Final Background Document
on the sector

Off Road
HANDHELD SPARK IGNITION ENGINES
(2-stroke ; < 19 kW)

Prepared by CITEPA, Paris

Summary

Small Spark-Ignition (SI) Handheld Engines

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.

Small SI Engines represent the category of engines below 19 kW: usually running with petrol, these engines are often used in lawn and garden equipment.

ACTIVITY: Consumption of fuel (GJ/year)
POLLUTANTS CONSIDERED : HC, NOx, TSP and SO_2

1 Data currently used in the RAINS model

Following data are just displayed for comparison purposes

Data are derived from reference [9].

- Activity

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

- Emission factors

Table 1.1: Emission factors used in the RAINS PM module for diesel off-road spark ignition engines [g/GJ]

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
Land based machinery gasoline (2-stroke)	289	381	423

- 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)
TRA_OT_LD2	Land based machinery gasoline (2-stroke)

- Techniques and associated costs

In its current stage of development, the RAINS model includes options to control emissions from gasoline engines, equivalent to EURO-I to EURO-V standards for gasoline cars. 2-stroke engines are considered with mopeds.

2 Short technology description

Two types of engines exist: 4-stroke engines and 2-stroke engines.

2.1 Current 2-stroke engines

These engines are widely used in non-road applications, especially for hand held portable products and recreational vehicles. These engines are known as charge scavenged 2-stroke engines. 2-stroke engines eliminate the intake and exhaust strokes, leaving only compression and power strokes. This is due to the fact that 2-stroke engines do not use intake and exhaust valves.

They have advantages comparing to 4-stroke engines:
High power-to-weight ratios, simplicity, ease of starting, lower manufacturing costs, but also much higher HC emission rates.

2.2 Emissions

The majority of HC emissions from traditional 2-stroke engines are a result of the short circuiting of fresh charge during scavenging and misfire or partial combustion at light loads and idle conditions. In addition, high HC and CO emissions also result from incomplete combustion due the rich air/fuel ratios. NOx emissions tend to be low because of the rich air/fuel ratio and the inherent EGR from imperfect scavenging.
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 sulphur content of petrol.

3 EU regulation: Directive 2002/88/EC amending Directive 97/68/EC [2]

3.1 Emission limit values developed in the proposal

The EU commission proceeded to an inventory of pollutant emissions for the amendment of the Directive 97/68/EC [3]. Data used for this study date from 1990.

Table 3.1.1: HCs emissions from spark ignition (SI) engines (kt)

Category per rated power (kW)	Emissions of 2-stroke engines (kt)	Emissions of 4-stroke engines (kt)	Total HC (kt)
0-2	108,86	24,74	133,60
2-5	323,58	29,18	352,76
5-10	217,57	18,53	236,10
10-18	113,54	3,48	117,02
18-37	29,29	2,65	31,94
37-75	11,72	27,67	39,39
75-130	5,25	6,10	11,35
130-300	5,30	5,52	10,82
Total			932,98

Engines below 18 kW emit 90% of the HC of spark ignition category.

Directive 2002/88/EC regulates these small engines which represent the main emission sources for SI off-road engines (as shown above).

Three types of engine families are considered handheld: class SH1, SH2 and SH3.

- Class SH1: engines are used almost solely in trimmers/cutters and are sold mainly to low use residential consumers.
- Class SH2: covers a wider range of applications from trimmers/cutters and blowers to chainsaws for use by low use residential consumers and high use commercial users.
- Class SH3: mainly used in chainsaws, rammers and cut-off saws aimed at the commercial users. Very few trimmers and blowers are certified in this class.

2 stages have been adopted:

Table 3.1.2: HC and NOx emission limit values for Stage I

Engine class	HC emission limit values [g/kWh]	NOx emission limit values [g/kWh]
Class SH1	295	5,36
Class SH2	241	5,36
Class SH3	161	5,36

Table 3.1.3: HC + NOx emission limit values for Stage II

Engine class	HC + NOx emission limit values [g/kWh]
Class SH1	50
Class SH2	50
Class SH3	72 *

* Application of certain technologies as the catalyst is not feasible for the Class SH3. That's why adopted emission limit values are less stringent than for Class SH1 and SH2.

