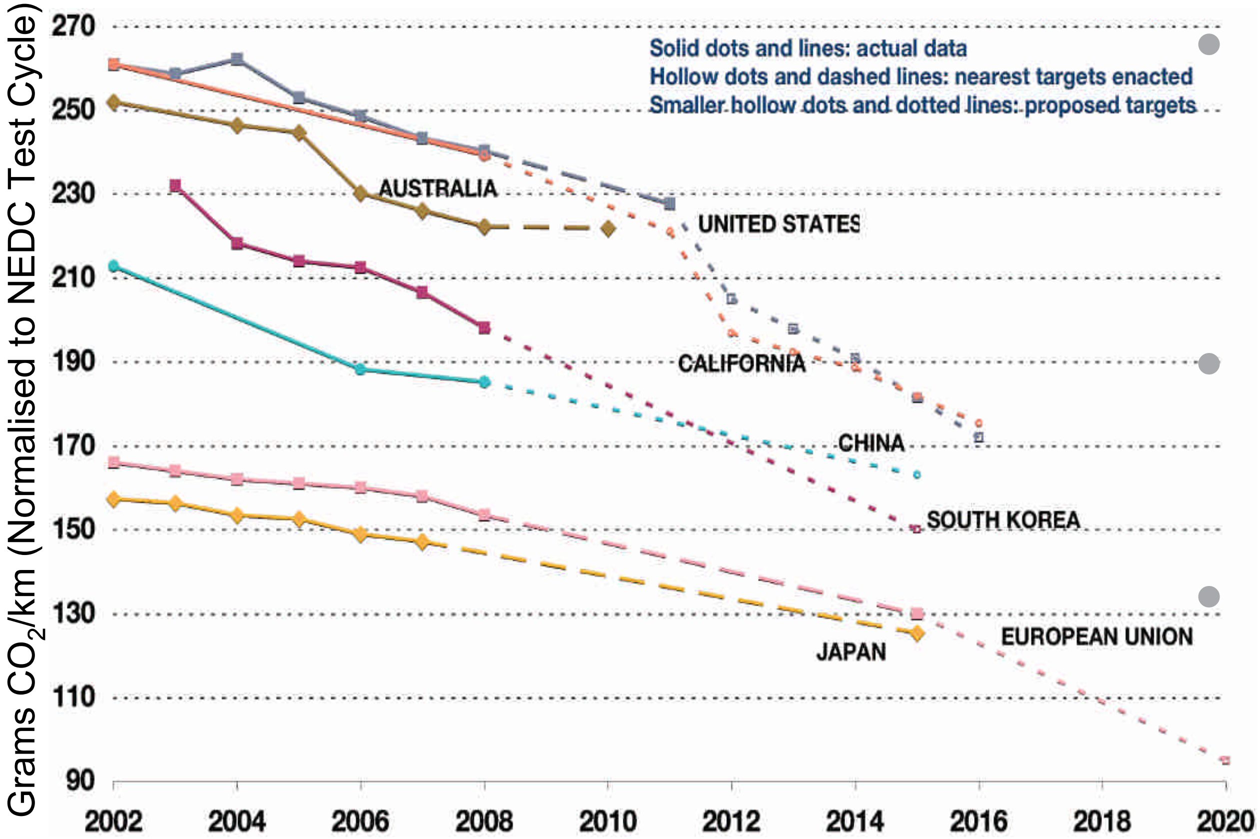

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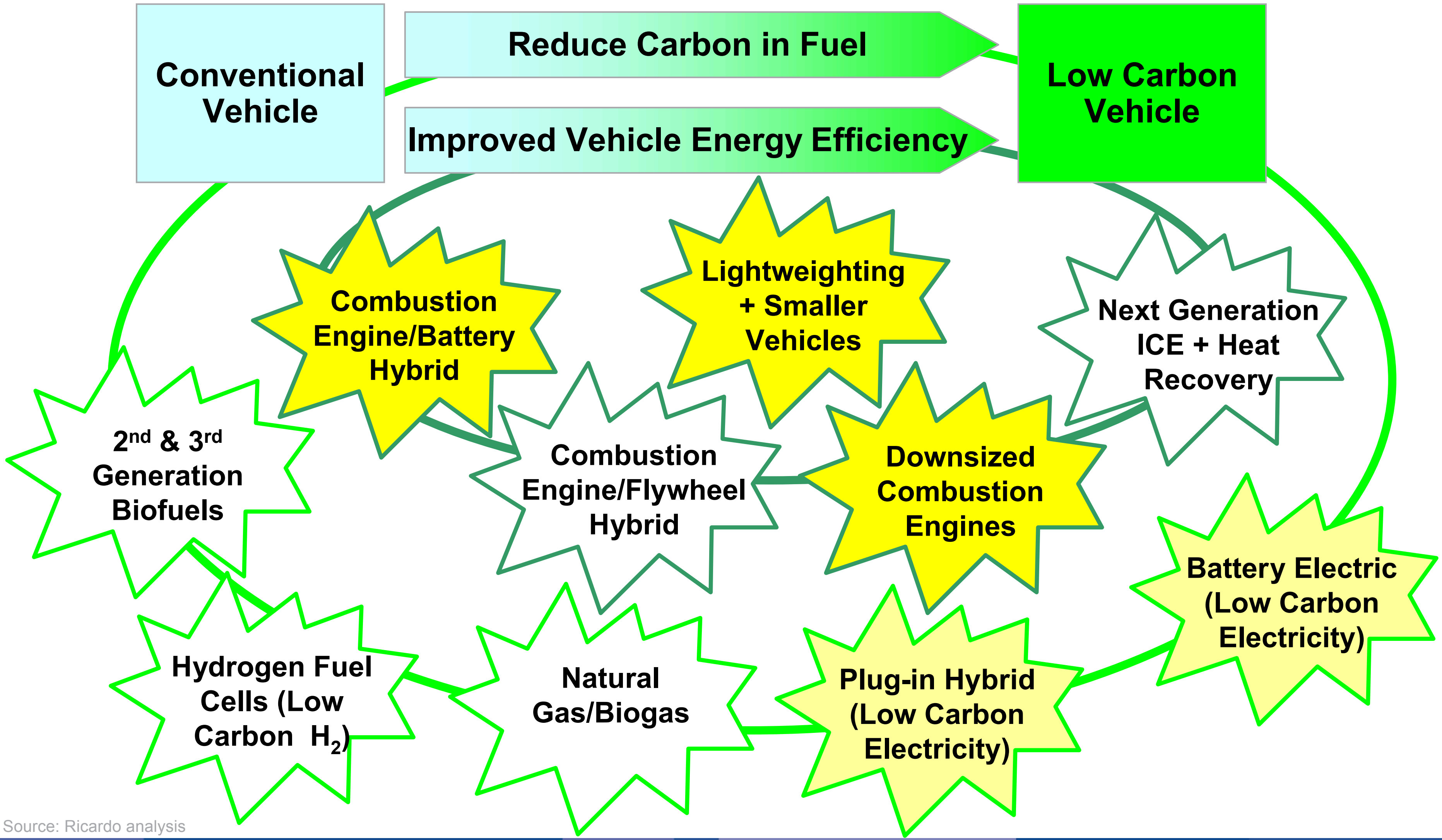
- EU, USA, Canada, Australia, China & Japan – all have legislation / agreements for fuel economy or CO_2
  - Generally set at 3% p.a.
- EU Proposal for Vans
  - 175 g/km from 2014-16
  - 135 g/km by 2020
- Pres. Obama has set target of 35.5 mpg by 2016
  - To be implemented over whole of USA by EPA

- Japan has been the first to introduce fuel economy legislation for Heavy Duty vehicles (15% reduction from 2002 by 2015)
- European Heavy Duty CO2 limits could be introduced from 2016–2018 post Euro 6
  - However interaction with emissions legislation could delay implementation

There are many technical options to reduce vehicle CO2 emissions - All have challenges & there are no clear winners – All are likely to be required to win the battle

