FPC2016

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Future Powertrain Demands, Energy Sources & Potential Technologies

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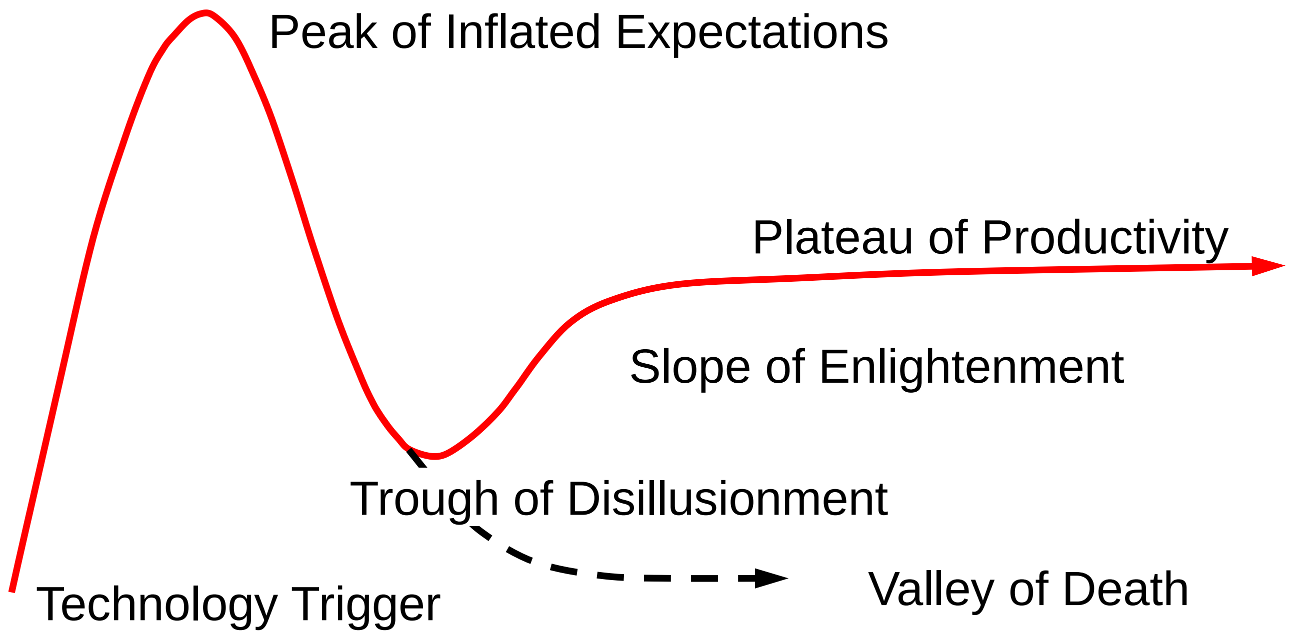
Be wary of jumping from one “favoured” technology to the next – There are no silver bullets

- Technology & “Fashion”

1980	Synthetic Fuels (Oil Crisis)
1985	“Adiabatic” Insulated Engines
1990	Methanol
1995	Electricity (CARB & EV1?)
2000	Hydrogen & Fuel Cells
2005	HCCI & “Alternative” Combustion
2007	Biofuels & Ethanol
2009	Plug-in Hybrids & EV’s
2014	“Driverless” Cars

Gartner Hype Cycle



- Policy makers often look for a “simple” solution that makes good headlines
- Industry sometimes too eager to promote promising “Green” techs for PR

- Where are they now?
  - Biofuels
  - Plug-in Hybrids & EV’s
  - HCCI/Alternative Combustion

