Final Background Document
on the sector

Off Road
INLAND WATERWAYS
(Excludes recreational marine engines)

Prepared by CITEPA, Paris

Summary

Inland navigation : engines above 37 kW and below 5000 kW

SNAP 0803 Inland waterways or NFR1A3dii National Navigation.

This report studies costs of emission limit values implementation for new marine diesel engines rated at or above 37 kW. For most marine engines of less than 5 000 kW techniques are expected to be derived from land-based engines already regulated.

ACTIVITY : fuel consumption (GJ/year)
POLLUTANTS CONSIDERED : NOx, HC, PM and SO_2

1 Data currently used in the RAINS model

Following data are just displayed for comparison reasons.

Data are derived from reference [12].

- 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 : Unabated emission factors used in the RAINS PM module for inland navigation

Sector	$PM_{2,5}$ [g/GJ]	PM_{10} [g/GJ]	TSP [g/GJ]	TSP [g/kWh] *
Inland navigation	0,105	111	117	1,05

* Coefficient expressed in g/kWh was calculated from the coefficient in g/GJ assuming 40% efficiency of diesel engine.

- Engine considered

Table 1.2 : Sector considered in RAINS

Abbreviations used in RAINS	Sector
TRA_OT_INW	Inland navigation

- Techniques and associated costs

Rail and inland waterways are studied together in the current stage of development of RAINS.

Table 1.3 : Cost parameters for control technologies used in rail and inland waterways

Technology	Unit investment [€/vehicle]	Fixed O+M [%]
1998, as EURO I for HDV	1 716	7,8
2000/02, as EURO II for HDV	5 148	3,9
As EURO III for HDV	11 575	2,9
As EURO IV for HDV	20 714	2,5
As EURO V for HDV	23 015	2,4
As Euro VI for HDV	24 575	2,4

2 Short technology description [1]

Three categories of engines are differentiated :

- Category 1 engines are small engines used in recreational and light commercial applications.
- Category 2 engines are medium-sized engines such as those used in tugboats.
- Category 3 engines are the largest engines used primarily for propulsion in ocean-going.

Engines can be derived from the land-based non-road technologies, locomotives or are manufactured on a unique basis for propulsion of very large ocean-going vessels.

Table 2.1 : Engine types in function of the engine categories

Category	Displacement per Cylinder	Basic Engine Type
1	Disp.* < 5 litres (Power > 37 kW)	Non-road
2	5 < disp. < 30 litres	Locomotive
3	Disp. > 30 litres	Unique, “Cathedral”

* Disp : displacement

Marinization of engines :
The most obvious changes made to a land-base engine concern the engine’s cooling system. Marine engines generally operate in closed compartments without much air flow for cooling.
These engines make use of the ambient water to draw the heat out of the engine coolant.
The goal of that types of engines is to enhance performance by burning more fuel. This can be done by modifications of the camshaft, cylinder head and injection timing and pressure.
Modifications made to the cooling system can also enhance performances.

Definitions :

- Turbocharger : this device compresses the charge air before it enters the cylinder. Then, more air mass is available in the cylinder for combustion. This increases the power-to-weight ratio of the engine and reduces PM formation.
- After cooler : this is usually used between the turbocharger and the engine to cool the charge air. This cooling makes the air denser and allows more air to enter the cylinder. Peak combustion is lowered reducing NOx emissions.

Three different technologies can be observed :

- Case 1 is the simplest case : naturally-aspired engine. No turbocharger and no after cooler are used. Sea water is directly brought through the heat exchanger to cool the coolant water. It is expected that naturally-aspirated water engines will have difficult time meeting new emissions standards.
- Case 2 : Turbocharger and after cooler in the engine coolant loop : the after-cooler is integrated into the engine’s coolant loop. The same coolant is used for the heat exchanger and the after cooler.
- Case 3 : Separate-circuit after cooler : in this case, two separate cooling loops are used allowing to reach lower temperature for the charge air.

3 EU regulations

3.1 International regulation

Mandatory controls on the exhaust emissions from marine sources have historically been of very limited extent. Situation has changed with the adoption of Annex VI “Regulation for the Prevention of Air Pollution from Ships” of the MARPOL 73/78 Convention [2].

NOx emissions : all diesel engines over 130 kW either installed on ships built after 1st January 2000 or those which are subject to major conversions must have a cycle weighted emission value within the limits of the IMO curve : this curve shows NOx emission limits (g/kWh) according to the engine rated speed (rpm) [3]. To simplify, the IMO limit curve levels are 17 g/kWh at slow speed, 12 g/kWh at medium speed and 9,8 g/kWh at high speed.

