Kopi

Informal Cross Government/Industry Scientific Group of Exports to evaluate the effects of the different fuel options proposed under the revision of Annex VI

Explanatory Note on a Report to assess: (a) the number of ships in the world fleet; ship type and installed power; (b) total volume of bunkers being consumed (residuals and distillates); (c) ship emissions, including CO_2 emissions

INTERTANKO

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1.0 Introduction

Pursuant to the proposed Terms of Reference as contained in IMO Document MEPC 56/4/15, an assessment has been carried out with regard to paragraphs 5.1.1, 5.1.2, 5.3.3.1 and part (ship emissions) of paragraph 5.4. The assessment relies upon the required bunkers needed for the defined operational conditions of the world fleet and therefore must be considered as a "bottom up" assessment.

The generated model developed for this purpose has been broken down into relevant sections for ease of review and description. For each section of the total model, the assumptions and relevant coefficients are stated and, where necessary, discussed to allow an overall evaluation of the concluding calculated results.

2.0 The basis of the model

The base data for the model is derived from the Lloyds/Fairplay Database of the world's fleet of merchant ships as existent for the first quarter of 2007. Although MARPOL Annex VI applies to all ships, the data developed from the database, for this model, is for all ships requiring an International Air Pollution Prevention Certificate to satisfy the requirements of Annex VI; namely, **all ships of 400 gross tons and over**.

The distribution used in this model is by ship type, one of the three stipulated alternative criteria in paragraph 5.1.1 of the Terms of Reference. By this method, which has been utilised earlier for bunker fuel estimations[i,ii], a closer estimation can be made of the utilisation of the machinery onboard can be made due to the varying operational modes of differing ship types. By undertaking the distribution by "gross tonnage and installed power" mixtures of vessels of a variety of differing ship categories will be made which could complicate the requirement to assess the machinery utilisation, and thereby bunker utilisation, of the "gross tonnage and installed power" category of a particular category. In Section 8 of this report, the age profile of the main engines was considered for developing the factor for fuel consumption of main engines.

Thus, the following ship type categories have been selected as the basis for the distribution within the developed model so as to obtain a reasonable overview of the differing trades and operations of the diverse vessels at sea.

Type
Dry Bulk
Chemical/ oil tankers
Chemical tankers
Combination Carriers
Container
Crude tankers
General cargo vessels
Gas Tankers – LNG
Gas Tankers – LPG
Miscellaneous
Offshore
Passenger/Ferry
Product tankers
Reefers
Ro.Ros
Tankers unspecified

Table 1

Within the foregoing categories there are several categories that require further clarification as to their content or reasoning for categorisation.

2.1 Gas Tankers – LNG

"Gas Tankers – LNG" have been selected as a separate category from the more generalised "Gas Tanker" category due to the predominant use by these vessels of the use of boilers and steam as the motive power source for these ships. Therefore, boiler fuel consumption compensated for "cargo boil off" rather than the more conventional "specific fuel consumption" had to be assessed for this vessel category.

2.2 Miscellaneous

This category of vessel contains approximately 60 differing vessel types. The following are examples of vessel types within this category; Anti-Pollution vessels, bucket dredgers, cable repair ships, cable ships, fisheries protection vessels, fishing vessels, hospital ships, icebreakers, oceanographic vessels, pilot vessels, sail training vessels, sludge carriers, Tugs, Whaling vessels.

2.3 Tankers unspecified

This category of tankers is those smaller types and more to be associated with coastal transportation including the delivery of bunkers to ships.

3.0 Vessel categories distributed with numbers

The following table supplies the distribution of the number of ships in each of the categories specified in paragraph 2 above as given by the Lloyds/Fairplay database for 1st April 2007. These numbers of vessels will be used to determine the final bunker consumptions for each ship category and as a total.

Type	Number
Dry Bulk	7,002
Chemical/ oil tankers	1,649
Chemical tankers	1,195
Combination Carriers	110
Container	3,991
Crude tanker	1,945
General cargo vessels	13,632
Gas Tankers - LNG	375
Gas Tankers - LPG	1,061
Miscellaneous	11,902
Offshore	4,326
Passenger/Ferry	3,759
Product tankers	2,926
Reefers	2,132
Ro.Ros	2,131
Tankers unspecified	1,723
Grand Total	**59,859**

Table 2

Within these numbers, ships on order or under construction have been excluded.