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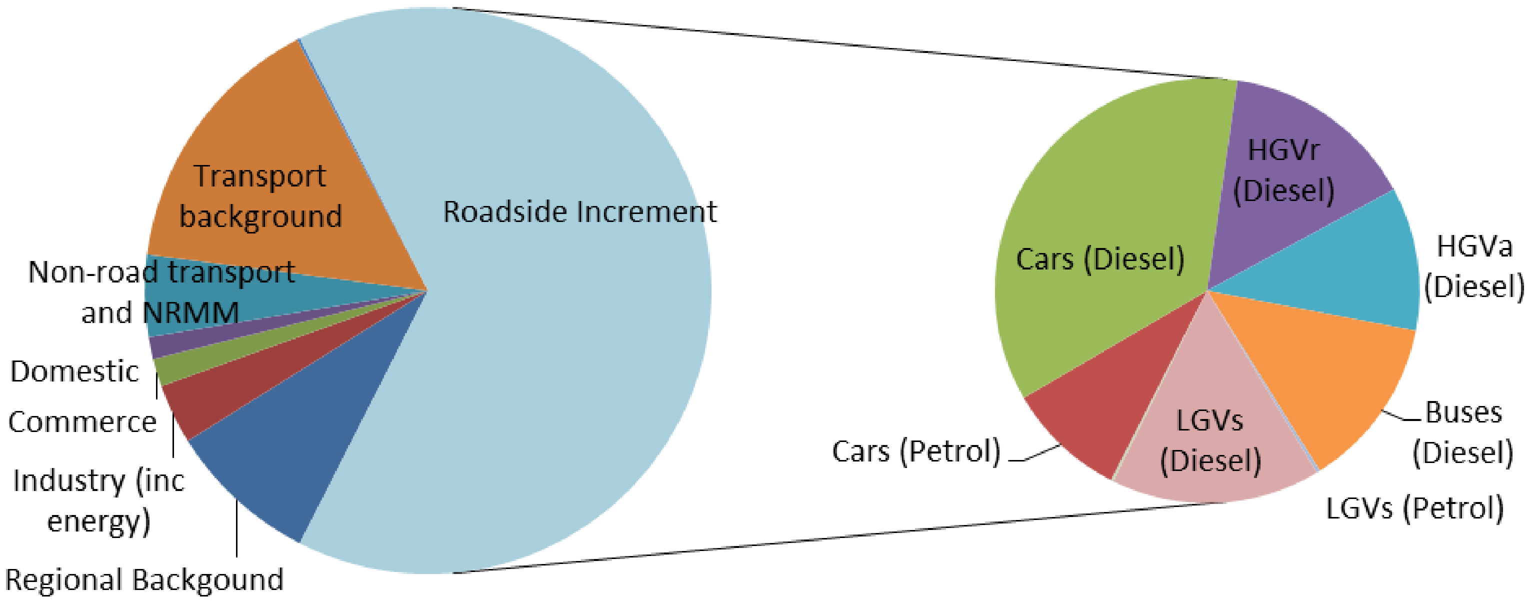
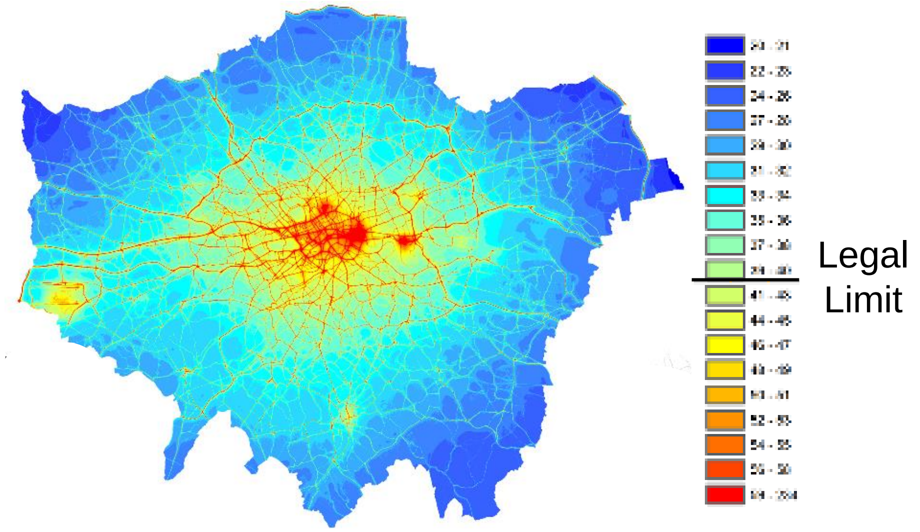
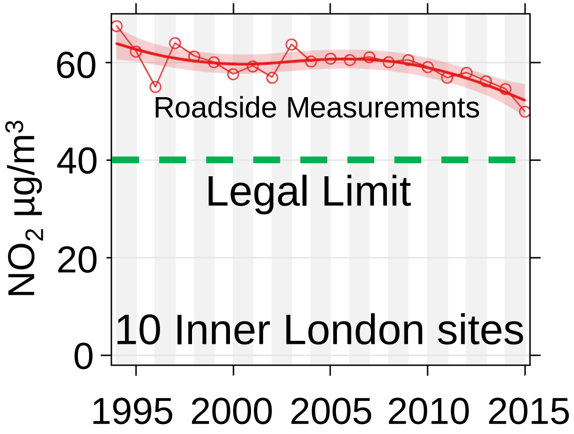
NOx emissions in cities and human exposure at roadside are dominated by road transport





Areas exceeding NO_2 limit



- **"Real World" Diesel NOx** has not reduced in line with drive cycle regulations
- In the EU, road transport emissions account for 64% of **NO_2 concentrations**
- Inner London has higher primary NO_2 emissions
  - More diesels (buses and taxis)
  - Transport for London buses (~6,000 CRT retrofits = high emissions of NO_2)

