Final Background Document
on the sector

Off road
LARGE SPARK IGNITION (SI) ENGINES
(4-stroke ; > 19 kW)

Prepared in the framework of EGTEI

Prepared by CITEPA, Paris

Summary

1. Data currently used in the RAINS model (p.3)

Data currently used in RAINS are displayed in this paragraph.

2. Short technology description (p.4)

3. Regulations (p.4)

4. Definition of Reference Engines (p.5)

Two reference engines are defined according to their fuel type.

5. Emission abatement techniques and costs (p.5)

Table 5.2.1 summarizes the emission factors with the corresponding abatement efficiencies for each combination of measures.
Table 5.2.2 summarizes investments and operating costs for each combination of measures.

6. Data to be provided by national experts for the completion of the database for their own country (p.6)

Table 6.2.1 : Fuel parameters

Table 6.2.2 : Fuel prices (net of taxes)

Table 6.2.3 Fuel consumptions (GJ / y)

Total activity (t fuel consumed / y) in 2000 to 2020.

Table 6.2.4 : Distribution of the different engine size

Table 6.2.5 : Engine characteristics in the base year 2000

Pollutant's emissions are assessed by the fuel consumption method.

Table 6.2.6 : Fuel efficiency improvement for individual engine sizes

Table 6.2.7 : Change in activity per engine relative to the base year

Table 6.2.8 : Application rate and Applicability (% of total activity (fuel use))

7. Explanatory notes on emission factors and costs (p.10)

Cost data are derived from reference [1]. Emission factors come from reference [4].

8. References (p.13)

9. Modifications compared to the draft document (p.14)

LARGE SPARK-IGNITION (SI) ENGINES
Engines rated above 19 kW

SNAP : 0806 and 0807 or NFR 1A4cii Off-road Vehicles and Other Machinery, **SNAP 0808** or NFR 1A2 Manufacturing Industries and Construction, **SNAP 0809** or NFR 1A4bii Household and gardening (mobile motors), **SNAP 0810** or NFR 1A3eii Other mobile sources and machinery.

This category of engines gathers forklifts, generator sets, commercial turfs, pumps, welders…

These engines can be categorized by cooling system and fuel type.
Two types of cooling systems are available : air and water cooling. Air-cooled engines represent a minority of the market.
[1] reports three types of fuels : gasoline, LPG and natural gas which is not very common. For our purpose, only gasoline and LPG engines are studied.

ACTIVITY : fuel consumption (GJ/year)
POLLUTANTS CONSIDERED : NOx, HC, PM and SO_2. PM are not studied in this document.

1 Data currently used in the RAINS model

Following data are just displayed for comparison reasons.

Data are derived from reference [5].

- Activity

Activity used in the current stage of development of the RAINS model is the fuel used (expressed in PJ of fuel consumed).

- Emission factors

Table 1.1 : Emission factors used in the RAINS PM module for off-road spark ignition engines

Sector	$PM_{2,5}$ [g/GJ]	PM_{10} [g/GJ]	TSP [g/GJ]
Land-based machinery gasoline (4-stroke)	28,0	30,4	33,8
Land-based machinery LPG/CNG (4-stroke)	3,90	4,20	4,24

- Engines considered

Table 1.2 : Sectors considered in RAINS

Abbreviations used in RAINS	Sector
TRA_OT_LB	Land-based machinery gasoline (4-stroke)
TRA_OT_LB	Land-based machinery LPG/CNG (4-stroke)

- Techniques and associated costs

The RAINS model includes options to control emissions from gasoline engines, equivalent to the EURO-I to EURO-V standards for gasoline cars.

2 Short technology description

According to USEPA [1], large non-road SI engines are exclusively 4-strokes.

2.1 Gasoline-fuel engines

Virtually all automobiles and many trucks are powered by four-strokes 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-road SI engines are exclusively 4-strokes.

Description : 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).

2.2 Gaseous fuel engines

These engines operate on LPG or natural gas. A mixer introduces the fuel into the intake system. Research are done to inject the fuel directly into the intake manifold.

3 Regulations

These engines are not regulated in Europe yet. Assumptions in this document are based on the American regulation. In Europe, only SI engines rated under 19 kW are regulated in the framework of Directive 2002/88/EC [2].

3.1 American regulation

This document is based on American data [1] related to standards for large SI engines rated above 19 kW.

The US have adopted two stages :

Table 3.1.1 : 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.

3.2 Sulphur content of fuels

We assume that petrol used in large SI engines is the same as petrol used in on-road vehicles. Sulphur content of this type of fuel is regulated by Directives 98/70/EC [3] and 2003/17/EC [6] relating to the quality of petrol and diesel fuels.

Table 3.2.1 : Sulphur content of petrol : standards (ppm) implemented by the two Directives

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

Some Member States have implemented more stringent national standards. This is a country specific information which has to be provided by national experts (chapter 6).

