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**A PROJECT MOVING TOWARDS SUSTAINABLE  
DEVELOPMENT:**

## ***THE USE OF RDF<sub>q</sub> FOR NAVAL PROPULSION***



### **A STUDY THE ENVIRONMENTAL IMPLICATIONS**

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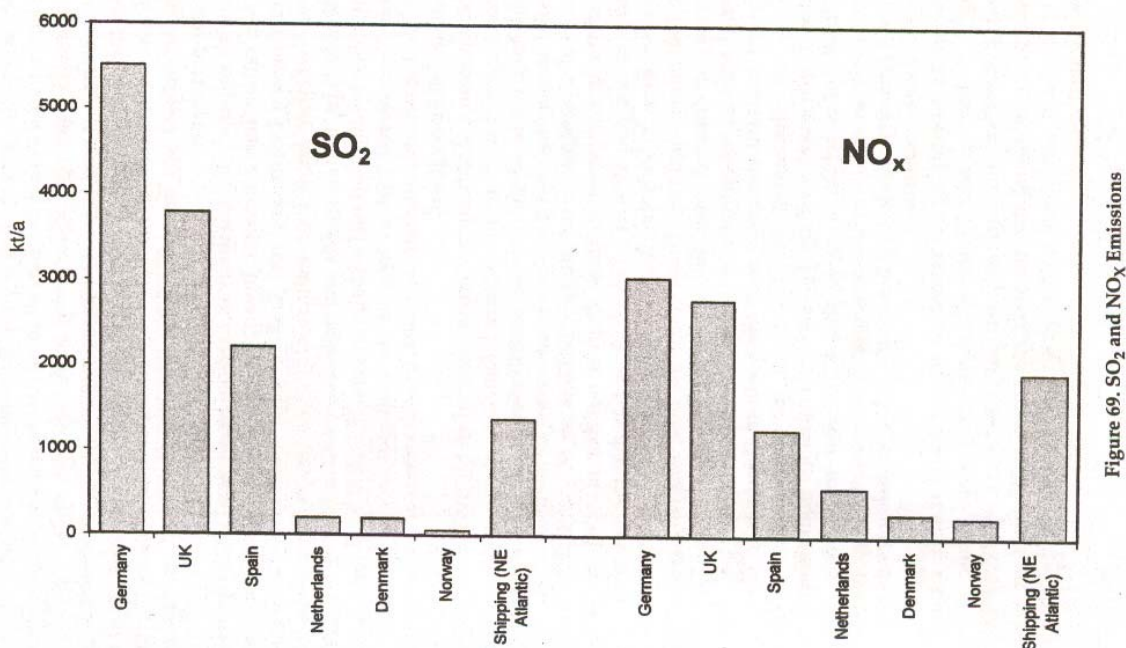
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# 1 PREFACE

In the last twenty years the per-capita production of MSW has more than doubled and in that same time period its cost for disposal has increased exponentially. In addition to the efforts to reduce waste production, increase recycling and re-use of disposed materials thermal recovery, through waste-to-energy facilities, is the technical solution universally accepted for recovery of the thermal energy (probably the most precious of the elements that can be recovered from wastes) as a substitute of fossil fuels. However, land based WTE facilities find it difficult to identify an appropriate site that meets with local approval.

Considering the various air pollutants sources of anthropogenic origin, those related to the shipping industry emissions are certainly of major importance (pollutants, especially NO<sub>x</sub> and SO<sub>x</sub> which contribute significantly to acid rain, both heavy and micro particulates and CO<sub>2</sub> emissions, on a global level. Since these emissions occur mainly in the open sea, the ships generally do not use abatement systems.