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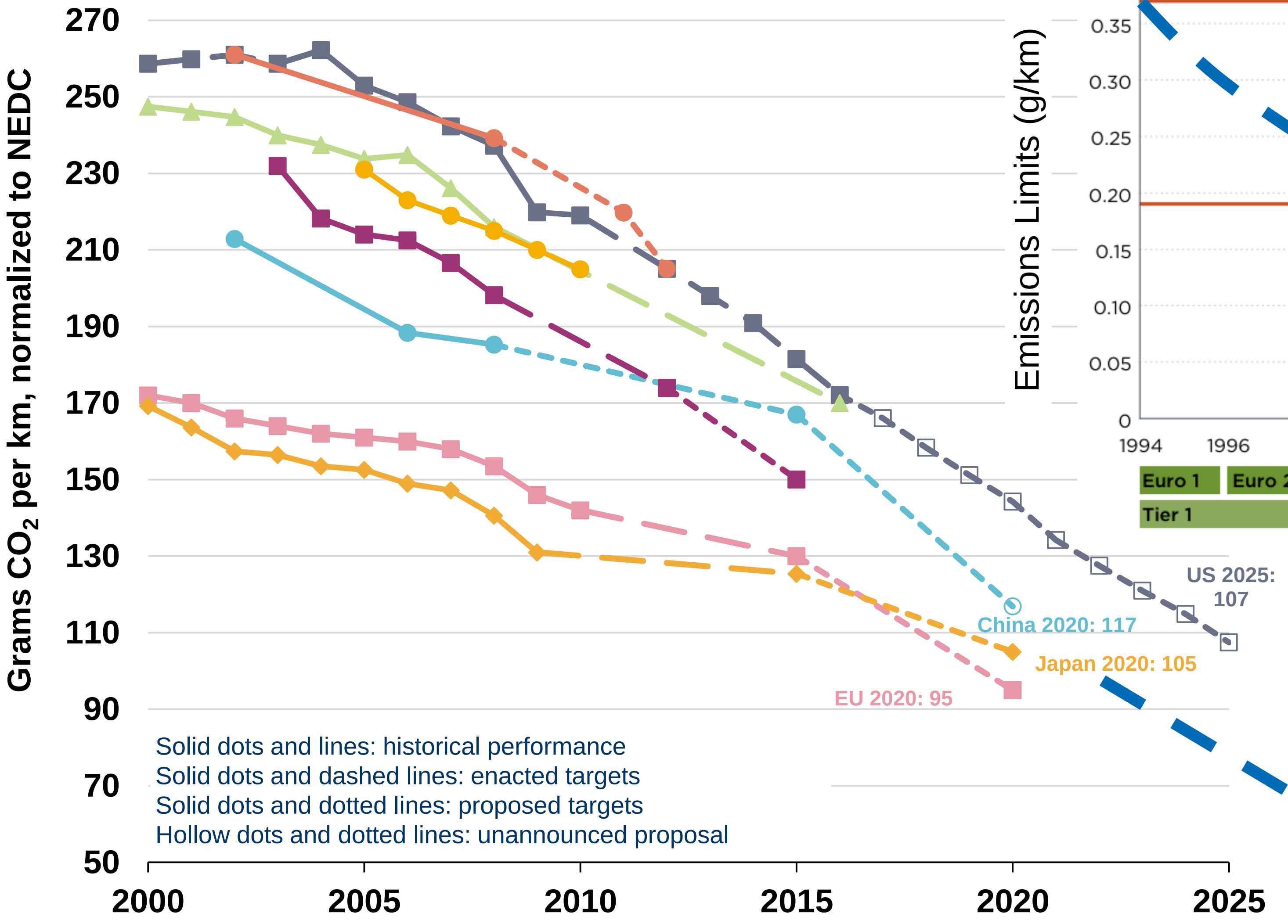
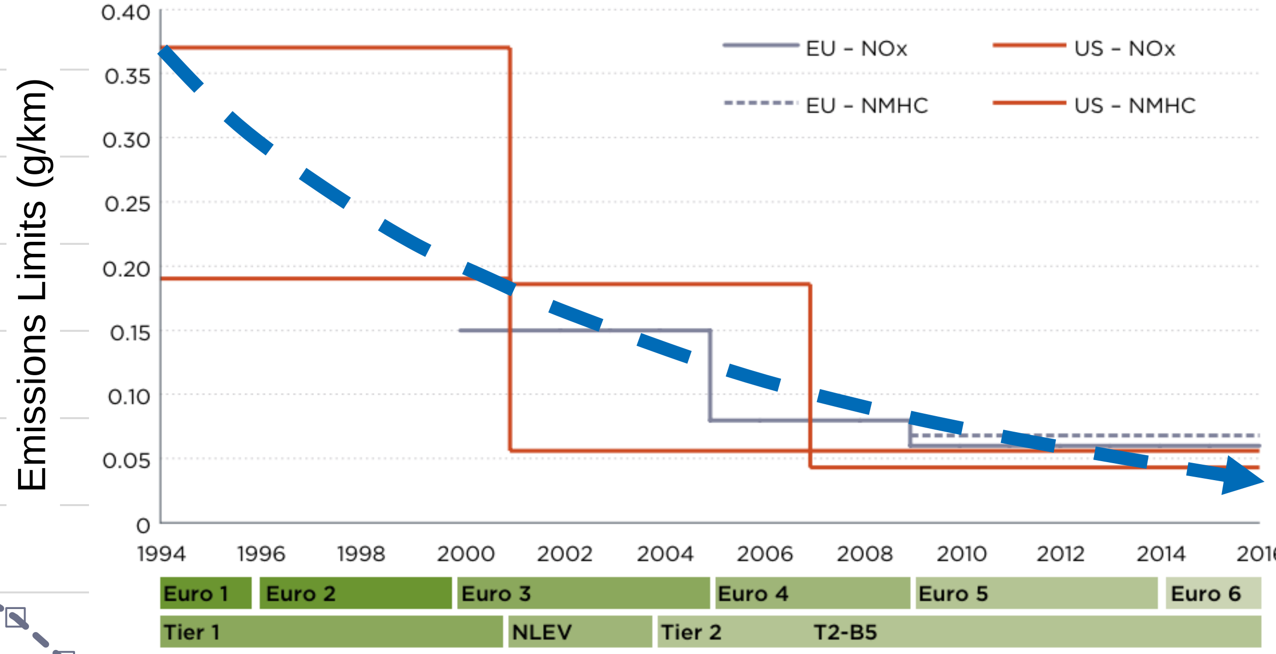
Legislative drivers demand ever lower CO_2 emissions and with zero air quality impact – Regulatory diversity increasingly challenging





- Regulatory diversity introduces significant engineering costs
- Efforts to introduce a harmonised cycle only partially successful

