SMALL HANDHELD 2-STROKE ENGINES

SYNOPSIS SHEET

Prepared in the framework of EGTEI

1. Activity description and EGTEI contribution - summary

Engines considered in EGTEI document [1] are widely used in non-road applications, especially for handheld portable products and recreational vehicles. These engines are known as charge scavenged 2-stroke engines. They 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 VOC emission rates.

The majority of VOC 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 VOC 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 gasoline sulphur content.

In RAINS, all off-road 2-stroke engines are considered together as country specific statistics on fuel consumption are not detailed enough. NOx emissions at a EU25 level (according to the RAINS model: version CP_CLE_Aug04(Nov04)) are about 1.5 kt representing only 0.02% of transport emissions. VOC emissions are much higher: 525.8 kt being about 12% of transport emissions.

These engines are addressed by the European Directive 2002/88/EC [2]. Fuels used are also regulated by the Directives 98/70/EC [3] and 2003/17/EC [4]. Only engines rated below 18kW are considered in the Directive because they emit 90% of VOC emissions from small off-road engines (according to an inventory from the European Commission). In order to be able to better represent the impact of these Directives in terms of emission reductions and costs, this sector **has been defined as an individual activity by EGTEI [1]**. In RAINS [5], off-road 2-stroke engines are considered separately for control strategy and emission calculation. Abatement measure investments are defined as the moped ones but, as annual consumptions are distinguished for these 2 engine types, unit costs are different. This allows the model treating these sectors separately even on the cost issue.

The representative unit used is the amount of fuel consumed annually (PJ/year). Three engine's sizes are considered as in the Directive 2002/88/EC. Two stages per engine's type are taken into account as in the regulation.

EGTEI provides default emission factors (EF) with abatement efficiencies, investments as well as unit costs (€/t pollutant abated) for each engine category. No information has been found concerning variable costs (corresponding to maintenance and repair and defined as a percentage (%) of the investment in RAINS). Only fuel savings according to the stage considered are provided.

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, types of fuel used according to the year and costs of the fuels used).

Simplified cost data have been used in RAINS but this is very difficult to determine precisely what has been taken into account.

In the future, any new regulation or new technical improvements should be defined with corresponding emission factors and costs in the EGTEI background document. Moreover, national data should be improved so this sector can be specifically represented in RAINS in terms of emissions and costs.

2. European regulation

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 2.1: 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 2.2: 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 is 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 are regulated separately),
- Recreational vehicles as snowmobiles (a majority of these engines are rated above 19 kW).

It is assumed that gasoline used in small SI engines is the same as gasoline used in on-road vehicles. Sulfur content of this fuel is regulated by Directive 98/70/EC [3] and Directive 2003/17/EC [4] relating to the quality of gasoline and diesel fuels.

Table 2.3: Sulphur content of gasoline: standards (ppm) implemented by the Directives

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

3. Methodology developed within EGTEI to represent the sector

3.1 Definition of reference engines for each type of engines

The three engine classes are considered as reference engines.

Table 3.1.1: Reference engines

Reference Engine Codes REC	***Description***	***Exemples***
01	Class SH1 < 20 cc 1 kW [6]	Residential equipment, String trimmers, leaf blowers, chainsaws
02	Class SH2 20 to 50 cc 1.5 kW [6]	
03	Class SH3 > 50 cc 2 kW [6]	Augers, Commercial equipment, chainsaws…

3.2 Definition of emission abatement techniques

According to the USEPA, 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.

Table 3.2.1: 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

4. Country specific data to be collected

National experts do not have to calculate emissions per vehicle category. Calculations will be done in RAINS. However, experts are requested to provide country-specific data for calculations. The formulas used and the appropriate coefficients are presented below (2 options are available):

- Option I: annual NOx, VOC and TSP 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.

According to [7] (appendix F: http://www.epa.gov/otaq/regs/nonroad/equip-ld/hhsfrm/apx-f-fr.xls), average load factors are very different from one engine 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.

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) with investments.