The effect on the overall level of emissions of major naval pollutants naval (SO<sub>2</sub>, NO<sub>x</sub> and CO<sub>2</sub>) is shown in Figures 1/1 and 1/2<sup>1</sup>



**Figure 1/1 – Comparison of the naval emissions of SO<sub>2</sub> e NO<sub>x</sub> in the North-East Atlantic area with respect to the overall production of several European countries (1990)**

<sup>1</sup> (Exhaust Emissions from Combustion Machinery, by A.A. Wight, ed. IMarEST 2005)

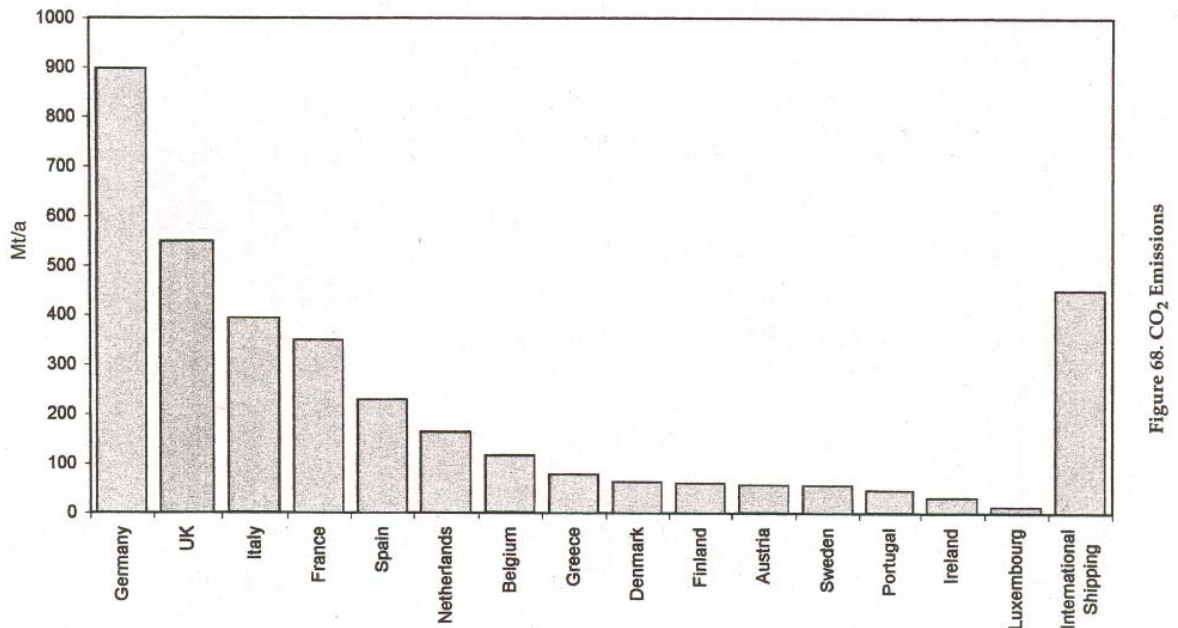


Figure 68. CO<sub>2</sub> Emissions

**Figure 1/2 – Comparison of the naval emissions of CO<sub>2</sub> with respect to the overall production of some European countries (1994)**

From the above figures it is evident that the level of naval emissions of the three pollutants considered are comparable to those of the major European countries such as UK or Italy.

From these considerations arose the idea of making a naval propulsion system fuelled by high quality RDF (Refuse Derived Fuel): the energy produced by combustion is used to produce sufficient electricity to meet both the propulsion as well as thermal and electric needs of the ship; applying the land based standard flue gas treatment technology, the air emissions are maintained at very low levels. Another environmental advantage is the reduction of the use of landfills for waste disposal and the associated local contamination that inevitably occurs.

The ship becomes a means of transportation of goods based on energy recovery of waste, significantly reducing the environmental effects both on land as well as at sea.

RDF<sub>q</sub> for maritime use is characterized by an elevated heating value and dense pellet form to facilitate fuel handling. This allows for the possibility to substitute fossil fuel and therefore notably reduce air emissions particularly those attributed to global warming.

## 1.1 GENERAL DATA AND DESCRIPTION OF THE PROJECT

In this report the WEST Logistics S.r.l. project applied to a 34.000 DWT DOUBLE HULL HANDYSIZE BULK CARRIER has been considered (for more detailed information see the WEST report attached).