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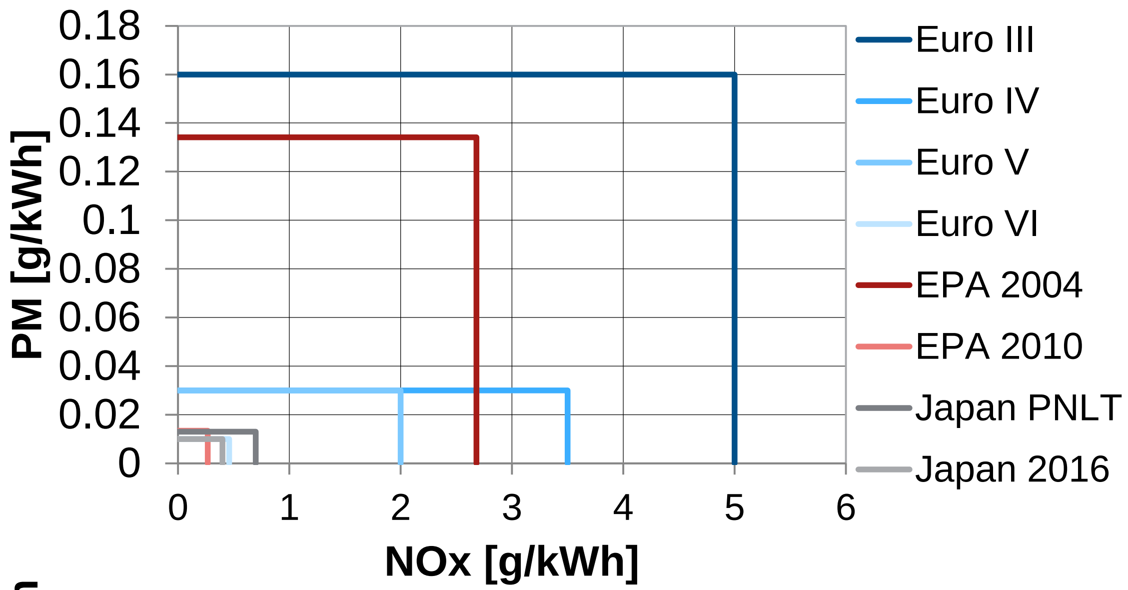
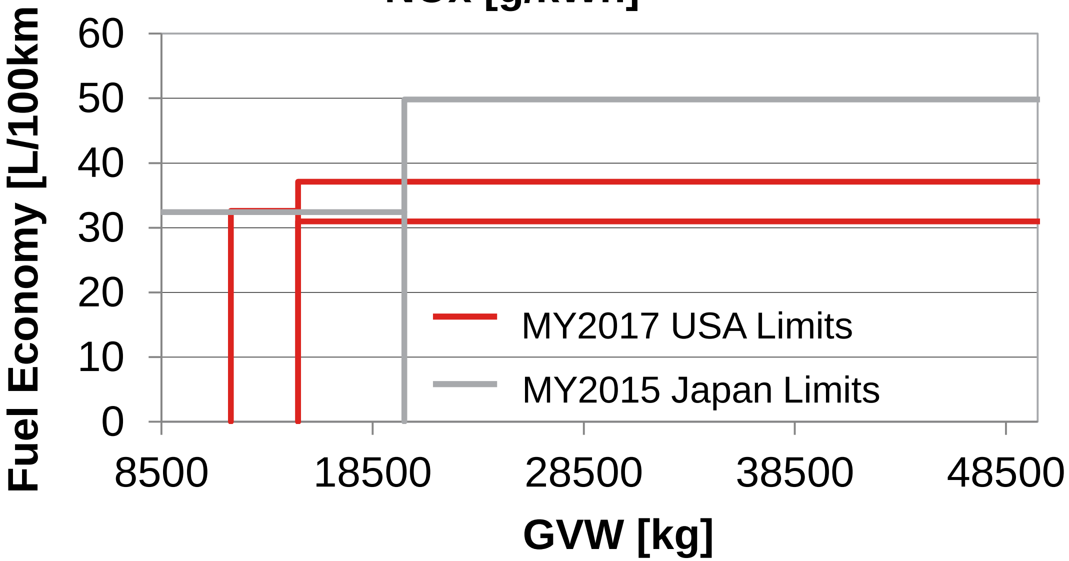
Heavy Duty Global emissions procedures and limits have shown increasing harmonisation, benefitting both OEMs and global emissions regulators





- EU has adopted the new World Harmonised Steady State Cycle (WHSC) and World Harmonised Transient Cycle (WHTC) in Euro VI (2014)
- Japan will adopt WHTC from 2016
- Regulatory harmonisation welcomed by HDV OEM's
  - reduces homologation costs
  - resources re-directed to emissions reduction

- Variations in HD fuel economy regulations reflect differing vehicle regulations and use in each market
- General trend towards combined component testing and vehicle simulation to predict fuel efficiency and CO_2 for a range of variants and duty cycles
  - More practical solution than requiring all HDV variants to tested on heavy duty chassis dyno

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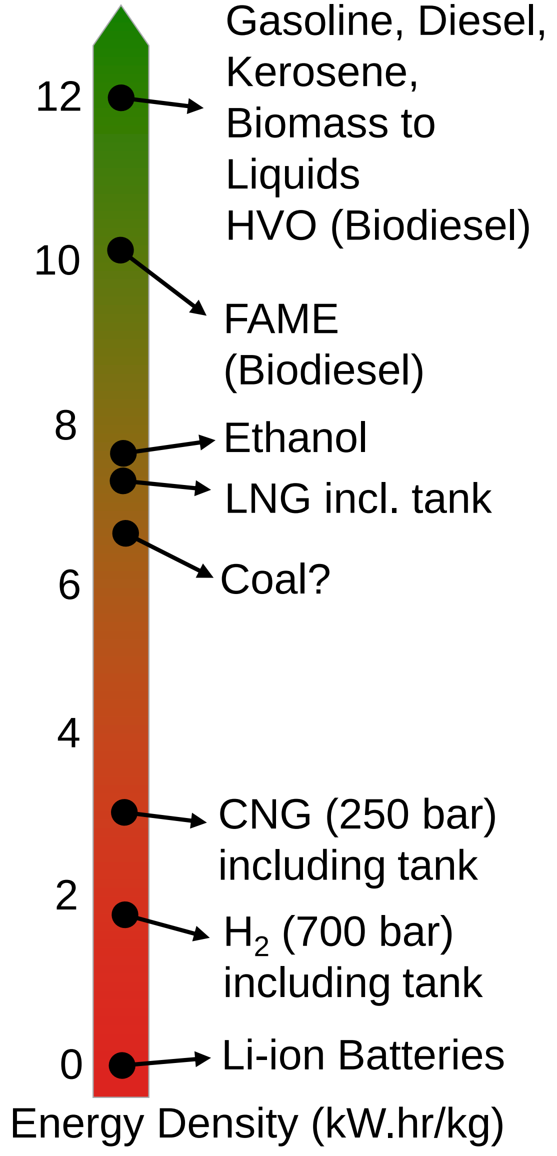
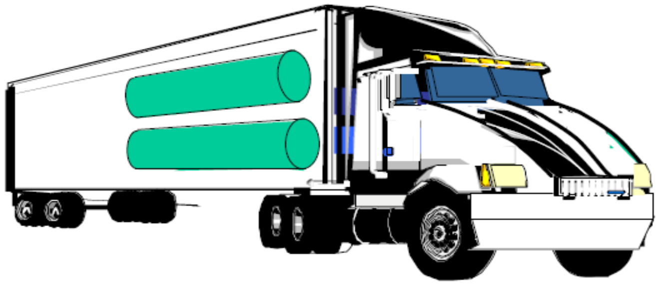
Long haul / heavy duty applications will require low carbon liquid fuels – light duty applications more suited to batteries





