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].

SO_2 emission levels are proportional to the sulphur content of the fuel used. The only way to reduce SO_2 emissions is to reduce the gasoline sulphur content.

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

- Heavy duty trucks (HDT) and buses gasoline (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).

- 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

	Euro I	**Euro II**	**Euro III**	**Euro IV**
Passenger cars	Dir. 91/441 of 26 June 1991 [3]	Dir. 94/12 of 23 March 1994 [10]	Dir. 98/69 of 13 October 1998 [5]	
Light duty vehicles	Dir. 93/59 of 28 June 1993 [9]	Dir. 96/69 of 8 October 1996 [11]		
Heavy duty vehicles	Dir. 91/542 of 1 October 1991 [12]		Dir. 99/96 of 13 December 1999 [6]	

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.

Gasoline and diesel sulphur contents are regulated by Directives 98/70/EC [7] and 2003/17/EC [8] relating to the quality of gasoline and diesel fuels.

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

Dates of compliance	**2000**	**2005**	**2008**
Sulphur content in petrol (ppm)	150	50	10
Sulphur content in diesel (ppm)	350	50	10

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

Reference engine codes (REC)	Description
01	Gasoline passenger cars
02	Gasoline light duty vehicles
03	Diesel passenger cars
04	Diesel light duty trucks
05	Diesel medium duty trucks
06	Diesel heavy duty trucks

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)

Euro emission standard	Euro 0	Euro I	Euro II	Euro III	Euro IV	Euro V	Euro VI
REC							
01	Carburettor / Single Point Injection / Distributor Ignition / Limited use of electronic control	3-way Catalyst / Lambda sensor / Electronic Injection / Electronic Ignition / Basic evaporative emissions equipment	Better hardware design / Higher cat loading / Some use of EGR / Multi-point Injection	Post cat O2 / Revised controller and software / Higher catalyst loading / Evaporative emissions equipment / Reduced base engine friction	Starter (pup) cat / revised high speed fuelling strategy (keep cat cool) / Increased use of EGR or variable cam phasing	Variable cam phasing / Increased use of lean burn direct Injection	General refinement / Increased use of direct injection / boosted downsized engines / wider introduction of hybrid technologies
02	Carburettor / Single Point Injection / Distributor Ignition / Limited use of electronic control	3-way Catalyst / Lambda sensor / Electronic Injection / Electronic Ignition / Basic evaporative emissions equipment	Better hardware design / Higher cat loading / Some use of EGR / Multi-point Injection	Post cat O2 / Revised controller and software / Higher catalyst loading / Evaporative emissions equipment / Reduced base engine friction	Starter (pup) cat / revised high speed fuelling strategy (keep cat cool) / Increased use of EGR or variable cam phasing	Variable cam phasing / Increased use of lean burn direct Injection	General refinement / Increased use of direct injection / boosted downsized engines
03	Mechanical fuel pump / IDI combustion system / Low pressure injectors	Mechanical / part-electrical fuel-control / IDI combustion system / Low pressure injectors / EGR system with electric control	Electric fuel timing / metering / cooled EGR circuit / Turbocharged	DI combustion system (HP injectors) / turbocharged, intercooled, Diesel oxidation catalyst	4V cylinder head design	2nd generation common rail or unit injectors; variable nozzle turbocharger, (catalysed) Diesel particulate filter, modulated EGR and/or Lean NOx trap	-
04	Idem	Idem	Idem	Idem	Idem	Idem	Idem
05	Improved combustion system and FIE match	Higher pressure FIE for PM control, timing retard for NOx reduction, move to TC/TCA	All engines are TCA, HP Electronic FIE for control of PM, Further timing optimisation for low NOx, EUPs and EUIs in some medium duty engines	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	As Euro III; further NOx reduction by either using EGR or SCR. Likely strategies are: either EGR+DPF, or EGR + updated FIE + Oxicat, or SCR + updated FIE	As Euro IV, but SCR may replace EGR in some medium duty engine applications	Difficult to estimate. Increased use of SCR and other aftertreatment. Further updated FIE, with ever more complex control systems
06	Idem	Idem	All engines are TCA, HP Electronic FIE for control of PM, Further timing optimisation for low NOx, EUI/EUP for Premium engines	All engines are TCA, HP FIE, electronic control. Timing retard for low NOx, some use of EGR, EUI/EUP widespread, CR introduced	As Euro III; further NOx reduction by either using EGR or SCR. Strategies: EGR+DPF, or EGR + updated FIE + Oxicat, or SCR + updated FIE	As Euro IV, but trend away from EGR towards SCR anticipated	Expect further increased use of SCR, updates FIE, more complex engine control system