The project foresees the implementation of a naval propulsion system fuelled by RDFq, < purposely prepared and certified for maritime in plants added to the normal waste disposal cycle. The ship is bi-fuel as it is fitted with back-up diesel engines which guarantee the ship meets all International requirements for ocean going of this class.

The naval propulsion system utilizing RDFq consists of the production of steam in a boiler fuelled by RDFq; the steam is then fed to a steam turbine generator for the production of electricity. The system is therefore equivalent to a traditional coal fired steam ship utilized for decades in the shipping industry, integrated with modern effluent treatment systems (solid, liquids and gases) to ensure environmental responsibility. The system is made up of the following sub-systems.

- Grate type boiler for RDFq, a reliable and consolidated technology;
- A classic steam cycle with the generation of electricity which provides the need power for the electric motor driver propellers;
- A system of control and emissions reduction;
- An integrated distributed control system to ensure maximum reliability and efficiency;
- Fuel storage area for the RDFq guaranteeing an autonomy of 5000 miles which is more than sufficient to arrive between any two intercontinental ports without the need to refuel..

The ship does not produce any additional wastes that are released into the waters.

This report compares the WEST system with a traditional diesel engine configuration which provide the same net power to the ship. The WEST system is 8.100 bhp and the traditional system 7.480 bhp taking into account the additional auto consumption of the WEST technology.

## 2 FUEL CONSUMPTION

In this study we separate the cruising consumption and the port side consumption, because the ship in port does not utilize RDFq, but the back-up diesel engines running on low sulphur fuel, as in traditional diesel systems. Therefore, the evaluation is strictly based upon the cruising consumption and emissions of the two alternative technologies.

### 2.1 CONSUMPTION OF BUNKER OIL IN THE TRADITIONAL DIESEL SYSTEM

Bunker oil is composed of predominantly carbon, hydrogen and sulphur, with secondary quantities of other components such as ash, heavy metals, nitrogen; oxygen is practically absent.

The typical composition is as follows (in weight)<sup>2</sup>:

Carbon (C)	85 – 87	% in avg.	86	%
Hydrogen (H)	10 – 12	% in avg.	11	%
Sulphur <sup>3</sup> (S)	1,5 – 3,5	% in avg.	2,5	%
Nitrogen (N)	0,1 – 0,8	% in avg.	0,45	%
Ash	0,01 – 0,08	% in avg.	0,05	%

Theoretically, in complete combustion, for every ton of bunker fuel burned with a ration of 7.82/1 of C/H and a 2.5% sulphur content, the emission of carbon in the form of CO<sub>2</sub> is 3.15 t, that of sulphur in the form of SO<sub>2</sub> is 50 kg, and that of hydrogen in the form of H<sub>2</sub>O is 1 t.

The amount of energy released during the combustion of the principal components is:

1 kg di Carbon	+	2,7 kg O <sub>2</sub>	→	3,7 kg CO <sub>2</sub>	+	33.830 kJ
1 kg di Hydrogen	+	8 kg O <sub>2</sub>	→	9 kg H <sub>2</sub> O	+	142.400 kJ
1 kg di Sulphur	+	1 kg O <sub>2</sub>	→	9 kg SO <sub>2</sub>	+	9.500 kJ

A combustion with a higher ration of carbon to hydrogen e a higher sulphur content would result in a lower specific energy production; for bunker oil it is usually assumed a C to H ratio and sulphur content of 9,05 e 4% respectively.

Considering the relative distribution of the main components and heat utilized for the evaporation of water, the complete combustion of 1 ton of bunker oil commonly used produces theoretically 40.2 MJ (11, 2 MWh or 9,600,000 Kcal).

Under normal navigation conditions, a ship with engine type 7L 27/38 MAN-B & W-60Hz-RPM 720 has a specific consumption of 0,148 kg/hp; to achieve a cruising speed of 14 knots are

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<sup>2</sup> (Exhaust Emissions from Combustion Machinery, by A.A. Wight, ed. IMarEST 2005)

<sup>3</sup> The content of sulphur in the bunker oil depends on the sulphur content of the crude oil and the refining process as such, the values can vary significantly from the above..

needed about 7480 HP (including onboard consumption) with a consumption of approximately 27 T/day of bunker oil, equal to approximately 1,125 T/h.