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

1000 mile range compressed H_2 Fuel Tank would require 3000 litre tank weighing ~ 3 tons*

Long Distance/Heavy Duty — **Short Distance/Light Duty**

Low Carbon Liquid Fuels	Liquid 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*

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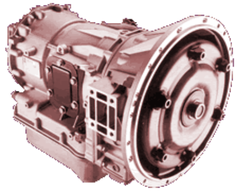
Heavy duty/high power applications offer opportunities for a range of efficiency enhancements

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

Source: Ricardo analysis

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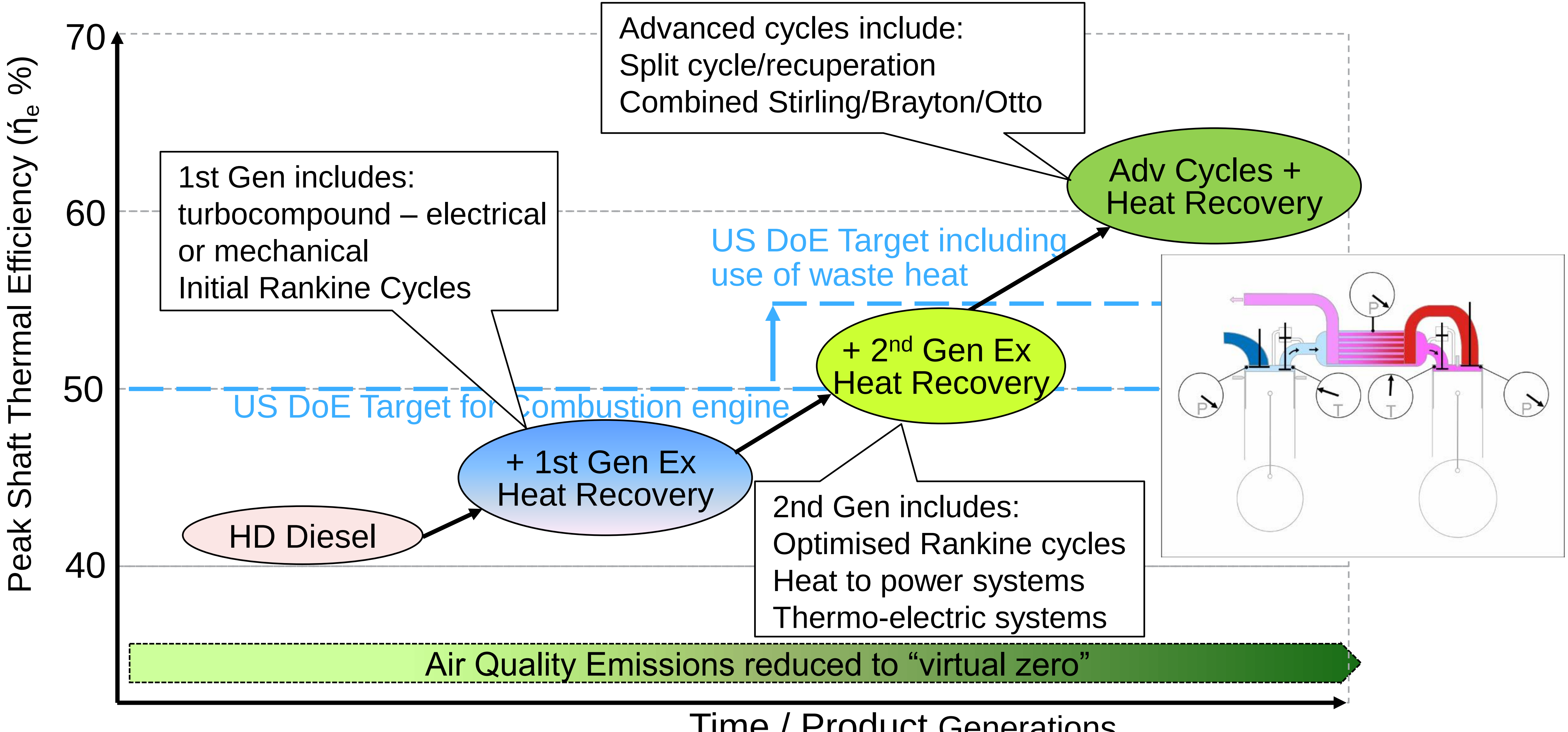
ICE Thermal Efficiency has considerable scope to improve & could reach over 60% in future products