A list of exemptions is available. Some examples are listed bellow:

- Recreational boats (which should be regulated by a modification of Directive 94/25/EC),
- Recreational vehicles as snowmobiles (a majority of these engines are rated above 19 kW).

3.2 Sulphur content of fuels

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 [4] and Directive 2003/17/EC [8] relating to the quality of petrol and diesel fuels.

Table 3.2.1: Sulphur content of petrol: standards (ppm) implemented by the 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 three engine classes are considered as reference engines.
Power ratings vary: average figures are given in table 4.1.

Table 4.1: Reference engines

Reference Engine Codes REC	Description	Exemples
01	Class SH1 < 20 cc 1 kW [11]	Residential equipment, String trimmers, leaf blowers, chainsaws
02	Class SH2 20 to 50 cc 1,5 kW [11]	
03	Class SH3 > 50 cc 2 kW [11]	Augers, Commercial equipment, chainsaws…

5 Emission abatement techniques and costs

5.1 Definitions of abatement techniques

5.1.1 Measures to meet Stage I emission limit values

According to USEPA, the big majority of engines sold are 2-stroke engines.

5.1.2 Measures to meet Stage II emission limit values

According to the USEPA and [11], in-use emission limit values can be met through conversion of 2 stroke to 4 stroke, stratified scavenging with lean combustion and a medium/high efficiency catalyst (in Classes SH1 and SH2) and without catalyst (in Class SH3), and compression wave technologies with a medium efficiency catalyst (Class SH1 and SH2) and without a catalyst (Class SH3).
Other supporting technologies include engine redesign with or without catalyst technologies.

- Compression Wave Technology

This technology relates to a compressed air assisted fuel injection system for internal combustion engines, specifically 2-stroke engines. Its primary characteristic is in its low emission performance, namely through almost total elimination of an unburned fuel charge during the scavenging process of the exhaust portion of the 2-stroke cycle.

- Stratified Scavenging with Lean Combustion (with and without catalyst)

A drawback of 2-stroke engines is that they use the incoming fuel charge to scavenge, or expel, exhaust gases from the previous combustion event. About 30% of the intake charges goes out the exhaust port with the exhaust.
Stratified scavenged engines means that the scavenging is done with something other than the fuel/oil/air charge.
This technique may lower the power but it also reduces fuel consumption and engine emissions.

- Conversion of handheld 2-stroke designs to 4-stroke designs

2-stroke engines are widespread used for handheld applications whereas 4-stroke engines have been limited to ground supported applications.
Mini-4-stroke engines have been improved but for the moment, this technology has not been demonstrated as able to cover the smallest (<20cc) range of engine sizes.

Table 5.1.1: Aggregated abatement measure definitions

Measure codes (MC)	Assumed Technologies
00	None
01	Mix of technologies to reach Stage I emission limit values
02	Mix of technologies to reach Stage II emission limit values

5.2 Emission factors and cost data for the different combinations

Table 5.2.1: Emission factors (EF) for each combination code

REC MC	EF VOC (g/kWh)	NOx EF (g/kWh)	EF TSP (g/kWh)	Q	CI %
01 00	355,4	1,0	5,3	3	30
01 01	230,0	1,5	3,5	3	35
01 02	49,1	1,5	3,5	3	35
02 00	300,0	1,0	5,3	3	30
02 01	188,0	1,5	3,5	3	35
02 02	44,0	1,5	3,5	3	35
03 00	158,0	1,1	2,7	3	30
03 01	126,0	2,0	1,8	3	35
03 02	64,0	1,2	1,8	3	35

Table 5.2.2: Investments and operating costs compared to the unabated measure MC00

