Updated Statement to CITEPA on Cost of European Diesel Emissions Regulation

30 April 2004
RD 04/140701.1

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Introduction

- Ricardo conducted a study for CITEPA between May and November 2003 detailing the impact of past, future and projected emissions legislation on the cost of European engines.

- Outputs from the study included:
  - Documented historical or projected future emissions reductions
  - Effect of the regulations on the production cost of engines

- A report was prepared and issued to CITEPA who distributed to various organisations for comment (RD 03/162101.5).

- Comments returned from ACEA highlighted concern over elements of the report relating to light-duty diesel engines (passenger car / light commercial vehicle):
  - Cost increases viewed as smaller than expected
  - Market penetration of certain technologies questioned

- A Ricardo response to these concerns (RD04/113001.1) was circulated and discussed at a meeting on 7 April 2004 involving Ricardo, ACEA, CITEPA and other stakeholders.
  - At this meeting, it was agreed that these issues arose from the assumptions surrounding the study, especially the effect of rising Diesel sales on costs.

- Ricardo agreed to re-evaluate according to new assumptions agreed at the meeting.
  - This report explains the changed assumptions and replaces data presented in RD03/162101.5.
Assumptions – New Technology Introduction Costs

- Ricardo’s original sources for this data included collated information from manufacturers and suppliers over many years.

- **Growth in passenger-car Diesel engines has been one of the biggest market trends in recent years.** It is clear that as a diesel engine technology is introduced, it is more expensive than after several years of production. Reasons for this are:
  - First introduction of Diesel engines, and of subsequent technology improvements, tended to be on low-volume “premium” or “niche” products, where margins are typically higher, high unit costs can be tolerated.
  - **Rising Diesel sales**, improvements in component manufacturing capabilities, “supply and demand” economics and the recovery of original tooling investment after many years of production, have all led to **substantial benefits in terms of price per unit**.

- **This effect arises to some extent for any new technology.** In the original study, these “volume” effects were generally **excluded**, with the “stabilised” cost of components in mainstream production being used. However, for Diesel engines the effect was so large that it was originally agreed to include it.

- Subsequent discussion led to the decision that these **volume effects should be removed from the analysis.** This updated analysis uses “stabilised” component prices at a level representing circa 1 year after volume technology introduction.

- As before, prices are corrected for inflation to current levels.
Assumptions - Expected Technology Penetration for Diesel Oxidation Catalyst and Exhaust Gas Recirculation; Diesel Car and LDT (Updated Statement – p. 30 of RD03/162101.5)

<table>
<thead>
<tr>
<th>Euro Emissions Standard</th>
<th>0 (ECE R15/04)</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5 (draft)</th>
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</thead>
<tbody>
<tr>
<td><strong>Emissions Technology Requirement (Majority of Vehicles) - Incremental</strong></td>
<td>Mechanical fuel pump / IDI combustion system / Low pressure injectors</td>
<td>Mechanical / part-electrical fuel-control / IDI combustion system / Low pressure injectors / EGR system with electric control</td>
<td>Electric fuel timing/metering / cooled EGR circuit / Turbocharged</td>
<td>DI combustion system (HP injectors) / turbocharged, intercooled, Diesel oxidation catalyst</td>
<td>4V cylinder head design</td>
<td>2nd generation common rail or unit injectors, variable nozzle turbocharger, (catalysed) Diesel particulate filter, modulated EGR and/or Lean NOx trap</td>
</tr>
</tbody>
</table>

**AIR MANAGEMENT**

- naturally aspirated: 79, 66, 44, 15, 7, 0
- wastegated turbocharger: 21, 34, 49, 71, 44, 29
- intercooler: 9, 17, 38, 52, 71, 89
- variable nozzle turbo: 0, 0, 7, 14, 49, 69
- two-stage turbocharging: 0, 0, 0, 0, 0, 2
- intercooler by-pass (for start-up): 0, 0, 0, 1, 0, 0
- 4V per cylinder: 0, 3, 5, 28, 73, 92
- inlet port deactivation (variable swirl): 0, 0, 2, 4, 16, 46

**NOx REDUCTION**

- EGR circuit: 0, 0, 100, 100, 100, 100
- EGR cooler: 0, 0, 56, 78, 92, 98
- modulated EGR cooling: 0, 0, 0, 0, 5, 27

