ROAD TRANSPORT
PASSENGER CARS, LIGHT DUTY VEHICLES, HEAVY DUTY VEHICLES

SYNOPSIS SHEET

Prepared in the framework of EGTEI
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1. Activity description and EGTEI contribution - summary

A specific study has been carried out in the scope of EGTEI for improving the knowledge on costs of emission reduction techniques for on-road mobile sources. The study has been subcontracted to Ricardo Consulting Engineers Ltd (Ricardo Consulting Engineers Ltd was founded during the early 1900’s and is involved in the provision of services to the engine industry over the range of gasoline, gas, diesel and alternate fuelled engines) as vehicle manufacturers could not provide any cost data for competition reasons. A matrix of required information was developed by EGTEI and IIASA and provided to RICARDO.

The report “support for updating the RAINS model concerning Road transport” provides a review of the technologies and associated costs for Euro 0 through Euro III emission limits and a vision of the technologies and associated costs required to meet Euro IV (2005) and Euro V (2008) on cars and trucks. It also provides a review of technologies beyond these proposed limits for Euro VI [1]. For the latest regulations not yet implemented (Euro V and VI), provisional emission limit values have been taken into account.

The following vehicle categories have been considered:

- Gasoline passenger cars (engine sizes between 1200 and 2000 cc excluding performance vehicles (e.g. GTI’s) considered for estimating costs),
- Gasoline light duty vehicles ((LDT) up to 3500 kg Gross Vehicle Weight (GVW)),
- Diesel passenger cars (engine sizes between 1500 and 2000 cc considered for estimating costs)
- Diesel light duty trucks (LDT),
- Diesel medium duty trucks (MDT),
- Diesel heavy duty trucks (HDT).

The review of the relative costs of technologies required to meet Euro I through Euro III has been prepared based on data provided by Ricardo OEM contacts. Due to the commercially sensitive nature for these data, most of sources remain anonymous. Cost estimation is also based on published data when available and experience combined with engineering judgment where otherwise necessary. The approach has consisted in determining mainstream technologies for each vehicle category and European emission legislation; in determining cost to manufacture and maintain the vehicles; in determining proportions within the fleet using each technology and amortising manufacturing and maintenance costs across the fleet for each vehicle category to produce an additional cost per vehicle; in estimating regulated emissions and fuel economy as unregulated emissions.

Comments from ACEA were considered and the initial results for diesel cars and light duty vehicles were revised (addendum: “updated statement to CITEPA on cost of European diesel emission regulation” 30 April 2001- RD 04/140801.1).

All details for cost and emission calculations are developed in the report [1].

SO₂ emission levels are proportional to the sulphur content of the fuel used. The only way to reduce SO₂ emissions is to reduce the gasoline sulphur content.

In RAINS [2], four vehicle categories are considered separately:

- Heavy duty trucks (HDT) and buses (TRA_RD_HD-GSL): emissions at a EU25 level (according to the RAINS model: version CP_CLE_Aug04(Nov04)) are about 0.2 kt for NOx and 0.2 kt for VOCs.
- HDT and buses medium distillates (TRA_RD_HD-MD): emissions at a EU25 level (according to the RAINS model: version CP_CLE_Aug04(Nov04)) are about 2,600 kt for NOx and 273.3 kt for VOCs (representing respectively about 36.6 and 7.4% of transport emissions).
- Light duty vehicles (LDV), 4-stroke (excl. GDI) gasoline (TRA_RD_LD4-GSL): emissions at a EU25 level (according to the RAINS model: version CP_CLE_Aug04(Nov04)) are about 1,880.5 kt for NOx and 1,648.8 kt for VOCs (representing respectively about 26.5 and 44.4% of transport emissions).
Road transport

- LDV, 4-stroke (excl. GDI) medium distillates (TRA_RD_LD4-MD): emissions at a EU25 level (according to the RAINS model: version CP_CLE_Aug04(Nov04)) are about 761.4 kt for NOx and 110.4 kt for VOCs (representing respectively about 10.7 and 3.0% of transport emissions).

These vehicles are addressed by the European Directives 91/441/EC [3], 94/12/EC [10], 93/59/EC [9], 96/69/EC [11], 98/69/EC [5] and 1999/96/EC [6] most known under EURO I to EURO IV. Fuels used are also regulated by the Directives 98/70/EC [7] and 2003/17/EC [8].

EGTEI economic parameters have been integrated into RAINS to update costs already existing.

No country specific data are required from national experts for this sector. The Ricardo study mainly provides costs which can be directly used by RAINS.