REC MC	Investments (€$_{2000}$)	Q	CI %	Operating costs (€$_{2000}$/y) *
01 00	0	-	-	-
01 01	8,5	3	20	-
01 02	33,5	3	20	-
02 00	0	-	-	-
02 01	8,5	3	20	-
02 02	30,1	3	20	-
03 00	0	-	-	-
03 01	8,5	3	20	-
03 02	69	3	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 of 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 petrol [GJ/t]						

Table 6.2.2: Fuel prices (net of taxes)

	2000	2005	2008	2010	2015	2020
Petrol 150 ppm (€$_{2000}$/l)						
Petrol 50 ppm (€$_{2000}$/l)						
Petrol 10 ppm (€$_{2000}$/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.

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										
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 of VOC, NOx and TSP per engine can be calculated with the following equation :

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

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.

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

This method is used in the RAINS model.

Ø 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.

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 (SH1)					
02 (SH2)					
03 (SH3)					
Total	**100**	**100**	**100**	**100**	**100**

Ø 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 (SH1)				
02 (SH2)				
03 (SH3)				

In this document, only average figures are required

According to [1] (appendix F: http://www.epa.gov/otaq/regs/nonroad/equip-ld/hhsfrm/apx-f-fr.xls), average load factors are very different from one device to another (for example, load factors can vary from 35 for snow blowers to 91 for trim/edge cutters).
Annual uses differ according to the type of use (i.e. residential or professional use) and the type of device: they are usually less than 10 h/year for residential use and can go up to about 700 h/y for professional use of turf.

Ø 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	
03	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	
03	100	100		100		100		100	

Ø 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									
01 02									
Total REC 01	**100**	**100**		**100**		**100**		**100**	
02 00									
02 01									
02 02									
Total REC 02	**100**	**100**		**100**		**100**		**100**	
03 00									
03 01									
03 02									
Total REC 03	**100**	**100**		**100**		**100**		**100**	

7 Explanatory notes

7.1 Emission factors (EF)

VOC unabated emission factors are derived from reference [5] for REC01 and from reference [15] fro REC02 and 03. They decrease with the size of the engine. NOx and TSP emission factors are all derived from reference [15]. As no data is given for REC01 (which is not used according to reference [15]), the same emission factors as for REC 02 are considered.

Table 7.1.1: MC 00 (Pre-control) emission factors (g/kWh)

REC	VOC EF	NOx EF	TSP EF	Q	CI %
01 (SH1)	355,4	1,0	5,3	3	30
02 (SH2)	300,0	1,0	5,3	3	30
03 (SH3)	158,0	1,1	2,7	3	30

For MC 01 and MC 02, emission limit values are used as in-use emission factors. Deterioration factors have not been taken into account in this study.
Emission factors for REC02 and 03 come from reference [15]. For REC01 which is not considered, a VOC emission factor of 230 g/kWh is considered (being about 78% of the emission limit value defined in the Directive 2002/88/EC as for REC02). NOx and TSP emission factors for REC01 are based on REC02's ones.

Table 7.1.2: MC 01 emission factors (g/kWh)

REC	VOC EF	NOx EF	TSP EF	Q	CI %
01 (SH1)	230	1,5	3,5	3	35
02 (SH2)	188	1,5	3,5	3	35
03 (SH3)	126	2,0	1,8	3	35

For MC 02, NOx and HC emission limit factors are given as the sum of HC and NOx. Emission factors are derived from reference [15].

Table 7.1.3: MC 02 emission factors (g/kWh)

REC	VOC EF	NOx EF	TSP EF	Q	CI %
01 (SH1)	49,1	1,5	3,5	3	35
02 (SH2)	44,0	1,5	3,5	3	35
03 (SH3)	64,0	1,2	1,8	3	35

7.2 Derivation of cost data

Cost data are derived from references [7] for MC 01 and from [6] for MC 02.

