Future Powertrain Demands, Energy Sources & Potential Technologies

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Contents

● The Great Divide: Policy Makers & Engineers

● Environmental Challenges & Responsibilities

● Future Energy Vectors for Propulsion Systems

● Technology Options – Heavy & Light Duty

● Impacts from i-Mobility
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

- 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

- “Real World” Diesel NOx has not reduced in line with drive cycle regulations
- In the EU, road transport emissions account for 64% of NO2 concentrations
- Inner London has higher primary NO2 emissions
  - More diesels (buses and taxis)
  - Transport for London buses (~6,000 CRT retrofits = high emissions of NO2)
Legislative drivers demand ever lower CO₂ 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
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 CO₂ 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 H₂ Fuel Tank would require 3000 litre tank weighing ~ 3 tons*

Energy Density (kW.hr/kg)
0
2
4
6
8
10
12

Long Distance/Heavy Duty
Low Carbon Liquid Fuels
CNG (250 bar) including tank
H₂ (700 bar) including tank
FAME (Biodiesel)
Coal?

Short Distance/Light Duty
Battery Electric
EV’s suited to short distance/light duty applications to minimise cost

Technology/Cost & Availability

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

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:

<table>
<thead>
<tr>
<th>Combustion</th>
<th>Ancillaries</th>
<th>Transmission Loss</th>
<th>Roll Resistance</th>
<th>Aero Drag</th>
</tr>
</thead>
</table>

- **Fuel Energy Loss**
  - Exhaust Heat Recovery? Split Cycle?
  - Electric & Variable Ancillaries?
  - Automated Manual Transmissions?
  - Low Resistance & Single Wide Tyres?
  - Aero Packs? “Teardrop” Trailers Platooning?

**Source:** Ricardo analysis
ICE Thermal Efficiency has considerable scope to improve & could reach over 60% in future products

Advanced cycles include:
- Split cycle/recuperation
- Combined Stirling/Brayton/Otto

US DoE Target including use of waste heat

Air Quality Emissions reduced to “virtual zero”

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

- 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?

**Transmission Technologies & Systems**

- Torsional damping technologies to reduce impact of downsizing
- **Low loss wet clutch** (dry clutch enabled by hybridisation)
- Low loss hydraulics (AT/DCT,/CVT) 48V actuation & pump drives
- **Clutch by wire** (coasting/sailing, abuse mgmt, improved NVH) (MT)
- **Low mass** gears, shafts, synchros, casings & differentials
- Control strategy (& skip-shifting for 8+ speeds)
- Waste heat for t/m warmup (exhaust, coolant)
- **Transmission “Downsizing”** torque ratios on demand

**Speed Ratios**

- **T/C Auto**
- **DCT**

<table>
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<th>Year</th>
<th>2010</th>
<th>2015</th>
<th>2020</th>
<th>2025</th>
<th>2030</th>
<th>2035</th>
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</table>
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
The combination of downsizing, boosting and low voltage electrification can deliver significant economy benefits

<table>
<thead>
<tr>
<th>Component</th>
<th>% Improvement</th>
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<tbody>
<tr>
<td>35% Engine Downsizing</td>
<td>+14%</td>
</tr>
<tr>
<td>+12+xV Micro Hybrid</td>
<td>+10%</td>
</tr>
<tr>
<td>+Revised Gearing</td>
<td>+5%</td>
</tr>
<tr>
<td>+Re-matched Turbo</td>
<td>+2%</td>
</tr>
</tbody>
</table>

HyBoost “Intelligent Electrification”
12+xV e-boost Micro Hybrid ~95 g/km CO₂

<table>
<thead>
<tr>
<th>Component</th>
<th>% Improvement</th>
</tr>
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<tbody>
<tr>
<td>25% Engine Downsizing</td>
<td>+15%</td>
</tr>
<tr>
<td>+48V Micro Hybrid</td>
<td>+10%</td>
</tr>
<tr>
<td>+48V Ancillaries</td>
<td>+5%</td>
</tr>
<tr>
<td>+Advanced Thermal/Oil Systems</td>
<td>+3%</td>
</tr>
<tr>
<td>+e-Turbine Energy Recovery (credit)</td>
<td>+3%</td>
</tr>
</tbody>
</table>

ADEPT Advanced 48V Diesel Electric Powertrain ~ 70-75 g/km CO₂

- Key short to medium term fuel efficiency improvements via downsizing and varying degrees of electrification
- Important to identify and combine complimentary systems
“Ultimate” PHEV where IC engine provides “average” road load power – would substantially change base engine requirements & Attributes

- 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

Increasing degree of vehicle electrification

- Micro Hybrid
- Mild Hybrid
- Full Hybrid
- Plug-in Hybrid
- Range
- Extended EV?
- Pure EV

Traction Motor

Fuel

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