Source: Ricardo Analysis

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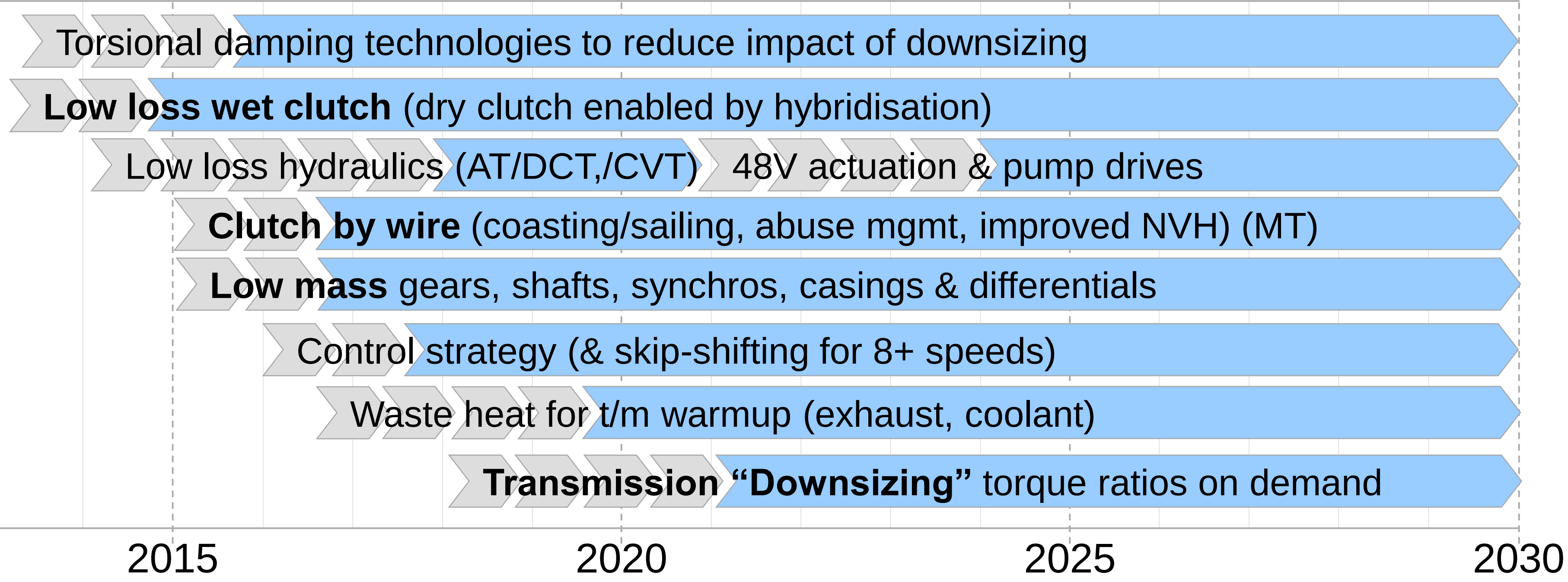
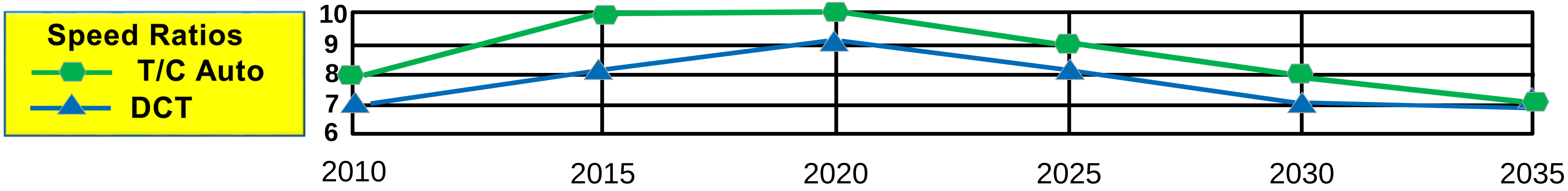
Wide range of transmission technologies in development to reduce losses/improve function – Number of ratios may reduce

Transmission Technologies & Systems



- Future engine technologies will deliver more efficient operation over wider speed & load range – fewer speed ratios required for efficiency
  - Opportunity for torque ratios & speed ratios?



