LARGE SI ENGINES > 19 KW

SYNOPSIS SHEET

Prepared in the framework of EGTEI

1. Activity description and EGTEI contribution - summary

Virtually all automobiles and many trucks are powered by 4-stroke engines. 4-stroke engines are also very common in motorcycles, all-terrain vehicles, boats, airplanes and numerous non-road applications such as lawn mowers, lawn and garden tractors and generators for examples. Large non-SI engines are exclusively 4-strokes.

Two types of engines are defined hereafter: gasoline-fuel engines and gaseous fuel engines:

Gasoline fuel engines: in a 4-stroke engine, a piston makes four passes or strokes in the cylinder to complete an entire cycle. The strokes are intake, compression, power and exhaust. Two of the strokes are downward (intake and power) and two are upward (compression and exhaust).

Gaseous fuel engines: these engines operate on LPG or natural gas. A mixer introduces the fuel into the intake system. Researches are done to inject the fuel directly into the intake manifold.

NOx and VOCs are the main pollutants emitted by 4-stroke SI engines. 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. TSP emissions are not a big issue for these types of engines. They are not considered in this document as no data has been found.

In RAINS [1], off-road 4-stroke engines are considered either separately or with on-road engines when no country specific data are available. NOx emissions at a EU25 level (according to the RAINS model: version CP_CLE_Aug04(Nov04)) are about 2.9 kt representing only 0.04% of transport emissions. VOC emissions are only 2.3 kt being about 0.05% of transport emissions. These figures do not take into account emissions from all countries as some of them are considered with on-road emissions.

4-stroke large SI engines are not specifically regulated in Europe even though they are in the US [2]. Gasoline used is also regulated by the Directives 98/70/EC [3] and 2003/17/EC [4]. In order to be able to better represent this sub-sector in terms of emission reductions and costs, it **has been considered as an individual activity by EGTEI [5]**.

This sector has not been specifically introduced in RAINS [1] yet: all 4-stroke SI engines are still considered together as very few data exist at national levels to split the different categories of engines according to their size and use.

The representative unit used is the amount of fuel consumed annually (PJ/year). Engines are distinguished according to the type of fuel used: LPG-fuel or gasoline-fuel.

EGTEI provides default emission factors (EF) with abatement efficiencies, investments as well as unit costs (€/t pollutant abated) for the different measures. No information has been found concerning variable costs (corresponding to maintenance and repair and defined as a percentage (%) of investments in RAINS).

National experts have to collect engine specific parameters (either load factor, yearly operating hours and lifetime for each category of engines or annual consumption in GJ/engine) and fuel parameters (annual fuel consumption from 2000 to 2020 and fuel costs according to the year).

Even if the representation of this sector in RAINS is not directly based on the EGTEI proposal, it is recommended to national experts to complete the Excel spreadsheet developed by EGTEI. It can help national experts during the bilateral consultations defining the share of activity powered with LPG-fuel as well as the share of activity not yet regulated (4-stroke engines rated below 18 kW are regulated).

In the future, any new stage of the American regulation should be considered with corresponding emission factors and costs.

2. European regulation

These engines are not regulated in Europe yet. Assumptions in this document are based on the American regulation. In Europe, only SI engines rated below 19 kW are regulated in the framework of Directive 2002/88/EC [6].

The US regulation is based on two stages :

Table 2.1: Emission limits values [g/kWhr]

	Testing Type	HC + NOx
Stage I	Duty-cycle testing	4.0
Stage II	Duty-cycle testing	3.4
	Field-testing	4.7

Stage II has been developed to achieve in-use emission reductions (new procedure for measuring emissions will be adopted). Manufacturers will have time to optimise designs to better control emissions.

Gasoline sulphur content is regulated by Directives 98/70/EC [3] and 2003/17/EC [4] 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

3. Methodology developed within EGTEI to represent the sector

3.1 Definition of reference engines

Engines are distinguished according to their fuel types: LPG or gasoline-fuel.

Table 3.1.1: Reference engines

Reference Engine Code (REC)	Description
01	Gasoline-fuel 4-stroke engines
02	LPG-fuel 4-stroke engines

3.2 Definition of emission abatement techniques

Baseline technology corresponds to the pre-control situation.

Gasoline large SI engines: these engines continue to rely on traditional carburetor designs rather than incorporating the automotive technology innovations introduced to address emission controls.

LPG large SI engines: Baseline technologies typically have an open-loop mechanical mixer. LPG is stored at 130 to 170 psi, remaining in a liquid state at normal ambient temperatures. The mixer typically consists of a diaphragm, exposed to manifold air pressure, attached to a needle and orifice assembly. The diaphragm responds to changes in intake manifold vacuum, raising and lowering the needle within the orifice to finely adjust the amount of LPG admitted and mixed with engine intake air.

Advanced technology: since most Large SI engines are derived from automotive counterparts, much of the technology developed for cars and trucks can be used for large SI engines.

All gasoline units should use advanced port-fuel injection for gasoline units.

Table 3.2.1: Technology improvements to reduce emissions

Measure Code (MC)	Technologies
00	None
01	Fuel system improvements + Catalyst

4. Country specific data to be collected

National experts are requested to provide country-specific data for emission calculations. The formulas used and the appropriate coefficients are presented below (2 options are available):

- Option I: annual NOx and VOC emissions per engine can be calculated with the following equation:

$$E\ [t/y] = \text{Load Factor} \times \text{Power [kW]} \times \text{Annual use [h/y]} \times \text{Emission Factor [g/kWh]} / 10^6$$

Country specific data (engine characteristics) are required for each Reference Engine:

- Load factor (<1 : gives the average power delivered by the engine),
- Annual use (h/y),
- Operating lifetime (year).