The IMO limit levels are modest reductions relative to the previous situation.

3.2 US regulation

Our study is based on a USEPA report [1] related to the impact of the emission control implementation for category 1 and 2 engines. The baseline is represented by the MARPOL requirements.

Standards studied are as follows :

Table 3.2.1 : Emission limit values (g/kWh)

Category	Displacement (liters/cylinder)	NOx + HC (g/kWh)	PM (g/kWh)
1	Power > 37 kW Disp. < 0,9	7,5	0,4
	0,9 < disp. < 1,2	7,2	0,3
	1,2 < disp. < 2,5	7,2	0,2
	2,5 < disp. < 5,0	7,2	0,2
2	5,0 < disp. < 15	7,8	0,27
	15 < disp. < 20 Power < 3300 kW	8,7	0,5
	15 < disp. < 20 Power > 3300 kW	9,8	0,5
	20 < disp. < 25	9,8	0,5
	25 < disp. < 30	11,0	0,5

3.3 Future European regulation [8]

The EC DG ENV is working on standards to control emissions from marine commercial engines used in inland waterway vessels.
EUROMOT made a proposal to extend the scope of the current Directive 97/68/EC to cover compression-ignition engines used in inland waterway vessels.
Emission limit values proposed in document [8] are similar to those displayed above.
Exemptions :

- Engines for recreational marine use (covered in Directive 94/25/EC as amended),
- Engines already certified according to IMO MARPOL 73/78 Annex VI (NOx code),
- Engines above 30 litres / cylinders : these engines are used predominantly in sea-going vessels operating in international waters. They are currently subject to existing and future IMO regulation.

3.4 Sulphur content of fuels

Two types of fuels can be used : diesel and marine distillate oil (gas-oil) used in territorial waters.

Table 3.4.1 : Regulations on sulphur content of fuels

Directive References	Scope	Exemptions
98/70/EC [5] *2003/17/EC [9]*	Quality of petrol and diesel fuels	-
99/32/EC [6] *COM(2000)595 [11]*	Sulphur content of fuels : gas-oil and heavy fuel	Diesel and petrol as defined in Directive 98/70/CE

Table 3.4.2 : Sulphur content of fuels : standards (ppm) implemented by the directives

Fuels	2000	2005	2008
Diesel	350	50	10
Gas-oil and heavy fuels	2 000	2 000	1 000

Some Member States have national standards [7]. This is a country specific information which has to be provided by national experts (chapter 6).

4 Definition of Reference Engines

Five engine types representing five power ranges (four Category 1 and one Category 2) are considered. The selected power rates generally correspond with the displacement values used to differentiate among the standards.

Base year being 2000, reference engines are supposed to respect MARPOL emission levels.

Table 4.1 : Reference marine diesel engines

Reference Engine Code (REC)	Nominal engine power [kW] (technology)
01	100 representing the range 37-225 (MARPOL)
02	400 representing the range 225-560 (MARPOL)
03	750 representing the range 560-1 000 (MARPOL)
04	1 500 representing the range 1 000-2 000 (MARPOL)
05	3 000 representing the range 2 000-5 000 (MARPOL)

5 Emission abatement techniques and costs

5.1 Primary measures

USEPA [1] supposes that to meet the new emission standards, Category 1 engine manufacturers will have to conduct basic engine modifications, upgrade fuel system and improve after cooling systems. For Category 2, manufacturers are expected to redesign combustion chambers, improve high-pressure fuel injection systems and upgrade or add turbo charging and after cooling.

The following technologies are applicable :

5.1.1 Combustion optimisation

Many parameters influence the combustion. These include injection timing, combustion chamber geometry (shape of the chamber and the location of injection, reduced crevice volumes, and compression ratio), compression ratio, valve timing, turbulence, injection pressure, fuel spray geometry and rate, peak cylinder temperature and pressure, and charge (or intake) air temperature and pressure.

5.1.2 Advanced Fuel Injection Controls

The principal variables being investigated are injection pressure, nozzle geometry, timing of the start of injection and rate of injection throughout the combustion process.

5.1.3 Improving Charge Air Characteristics

- Jacket-water after cooling

Raw water is pumped to a heat exchanger which is used to cool the engine coolant. Raw water is then used to cool the exhaust.
In commercial application where the water temperature is expected to be near zero, a keel cooling may be used.

- Raw-water after cooling

Here, raw water is used rather than engine coolant (only in recreational and light commercial applications).