- Low carbon vehicles achieved through improved efficiency and/or low carbon fuels:

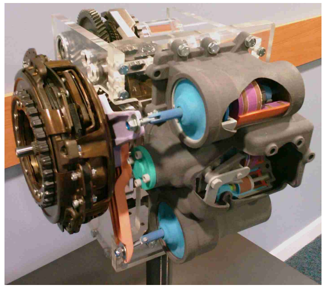


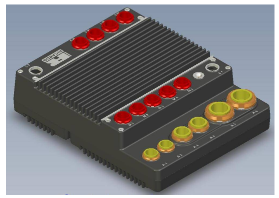
Source: Ricardo analysis

Conventional powertrain technology can continue to offer improved efficiencies for at least the next 20 years -

- **Clean Diesel engines** offer 20%+ fuel economy improvement over a conventional Gasoline; down-sizing via advanced turbocharging technology offers perhaps 10-20% more improvement
- **2nd Generation Gasoline engines** including downsized “flexible” systems will achieve near-Diesel economy at 80% of the unit engine cost
- **Efficient automated transmissions** can offer up to 5% benefit over a Manual, enabling down-sized engines to be more driveable, and are attractive to customers on our more congested roads
- **Advanced control technology** allows the vehicle to operate as an integrated whole, and ultimately be more efficient by knowing what lies ahead -via GPS / map or telematics information
- **Hybrid Powertrains** are the next major step, offering up to 50% reduction on today's city/urban fuel consumption, and providing a stepping stone to Fuel Cell & Plug-in systems if these prove viable
- **Electric Vehicles** could be attractive for city use but will not provide the utility of current vehicles





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Comparison of electric & ICE powered city cars shows that battery cost must be reduced to < £400/kW.hr for EV to be competitive

