Long term trends in vehicle development
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Providing technology, product innovation, engineering solutions and strategic consulting to the world’s automotive industries since 1915.

Today

Ricardo is a global strategic, technical and environmental consultancy and specialist niche manufacturer of high performance products. We also provide independent assurance services in the rail sector.
Agenda

- Long term vehicle trends
- Impact on Lubricants
Agenda

- Long term vehicle trends
- Impact on Lubricants
3 well established drivers of change continue to shape improvements in automotive emissions and fuel efficiency

Major drivers of change

1. Air Quality
2. Climate Change (and Security of Energy Supply)
3. Urbanisation / Demographics

- Tailpipe Pollutant Emission Legislation
- CO₂ and Fuel Economy Legislation, including fuel tax
- Shared Mobility Zero Emission Travel
Regulators around the world continue to tighten regulatory emissions standards for passenger cars

Passenger car noxious emissions legislation - global

<table>
<thead>
<tr>
<th>Year</th>
<th>Regulation</th>
<th>Country</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td>Euro 4</td>
<td>Europe</td>
<td>Implemented</td>
</tr>
<tr>
<td></td>
<td>Euro 5a</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Euro 5b</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2010</td>
<td>Euro 6b</td>
<td></td>
<td>Proposed</td>
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<tr>
<td></td>
<td>Euro 6c</td>
<td></td>
<td>Proposed</td>
</tr>
<tr>
<td></td>
<td>Euro 6d - TEMP</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>LEV II (2004 – 2010 phase-in)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2020</td>
<td>Tier 3</td>
<td></td>
<td>Proposed</td>
</tr>
<tr>
<td></td>
<td>LEV III</td>
<td></td>
<td>Proposed</td>
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<tr>
<td>2025</td>
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</tbody>
</table>

Sources: National government sources, Ricardo Analysis
\( \text{CO}_2 \) and fuel economy regulations are now driving energy efficiency with steep targets of c. 5~6% annual improvement by 2025

- Fuel consumption legislation already in place for major vehicle markets globally
- EU has led global FC regulation for several years with fleet average target set aggressively at 95g/km by 2020
- China has proposed ambitious phase 4 target for 2020 with 117g/km (~5.0L/100km), which will rapidly close the gap with EU
- Tightened fuel emissions legislation is main driver for push into xEVs

India has announced a target of 4.8L/100 km (113 g/km \( \text{CO}_2 \)) for 2025
Also, in the last 4 years there have been powerful and disruptive drivers of change, affecting both regulator and consumer behaviour.

The shift from urban Diesel towards electrification

<table>
<thead>
<tr>
<th>Air pollution in Megacities</th>
<th>Local authorities decide…</th>
<th>Loss of trust in OEMs</th>
</tr>
</thead>
<tbody>
<tr>
<td>“The 21 million inhabitants of China’s capital appear to be engaged in a battle for life on an inhospitable planet…”</td>
<td>“The Mayor of London has pledged to introduce only hybrid or zero-emission double-decker buses to London’s bus fleet from 2018…”</td>
<td>VW agreed with US authorities to pay ~$15bn to settle claims over Diesel pollution tests</td>
</tr>
</tbody>
</table>

Indian govt. has also initiated multiple programs on Electrification & Fuel efficiency monitoring to address the situation

Recent Developments (Govt.) – India Market

<table>
<thead>
<tr>
<th>2011</th>
<th>2012</th>
<th>2013</th>
<th>2014</th>
<th>2015</th>
<th>2017</th>
</tr>
</thead>
<tbody>
<tr>
<td>National Mission on Electric Mobility formulated</td>
<td>National Electric Mobility Mission Plan 2020 (NEMMP) launched</td>
<td>• India becomes member of EVI (Electric Vehicle Initiative) • Make in India campaign launched</td>
<td>FAME scheme was launched to meet NEMMP goals</td>
<td>Implementation of CAFÉ Norms 2017<del>22: 130 g/km 2022</del>25: 113 g/km</td>
<td></td>
</tr>
</tbody>
</table>

Pollution Situation

- Fine Particulate Matter (PM) Comparison
  - New Delhi: 128 microgm/cu. mtr.
  - Beijing: 81 microgm/cu. mtr.
  - WHO Target: 10 microgm/cu. mtr.
- 13 of top 20 cities in the world with highest annual levels of PM 2.5 are in India
- Contribution of transport sector to air pollution in India – 20%