Option II (consumption method): emission factors are expressed in g of pollutant/GJ using the engine's efficiency. This method is used to estimate emissions in RAINS because it is a simplified approach.

According to CIAM, engine's efficiency is considered to be about 35% for gasoline engines. Currently, no better data have been provided.

$$E\ [t/y] = \text{Fuel consumption [GJ/y]} \times \text{Emission Factor [g/GJ]} / 10^6$$

In this case, only the total fuel consumption and the operating lifetime per size of engines have to be provided.

Default values for all types of use are based on reference [2]. They are presented hereafter. Annual use (h/year) can be derived from the operating lifetime in hours divided by the operating lifetime in years.

Table 4.1: Default values to calculate emissions per engine

REC	Average power (kW)	Load factor	Annual use (h/y)	Operating lifetime (years)
01	39	0.58	536	12.3
02	50	0.39	1,365	12

These data have been used to calculate annual emissions per engine and then unit costs presented in table 5.1.1

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

Table 5.1.1 gives an overview of all data provided by EGTEI: default emission factors (EF), investments as well as unit costs per t pollutant abated.

5.1 Reduction of VOC and NOx

To calculate unit costs, annual emissions per engine are first calculated with the equation given in paragraph 4. Then, total investments are annualised (taking into account lifetimes shown in table 4.1 and an interest rate of 4%) to calculate unit costs for the two pollutants.

When the technique does not reduce a pollutant, no abatement cost is calculated.

Table 5.1.1: Emission factors (EF), investments and unit costs for each combination

REC MC	VOC EF [g/outp.kWh]	NOx EF [g/outp.kWh]	Invest. [€/engine]	Unit costs [€/t VOC]*	Unit costs [€/t NOx]*
01 00	4.15	10.88	0	-	-
01 01	1.1	2.9	805	870	2,275
02 00	10	13.5	0	-	-
02 01	1.7	2.3	559	200	270

* Only investments are taken into account in the calculations

5.2 Sulphur content of fuels

Gasoline used in large SI engines is assumed to be the same as the one used in on-road vehicles. Sulphur content of fuel is regulated by Directives 98/70/EC [3] and 2003/17/EC [4] 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 [7], 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 5.2.1: Costs of lowering the sulphur content of gasoline [7]

	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)

In RAINS, off-road 4-stroke engines are considered either separately or with on-road engines when no country specific data are available. EGTEI data have not been used and will not be used for the moment.

7. Perspective for the future

In the future, any new technology development should be considered by EGTEI in the background document to continuously improve the representation of the sector. This is crucial to well represent this sector in RAINS.

8. Bibliography

[1] Review of data used in RAINS model: http://www.iiasa.ac.at/web-apps/tap/RainsWeb/
[2] Draft Regulatory Support Document: Control of Emissions from Unregulated Non-road Engines. Assessment and Standards Division. Office of Transportation and Air Quality. USEPA - EPA420-D-01-004 - September 2001.
[3] 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 [Official Journal L 350, 28.12.1998].
[4] Directive 2003/17/EC of the European Parliament and of the Council of 3 March 2003 amending Directive 98/70/EC relating to the quality of petrol and diesel fuels.
[5] EGEI background document. http://citepa.org/forums/egtei/large_SI_engines_270603.pdf
[6] Directive 2002/88/EC of the European Parliament and of the Council of 9 December 2002 amending Directive 97/68/EC on the approximation of the laws of the Member States relating to measures against the emission of gaseous and particulate pollutants from internal combustion engines to be installed in non-road mobile machinery.
[7] The costs and benefits of lowering the sulphur content of petrol & diesel to less than 10 ppm. Prepared by Directorate-General Environment. 9 September 2001.

ANNEXE: Example of data collection and use of EGTEI data – Case of France

A. Country specific data collection and scenario developed

Activity levels are derived from the French national statistics on fuel consumption per sector (after a pre-treatment of the data). Only LPG-fuel engines are studied separately in the French inventory. Large 4-stroke off-road engines are considered with on-road vehicles as energy statistics do not distinguish both sectors.

Fuel consumption forecasts are based on a scenario developed by France in June 2004. This exercise is under revision for the CAFÉ programme so data presented in table A.1 are provisional. LPG consumption is assumed to decrease from 2000 to 2010 and to remain constant from 2010 to 2020. These figures have not been validated by the French expert yet.

Table A.1: LPG consumption (PJ / y)

Activity	2000	2005	2010	2015	2020
LPG [PJ]	1.35	1.28	1.21	1.21	1.21

Fuel parameters for 2000 are based on annual data provided by the French Petroleum association (UFIP).

Table A.2: Fuel parameters

	2000	2005	2010	2015	2020
LPG sulphur content (%)	0.005	0.005	0.005	0.005	0.005
Heat value of LPG [GJ/t]	46	46	46	46	46

Fuel costs should be provided by the French Ministry of economy and industry (MINEFI).

Emission factors used in the French inventory are given in the following table. Unabated emission factors are derived from data provided in the EGTEI document.

Table A.3: VOC and NOx emission factors for LPG-fuel engines (g/GJ)

REC	NMVOC	NOx
02 00	839	621
02 01	Not applicable	Not applicable

No control strategy is defined as these engines are not regulated in Europe.

B. Trends in emission factors and emissions

Emissions are easily calculated by multiplying the LPG consumption by appropriate emission factors.

Table B.1: Emissions from 2000 to 2020 for LPG-fuel engines

REC	2000	2005	2010	2015	2020
SO_2 (t)	2.7	2.6	2.4	2.4	2.4
NMVOC (t)	1,133	1,074	1,016	1,016	1,016
NOX (t)	839	795	752	752	752

VOC and NOx emissions could be reduced by more than 80% with the implementation of the measure MC 01.