4 Definition of Reference Engines

The study distinguishes engines according to their fuel types : LPG-fueled or gasoline-fueled.

Table 4.1 : Reference engines

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

5 Emission abatement techniques and costs

5.1 Definition of abatement measures

5.1.1 Baseline technology

Baseline technology correspond 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.

5.1.2 Advanced technology

Since most Large SI engines are derived from automotive counterparts, much of the technology developed for cars and trucks can be utilized for Large SI engines.
All gasoline units should use advanced port-fuel injection for gasoline units.

- Fuel system technologies

To facilitate better control of the air/fuel ration when using three-way catalysts, gasoline fuel systems will probably need to be closed-loop controlled with port fuel injection.

- Oxygen sensors

Oxygen sensors will need to be added before the catalysts for closed-loop control.

- Electronic control modules

Manufacturers will need electronic control modules to handle fuel injection, ignition timing, and diagnostic functions.

- Catalysts

The use of three-way catalyst will be essential.

- Diagnostic functions

Diagnostic is fundamental for air/fuel ratio control. The diagnostic can also include oxygen sensor malfunction, catalyst performance variables…

Table 5.1.1 : Technology improvements to reach Stage I emission limits

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

5.2 Emission factors and costs data for the different combinations

Table 5.2.1 : Emission factors for each combination code

REC MC	EF HC (g/kWh)	Q	CI %	EF NOx (g/kWh)	Q	CI %
01 00	10,88	4	30	4,15	4	30
01 01	2,90	2	40	1,10	2	40
02 00	13,50	3	30	10,00	3	30
02 01	2,30	2	40	1,70	2	40

EF : Emission Factor
Q : Quality of data
CI % : Coefficient of variation

Table 5.2.2 : Investments and operating costs

REC MC	Investments (€$_{2000}$)	Q	CI %	Operating costs (€$_{2000}$/y) *
01 00	0	-	-	-
01 01	805	4	20	-
02 00	0	-	-	-
02 01	559	4	20	-

* Operating costs are a mix of different components. See chapter 7.2.2 for further explanations

6 Data to be provided by national experts for the completion of the database for their own country

The following tasks are required :

6.1 Validation work

For representing costs in this sector, the national expert is invited to comment data provided by the Secretariat.

- Validate investments provided,

Or

- Provide other costs for the same combination of techniques and justify them.

6.2 Provision of specific data

Tables to be filled in by national experts

➢ Fuel parameters

Table 6.2.1 : Fuel parameters

	2000	2005	2008	2010	2015	2020
Heat value of diesel [GJ/t]						
Heat value of gas-oil [GJ/t]						

Table 6.2.2 : Fuel prices (net of taxes)

	Fuel prices [(€$_{2000}$ / l]
Petrol 150 ppm (€$_{2000}$/l)	
Petrol 50 ppm (€$_{2000}$/l)	
Petrol 10 ppm (€$_{2000}$/l)	
LPG price (€$_{2000}$/l)	

➢ Activity level

IIASA uses international fuel statistics to define fuel consumption in each country.

Although IIASA tries to derive fuel consumption in each sub-sector from international energy statistics and available energy projections, a high uncertainty still exists. Thus the experts are requested to give the total fuel use for the base year (2000) and a national projection up to 2020 in 5-years intervals. As the use of fuel containing less sulphur is considered as a measure to reduce SO_2 emissions, the consumption of each type of fuels is requested hereafter for 2000 up to 2020 in 5-years intervals.

Table 6.2.3 : Fuel consumptions (GJ / y)

Type of fuel used	**Activity (GJ) 2000**	**CI %**	**Activity (GJ) 2005**	**CI %**	**Activity (GJ) 2010**	**CI %**	**Activity (GJ) 2015**	**CI %**	**Activity (GJ) 2020**	**CI %**
Petrol 150 ppm sulphur										
Petrol 50 ppm sulphur										
Petrol 10 ppm sulphur										
LPG										
Default values proposed for CI		10		20		50		100		100

For explanations on the coefficient of variation (CI), please refer to the Methodology.

➢ Emissions

National experts do not need to calculate the emissions for individual engine/vehicle categories. The calculations will be done by the RAINS model. However, experts are requested to provide country-specific data for calculations. Below the formulas used and the appropriate coefficients are presented.

Annual SO_2 emissions can be calculated as follows :

$$\textbf{Emissions [t/y] = 2} \times \textbf{Fuel Consumption (t/y)} \times \textbf{S content (\%) / 100}$$

For other pollutants, two methods can be used to estimate emissions from non road engines :

- Annual emissions per engine of NOx and HC can be calculated with the following equation :

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

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),

- Consumption method : emission factors are expressed in g of pollutant / GJ using the engine's efficiency.