## **2.2 CONSUMPTION OF RDFq FOR MARITIME USE**

Using RDFq, the quantity necessary for the production of the electricity needed for the propulsion depends on its heating value, which again depends on its composition (dried biomasses and, in part fossil based materials).

Assuming a LHV of 6.000 kcal/kg (7 kWh/kg) for the RDFq, in order to provide the same net power to the propeller, and considering the higher auto consumption a 6 MW of electricity, a production of approximately 30 MWt is required from the combustion process, with a consumption of 103 t/day (4,3 t/h) of RDFq.

The resulting flue gas would be 55.000 Nm<sup>3</sup>/h.

### 3 NATURE OF THE EMISSIONS

#### 3.1 EMISSIONS FROM A DIESEL ENGINE BURNING BUNKER OIL

The quantity and quality of fuel burned determines the flue gas emissions. The wet flue gas mass flow rate (kg/h) can be estimated based upon the fuel consumption in kg/h:

$$\text{Flue gas flow rate (kg/h)} = 38 \times \text{bunker oil consumption (kg/h)}$$

The density of the flue gas is estimated to be 1,293 kg/m<sup>3</sup>.

Using the assumption that the bunker oil consumption during navigation is 27 t/day, equal to 1,125 t/h, the flue gas flow rate shall be 42.750 kg/h, equal to approximately 51.230 Nm<sup>3</sup>/h.

In addition to the water vapour, the pollutants produced and released into the atmosphere by the motor are those present in the bunker oil as well as those produced by the combustion, principally the following:

- ⇒ Carbon Dioxide (CO<sub>2</sub>)
- ⇒ Carbon Monoxide (CO)
- ⇒ Nitrous Oxides (NO, NO<sub>2</sub>)
- ⇒ Sulphur Oxides (SO<sub>2</sub>, SO<sub>3</sub>)
- ⇒ Hydrocarbons
- ⇒ Particulates

A theoretical estimate of the concentration of the various pollutants present in the flue gas are presented in Table 3.1/1:

Table 3.1/1

POLLUTANT	CONCENTRATION(*) (ppm)	CONCENTRATION mg/Nm <sup>3</sup>	EMISSION (kg/h)
CO <sub>2</sub>	56.000	100.688	5.158
CO	45	51	2,6
NO <sub>x</sub>	1220	1.496	76,6
SO <sub>2</sub>	660	1.727	88,4 (**)
HC	122 C	n.c.	n.c.
PTS		120	6,1

(\*) taken from Exhaust Emissions from Combustion Machinery, by A.A. Wight, ed. IMarEST 2005

(\*\*)The combustion of 1,125 t/h of bunker oil (4% S in weight) produces 90 kg/h of SO<sub>2</sub>

### 3.2 EMISSIONS FROM A RDFq PROPULSION SYSTEM

No experimental or theoretical data is available regarding the combustion of RDFq that provides indication of the characteristics of the flue gas generated. Therefore, we utilized data available from the combustion of normal RDF and the limits of law applied to such for dedicated power plants that meet EMAS and ISO 14000 standards; in order to be conservative we utilize the law emission limits, as the plants are design to stay significantly under any such limits.

In order to calculate of the flue gas we will consider a flow rate of 55.000 Nm<sup>3</sup>, compatible with the combustion of 4.3 t/h of RDF with a LHV of 6.000 kcal/kg.

The carbon content in RDFq can be considered 50% of the its actual value as half of the content in the RDFq is derived from renewable biomasses, therefore are not taken into consideration for greenhouse gas production.

In the same vain the RDF, derived from municipal wastes, if used as a fuel shall not be disposed of in landfills and additional CO<sub>2</sub> emissions are avoided as well as the CH<sub>4</sub> that landfills normal produce during the biodegradation of the biomasses.