- Separate-circuit after cooling

One coolant loop is devoted to engine cooling and a second one is devoted to removing heat from the after cooler.

5.1.4 Electronic Control

Allows a better control of the fuel injection system and is necessary for advanced technology.

5.1.5 Exhaust Gas Recirculation (EGR)

Peak combustion temperature is reduced leading to NOx emission reduction.

Table 5.1.1 : Aggregated abatement measure definitions

Measure codes (MC)	Description
00	None
01	Mix of technologies to reach emission limit values

5.2 Secondary measures

According to [1], techniques such as oxidation catalysts, particulate traps, selective catalytic reduction (SCR) or water emulsification do not have to be used to reach the standards.

These techniques are developed in the report concerning maritime activities.

5.3 Emission factors and costs data for the different combinations

Table 5.3.1 : Emission factors for each measure

REC MC	EF HC [g/kWh]	Q	CI %	EF NOx [g/kWh]	Q	CI %	EF PM [g/kWh]	Q	CI %
01 00	0,27	3	30	10-11	3	30	0,40-0,90	3	30
01 01	0,20	3	30	7,30	3	30	0,40	3	30
02 00	0,27	3	30	10,00	3	30	0,30	3	30
02 01	0,20	3	30	7,00	3	30	0,30	3	30
03 00	0,27	3	30	10,00	3	30	0,30	3	30
03 01	0,20	3	30	7,00	3	30	0,20	3	30
04 00	0,27	3	30	13,00	3	30	0,30	3	30
04 01	0,20	3	30	7,00	3	30	0,20	3	30
05 00	0,27	3	30	13,00	3	30	0,30	3	30
05 01	0,20	3	30	7,60-10,80	3	30	0,27-0,50	3	30

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

Table 5.3.2 : Investments and operating costs

REC MC	Investment (€$_{2000}$)	Q	CI %	Operating costs (€$_{2000}$/y) *
01 00	0	-	-	-
01 01	2 106	4	20	-
02 00	0	-	-	-
02 01	3 743	4	20	-
03 00	0	-	-	-
03 01	29 622	4	20	-
04 00	0	-	-	-
04 01	26 618	4	20	-
05 00	0	-	-	-
05 01	63 211	4	20	-

* Operating costs are a mix of different components. See chapter 7.2.3 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 the methodology defined by the Secretariat.

- Validate of investment costs provided or,
- Provide other costs for the same abatement techniques and justify them.

Comments have to be sent to the Secretariat in the two weeks after electronic publication of the document.

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]
Diesel 350 ppm sulphur (€$_{2000}$/l)	
Diesel 50 ppm sulphur (€$_{2000}$/l)	
Diesel 10 ppm sulphur (€$_{2000}$/l)	
Gas-oil 2 000 ppm sulphur (€$_{2000}$/l)	
Gas-oil 1 000 ppm sulphur (€$_{2000}$/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 consumption [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 %
Diesel 350 ppm sulphur										
Diesel 50 ppm sulphur										
Diesel 10 ppm sulphur										
Gasoil 2000 ppm sulphur										
Gasoil 1000 ppm sulphur										
Default values proposed for CI		10		20		50		100		100

For explanations on the coefficient of variation (CI), please refer to the document 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 :

Emissions [t/y] = 2 × Fuel Consumption (t/y) × S content (%) / 100

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

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

E [t/y]=Load Factor × Power [kW] × Annual use [h/y] × Emission Factor [g/kWh]/10^6

Country specific data (engine characteristics) are required for each type of engines :
- 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 [14], engine's efficiency is considered to be about 40% for diesel 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.

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					
03					
04					
05					
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				
03				
04				
05				

Default values used by reference [1] for commercial engines are displayed hereafter.

REC	Load factor	Annual use (h/y)	Operating lifetime (years)
01	60	2 270 – 2 350	16
02	72	3 240 – 3 770	16
03	79	4 500	16
04	79	4 500	16
05	79	4 500	23

- 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	
04	100	98		96		94		92	
05	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	
04	100	100		100		100		100	
05	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**	
03 00									
03 01									
Total REC 03	**100**	**100**		**100**		**100**		**100**	
04 00									
04 01									
Total REC 04	**100**	**100**		**100**		**100**		**100**	
05 00									
05 01									
Total REC 05	**100**	**100**		**100**		**100**		**100**	

7 Explanatory notes

The emission part for inland waterways will also be studied by the European programme Tremove.