2. European regulation
(http://europa.eu.int/comm/environment/air/transport.htm)

Motor vehicle emissions are regulated by Directives 70/220/EEC (light vehicles) and 88/77/EC (heavy vehicles) [4] and amendments to those directives. A whole series of amendments has been issued to stepwise tighten the limit values. Emissions are measurably falling because of this, even though traffic volumes continue to rise. The implementation of the Auto-Oil Programme will result in a notably improved air quality in our cities. The programme focused on the emissions of carbon monoxide (CO), Volatile Organic Compounds (VOC), nitrogen oxides (NOx) and particles. With the programme, stricter limit values have been defined. The table 2.1 presents the directives implemented.

Table 2.1: EC Directives implementing the emission values for on-road vehicles

<table>
<thead>
<tr>
<th></th>
<th>Euro I</th>
<th>Euro II</th>
<th>Euro III</th>
<th>Euro IV</th>
</tr>
</thead>
</table>

In addition, legislation has been implemented on the use of on-board diagnostic systems (OBD) which will indicate if the vehicle emissions are too high and a light on the instrument panel will indicate if there is a need to repair the vehicle.

Further reductions of road vehicle emissions (introduction of Euro V and Euro VI) are in discussion at the European Commission level.


Table 2.2: Gasoline sulphur content: standards (ppm) implemented by the two Directives

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Sulphur content in petrol (ppm)</td>
<td>150</td>
<td>50</td>
<td>10</td>
</tr>
<tr>
<td>Sulphur content in diesel (ppm)</td>
<td>350</td>
<td>50</td>
<td>10</td>
</tr>
</tbody>
</table>

3. Methodology developed within EGTEI to represent the sector

3.1 Definition of reference engines

The approach was to split the total European fleet into categories in line with exhaust emissions legislation: gasoline cars (typical engine size 1200cc to 2000cc excluding "performance" vehicles (e.g. GTI’s) taken into account, gasoline light duty truck (LDT), diesel cars (engine sizes 1,500cc to 2,000cc, diesel LDT (up to 3,500kg Gross Vehicle Weight (GVW)), diesel medium duty truck (3,500 to 12,000kg GVW) and diesel heavy duty truck (12,000kg GVW and above)).
Table 3.1.1: Reference engines

<table>
<thead>
<tr>
<th>Reference engine codes (REC)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>Gasoline passenger cars</td>
</tr>
<tr>
<td>02</td>
<td>Gasoline light duty vehicles</td>
</tr>
<tr>
<td>03</td>
<td>Diesel passenger cars</td>
</tr>
<tr>
<td>04</td>
<td>Diesel light duty trucks</td>
</tr>
<tr>
<td>05</td>
<td>Diesel medium duty trucks</td>
</tr>
<tr>
<td>06</td>
<td>Diesel heavy duty trucks</td>
</tr>
</tbody>
</table>

3.2 Definition of emission abatement techniques

Mainstream technologies for each vehicle category and each level of existing European emissions legislation (Euro I to Euro IV) and future expectations (Euro V and Euro VI) have been defined as well as the penetration of each technology on the market.

Many forces can contribute to the technologies in the market place, such as:
- Customer requirements (performance, comfort, reliability, etc),
- Environmental (unregulated pressure) e.g. CO$_2$ reductions,
- Other governmental e.g. taxation schemes.

If the pressure on motor manufacturers since the advent of European emission limits was purely related to reduction of exhaust emissions then the technology mix would be quite different from today. For example, if pressures to improve fuel economy and CO$_2$ emissions were not present, stratified charge (direct injection, lean burn) gasoline engines would not unlikely exist as they provide additional emission challenges. Additionally, some technologies which were adopted for reasons other than emission control, have subsequently become necessary in meeting ever tightening limits. An example is turbochargers for diesel cars. They were initially introduced for performance and customer acceptance reasons but they are now a key part of the emission reduction technology.

Given this complexity of issues, the adopted strategy for dealing with the assumed technology mix, has been as follows:
- An artificial, emissions driven only, technology pack has not been used,
- The historic technology mix is “as was”,
- Future technology mix is based on general technology trends,
- No attempt has been made to rationalise these with other scenarios such as CO$_2$ targets,
- Technologies with extremely low market share have not been considered.

Estimates have been made on the penetration of different technologies present at the various emission introduction levels. These estimates have been particularly used in the definition of costs, future fuel consumptions and emission values.