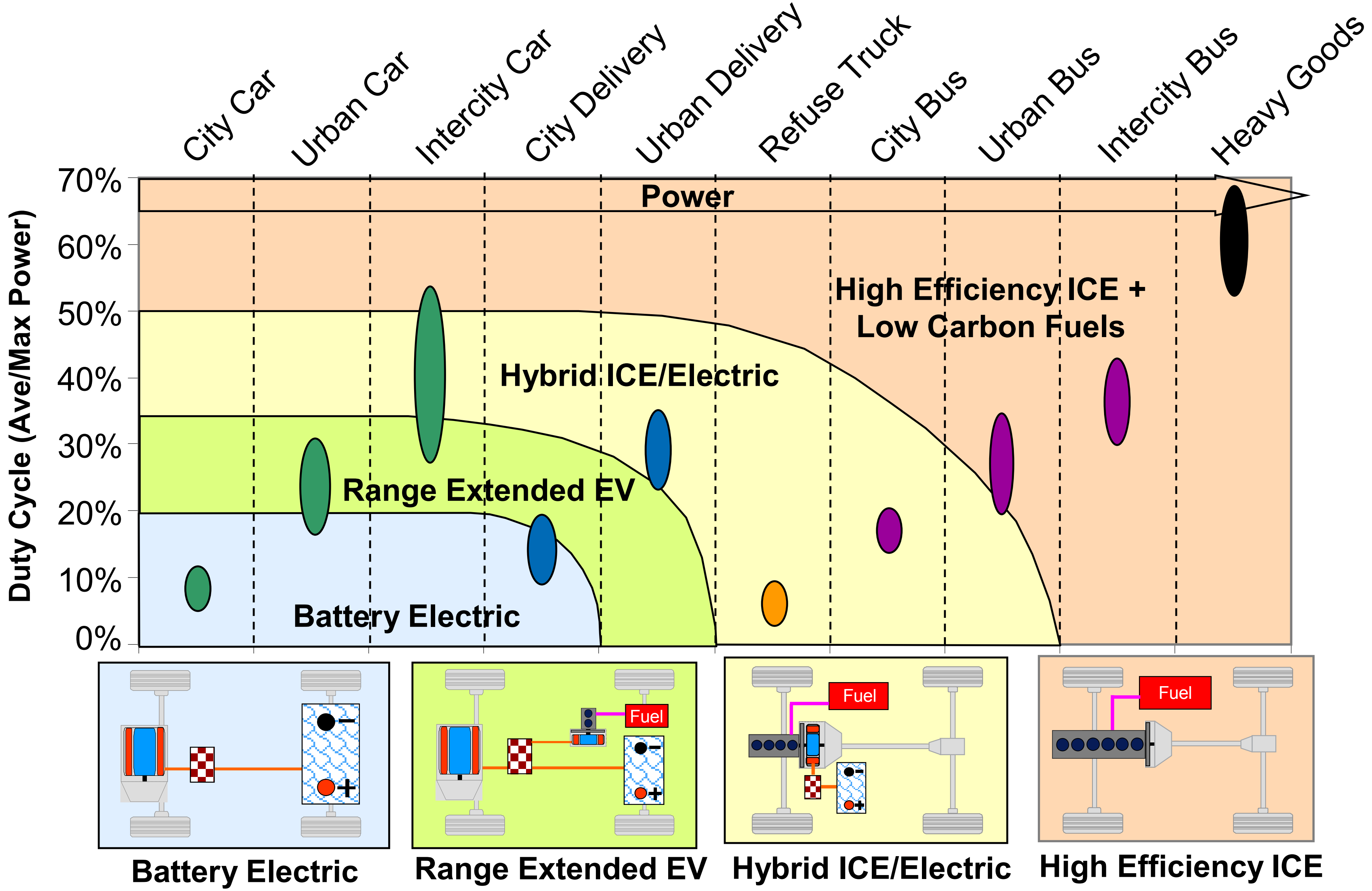
Toyota IQ

Toyota EV

with	Vehicle Price without Battery	Vehicle Range	Annual Mileage	Battery Cost (£)	Annual Fuel Bill (£)	Assumptions:
Typical 1.0 litre City Car	£10k	Unlimited	8,000		550	4.3 litres/100km - Fuel cost £1/litre
City Electric Vehicle (50 kW)	£10k	80 miles	8,000	9600	1100	Li-Ion £800/kW.hr - 10 Year Life

- 50 kW Motor+Power Electronics+Electric HVAC cost ≈ 50 kW Gasoline Engine
- Assumes that battery and electricity use is paid via “lease” package – battery remains property of vehicle manufacturer or supplier
  - Low cost electricity tariff available for EV charging
- Battery cost must be reduced to ~ £400/kW.hr for City EV to be Competitive
  - Possible in time but price requires interim subsidy
- Plug-in Hybrid could be more cost competitive as it minimises size of battery…

Powertrain configuration will be a function of application & power – EV dominates city – ICE for heavy duty & highway

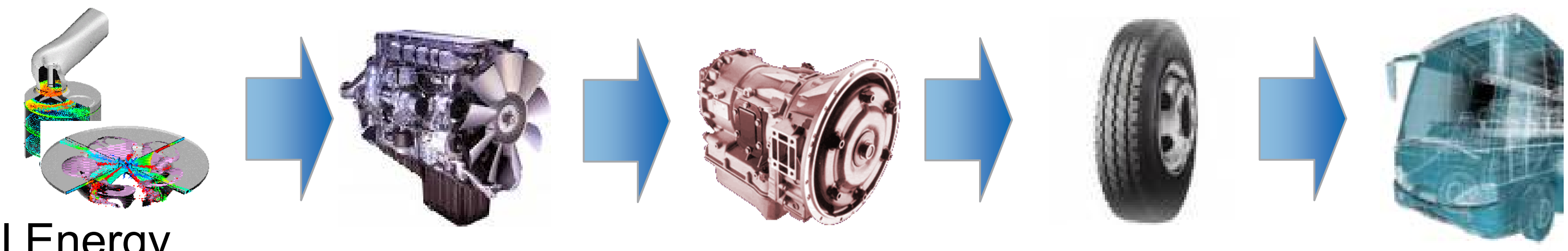


Typical energy flow losses for a Heavy Duty vehicle at 100 km/h show opportunities to improve engine efficiency, ancillaries, transmission, aerodynamics and rolling resistance