Recent Activities / Developments

- Paris convention pledge – India to cut GHG emissions intensity by 33% based on 2005 levels by 2030
- CAFÉ Standards roadmap declaration & implementation
- Vehicle ageing – NGT intervention on end of life, with 10 years old diesel vehicle to be taken off road. Other states also identified.
- Prototype testing – DHI in collaboration with various states launched testing of Hybrid & Electric Buses

NEMMP: National Electric Mobility Mission Plan 2020; FAME: Faster Adoption & Manufacturing of Electric Vehicle
Source: Ricardo analysis, Public domain
Automotive industry approach towards Carbon footprint & Fuel efficiency improvement

Automotive Industry – Carbon Reduction Framework

**Doing same things better**

Return

Upgraded activity

Current activity

Time

**Vehicle Technology Improvement – Whole Vehicle**

- OEMs are responding by look across the whole vehicle for solutions to deliver affordable, low carbon transport

**Doing newer things**

Return

New activity

Current activity

Time

**Electrification & Energy Storage – Powertrain / Engine**

- Electrification is a key pillar of OEMs’ fuel economy strategies, employing the full spectrum of electrification as costs fall
OEMs are responding by look across the whole vehicle for solutions to deliver affordable, low carbon transport.

There is no silver bullet. We will need a range of technologies.
In powertrain, OEMs are adopting a range of approaches to meet the medium term CO₂ and noxious emissions targets

**Powertrain medium-term approaches to CO₂ reduction**

- Reduced Combustion Heat Losses
- Exhaust Energy Recovery
  - Adv. Regen or Split Cycle
- Improved Boost Efficiency/ Operating Range
- Downsizing & Boosting
- Electrification & Energy Recovery
- Lower Friction & Auxiliary Losses
- Flexible/Fast Response Boost
- Gasoline Particulate Filter
- Shift from Diesel to gasoline
- 2nd Gen Biofuels (Waste Re-use)
- Charge Thermal Management
- Flexible Valve Trains

Source: Daimler, Lastauto Omnibus, Ricardo analysis
Electrification is a key pillar of OEMs’ fuel economy strategies, employing the full spectrum of electrification as costs fall.

### Electrification Landscape – Light Duty

<table>
<thead>
<tr>
<th>Hybrid Type</th>
<th>Hybrids</th>
<th>Electrical Vehicle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Micro Hybrid</td>
<td>Citroen C4 e-HDI</td>
<td>Toyota Prius</td>
</tr>
<tr>
<td>Mild Hybrid</td>
<td>Audi SQ7 TDI</td>
<td>BYD F3DM</td>
</tr>
<tr>
<td>Full Hybrid</td>
<td></td>
<td>BMW i3</td>
</tr>
<tr>
<td>Plug-in Hybrid</td>
<td></td>
<td>Nissan Leaf</td>
</tr>
<tr>
<td>Range Extended EV</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pure EV</td>
<td></td>
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</tr>
</tbody>
</table>

**Increasing electric power and energy storage >>>

<table>
<thead>
<tr>
<th>Fuel savings*</th>
<th>3-10% but up to 20% in heavy traffic</th>
<th>8-20% but up to 30% in heavy traffic</th>
<th>20-35% but 50%+ if downsizing applied</th>
<th>30-50% but slightly worse at high speed cruise</th>
<th>50-70% significantly worse at high cruise speed</th>
<th>100% since all electric</th>
</tr>
</thead>
</table>

* tank to wheels percentage improvement

**Increasing cost >>>

Source: Ricardo research
OEMs are progressively introducing mild hybrids; 48V technology is emerging as one of today’s most cost-effective solutions.