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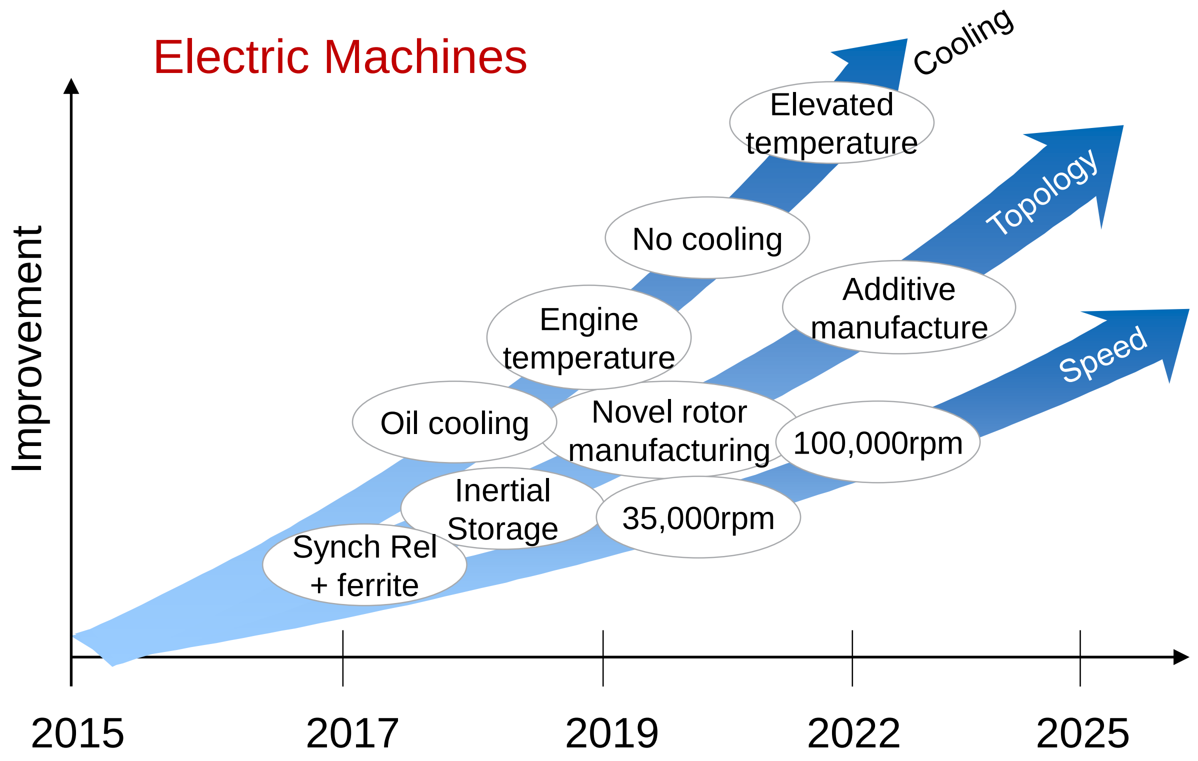
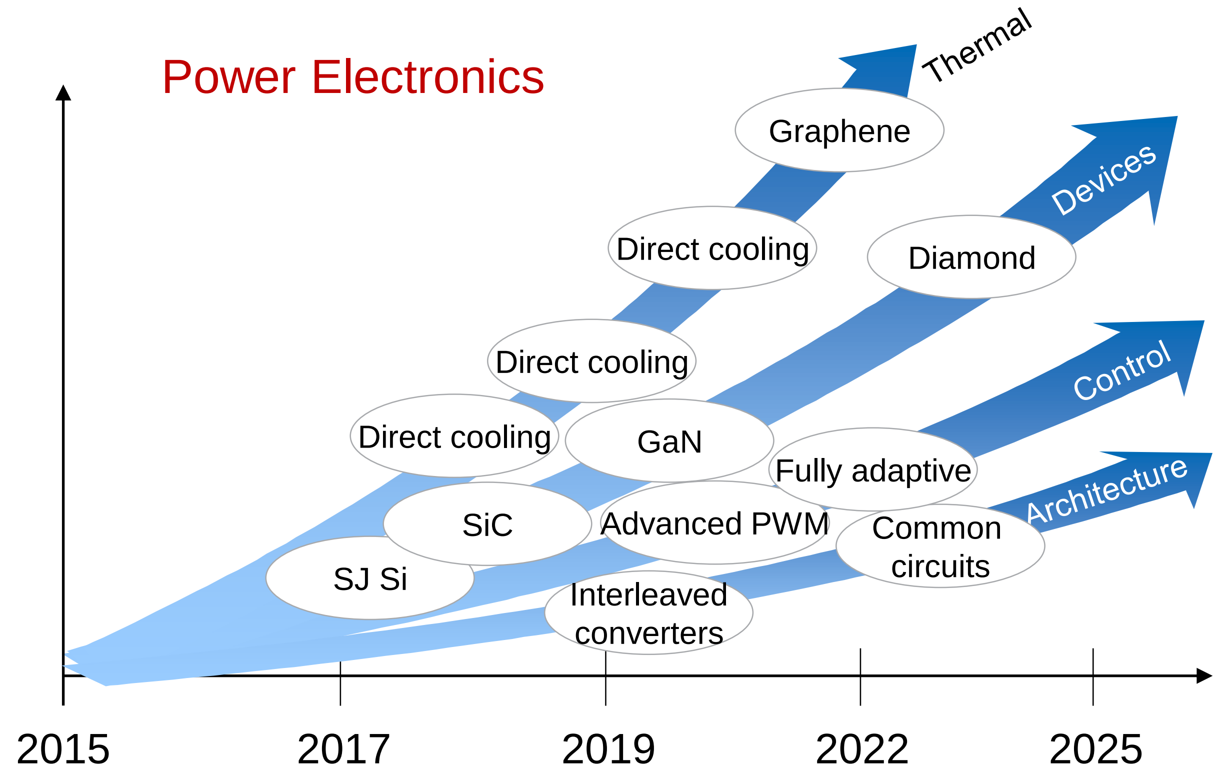
Potential for new technologies & future capabilities applied to both e-Machines and Power Electronics to improve efficiency & reduce costs





- Increasing speed provides power density benefits
- Use of the electric machine as an inertial store can improve system efficiency and reduce peak demand
- Elimination of rare-earth components reduces cost

- Wide band-gap devices significantly improve efficiency
- Advanced direct cooling systems in the short term & high temperature operation in the longer term
- Ultra high efficiency hardware and control designs

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The combination of downsizing, boosting and low voltage electrification can deliver significant economy benefits

- 35% Engine Downsizing **+14%**
- +12+xV Micro Hybrid **+10%**
- +Revised Gearing **+5%**
- +Re-matched Turbo **+2%**

HyBoost “Intelligent Electrification”
12+xV e-boost Micro Hybrid ~95 g/km CO_2

- 25% Engine Downsizing **+15%**
- +48V Micro Hybrid **+10%**
- +48V Ancillaries **+5%**
- +Advanced Thermal/Oil Systems **+3%**
- +e-Turbine Energy Recovery (credit) **+3%**