4.0 Vessel categories distributed with Average Gross Tons

This next section of the model uses the base data selection of ship type category but also supplies the total gross tonnage for that category. By use of the individual numbers of ships in each category the average gross tons for each type of ship can be then calculated. This may be seen in the following table:

Type	Number	Gross Tons	Average Gross Tons
Dry Bulk	7,002	204,015,411	29,137
Chemical/ oil tankers	1,649	21,871,291	13,263
Chemical tankers	1,195	6,190,594	5,180
Combination Carriers	110	3,460,114	31,456
Container	3,991	113,280,678	28,384
Crude tanker	1,945	150,794,127	77,529
General cargo vessels	13,632	53,030,819	3,890
Gas Tankers - LNG	375	37,135,473	99,028
Gas Tankers - LPG	1,061	10,675,577	10,062
Miscellaneous	11,902	16,666,818	1,400
Offshore	4,326	10,341,820	2,391
Passenger/Ferry	3,759	30,261,871	8,051
Product tankers	2,926	29,559,806	10,102
Reefers	2,132	9,660,901	4,531
Ro.Ros	2,131	38,258,816	17,953
Tankers unspecified	1,723	9,034,692	5,244
Grand Total	**59,859**	**744,238,808**	**12,433**

Table 3

The database used for the collation of this data (Lloyds/Fairplay database) does not record the gross tons for every ship in every category although this parameter is more regularly recorded for most ships within the database. In the event that a deadweight tonnage is recorded for an individual ship without a gross ton record, the gross tonnage for the individual ship is estimated by calculating the average factor

between gross tons and deadweight tonnes for the specific ship type and then by use of this factor estimating the gross tons for the ship without the gross tons data. An example of this calculation methodology will be shown below in paragraph 5

5.0 Vessel categories distributed with Average Gross Tons and Deadweight tonnes

Type	Number	DWT	Average DWT	Gross Tons	Average Gross Tons
Dry Bulk	7,002	366,672,852	52,367	204,015,411	29,137
Chemical/ oil tankers	1,649	34,680,430	21,031	21,871,291	13,263
Chemical tankers	1,195	9,952,079	8,328	6,190,594	5,180
Combination Carriers	110	5,896,906	53,608	3,460,114	31,456
Container	3,991	131,287,522	32,896	113,280,678	28,384
Crude tanker	1,945	279,171,957	143,533	150,794,127	77,529
General cargo vessels	13,632	74,952,470	5,498	53,030,819	3,890
Gas Tankers - LNG	375	27,793,870	74,117	37,135,473	99,028
Gas Tankers - LPG	1,061	15,381,073	14,497	10,675,577	10,062
Miscellaneous	11,902	16,869,255	1,417	16,666,818	1,400
Offshore	4,326	10,698,098	2,473	10,341,820	2,391
Passenger/Ferry	3,759	6,185,630	1,646	30,261,871	8,051
Product tankers	2,926	49,021,104	16,754	29,559,806	10,102
Reefers	2,132	8,901,200	4,175	9,660,901	4,531
Ro.Ros	2,131	19,060,654	8,944	38,258,816	17,953
Tankers unspecified	1,723	15,628,404	9,070	9,034,692	5,244
Grand Total	**59,859**	**1,072,153,505**	**17,911**	**744,238,808**	**12,433**

Table 4

Within the database used for the collection of base data not all ships are recorded with either their Gross Tons or Deadweight tonnage. When this occurs for a particular ship entry, and so that the data is as extensive as possible without distorting same for a particular ship type for the total gross tons or deadweight tons, a mean conversion factor for the ship type is calculated for either the conversion of Gross tons to Deadweight tonnes or the reverse conversion. Thus, for example, in the event that a Crude Oil tanker's Deadweight tonnes figure is not recorded in the database but its Gross Tons is recorded then:

Conversion Factor would be: 279,171,957 divided by 150,794,127 = **1.851345**. (see the blue figures in Tables 3 & 4 respectively)

By multiplying the recorded Gross Tons by this factor the approximate equivalent Deadweight tonnes would be obtained for entry into the total Deadweight tonnes for this ship type for the specific vessel.

6.0 Average Main Engine Power (MCR) and period of operation

The Lloyds/Fairplay database supplies data for each individual ship as to its main engine power. This is recorded as either a Horse Power or a Kilowatt rating. Both have been used in this spreadsheet for completeness with the average horse power and kilowatt rating for each ship type being calculated and recorded. The corresponding values for horse power and kilowatt do not comply accurately with the conversion factor (0.7457 k.Watts per horse power[iii]) between the two power ratings and this is due to the omission in the data base of one or another power rating for a few individual vessels within a category.

The days for the operation of the main engine have been obtained as a result of a "straw poll" of the differing ship type operators, consultants and applying a degree of estimation (averaging) for the ship type categories containing diverse ship types within the specific category.