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

E [t/y]= Fuel consumption [GJ/y] × Emission Factor [g/GJ] / 10^6

This method is used in the RAINS model.

- Distribution of engine's sizes

- Distribution of power ranges (% of total activity (fuel use)) has to be determined for the base year 2000 and projection years 2005, 2010, 2015, 2020. This corresponds to data provided in table 6.2.3.

Table 6.2.4 : Distribution of the different engine sizes (% of total activity (fuel use))

REC	Proportion [%] in 2000	Proportion [%] in 2005	Proportion [%] in 2010	Proportion [%] in 2015	Proportion [%] in 2020
01					
02					
Total	**100**	**100**	**100**	**100**	**100**

- Number of engines

For cost calculations, number of engines in the base year (2000) is necessary. If this information is available, this should be specified in column 2 of table 6.2.5. Alternatively, data about load factor and annual engine use (columns 3 and 4) should be estimated. In both cases a typical operating lifetime of each engine category (column 5) should be given.

Table 6.2.5 : Engine characteristics in the base year 2000

To be completed	Either 2	Or 3 and 4		And 5
Type of engine REC	**Total number of engines**	**Load factor**	**Annual use (h/y)**	**Operating lifetime (years)**
01				
02				

Default values used by reference [1]

REC	Average power (kW)	Load factor	Annual use (h/y)	Operating life (years)
01	39	0,58	536	12,3
02	50	0,39	1 365	12

- Other parameters

Engine characteristics given in Table 6.2.5 are valid for the base year 2000. For other years, two additional parameters should be specified :

- fuel efficiency improvement (Table 6.2.6),
- change in activity per engine, i.e. combined effect of the change in annual use and load factor (Tables 6.2.7).

If country specific data are not available, default values already included in the following tables will be used .

Table 6.2.6 : Fuel efficiency improvement for individual engine sizes relative to the base year (Fuel consumption per unit of output in year 2000 = 100 %)

REC	2000	2005	2005	2010	2010	2015	2015	2020	2020
01	100	98		96		94		92	
02	100	98		96		94		92	

Table 6.2.7 : Change in activity per engine relative to the base year (Activity per engine in year 2000 = 100 %)

REC	2000	2005	2005	2010	2010	2015	2015	2020	2020
01	100	100		100		100		100	
02	100	100		100		100		100	

- Application rate and applicability

IIASA experts assume a certain lifetime of engines and from this they calculate what proportion of total fuel use will be by vehicles purchased after the date of enforcing of a certain regulation.
Since national experts may have more detailed data, it is worth to ask them about application rates and applicability factors.

Table 6.2.8 : Application rate and Applicability (% of total activity (fuel use))

REC MC	Application rate in 2000 [%]	Application rate in 2005 [%]	Appl. [%]	Application rate in 2010 [%]	Appl. [%]	Application rate in 2015 [%]	Appl. [%]	Application rate in 2020 [%]	Appl. [%]
01 00									
01 01									
Total REC 01	**100**	**100**		**100**		**100**		**100**	
02 00									
02 01									
Total REC 02	**100**	**100**		**100**		**100**		**100**	

7 Explanatory notes

7.1 Emission factors

According to reference [1], average rated powers for REC 01 and REC 02 are respectively 39 kW and 50 kW. Unabated emission factors (table 7.1.1) correspond to the power range 37-75 kW.

Table 7.1.1 : MC 00 (baseline) emission factors for 4-stroke gasoline-fuel engines (g/kWh) [4]

Power (kW)	37-75	Q	CI %
NOx	4,15	4	30
HC	10,88	4	30

The following emission factors are derived from [5] and are considered similar for all power outputs.

Table 7.1.2 : MC 00 (baseline) emission factors for 4-stroke LPG-fuel engines (g/kWh) [4]

Power (kW)	All range	Q	CI 30%
NOx	10,00	3	30
HC	13,50	3	30
CH_4	1,00	3	30

For MC 01 where standards are given as the sum of HC and NOx pollutants, we assumed the HC/NOx ration would remain the same as for the pre-control stage.

Table 7.1.3 : MC 01 emission factors for 4-stroke gasoline-fuel engines (g/kWh)

Power (kW)	37-75	Q	CI %
NOx	1,10	2	30
HC	2,90	2	30

Table 7.1.4 : MC 01 emission factors for 4-stroke LPG-fuel engines (g/kWh)

Power (kW)	20-100	Q	CI %
NOx	1,70	2	30
HC	2,30	2	30

7.2 Derivation of cost data

Cost data are derived from the EPA reference [1].