These technologies are presented below. Expected technology penetrations for each vehicle type are available in the full RICARDO report [1].
### Table 3.2.1: Emissions technology requirement (majority of vehicles)

<table>
<thead>
<tr>
<th>Euro emission standard</th>
<th>Euro 0</th>
<th>Euro I</th>
<th>Euro II</th>
<th>Euro III</th>
<th>Euro IV</th>
<th>Euro V</th>
<th>Euro VI</th>
</tr>
</thead>
<tbody>
<tr>
<td>REC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>01</td>
<td>Carburettor / Single Point Injection / Distributor Ignition / Limited use of electronic control</td>
<td>3-way Catalyst / Lambda sensor / Electronic Injection / Electronic Ignition / Basic evaporative emissions equipment</td>
<td>Better hardware design / Higher cat loading / Some use of EGR / Multi-point Injection</td>
<td>Post cat O2 / Revised controller and software / Higher catalyst loading / Evaporative emissions equipment / Reduced base engine friction</td>
<td>Starter (pup) cat / revised high speed fuelling strategy (keep cat cool) / Increased use of EGR or variable cam phasing</td>
<td>Variable cam phasing / Increased use of lean burn direct injection</td>
<td>General refinement / Increased use of direct injection / boosted downsized engines / wider introduction of hybrid technologies</td>
</tr>
<tr>
<td>02</td>
<td>Carburettor / Single Point Injection / Distributor Ignition / Limited use of electronic control</td>
<td>3-way Catalyst / Lambda sensor / Electronic Injection / Electronic Ignition / Basic evaporative emissions equipment</td>
<td>Better hardware design / Higher cat loading / Some use of EGR / Multi-point Injection</td>
<td>Post cat O2 / Revised controller and software / Higher catalyst loading / Evaporative emissions equipment / Reduced base engine friction</td>
<td>Starter (pup) cat / revised high speed fuelling strategy (keep cat cool) / Increased use of EGR or variable cam phasing</td>
<td>Variable cam phasing / Increased use of lean burn direct injection</td>
<td>General refinement / Increased use of direct injection / boosted downsized engines</td>
</tr>
<tr>
<td>03</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>-</td>
<td></td>
</tr>
<tr>
<td>04</td>
<td>Idem</td>
<td>Idem</td>
<td>Idem</td>
<td>Idem</td>
<td>Idem</td>
<td>Idem</td>
<td>Idem</td>
</tr>
<tr>
<td>05</td>
<td>Improved combustion system and FIE match</td>
<td>Higher pressure FIE for PM control, timing retard for NOx reduction, move to TC/TCA</td>
<td>All engines are TCA, HP Electronic FIE for control of PM, further timing optimisation for low NOx, EUPs and EUs in some medium duty engines</td>
<td>All engines are TCA, HP Electronic FIE for control of PM-NOx trade-off. Timing retard for low NOx, some use of EGR and/or EUPs, CR introduced</td>
<td>As Euro III; further NOx reduction by either using EGR or SCR. Likely strategies: either EGR+DPF, or EGR + updated FIE + Oxicat, or SCR + updated FIE</td>
<td>As Euro IV, but SCR may replace EGR in some medium duty engine applications</td>
<td>Difficult to estimate. Increased use of SCR and other aftertreatment. Further updated FIE, with ever more complex control systems</td>
</tr>
<tr>
<td>06</td>
<td>Idem</td>
<td>Idem</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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4. Country specific data to be collected

No country specific data are required for this sector. The Ricardo study provides costs data which can be directly used in RAINS.

5. Default emission factors and cost data defined with the EGTEI methodology

5.1 Default emission factors

Emission factors are presented for each vehicle type and regulation. They are available expressed in g/km and g/GJ. Efficiencies are also provided. Emission factors have been defined according to test cycle monitoring results.

Emission factors and efficiencies are not presented in this synopsis sheet due to the amount of data available. Refer to the RICARDO report [1] for more details.

5.2 Default costs

Investment costs consist in:

- Component costs on a per vehicle basis
- Tooling costs: assumed fully amortised at 100,000 units
- Development and calibration costs. Additional cost for vehicle development attributable to emissions compliance amortised for 100,000 vehicles

The component costs used are the stabilised value and not the initial introduction levels except for light duty vehicles. The component costs vary from initial introduction to the stabilised levels achieved after a number of years. This approach gives costs which are most comparable across the emission limits.

In a first step, the preceding assumption was applied for all vehicle types. However, following comments from ACEA, another assumption has been developed for diesel cars and LDT. In the case of diesel passenger cars and LDT, the changes in volumes produced have resulted in significant changes in the costs of fuel injection equipment and turbochargers. In this case, the higher costs at the earlier European emission levels could not be ignored. The cost for diesel passenger cars are consequently stabilised component prices obtained about 1 year after volume technology introduction. For diesel cars and LDT, 100% of the costs of some techniques have been attributed to emission legislation from introduction of the technology.