The methane in fact has a much more significant greenhouse effect estimated to be 21 times greater than that of CO<sub>2</sub>.<sup>4</sup>

Based upon the above assumptions, calculations were performed to determine the emissions produced from the use of RDFq for navigation. The emission of CO<sub>2</sub> are surely overestimated due to the fact that the reduction of CO<sub>2</sub> derived from not disposing of the waste in landfills was not quantified or taken into consideration.

Table 3.2/1

<b>POLLUTANTS</b>	<b>CONCENTRATION <sup>5</sup> (mg/Nm<sup>3</sup>)</b>	<b>TOTAL EMISSIONS (kg/h)</b>	<b>EQUIVALENT EMISSIONS (kg/h)</b>
<b>CO<sub>2</sub></b>	<b>180.300<sup>6</sup></b>	<b>9.844</b>	<b>4.922</b>
<b>CO</b>	<b>50</b>	<b>2,75</b>	<b>2,75</b>
<b>NO<sub>x</sub></b>	<b>200</b>	<b>11,00</b>	<b>11,00</b>
<b>SO<sub>2</sub></b>	<b>50</b>	<b>3,06</b>	<b>3,06</b>
<b>COT</b>	<b>10</b>	<b>0,55</b>	<b>0,55</b>
<b>PTS</b>	<b>10</b>	<b>0,45</b>	<b>0,45</b>

<sup>4</sup> Waste Management Options and Climate Change - Final report to the European Commission, DG Environment n° ED21158R4.1 - 2001

<sup>5</sup> Daily avg. limit imposed under Italian law D.Lgs 133/05, in mg\Nm<sup>3</sup>

<sup>6</sup> Estimate based upon measurements of combustion of traditional RDF

<sup>7</sup> The value was reduced by 50% as half of the carbon s derived from a renewable source.

It is evident the substantial difference between the emissions from bunker oil and RDF, especially with respect to  $\text{NO}_x$  e  $\text{SO}_2$ . The emissions in Table 3.2/1 are based upon the limits allowed by law, in reality, the flow rates are significantly below the limits of law.

In order to give a more realistic estimate of true emission levels from the combustion of RDF, we will take into consideration the actual emissions produced by the waste-to-energy facility in Bologna (Italy) that burns exclusively RDF. The two lines each represent a production capacity similar to the naval propulsion system under study.

The below listed values are easily verified via the internet, they represent the daily average emission levels during the month of January 2009 for the above referenced WTE facility.

Table 3.2/2

Actual emission levels of the waste-to-energy WTE facility burning traditional RDF in Bologna Italy owned by HERA S.p.A.