5.1 Reduction of VOC, NOx and TSP

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 the engine's lifetimes and an interest rate of 4%). Unit costs for NOx and TSP are not calculated because big uncertainties remain on emission factors and investments are incurred to reduce VOC emissions.

Examples of unit costs are given in table 5.1.2 according to different engine's uses [8].

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

REC MC	VOC EF [g/outp.kWh]	NOx EF [g/outp.kWh]	TSP EF [g/outp.kWh]	Invest. [€/engine]
01 00	355.4	1.0	5.3	0
01 01	230	1.5	3.5	8.5
01 02	49.1	1.5	3.5	23.5
02 00	300	1.0	5.3	0
02 01	188	1.5	3.5	8.5
02 02	44	1.5	3.5	30.1
03 00	158	1.1	2.7	0
03 01	126	2.0	1.8	8.5
03 02	64	1.2	1.8	69

* Only investments are taken into account in the calculations

Table 5.1.2: Emission factors (EF), investments and abatement costs for each combination

REC MC	Engine's use	Power rate (kW)	Load factor	Hours in use (h/y)	Unit costs [€/t VOC]*
01 00	Trimmer/household&gardening	1.0	0.4	10	-
01 01					1,524
01 02					2,459
01 00	Plate compacter/industry	2	0.75	200	-
01 01					20
01 02					33
02 00	Chain saw/household&gardening	1.5	0.4	15	-
02 01					758
02 02					1,175
02 00	Professional chain saw	3	0.6	650	-
02 01					6
02 02					9
03 00	Other household&gardening	5	0.5	15	-
03 01					637
03 02					1,761
03 00	Other agricultural equipment	10	0.4	500	-
03 01					119
03 02					330

5.2 Sulphur content of fuels

Gasoline used in small SI engines is assumed to be the same as the one used in on-road vehicles. Sulphur content of this 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 [9], 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 petrol [9]

	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, small 2-stroke engines are considered all together. No distinction is made between handheld and non-handheld engines because no statistics exist at this level of detail. Investments for the different abatement measures are the same than for mopeds. Annual fuel consumptions per vehicle are differentiated so that unit costs can be considered separately. It is then very difficult to compare economic data presented in the EGTEI background document [1] and data currently used in RAINS.

The unabated VOC emission factor used in RAINS is 10,000 g/GJ being 102 g/kWh (when converting with an engine efficiency of 35% as defined by CIAM). The value expressed in g/kWh is underestimated compared to data defined in the EGTEI document (varying from 158 to 355 g/kWh). Three abatement stages are considered in RAINS with efficiencies on VOC emissions of 65, 87 and 88%. Efficiency of the first stage goes further than the one defined in EGTEI. The second stage is rather the same. No third stage is studied in EGTEI for off-road 2-stroke engines.

7. Perspective for the future

In the future, any new regulation should be considered by EGTEI in the background document to continuously improve the representation of the sector.

Emission factors and country specific parameters should also be reviewed as new reports have been released.

8. Bibliography

[1] EGEI background document.
http://citepa.org/forums/egtei/small_SI_handheld_engines_2_stroke_300603.pdf
This background document has been updated and a new version from 01/04/05 will be released.

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

[6] Common meeting. Euromot-EGTEI. March 2003.

[7] 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.

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

[9] 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.

[10] OFEFP- Report n° 136 - p.103

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

A. Country specific data collection and scenarios developed

2 and 4-stroke engines are studied together in the following example as they are considered together in the French inventory. It is assumed that all handheld engines are 2-stroke and all non-handheld engines are 4-stroke.

Activity levels are derived from the French national statistics on fuel consumption per sector (after a pre-treatment of the data). Fuel consumption is defined for 2 sub-sectors: agriculture and household applications.

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. Gasoline consumption is assumed to decrease from 2010 to 2020. This can be explained by the increasing use of electric lawn mowers for example. These figures have not been validated by the French expert yet. For the years 2005 and 2015, average figures are taken into account.