Maintenance costs are borne by the end user. Estimations take into account the following factors:

- Routine replacement as dictated by the manufacturer
- Statutory in use testing
- Replacement due to unexpected failure, based on warranty information,

Total investments and operating costs are presented in the following tables.

**Table 5.2.1:** Investment costs for compliance with Euro I to Euro VI (€/vehicle)

<table>
<thead>
<tr>
<th>Type of vehicle</th>
<th>Euro I</th>
<th>Euro II</th>
<th>Euro III</th>
<th>Euro IV</th>
<th>Euro V</th>
<th>Euro VI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasoline passenger cars</td>
<td>262</td>
<td>269</td>
<td>341</td>
<td>382</td>
<td>445</td>
<td>585</td>
</tr>
<tr>
<td>Gasoline light duty vehicles</td>
<td>283</td>
<td>286</td>
<td>354</td>
<td>375</td>
<td>402</td>
<td>453</td>
</tr>
<tr>
<td>Diesel passenger cars</td>
<td>59</td>
<td>183</td>
<td>355</td>
<td>536</td>
<td>738</td>
<td>994</td>
</tr>
<tr>
<td>Diesel light duty trucks</td>
<td>59</td>
<td>183</td>
<td>355</td>
<td>536</td>
<td>738</td>
<td>994</td>
</tr>
<tr>
<td>Diesel medium duty trucks</td>
<td>943</td>
<td>1,778</td>
<td>3,048</td>
<td>5,271</td>
<td>5,657</td>
<td>6,250</td>
</tr>
<tr>
<td>Diesel heavy duty trucks</td>
<td>1,983</td>
<td>3,734</td>
<td>5,121</td>
<td>9,730</td>
<td>10,809</td>
<td>12,250</td>
</tr>
</tbody>
</table>

**Table 5.2.2:** Operating costs for compliance with Euro I to Euro VI (€/vehicle for its entire lifetime)

<table>
<thead>
<tr>
<th>Type of vehicle</th>
<th>Euro I</th>
<th>Euro II</th>
<th>Euro III</th>
<th>Euro IV</th>
<th>Euro V</th>
<th>Euro VI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasoline passenger cars</td>
<td>140</td>
<td>103</td>
<td>123</td>
<td>105</td>
<td>125</td>
<td>155</td>
</tr>
<tr>
<td>Gasoline light duty vehicles</td>
<td>220</td>
<td>183</td>
<td>170</td>
<td>125</td>
<td>126</td>
<td>120</td>
</tr>
<tr>
<td>Diesel passenger cars</td>
<td>125</td>
<td>118</td>
<td>120</td>
<td>132</td>
<td>145</td>
<td>165</td>
</tr>
<tr>
<td>Diesel light duty trucks</td>
<td>125</td>
<td>118</td>
<td>120</td>
<td>132</td>
<td>145</td>
<td>165</td>
</tr>
</tbody>
</table>
5.3 Fuel characteristics


The different fuel type costs have to be entered only once in ECODAT in the table “Fuel characteristics”. Additional investment and refinery operating costs associated with lowering the sulphur content from a maximum of 50 ppm to a maximum of 10 ppm. EGTEI proposes two sets of default costs for EU North and EU South. According to reference [8], the main driver of cost difference between north and south EU is the crude oil quality (in particular the sulphur content) handheld in refineries.

Table 5.3.1: Costs of lowering the sulphur content of gasoline [8]

<table>
<thead>
<tr>
<th></th>
<th>Min. (€/l)</th>
<th>Max. (€/l)</th>
<th>Average (€/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EU. North</td>
<td>0.001</td>
<td>0.003</td>
<td>0.002</td>
</tr>
<tr>
<td>EU. South</td>
<td>0.002</td>
<td>0.003</td>
<td>0.0025</td>
</tr>
</tbody>
</table>

6. Relevance of EGTEI information for Integrated Assessment Modelling (IAM)

Only EGTEI economic data have been introduced in RAINS to update costs already used in the model. Only four types of engines are defined as explained in the introduction so average costs are considered in RAINS.

7. Perspective for the future

In the future, any new technology development should be considered by EGTEI to continuously improve the representation of the sector.

8. Bibliography

http://europa.eu.int/eur-lex/lex/LexUriServ/LexUriServ.do?uri=CELEX:31999L0096:EN:HTML