Analysis of Vehicle Energy Flows (Heavy Duty Example)

- From the total amount of fuel used (at 100km/h), the energy flows are as follows:

Combustion	Ancillaries	Transmission Loss	Roll Resistance	Aero Drag



Fuel Energy Loss

65%	5%	5%	10%	15% (Underbody ~ 1/3)
Exhaust Heat Recovery? Split Cycle?	Electric & Variable Ancillaries?	Automated Manual Transmissions?	Low Resistance & Single Wide Tyres?	Aero Packs? "Teardrop" Trailers Platooning?

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Incremental improvements are the most cost effective route and make sense in context of CO_2 / fuel consumption penalties

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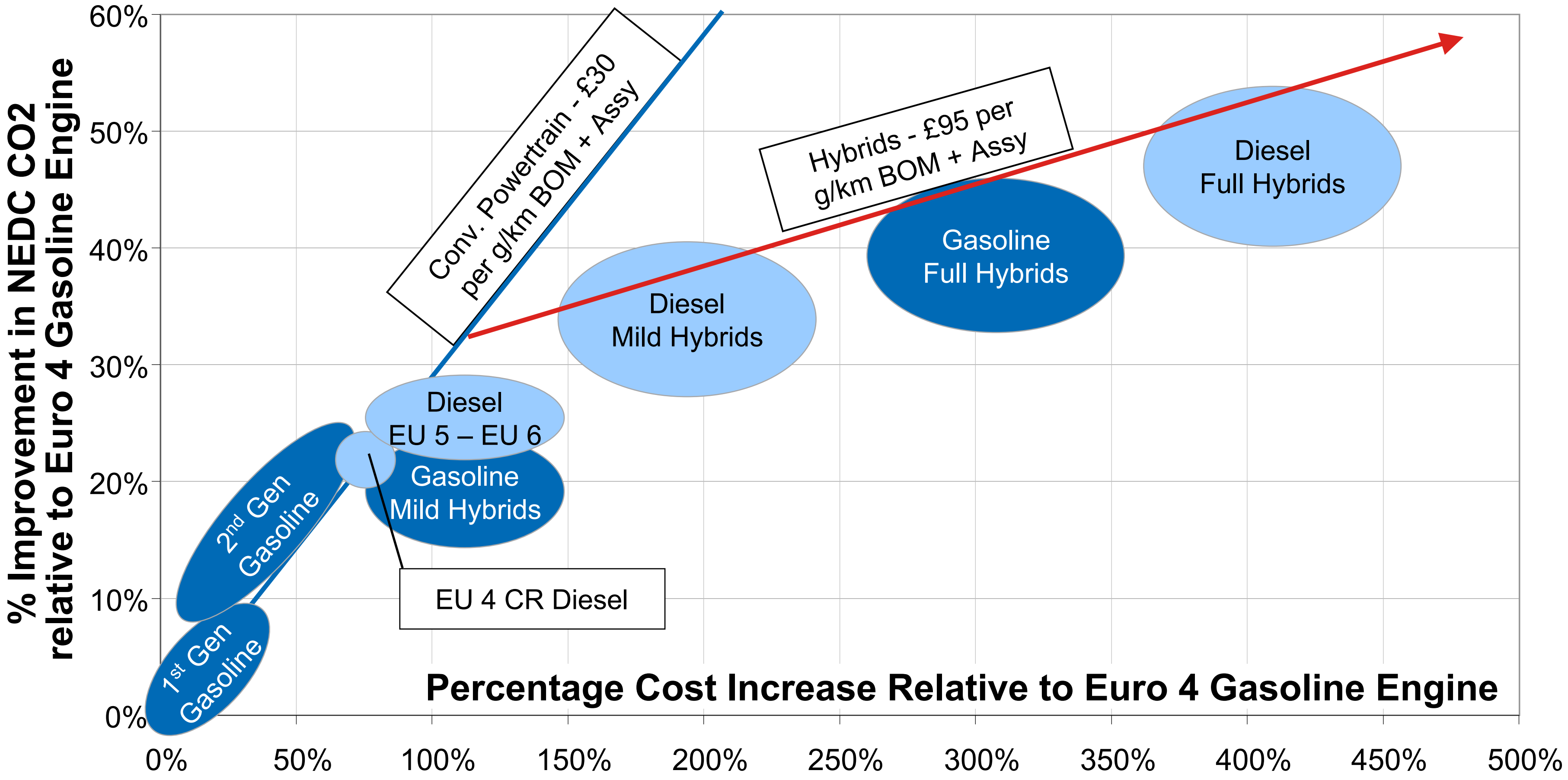
Benchmark Europe Passenger Car: - C02 Cost Benefit for Powertrain Technologies