Day	<u>HCL</u> (mg/Nm3)	<u>CO</u> (mg/Nm3)	<u>SO2</u> (mg/Nm3)	<u>NOX</u> (mg/Nm3)	<u>HF</u> (mg/Nm3)	<u>Particulates</u> (mg/Nm3)	<u>TOC</u> (mg/Nm3)
Limit *	10	50	50	200	1	10	10
Limit <u>IPPC</u>	5	35	25	150	1	5	10
Day	<u>HCL</u> (mg/Nm3)	<u>CO</u> (mg/Nm3)	<u>SO2</u> (mg/Nm3)	<u>NOX</u> (mg/Nm3)	<u>HF</u> (mg/Nm3)	<u>Particulates</u> (mg/Nm3)	<u>TOC</u> (mg/Nm3)
Limit *	10	50	50	200	1	10	10
Limit <u>IPPC</u>	5	35	25	150	1	5	10
01/01/2009	0,00	14,23	0,00	71,92	0,00	0,08	0,69
02/01/2009	0,00	13,36	0,22	69,99	0,01	0,10	0,66
03/01/2009	0,00	11,22	0,00	70,04	0,02	0,09	0,59
04/01/2009	0,00	12,06	0,00	70,87	0,02	0,09	0,57
05/01/2009	0,00	13,13	0,09	70,24	0,00	0,09	1,02
06/01/2009	0,00	12,98	0,00	72,51	0,00	0,09	0,72
07/01/2009	0,00	13,12	0,29	68,15	0,00	0,09	0,67
08/01/2009	0,00	15,85	0,00	71,81	0,00	0,09	0,52
09/01/2009	0,00	20,02	0,28	67,23	0,00	0,10	0,61
10/01/2009	0,00	19,60	0,00	67,41	0,00	0,09	0,59
11/01/2009	0,00	16,26	0,00	66,88	0,00	0,09	0,70
12/01/2009	0,00	16,00	0,00	70,34	0,00	0,09	0,50
13/01/2009	0,00	18,27	0,12	69,68	0,01	0,09	0,35
14/01/2009	0,00	16,46	2,61	70,76	0,05	0,08	0,25
15/01/2009	0,00	15,49	1,05	62,81	0,00	0,08	0,77
16/01/2009	0,04	16,21	3,96	65,67	0,00	0,09	0,33
17/01/2009	0,00	14,97	0,07	68,26	0,01	0,08	0,44
18/01/2009	0,00	16,55	0,27	71,87	0,00	0,08	0,50
19/01/2009				Plant Off-line			
20/01/2009	0,00	13,19	0,77	62,73	0,01	0,09	1,08
21/01/2009	0,00	16,09	4,22	69,49	0,00	0,08	0,35
22/01/2009	0,00	16,84	1,40	67,75	0,00	0,08	0,64
23/01/2009	0,00	14,04	1,19	67,73	0,00	0,08	0,39
24/01/2009	0,00	16,65	0,57	64,31	0,01	0,10	0,66
25/01/2009	0,00	16,10	0,08	70,84	0,01	0,07	0,53
26/01/2009	0,00	15,13	2,93	72,80	0,01	0,07	0,37
27/01/2009	0,00	18,30	2,23	70,11	0,00	0,09	0,29
28/01/2009	0,00	14,94	0,43	61,12	0,00	0,08	1,46
29/01/2009	0,00	15,24	0,95	66,88	0,00	0,08	0,89
30/01/2009	0,00	15,32	3,34	67,38	0,01	0,07	0,44
31/01/2009	0,00	15,01	3,72	71,90	0,00	0,09	0,58

\* Daily avg. limit imposed under Italian law D.Lgs 133/05, in mg\Nm<sup>3</sup>

Line 1	<u>HCL</u> (mg/Nm3)	<u>CO</u> (mg/Nm3)	<u>SO2</u> (mg/Nm3)	<u>NOX</u> (mg/Nm3)	<u>HF</u> (mg/Nm3)	<u>Particulates</u> (mg/Nm3)	<u>TOC</u> (mg/Nm3)
Limit *	10	50	50	200	1	10	10
Limit <u>IPPC</u>	5	35	25	150	1	5	10
Lowest value	0	11,22	0	61,12	0	0,07	0,25
Highest value	0,04	20,02	4,22	72,8	0,05	0,1	1,46
Average Value	0,001333	15,4	1,0	68,6	0,005667	0,086	0,605

Table 3.2/3

Actual emission levels of the waste-to-energy WTE facility burning traditional RDF in Bologna Italy owned by HERA S.p.A.