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)

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

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

Type of vehicle	Euro I	Euro II	Euro III	Euro IV	Euro V	Euro VI
Gasoline passenger cars	140	103	123	105	125	155
Gasoline light duty vehicles	220	183	170	125	126	120
Diesel passenger cars	125	118	120	132	145	165
Diesel light duty trucks	125	118	120	132	145	165

Diesel medium duty trucks	274	1,291	1,962	4,054	3,596	3,222
Diesel heavy duty trucks	80	1,332	2,229	3,867	3,885	4,053

5.3 Fuel characteristics

Sulphur content of gasoline is regulated by Directives 98/70/EC [7] and 2003/17/EC [8] related to the quality of gasoline and diesel fuels.

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]

	Min. (€/l)	Max. (€/l)	Average (€/l)
EU. North	0.001	0.003	0.002
EU. South	0.002	0.003	0.0025

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

[1] RIACRDO report: http://citepa.org/forums/egtei/egtei_doc-On_road.htm

[2] Review of data used in RAINS model: http://www.iiasa.ac.at/web-apps/tap/RainsWeb/

[3] Council Directive 91/441/EEC of 26 June 1991 amending Directive 70/220/EEC on the approximation of the laws of the Member States relating to measures to be taken against air pollution by emissions from motor vehicles

http://europa.eu.int/smartapi/cgi/sga_doc?smartapi!celexplus!prod!DocNumber&lg=en&type_doc=Directive&an_doc=1991&nu_doc=441

[4] Council Directive of 3 December 1987 on the approximation of the laws of the Member States relating to the measures to be taken against the emission of gaseous pollutants from diesel engines for use in vehicles (88/77/EC)

[5] Directive 98/69/EC of the European Parliament and of the Council of 13 October 1998 relating to measures to be taken against air pollution by emissions from motor vehicles and amending Council Directive 70/220/EEC

http://europa.eu.int/smartapi/cgi/sga_doc?smartapi!celexplus!prod!DocNumber&lg=en&type_doc=Directive&an_doc=1998&nu_doc=69

[6] Directive 1999/96/EC of the European Parliament and of the Council of 13 December 1999 on the approximation of the laws of the Member States relating to measures to be taken against the emission of gaseous and particulate pollutants from compression ignition engines for use in vehicles, and the emission of gaseous pollutants from positive ignition engines fuelled with natural gas or liquefied petroleum gas for use in vehicles and amending Council Directive 88/77/EEC

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

[7] Directive 98/70/EC of the European Parliament and of the Council of 13 October 1998 relating to the quality of petrol and diesel fuels and amending Council Directive 93/12/EEC

[8] Directive 2003/17/EC of the European Parliament and of the Council of 3 March 2003

[9] Council Directive 93/59/EEC of 28 June 1993 amending Directive 70/220/EEC on the approximation of the laws of the Member States relating to measures to be taken against air pollution by emissions from motor vehicles

http://europa.eu.int/smartapi/cgi/sga_doc?smartapi!celexplus!prod!DocNumber&lg=en&type_doc=Directive&an_doc=1993&nu_doc=59

[10] Directive 94/12/EC of the European Parliament and the Council of 23 March 1994 relating to measures to be taken against air pollution by emissions from motor vehicles and amending Directive 70/220/EEC

http://europa.eu.int/smartapi/cgi/sga_doc?smartapi!celexplus!prod!DocNumber&lg=en&type_doc=Directive&an_doc=1994&nu_doc=12

[11] Directive 96/69/EC of the European Parliament and of the Council of 8 October 1996 amending Directive 70/220/EEC on the approximation of the laws of the Member States relating to measures to be taken against air pollution by emissions from motor vehicles

http://europa.eu.int/smartapi/cgi/sga_doc?smartapi!celexplus!prod!DocNumber&lg=en&type_doc=Directive&an_doc=1996&nu_doc=69