7.1 Emission factors

Table 7.1.1 : MC 00 (baseline) emission factors (g/kWh) [1]

REC	01	02	03	04	05	Q	CI %
HC	0,27	0,27	0,27	0,27	0,27	3	30
NOx *	10,00-11,00	10,00	10,00	13,00	13,00	3	30
PM **	0,40-0,90	0,30	0,30	0,30	0,30	3	30

* NOx emission factors are 11 g/kWh for engines rated between 37-75 and 10 for engines rated between 75-225.
** PM EF are 0,9 g/kWh for engines rated between 37-75 and 0,4 for engines rated between 75-225.

As presented in [1], new emission limits are used as in-use emission factors for controlled engines. To separate HC and NOx standards which are given as the sum of the pollutants, USEPA estimates that HC emissions will be reduced by 0,07 g/kWh.

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

REC	01	02	03	04	05	Q	CI %
HC	0,20	0,20	0,20	0,20	0,20	3	30
NOx	7,30	7,00	7,00	7,00	7,60-10,80	3	30
PM	0,40	0,30	0,20	0,20	0,27-0,50	3	30

7.2 Derivation of Cost data

In [1], costs are given in $\$_{1995}$. $\$_{2000}$ are calculated from the inflation rate [13]. The following equivalence is used : 1 US$\$_{1997}$ = 1,08 $\$_{2000}$ and 1$\$_{2000}$ = 1,08€$_{2000}$. 1 US$\$_{1997}$ = 1,16 €$_{2000}$

MARPOL technical requirements are considered as baseline for cost assessment.

7.2.1 Investments

A single cost is estimated to represent the whole Category 2 engine’s range.
To estimate the incremental costs of the measures, it is important to establish the baseline technology package from which changes will be made.

Table 7.2.1.1 : Baseline technologies for Marine engines as considered in [1] for the US situation

REC	Naturally Aspirated [%]	Turbocharged [%]	Jacket-water After cooling [%]	Separate-circuit After cooling [%]
01	65	35	15	0
02	0	100	55	15
03	0	100	100	0
04	0	100	100	0
05	10	90	80	10

- R&D costs

These costs are related to the transfer of established engine technologies to marine engines.

- Unit Injection Improvements costs

Injection improvements can be achieved by a better control of injection timing and the increase of the injection pressure.

Table 7.2.1.2 : Injection improvement costs [€$_{2000}$]

REC	01	02	03	04	05	Q	CI %
Hardware cost per engine	116	176	-	-	7 176	4	
Fixed cost per engine	106	283	-	-	*	4	
Composite Unit Cost	222	459	-	-	7 176	4	20

* Fixed costs for developing unit injectors are included under Engine Modifications

- Common Rail Fuel Injection

Injection pressure is not dependent on engine speed.

Table 7.2.1.3 : Common Rail Fuel Injection costs [€$_{2000}$]

REC	01	02	03	04	05	Q	CI %
Hardware cost per engine	126	183	322	992	2 361	4	
Fixed cost per engine	235	283	6 287	5 494	21 878	4	
Composite Unit Cost	361	466	6 609	6 486	24 239	4	20

- Engine modifications

This includes routing of the intake air, piston crown geometry and placement and orientation of injectors and valve.

Table 7.2.1.4 : Engine modification costs [$€_{2000}$]

REC	01	02	03	04	05	Q	CI %
Hardware cost per engine	-	-	-	-	933	4	
Fixed cost per engine	450	540	22 037	19 257	31 376	4	
Composite Unit Cost	450	540	22 037	19 257	32 309	4	20

- Turbo charging and after cooling

Table 7.2.1.5 : Turbo charging costs [$€_{2000}$]

REC	01	02	03	04	05	Q	CI %
Hardware cost per engine	243	-	-	-	2 488	4	
Fixed cost per engine	225	-	-	-	6 275	4	
Composite Unit Cost	468	-	-	-	8 763	4	20

Table 7.2.1.6 : Costs of adding Jacket-Water After cooling [$€_{2000}$]

REC	01	02	03	04	05	Q	CI %
Hardware cost per engine	723	1 919	-	-	-	4	
Fixed cost per engine	963	3 607	-	-	-	4	
Composite Unit Cost	1 687	5 525	-	-	-	4	20

Table 7.2.1.7 : Costs of adding Separate-circuit After cooling [$€_{2000}$]

REC	01	02	03	04	05	Q	CI %
Hardware cost per engine	1 617	4 158	-	-	36 864	4	
Fixed cost per engine	1 157	4 329	-	-	32 229	4	
Composite Unit Cost	2 774	8 487	-	-	69 093	4	20

Table 7.2.1.8 : Costs to convert Jacket-Water to Separate-circuit After cooling [$€_{2000}$]

REC	01	02	03	04	05	Q	CI %
Hardware cost per engine	893	2 239	4 330	7 395	12 955	4	
Fixed cost per engine	194	722	3 001	3 746	5 371	4	
Composite Unit Cost	1 087	2 961	7 331	11 141	18 326	4	20

7.2.2 Aggregated engine investments

Table 7.2.2.1 gives the total costs per engine category to reach the emission limit values. “Fraction” data denote the percentage of reference engines estimated to require the given technology to comply with emission limit values.