Day	<u>HCL</u> (mg/Nm3)	<u>CO</u> (mg/Nm3)	<u>SO2</u> (mg/Nm3)	<u>NOX</u> (mg/Nm3)	<u>HF</u> (mg/Nm3)	<u>Particulates</u> (mg/Nm3)	<u>TOC</u> (mg/Nm3)
Limit *	10	50	50	200	1	10	10
Limit <u>AIA</u>	5	35	25	150	1	5	10
Day	<u>HCL</u> (mg/Nm3)	<u>CO</u> (mg/Nm3)	<u>SO2</u> (mg/Nm3)	<u>NOX</u> (mg/Nm3)	<u>HF</u> (mg/Nm3)	<u>Particulates</u> (mg/Nm3)	<u>TOC</u> (mg/Nm3)
Limit *	10	50	50	200	1	10	10
Limit <u>AIA</u>	5	35	25	150	1	5	10
01/01/2009	0,00	14,15	0,00	110,80	0,02	0,49	3,48
02/01/2009	0,00	14,77	0,08	107,20	0,05	0,52	3,92
03/01/2009	0,00	14,88	0,07	95,72	0,00	0,51	3,87
04/01/2009	0,00	0,00	0,00	0,00	0,00	0,00	0,00
05/01/2009	0,00	15,47	0,00	95,06	0,01	0,73	3,64
06/01/2009	0,00	13,17	0,53	82,37	0,02	0,45	3,06
07/01/2009	0,00	15,33	0,00	93,13	0,10	0,59	4,12
08/01/2009	0,00	14,95	0,00	87,76	0,01	0,50	3,81
09/01/2009	0,00	17,25	0,00	86,38	0,04	0,49	4,13
10/01/2009	0,00	13,91	0,00	87,94	0,03	0,50	3,93
11/01/2009	0,00	12,23	0,39	87,09	0,02	0,50	4,11
12/01/2009	0,00	13,93	0,00	84,77	0,02	0,50	4,00
13/01/2009	0,00	13,88	0,00	85,86	0,05	0,49	4,14
14/01/2009	0,00	15,20	1,35	76,46	0,01	0,48	4,10
15/01/2009	0,00	14,06	0,61	73,27	0,00	0,47	3,94
16/01/2009	0,00	14,82	0,38	67,34	0,01	0,45	3,62
17/01/2009	0,00	10,00	0,02	103,50	0,01	0,46	2,40
18/01/2009	0,00	8,27	0,01	99,90	0,00	0,41	1,43
19/01/2009	0,00	7,92	0,00	107,20	0,00	0,43	1,60
20/01/2009	0,00	7,76	0,00	95,57	0,00	0,43	1,51
21/01/2009	0,00	8,47	0,00	98,03	0,00	0,46	1,63
22/01/2009	0,00	9,90	1,82	88,68	0,01	0,45	2,60
23/01/2009	0,00	12,56	0,30	63,58	0,01	0,45	3,95
24/01/2009	0,00	13,70	0,31	79,25	0,05	0,48	4,42
25/01/2009	0,00	16,30	0,60	68,74	0,08	0,47	4,44
26/01/2009	0,00	13,94	2,75	68,92	0,02	0,47	4,25
27/01/2009	0,00	16,59	0,69	69,03	0,04	0,48	4,34
28/01/2009	0,00	14,31	3,17	75,32	0,02	0,45	2,90
29/01/2009	0,00	9,02	1,24	90,87	0,00	0,43	1,65
30/01/2009	0,00	10,31	2,08	87,32	0,00	0,41	1,59
31/01/2009	0,00	9,52	3,10	98,35	0,00	0,42	1,75

\* Daily avg. limit imposed under Italian law D.Lgs 133/05, in mg\Nm<sup>3</sup>

Line 2	<u>HCL</u> (mg/Nm3)	<u>CO</u> (mg/Nm3)	<u>SO2</u> (mg/Nm3)	<u>NOX</u> (mg/Nm3)	<u>HF</u> (mg/Nm3)	<u>Particulates</u> (mg/Nm3)	<u>TOC</u> (mg/Nm3)
Limit *	10	50	50	200	1	10	10
Limit <u>IPPC</u>	5	35	25	150	1	5	10
Lowest value	0	0	0	0	0	0	0
Highest value	0	17,25	3,17	110,8	0,1	0,73	4,44
Average Value	0	12,5	0,6	84,4	0,020323	0,464	3,172

Taking into consideration the above actual emissions, the following Table compares the estimated emission for the RDFq propulsion system based upon the limits of law and the maximum actual emission levels of the Bologna WTE facility.