- **Engine Stop / Start**
  - **Basic micro-hybrid (12-24V)**
  - **48V micro/mild hybrid**
  - **48V Ancillaries**

- **Energy Storage**
  - Lead Acid (Absorbent Glass Mat)
  - Advanced Lead Acid (Bipolar, Spiral wound) or + Supercapacitor
  - NiMH
  - Li-Ion

- **Passenger car improvements over NEDC**
  - **3-4% CO₂**
  - **4-10% CO₂**
  - **10-15% CO₂**
  - **15-20% CO₂**

**Source:** Ricardo analysis
By 2030, we may be heading towards a three pronged powertrain world with little room for non-electrified ICE or traditional hybrids

Powertrain paths – developed markets

Today

Internal Combustion Engine

2030

- Optimised ICE, mainly gasoline
- Hybridisation, e.g. 48V, or higher voltage without plug-in capability
- CO2 neutral fuels?
- <50g CO2, >50km pure electric range
- Transitional technology until BEV have achieved attractive range and cost?
- >400 km range, battery system cost <$150/kWh
- Public / semi-public charging infrastructure in place

BEV

PHEV

Internal Combustion Engine – mild / non-plug-in hybrid

(high cost – absolute and per gram of CO₂ reduction)

Source: Ricardo analysis

Automotive Industry – Market Outlook
Mainstream forecasts show that 97% of light vehicles made in 2025 will still have a combustion engine; BEVs command only 3% share.

Global light vehicle production forecast

Source: Ricardo, IHS Autoinsight (Sep. 16)
Slight penetration of micro hybrids & increasing AMT adoption by 2025; degree of electrification depends on govt’s participation

PV production (millions)

Propulsion Type (millions) – ICE Mainstream

<table>
<thead>
<tr>
<th>Year</th>
<th>BEV</th>
<th>Hybrid - Micro/mild</th>
<th>Hybrid - Full</th>
<th>ICE</th>
</tr>
</thead>
<tbody>
<tr>
<td>2015</td>
<td>3.4</td>
<td>0.2</td>
<td>3.2</td>
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<tr>
<td>2016</td>
<td>3.5</td>
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<td>2017</td>
<td>3.8</td>
<td>0.3</td>
<td>3.5</td>
<td></td>
</tr>
<tr>
<td>2018</td>
<td>4.1</td>
<td>0.3</td>
<td>3.8</td>
<td></td>
</tr>
<tr>
<td>2019</td>
<td>4.4</td>
<td>0.4</td>
<td>4.0</td>
<td></td>
</tr>
<tr>
<td>2020</td>
<td>4.6</td>
<td>0.4</td>
<td>4.2</td>
<td></td>
</tr>
<tr>
<td>2025</td>
<td></td>
<td></td>
<td>6.5</td>
<td>0.6</td>
</tr>
</tbody>
</table>

Transmission Type (millions) – MT Mainstream

<table>
<thead>
<tr>
<th>Year</th>
<th>Reduction</th>
<th>Automatic</th>
<th>AMT</th>
<th>DCT</th>
<th>CVT</th>
<th>Manual</th>
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</thead>
<tbody>
<tr>
<td>2015</td>
<td>3.4</td>
<td>0.1</td>
<td>0.1</td>
<td>3.2</td>
<td>3.2</td>
<td>0.0</td>
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<tr>
<td>2016</td>
<td>3.5</td>
<td>0.0</td>
<td>0.2</td>
<td>3.2</td>
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<td>0.0</td>
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<tr>
<td>2017</td>
<td>3.8</td>
<td>0.1</td>
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<td>2018</td>
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<td>0.1</td>
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<td>3.6</td>
<td>3.6</td>
<td>0.0</td>
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<tr>
<td>2019</td>
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<td>0.1</td>
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<td>3.9</td>
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<td>2020</td>
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<td>0.1</td>
<td>0.1</td>
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<td>0.0</td>
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<tr>
<td>2025</td>
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<td>6.5</td>
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</tbody>
</table>

Source: IHS, Ricardo analysis

Market Trends – India – Market analysis

LV – 0-3.5 T GVW

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Agenda

- Long term vehicle trends

- Impact on Lubricants
Multiple changes in vehicle technology will impact the usage volumes & product characteristics of lubricants

Drivers – Lubricants impact

Direct Drivers – ENGINE
- Engine Downsizing
- Friction reduction
- Engine downspeeding

In-direct Drivers –
- After-treatment
- Combustion Technology
- Alternate Fuels / BioFuels
Despite engine downsizing, lubricant volumes are likely to be maintained in order to support higher performance targets

Automotive Lubricants

- Historically, there has been a good correlation between engine displacement and lubricant volume

- In order to improve fuel economy without a loss of performance, engines are downsizing, while maintaining or increasing output

- Meanwhile, to reduce internal friction under a broader range of operating conditions, oil viscosity is reducing, with higher viscosity index

- The lubricant has to protect components and at the same time survive much higher levels of thermal loading, with a service interval that is maintained or even extended

- Given these demands, OEMs are tending to maintain lubricant volume despite the smaller engine displacements
Downsizing, friction reduction and downspeeding will be common to all engines and have important implications for lubricants.