ADEPT Advanced 48V Diesel Electric Powertrain ~ 70-75 g/km CO_2

- Key short to medium term fuel efficiency improvements via downsizing and varying degrees of electrification
- Important to identify and combine complimentary systems

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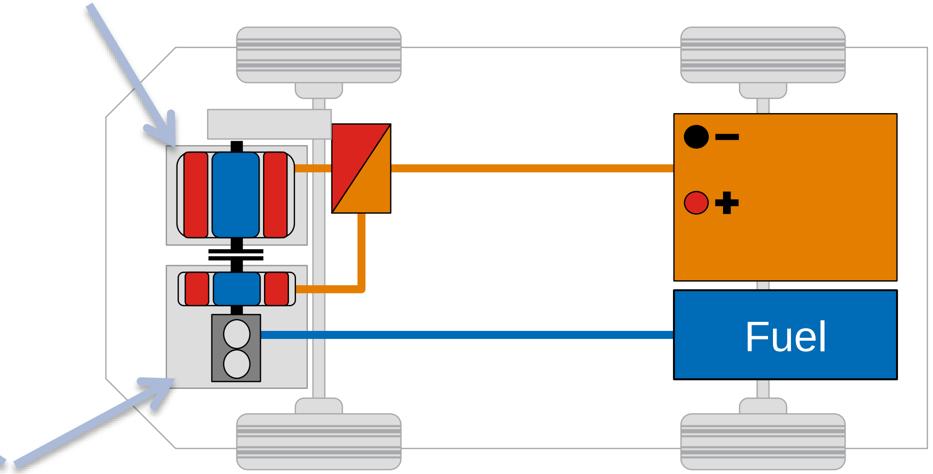
"Ultimate" PHEV where IC engine provides "average" road load power – would substantially change base engine requirements & Attributes

Increasing degree of vehicle electrification

Micro Hybrid → Mild Hybrid → Full Hybrid → Plug –in Hybrid → Range Extended EV? → Pure EV

- Unless there is a breakthrough in Biofuel availability/economics, the Gasoline/Plug-in Hybrid likely to be a primary route to higher performance/heavier vehicles
- Example: Series/parallel hybrid system based on Twin Air (875cc) engine & Ricardo generator & transmission
  - (Engine provides "average" road load power) – Engine connects directly to driveline when appropriate

Traction Motor



2 Cyl Engine

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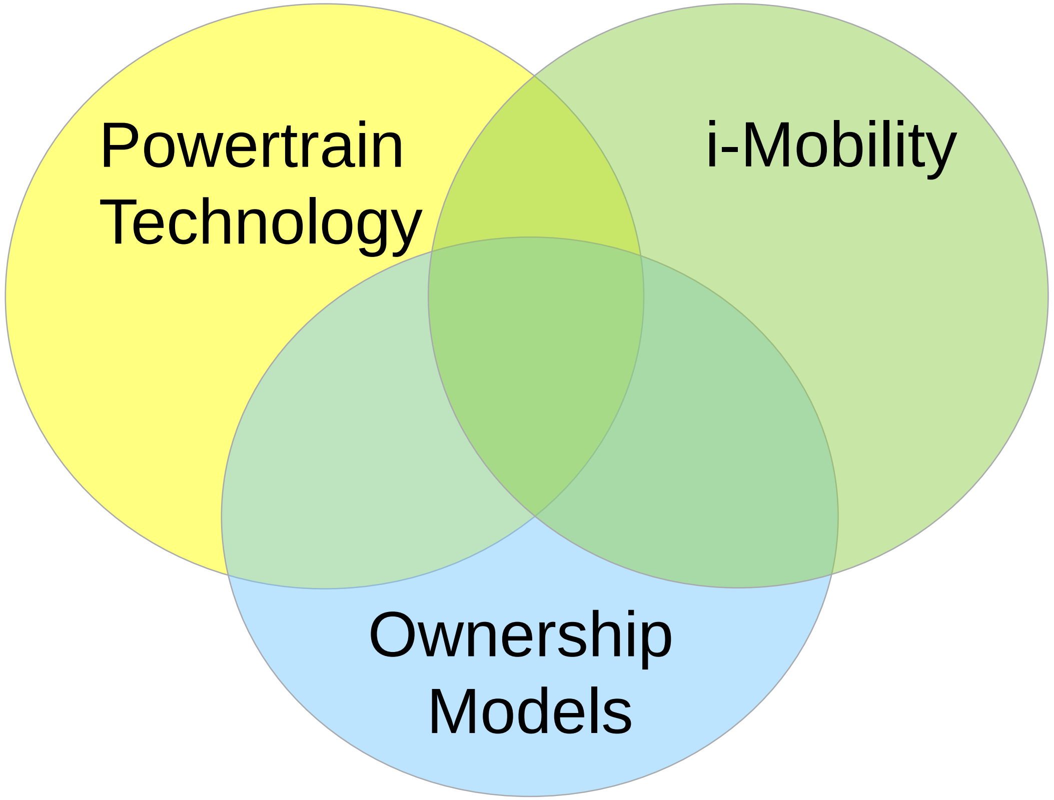
Future Powertrain choices may well be more dependent on new Ownership/Business models than technology developments



- Current ownership models require powertrains with very broad utility
- Expansion in i-Mobility technologies will increase “on-demand” services:
  - Significant impact on traditional ownership models
- Increased use of “on demand” vehicles enables more dedicated utility:
  - Electric Vehicles for inner city use
  - Plug-in for urban mobility
  - Advanced ICE/Low GHG fuels for intercity
- Change in business/ownership models may have more impact on future powertrain diversity than technology advances

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