**AFTER TREATMENT**

- Diesel oxidation catalyst: 0, 0, 0, 100, 100, 100
- 2nd Diesel oxidation catalyst: 0, 0, 0, 5, 10, 15
- Diesel particulate filter: 0, 0, 0, 1, 9, 31
- Catalysed Diesel particulate filter: 0, 0, 0, 0, 8, 69
- Lean NOx trap: 0, 0, 0, 0, 1, 25
- Selective Catalytic Reduction (Urea required): 0, 0, 0, 0, 0, 5

Updates to DOC and EGR market penetration according to ACEA-supplied data
Assumptions – Technology Requirements

- Ricardo had prepared the report according to the assumption that . . . ‘the minimum technology required to satisfy the emissions legislation would be used’
  - For example, an average 2.0-litre engine in an average application will not require a DPF in order to meet Euro 4 emissions legislation, but several vehicles are currently fitted with DPFs in this category
  - Possible reasons for adopting this strategy include obtaining warranty and field trial information which will assist with later high-volume introduction to meet legislation

- In this example, a DPF is a relatively expensive technology and so the interpretation of technology requirements is very influential
  - The same argument can be applied to many different Light Duty Diesel technologies in the study

- This updated statement for market penetration of emissions reduction technology, as suggested in the comments from ACEA, estimates ‘what will actually happen in the market’, whether purely for current emissions purposes, or for other reasons (e.g. DPF example above) which may assist future emission control
Assumptions - Technology Incorporation for Reasons other than Emissions Legislation

- Some technologies were originally implemented to improve engine performance as well as for reasons of emissions control. Examples of this include:
  - **Diesel DI combustion systems** were implemented to improve fuel consumption, not for reasons of legislated emissions reduction at that time
    - However, it is unlikely the older IDI combustion system would be capable of complying with the speculated “Euro 5 legislation (or possibly “Euro 4”)
    - Therefore it is necessary to account for the full cost of the switch to DI somewhere
  - **Turbochargers** were introduced as a means to increase power density, but are now an essential component for reasons of emissions compliance
    - Likewise, it is therefore necessary to include the full cost of the adoption of turbocharging
  - **The updated statement retains the historically correct market penetration figures** and future projections, as before, but now 100% of the cost is attributed to emissions legislation from introduction of the technology.
## Revised Analysis Result

(Updated Statement – p. 62 of RD03/162101.5)

Expected Technology Penetration; Diesel Car and LDT

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<tbody>
<tr>
<td>1</td>
<td>Technology Requirement</td>
<td>R</td>
<td>0</td>
<td>69</td>
<td>183</td>
<td>355</td>
<td>536</td>
<td>738</td>
<td>994</td>
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<td>Assumptions</td>
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<td>2</td>
<td>Incremental Emissions Costs From 1990 [Euro]</td>
<td>f R</td>
<td>0</td>
<td>69</td>
<td>183</td>
<td>355</td>
<td>536</td>
<td>738</td>
<td>994</td>
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<td>3</td>
<td>Additional Operating and Maintenance costs [Euro]</td>
<td>f R</td>
<td>0</td>
<td>125</td>
<td>119</td>
<td>120</td>
<td>132</td>
<td>145</td>
<td>165</td>
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<tr>
<td>5</td>
<td>Lifetime of control Equipment [years]</td>
<td>f R</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
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<tr>
<td>9</td>
<td>Change in fuel consumption caused by implementation of the Euro (??) measures [%]</td>
<td>R 3</td>
<td>100</td>
<td>92</td>
<td>87</td>
<td>82</td>
<td>84</td>
<td>86</td>
<td>87</td>
</tr>
<tr>
<td>10</td>
<td>Average fuel consumption 2005-2010 relative to 1990 [fraction]</td>
<td>R</td>
<td>1.000</td>
<td>1.006</td>
<td>1.166</td>
<td>1.063</td>
<td>1.040</td>
<td>1.005</td>
<td>1.020</td>
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- Maintenance costs estimated for 200,000km (emissions system only)
- Line 9 based on known effect of individual emissions reduction measures
- Line 10 based on averaged fuel economy results
Data Comparison & Discussion
Diesel costs now rise above Gasoline post TWC introduction

- Plot indicates how assumptions requested have changed the on-cost of emissions technologies for Diesel cars

Comparative On-Cost of Diesel and Gasoline Technologies

- Gasoline: Steep cost increase with introduction of Three Way Catalyst
- Gasoline: Smaller impact per year from introduction of new valve, fuel & control technologies, increased catalyst specification
- Diesel: Progressive cost increase due to adoption of DI, turbocharging, common rail, EGR, DPF, LNT/SCR
- Original Study Diesel: Mainly lower due to counter-impact of rising volumes