Table 7.2.2.1 : Total engine costs [$€_{2000}$]

REC	01		02		03		04		05	
	Fraction [%]	Cost [€]	Fraction [%]	Cost [€]	Fraction [%]	Cost [€]	Fraction [%]	Cost [€]	Fraction [%]	Cost [€]
Common Rail	0	-	0	-	100	6609	100	6486	0	-
Unit injection upgrade	100	222	100	459	0	-	0	-	100	7176
Engine modifications	100	450	100	540	100	22037	100	19257	100	32309
Turbocharger	65	304	0	-	0	-	0	-	10	876
Jacket-water aftercooling	30	506	30	1658	0	-	0	-	0	-
Separate-circuit aftercooling	10	277	0	-	0	-	0	-	10	8909
Upgrade to separate-circuit aftercooling	15	163	30	888	0	-	0	-	80	14661
Certf+PLT	100	184	100	198	100	976	100	875	100	1 280
Aggregated costs MC 00 to MC 01	-	**2 106**	-	**3743**	**-**	**29622**	**-**	**26618**	**-**	**63211**

* Certf + PLT : cots incurred for certification and Production Line Testing

7.2.3 Operating costs

Several data are required in the RAINS model

- Rebuild costs are taken into account
  - For Category 1 engines, rebuild costs are based on a sixteen-year life, with two rebuilds occurring at the end of the fifth and tenth years.
  - For Category 2 engines, rebuild costs are base on a 23 year lifetime with three rebuilds occurring after years six, twelve and eighteen.

Table 7.2.3.1 : Rebuild Costs [$€_{2000}$]

REC	01		02		03		04		05	
	Fraction [%]	Cost [€]	Fraction [%]	Cost [€]	Fraction [%]	Cost [€]	Fraction [%]	Cost [€]	Fraction [%]	Cost [€]
Common Rail	0	-	0	-	100	197	100	607	0	-
Unit injection upgrade	100	47	100	72	0	-	0	-	100	2 986
Turbocharger	65	101	0	-	0	-	0	-	10	160
Jacket-water after cooling	30	54	30	202	0	-	0	-	0	-
Separate-circuit after cooling	10	44	-	-	0	-	0	-	10	1 529
Upgrade to separate-circuit after cooling	15	40	30	202	0	-	0	-	80	3 562
Hardware cost per engine		286	-	476	-	197	-	607	-	8 237
Incremental labour cost per engine		135	-	196	-	0	-	0	-	2 074
Total cost per rebuild		**421**	**-**	**672**	**-**	**197**	**-**	**607**	**-**	**10 311**

- Fuel consumption variations

Application of certain technologies leads to fuel consumption variations. According to [1], fuel variation should be limited.

Table 7.2.3.2 : Average fuel consumption variation [%] compared to MC 00 according to technologies used

MC	Consumption variation [%]	Q	CI %
00	-	-	-
01	0	2	-

- Sulphur content of fuels [10]

To supply DMA (distillate marine fuel) to lower sulphur content specifications than the ISO 8217 specification of 1,5%S, the European refining industry would need to invest in additional middle distillate desulphurisation capacity. Based on the cost of adding additional middle distillate desulphuration capacity, the price premia for producing lower sulphur content DMA versus 1,5%S DMA has been estimated and displayed as example in table 7.2.3.3 :

Table 7.2.3.3 : Additional costs for the use of low sulphur fuel

Description	Cost (€/tonne)	Q	CI %
Reduction of S from 1,5% S to 0,2%	12 – 19	4	20
Reduction of S from 1,5% S to 0,1%	14 - 21	4	20

8 References

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9 Modifications compared to the draft document

9.1 Modifications of Chapter 5

Table 5.3.2 : Investments have been modified. Equivalences between $ and € have been reviewed and in this final document, investments are all compared to the unabated case (MC 00).

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 11.

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 €.
About operating costs, no variation in fuel consumption is considered in this document because figures found in the literature are not specific enough to give accurate factors.