Table A.1: Gasoline consumptions (PJ / y)

Activity	2000	2005	2010	2015	2020
Agriculture [PJ]	1.15	1.21	1.28	1.28	1.28
Household [PJ]	3.75	3.92	4.08	3.76	3.43
Total [PJ]	4.90	5.13	5.36	5.04	4.71

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
Gasoline sulphur content (%)	0.015	0.005	0.001	0.001	0.001
Heat value of gasoline [GJ/t]	44	44	44	44	44

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

French specific data are available at different level of detail according to the sub-sector:

Types and number of engines are assumed for the 2 sub-sectors (i.e. agricultural and household). Engine characteristics (load factor, operating hours…) are derived from the reference [8]: this makes it possible to estimate the annual fuel consumption per engine and then the total fuel consumption for 2-stroke and 4-stroke engines. The consumption share is assumed to remain the same from 2000 to 2020 as no detailed data are available.

Table A.4: Share of fuel consumption in 2- and 4-stroke engines [% of total fuel consumption]

	2000	2005	2010	2015	2020
2-stroke engines	23.3	23.3	23.3	23.3	23.3
4-stroke engines	76.7	76.7	76.7	76.7	76.7

Emission factors used in the French inventory are given for two types of engines as an example. Chain saws are representative for 2-stroke engines and lawn mowers for 4-stroke engines.

Unabated emission factors are derived from reference [8] where they are provided in g/kWh per type of engines. As all engine characteristics are also given (load factor, annual consumption of fuel, annual use and average power rate), it is possible to calculate annual emissions. Emission factors in g/GJ are then deduced.

Table A.5: VOC emission factors for 2 engine types (g/GJ)

REC	Chain saws (2-stroke)	Lawn mowers (4-stroke)
None	11,837	1,039
Stage I	11,411	726
Stage II	2,289	726

Table A.6: NOx emission factors for 2 engine types (g/GJ)

REC	Chain saws (2-stroke)	Lawn mowers (4-stroke)
None	48	325
Stage I	71	319
Stage II	78	319

Table A.7: TSP emission factors for 2 engine types (g/GJ)

REC	Chain saws (2-stroke)	Lawn mowers (4-stroke)
None	220	30
Stage I	220	30
Stage II	220	30

These emission factors are consistent with data provided in the EGTEI document. They are not exactly the same because EGTEI emission factors are given as average figures for each engine category: in the French inventory, engines are considered separately. TSP emissions are also considered for 4-stroke engines [10] even if these emissions are not taken into account in some references.

The control strategy is defined by considering average lifetime of each engine's category (between 7 and 15 years according to the use) and by considering different dates of entry into force for the two abatement stages as defined in the regulation.

This is not further developed in this synopsis sheet because of the complexity of this exercise and for confidentiality reasons. Average emission factors for the totality of the fleet and corresponding emissions are presented in paragraph B bellow.

B. Trends in emission factors and emissions

Emissions are calculated with a simplified approach by considering average emission factors and control strategies for each type of engine (2 and 4-stroke engines).

Table B.1: Emission factors evolving with the control strategy

REC	2000	2005	2010	2015	2020
NMVOC (g/GJ)	3,620.5	3,576.7	2,837.4	2,125.8	1,452.5
NOX (g/GJ)	241.8	243.2	253.2	252.4	250.1
TSP (g/GJ)	74.6	74.9	75.3	78.0	80.9
SO_2 (g/GJ)	6.8	2.3	0.5	0.5	0.5

Emissions are presented in table B.2.

Table B.2: Emissions from 2000 to 2020 for gasoline engines (2- and 4-stroke)

REC	2000	2005	2010	2015	2020
NMVOC (kt)	17.74	18.35	15.22	10.71	6.84
NOX (kt)	1.18	1.25	1.36	1.27	1.18
TSP (kt)	0.37	0.38	0.40	0.39	0.38
SO_2 (kt)	0.033	0.012	0.003	0.003	0.002

NMVOC and SO_2 emissions will be dramatically reduced. NOx and TSP emissions remain constant but this is not a big issue for this sector.