In [1], costs are given in $\$_{2001}$. $\$_{2000}$ are calculated from the inflation rate [8]. The following equivalence is used : 1 US$\$_{2001}$ = 0,98 $\$_{2000}$ and 1$\$_{2000}$ = 1,08$€_{2000}$. 1 US$\$_{1997}$ = 1,22 $€_{2000}$

7.2.1 Investments

- Gasoline-fuel engines costs

Table 7.2.1.2 : Gasoline-fueled engine costs [$€_{2000}$]

	Baseline situation	**Controlled situation**	**Q**	**CI %**
Fuel system	144	538	4	
Catalyst/muffler	-	229	4	
Muffler	45	-	4	
Total hardware costs *	244	1 018	4	
Fixed cost per engine **	-	30	4	
Total engine cost	244	1 048	4	
Incremental total cost	805		4	20

* Hardware costs comprise the fuel system, the catalyst and muffler, the markup of 29% and warranty markup @ 5%.
** Fixed costs correspond to R&D costs.

- LPG fuel engines costs

Table 7.2.1.1 : LPG fuel engines costs [$€_{2000}$]

	Baseline situation	**Controlled situation**	**Q**	**CI %**
Fuel system	217	431	4	
Catalyst/muffler	-	229	4	
Muffler	45	-	4	
Total hardware costs *	338	871	4	
Fixed cost per engine **	0	26	4	
Total engine cost	338	897	4	
Incremental total cost	559		4	20

* Hardware costs comprise the fuel system, the catalyst and muffler, the markup of 29% and warranty markup @ 5%.
** Fixed costs correspond to R&D costs.

7.2.2 Operating costs

Several data are required in the RAINS model.

- Fuel consumption variations

Benefits of gasoline fuel injected systems and electronic closed loop control LPG mixers over open loop carburetors and mixers are estimated at 10 to 20%. An average value of 15% is used.

Table 7.2.2.1 : Average fuel consumption variation [%] compared to MC 00

MC	**Consumption variation [%]**	**Q**	**CI %**
00	0	-	-
01	- 15	3	5

- Maintenance and engine life improvements [1]

A 15% in engine life between rebuilds and a 15% longer maintenance intervals are assumed.

No information is available to translate it as a percentage of investment.

- Additional costs for the use of low sulphur fuel

We assume that petrol used in small SI engines is the same as petrol used in on-road vehicles. Sulfur content of this type of fuel is regulated by Directive 98/70/EC [3] and Directive 2003/17/EC [6] relating to the quality of petrol and diesel fuels.

Costs of the different types of fuel have to be entered only once in the tool in table "Fuel characteristics". Costs displayed in table 7.2.2.2 are given as example.

Additional investment and refinery operating costs associated with lowering the sulphur content from a maximum of 50 ppm to a maximum of 10 ppm. The main driver of cost difference between north and south EU is the quality of the crude oil (in particular the sulphur content) that the refineries are currently to handle.

Table 7.2.2.2 : Costs of lowering the sulphur content of petrol [7]

	Min. (€/l)	**Max. (€/l)**	**Average (€/l)**
EU, North	0,001	0,003	0,002
EU, South	0,002	0,003	0,0025

8 References

[1] 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.

[2] 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.

[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] Z. SAMARAS, K.-H. ZIEROCK. Guidebook on the Estimation of the Emissions of “Other Mobile Sources and Machinery. Final Report. September 1994.

[5] Z. KLIMONT; J. COFALA ; I. BERTOK ; M. AMANN ; C. HEYES and F. GYARFAS. Modelling Particulate Emissions in Europe. A Framework to Estimate Reduction Potential and Control Costs. Interim Report. IR-02-076. IIASA. 2002.
http://www.iiasa.ac.at/rains/reports/ir-02-076.pdf

[6] 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.

[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.

[8] http://www.gpec.org/InfoCenter/Topics/Economy/USInflation.html

9 Modifications compared to the draft document

It has to be highlighted that PM are not considered in this document.

9.1 Modifications of Chapter 5

Table 5.2.1 : Emission factor of REC 01 have been modified according to reference [4].

Table 5.2.2 : Investments have been modified. Equivalences between $ and € have been reviewed and in this final document.

9.2 Modifications of Chapter 6

Some tables have been added to be in compliance with IIASA's requirements.

As the use of fuel containing less sulphur is considered as a measure to reduce SO_2 emissions, the consumption of each type of fuels is requested (**table** 6.2.3).

Somme parameters are necessary to define the number of engines. National experts have to provide either the number of engines or the load factors and the annual use for each type of engines. Some default values are provided on page 8.

New tables have been added : the fuel efficiency improvement and the change in activity per engine (if no national statistic is available, default values will be used in the model RAINS).

Application rate and applicability (% of total activity (fuel use)) are also requested (**table** 6.2.8).

9.3 Modifications of Chapter 7

Costs have been recalculated with the new equivalence between $ and €.
Available data are not precise enough to provide maintenance costs as a percentage of the investment.