In [7], costs are given in $\$_{1995}$. $\$_{2000}$ are calculated from the inflation rate [13]. The following equivalence is used: 1 US$\$_{1995}$ = 1,13 $\$_{2000}$ and 1$\$_{2000}$ = 1,08€$_{2000}$ [12]. 1 US$\$_{1995}$ = 1,22 €$_{2000}$.
In [6], costs are given in $\$_{2000}$. The following equivalence is used:
1$\$_{2000}$ = 1,08€$_{2000}$ [12].

For MC 01, only average over-costs of techniques for all categories of engines are given.
For MC 02, average over-costs are given by type of engines [6].

Average retail price of equipment that uses handheld engines ranges from 75 to 1 200€. According to [7], average cost increase should be around 8,5 €.

7.2.1 Investments

Table 7.2.1.1: Incremental costs <u>from Pre-control to Stage I and from Stage I to Stage II engines</u> [€$_{2000}$]

REC MC	Investments	Q	CI %
01 00	0	-	-
01 01	8,5	3	20
01 02	25	3	20
02 00	0	-	-
02 01	8,5	3	20
02 02	21,6	3	20
03 00	0	-	-
03 01	8,5	3	20
03 02	60,5	3	20

7.2.2 Operating costs

- Fuel consumption variations

According to [7], completion with Stage I emission limit values is expected to decrease fuel consumption by 13% in average.
According to [1], fuel consumption will be reduced by 30% between MC 01 and 02 which represent a fuel consumption reduction of 39 % compared to MC 00.
After treatment devices do not result in operational cost savings as the emission reduction is based on the post combustion oxidation of the fuel [11].

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

MC	Consumption variation [%]	Q	CI %
00	0	-	-
01	- 13	3	25
02	- 39	3	25

- 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 [4] and Directive 2003/17/EC [8] 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".

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 7.2.2.1: Costs of lowering the sulphur content of petrol [10]

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

- Maintenance and repair

According to EPA [7], engines complying with MC 01 emission limit values will be of higher quality than current engines. The parts and raw materials will be more durable and less likely to malfunction: effects on operation and maintenance will be minimal.

However, no quantification is available.

8 References

[1] Final Regulatory Impact Analysis. Phase 2 Final Rule : Emission Standards for New Non-road Handheld Spark-Ignition Engines At or Below 19 Kilowatts. Assessment and Standards Division. Office of Transportation and Air Quality. USEPA. EPA420-R-00-004. March 2000.

[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 97/68/EC of the European Parliament and of the Council of 16 December 1997 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 [Official Journal L 59, 27.02.1998].

[4] 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].

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

[6] Regulatory announcement. Office of Transportation and Air Quality. EPA420-F-00-007. March 2000.

[7] Control of Air Pollution; Emission Standards for New Nonroad Spark-ignition Engines At or Below 19 Kilowatts. July 3, 1995 (Volume 60, Number 127).
http://www.epa.gov/EPA-AIR/1995/July/Day-03/pr-805.txt.html

[8] 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.

[9] 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

[10] 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.

[11] Common meeting. Euromot-CITEPA. March 2003.

[12] ECB monthly bulletin.

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

[14] Exhaust Emission Factors for Nonroad Engine Modelling-Spark Ignition. Report No. NR-010b. EPA420-R-99-009.

[15] Entwicklung eines Modells zur Berechnung der Luftschadstoffemissionen und des Kraftstoffverbrauchs von Verbrennungsmotoren in mobilen Geraten und Maschinen. IFEU. January 2004.

9 Modifications compared to the previous document

TSP emissions are now considered in the document. Information comes from reference [15] which deals especially with emissions from off-road engines.

9.1 Modifications of Chapter 5

Table 5.2.1: Emission factors have been reviewed according to new data released in 2004.

9.2 Modifications of Chapter 7

Explanations about emission factor modification and update are given in this chapter. These new data are based on the latest reference on the subject. As REC01 is not considered in reference [15], emission factors for this reference engine gave been assumed.