**Downsizing**
- Reducing engine size, keeping the same power by increased turbocharging
- Impact on lubricants:
  - Higher cylinder pressure and more blow-by
  - Increased oil temperature lead to higher oxidation
  - Higher bearing loads

**Friction reduction**
- A number of friction reduction technologies might affect lubricants:
  - Lower oil viscosity
  - Coatings
  - Roller bearings
  - Increased sump temperatures and oil warm up rate
  - Wet belt drives

**Downspeeding**
- Reducing the speed necessary to achieve a determined torque target
- Impact on lubricants via increased bearing loads at lower speeds:
  - Low speed, high pressure can lead to oil being squeezed out of bearings
  - Lubrication of crank bearings challenging

Source: Ricardo, Mercedes Benz
Latest aftertreatment and combustion technology developments, plus adoption of biofuels, will also create challenges for lubricants.

**Lubricant implications**

### Aftertreatment
- Specific particulate filter regeneration mode issues:
  - Increased fuel-in-oil dilution
  - Metal catalyst sensitivity to lubricant additives (e.g. P, Zn, S)
  - Ash from combusted oil could be trapped in the DPF and GPF...
  - ... impacting soot storage and filter regeneration

### Combustion
- Widespread adoption of direct injection with higher specific power can lead to:
  - Increased soot in oil contamination for gasoline engines
  - Increased fuel-in-oil dilution
  - Risk of auto-ignition or Low Speed Pre-Ignition (LSPI) with gasoline

### Biofuels
- Ethanol's inherent acidity can impact seal integrity
- Ethanol's polarity can affect the solubility of the additive pack
- Any fuel-in-oil dilution can affect lubricant viscosity and other properties

Source: Ricardo
Hybrid powertrains do not appear to pose new challenges for the lubricant; BEVs do not pose an imminent threat for lubricant suppliers.

Hybridisation and electrification – impact on engine lubricants

- There appear to be minimal differences between engine oil volumes needed for conventional and hybridised powertrains used in similar vehicles.

- Water-in-oil contamination is a potential issue for plug-in hybrids, though perhaps no more so than for some existing real world drive cycles.

- Given the low penetration of BEV expected over the next 10 years, they are not an imminent threat for the engine or transmission lubricants industry.

Source: Ricardo, BMW, Volvo
Hybridisation requires automated transmissions with lubricants that enable low friction, high torque density and electrical compatibility

Hybridisation and electrification – impact on transmission lubricants

- Hybrid vehicles must safely manage torque from multiple sources, so require automated transmissions, not a manual gearbox
- High dielectric strength, retaining excellent viscosity properties
- The number of transmission ratios is peaking, as engines become more flexible

| AT (Automatic) | More gears, higher power density
|               | Lubricants to reduce torque convertor & actuation losses, and to prevent fatigue |
| DCT (Dual Clutch) | Fluids to deliver high torque transfer & controlled clutch friction
|                   | Wet clutch performance combined with manual transmission performance
|                   | Lubricants to work with submerged electronics and seal materials |
| CVT (Continuous) | Lower viscosity, better electronics compatibility and improved air release |

Source: Ricardo, Toyota, BMW, Volvo
Market demand for lubricants is here for some time yet, though regulatory changes mean higher performance specifications

- **REGULATIONS**: The regulatory focus on light duty noxious emissions and CO$_2$/fuel economy is intensifying in many countries
- **FUEL ECONOMY CHALLENGE**: Fuel economy is no longer “Powertrain Engineering’s challenge”; it is a whole vehicle challenge
- **IC ENGINE OPTIMIZATION**: 93-97% of a growing, global market for light duty vehicles will need an internal combustion engine in 2025
- **ELECTRIFICATION**: Powertrain electrification is now a central thrust in the development of mainstream vehicles
- **AUTO TRANSMISSION**: Efficient, automated transmissions and electrical reduction drives will gain share from traditional manuals and automatics
- **OVERALL OUTLOOK**:
  - **Overall stable demand** for powertrain lubricants for the medium term
  - **Performance requirements will all continue to rise over time** for wear protection, friction reduction, contamination and high temperature tolerance