- Consumers buy vehicles – not powertrains – technologies must also compete on image, utility and lifestyle requirements and deliver fundamentally **Good Cars**

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New initiatives to co-ordinate & focus investment provide real opportunities for UK Investment & Exploitation

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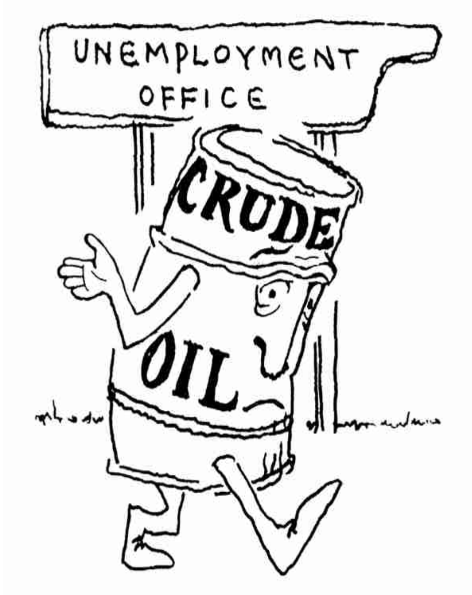
Major Initiatives

- Formation of the new Automotive Council has stimulated UK Auto industry co-operation
- UK Research Council focus on Economic Impact and co-ordination with Technology Strategy Board
- Public Procurement of Low CO_2 Vehicles
- Emerging common consensus on future Automotive Technology roadmap
- The UK automotive supply chain is highly responsive to change with best practice engineering and manufacturing
- UK's leading position in motorsport could be used to stimulate automotive skills development especially in engineering
- The Japanese Auto Manufacturers now operating in the UK have developed much more cohesive supply networks



UK Opportunities

- Next generation Clean Diesel
- Downsized boosted Petrol Engines
- Intelligent Transport Systems
- Next generation Battery Chemistries – "Leapfrog"
- Lightweight Structures/Composites
- Design/Engineering Services
- KERS for road cars

Source: Vision for the UK Automotive Industry in 2020 – B McGinty & S Parker

Innovation in boost systems, energy storage, heat recovery & improved thermal efficiency could bring substantial rewards

Technology/Goal	Opportunity/Target
Flexible capacitive boost systems for downsizing	Need for next generation systems that provide higher boost levels over wider speed range but with instant response
On-board energy storage systems	Batteries/Alternatives: Breakthroughs & short/ medium term research to improve quality, durability and reduce cost
Low cost high performance Motors/power electronics	Need lower cost alternatives to “rare earth” permanent magnet motors and low cost silicon devices for power electronics
Practical exhaust energy recovery/Thermo-electrics	60-90% of fuel energy in IC engine lost to heat! – Major opportunity to improve fuel efficiency – at less than $25/kW
Sustainable lower carbon low cost fuels	2nd/3rd generation fuels with volume production capacity competitive on cost with current fuels – no conflict with food!
Combustion engines with 60-70% thermal efficiency	Current engines achieve 35-42% - Thermal efficiency is major parameter for long haul truck & city to city driving
Low cost/compact Hydrogen storage	Hydrogen storage is the limiting factor for fuel cell vehicles – Need to reduce cost from $5-10,000 per 5 kg tank to < $1000