Table 3.2/4

<b>POLLUTANT</b>	<b>Concentration <sup>8</sup> (mg/Nm<sup>3</sup>)</b>	<b>Hourly Concentration max measured<sup>9</sup> (mg/Nm<sup>3</sup>)</b>
<b>CO<sub>2</sub></b>	<b>90.150<sup>10</sup></b>	
<b>CO</b>	<b>50</b>	<b>20</b>
<b>NO<sub>x</sub></b>	<b>200</b>	<b>111</b>
<b>SO<sub>2</sub></b>	<b>50</b>	<b>4</b>
<b>HCl</b>	<b>10</b>	<b>0,04</b>
<b>HF</b>	<b>1</b>	<b>0,1</b>
<b>COT</b>	<b>10</b>	<b>4</b>
<b>PTS</b>	<b>10</b>	<b>0,73</b>

<sup>8</sup> Daily avg. limit imposed under Italian law D.Lgs 133/05, in mg/Nm<sup>3</sup>

<sup>9</sup> Maximum hourly emissions measured at the Bologna WTE facility in the month of January 2009

<sup>10</sup> Estimate based upon reducing the resulting emissions from the combustion of traditional RDF by 50% as half of the carbon s derived from a renewable source

#### 4 EVALUATION OF THE EMISSIONS PRODUCED ON A SPECIFIC NAVIGATIONAL ROUTE

In this section we the emission reduction along an actual navigational route, assuming a cruising speed of 14 knots and a hourly consumption rates (as defined in the previous section for the traditional diesel engine and the RDFq naval propulsion system ) of 1.125 T/h and 4.3 T/h respectively. We consider the route from Genoa to Palermo of approximately 370 miles, covered in 26 hour.

The total emissions released to the atmosphere during this trip from Genoa to Palermo are summarized below.

POLLUTANTS	Emissions from Bunker Oil (kg/26h)	Emissions from RDFq <sup>11</sup> limits of law (kg/26h)	Emissions from RDFq <sup>12</sup> max actually measured (kg/26h)	Reduction (%)
CO <sub>2</sub>	134.112	n.c.	127.976 <sup>13</sup>	-4,6%
CO	69	59	29	-58,3%
NO <sub>x</sub>	1.992	234	159	-92,0%
SO <sub>2</sub>	2.340	59	6	-99,8%
COT	n.c.	12	5,7	n.c.
PTS	160	12	1,0	-99,3%

The emissions from the use of RDFq for the propulsion system are significantly below that of bunker oil especially that of NO<sub>x</sub> (reduction of 92%) and of SO<sub>2</sub> & Particulates (reduction of more than 99%).

The reduction of the CO<sub>2</sub> emissions does not appear to be similarly significant only because the calculations do not take into account the saving of CO<sub>2</sub> emissions from not disposing of the biodegradable portion of the RDF in landfills. An estimate sufficiently precise the quantity of CO<sub>2</sub>/methan emissions avoided were not available at the time of this report, however in order to provide a qualitative idea as to the savings one can consider that the quantities of CH<sub>4</sub> e di CO<sub>2</sub> released by biodegradable wastes in landfills have a ratio (tons of waste:tons of pollutants) of approximately 1:4,7 (21,2%)<sup>14</sup>; further considering that methane's greenhouse effect is 21 times greater than that of CO<sub>2</sub>, it is evident that there is a drastic savings from the avoided emissions.

<sup>11</sup> Values calculates based on the limits of law with the exception of CO<sub>2</sub>

<sup>12</sup> Values calculated based upon the max. actual emissions from the Bologna WTE facility.

<sup>13</sup> Values take into consideration a reduction of by 50% as half of the carbon s derived from a renewable source, but not the saving of not land filling the wastes.

<sup>14</sup> Waste Management Options and Climate Change citato

## **5**            **CONCLUSIONS**

The emission values provided in section 4 of this report are based upon actual measurements, therefore represent a reasonable reality.

The results show that substituting bunker oil with RDFq for naval propulsion could provide significant reduction in air emissions particularly, NO<sub>x</sub> (92%) and particulates & SO<sub>2</sub> (> 99%); the emissions of CO are reduced by more than 55%, while CO<sub>2</sub> is reduced by 4,6% without taking into consideration the avoided emission of CO<sub>2</sub> and methane derived from not disposing of the biodegradable waste present in the RDFq in landfills.

In addition to the very significant benefit in terms of reduced air emissions, the use of RDFq for naval propulsion could significantly reduce that amount of waste that needs to be disposed of in landfills, without underestimating the reduced cost of naval transport for the economy as a whole.