Thus, the following data is derived for each ship type as their individual average main engine (M.E.) power together with the average number of days of operation per annum of the main engine:

Vessel Type	Average Main Engine (HP)	Average Main Engine (kW)	M.E. Operation time (Days)
Dry Bulk	10,367	7,625	200
Chemical/ oil tankers	7,433	5,467	200
Chemical tankers	4,120	3,031	250
Combination Carriers	9,395	6,910	200
Container	28,234	20,767	280
Crude tanker	19,415	14,280	300
General cargo vessels	3,186	2,344	150
Gas Tankers - LNG	36,175	26,608	220
Gas Tankers - LPG	6,152	4,525	250
Miscellaneous	3,199	2,354	100
Offshore	5,788	4,257	250
Passenger/Ferry	11,526	8,481	250
Product tankers	5,455	4,012	200
Reefers	5,790	4,259	200
Ro.Ros	9,994	7,351	250
Tankers unspecified	3,071	2,259	200
Average	**7,608**	**5,596**	
Total Main Engine Power	**452,538,704**	**332,888,947**	

Table 5

The foregoing table sets the basis for the calculation of the amounts of fuel required to operate the respective engines on the relevant number of ships in each category.

7.0 Average Auxiliary Engine Power requirement and period of operation

The Lloyds/Fairplay database does not supply information on the number and power of the auxiliary engines installed on individual ships. Given this situation investigations and "straw polls" have had to be undertaken to gain an estimate of the likely and average electrical power requirement for the individual ship category types. This aspect has been further complicated by the requirement for additional power for port usage and port entry; i.e. the use of more than one generator set during certain periods of a particular voyage, as well as the increased use of shaft generators and diesel electric main powering of certain vessel types. However, average maximum power requirements have been assessed for the purposes of this study in order to gain an indication of the likely fuel consumption to be associated with this type of auxiliary power sources.

The number of days of operation per year is, in principle, a more simple evaluation if a five year ship operational cycle is taken into consideration. In this respect requirement for electrical power and thus Generator sets whilst in dry-dock is not possible and therefore allowance of a number of days per annum has been adjusted to compensate for this event. In the case of LNG type vessels, their main electrical power is derived from steam turbines and thus the auxiliary Generator Set is only used for port entry and periods of cargo discharge. Thus a reduced annual usage of only 40 days is shown in the overall calculation model.

Given the foregoing the relevant data used for the calculation of this bunker consumption is:

Vessel Type	Average Aux Power requirement (kW)	Aux. Operation time (Days)	Aux. Operation time (Hours)
Dry Bulk	1000	360	8640
Chemical/ oil tankers	1000	360	8640
Chemical tankers	1300	250	6000
Combination Carriers	1000	360	8640
Container	1000	250	6000
Crude tanker	1000	360	8640
General cargo vessels	500	250	6000
Gas Tankers - LNG	1200	40	960
Gas Tankers - LPG	1000	360	8640
Miscellaneous	500	250	6000
Offshore	1000	250	6000
Passenger/Ferry	1000	360	8640
Product tankers	1000	360	8640
Reefers	1500	360	8640
Ro.Ros	1000	250	6000
Tankers unspecified	500	250	6000
Average power requirement kW	**795**		
Total Aux. power requirement kW	**47,578,063**		

Table 6

The foregoing table sets the basis for the calculation of the amounts of fuel required to operate the respective engines on the relevant number of ships in each category. However, given the variety of differing types of auxiliary engines, their Maximum Continuous Rating (MCR) and revolutions per minute, greater consideration has to be given as to the type of fuel used by these engines and the actual fuel consumption for the averaging loading on the differing engines. These considerations and associated assumptions will be discussed below.

8.0 Main Engine fuel consumption

The Main Engine fuel consumption has been calculated for each of the sixteen differing categories of vessel individually and then summed together to gain the total. The method used avoids the generalisation of using the total combined main engine power. The main engine fuel consumption has been calculated for both the horsepower rating and the stated kilowatt power of the engines. However, the fuel consumption used for further calculations is that derived from the kilowatt power of the engines.

Thus the following table data has been used for this calculation:

Type	Number	Average Main Engine (HP)	Average Main Engine (kW)	M.E. Operation time p.a. (Days)	M.E. Operation time p.a. (Hours)
Dry Bulk	7,002	10,367	7,625	200	4800
Chemical/ oil tankers	1,649	7,433	5,467	200	4800
Chemical tankers	1,195	4,120	3,031	250	6000
Combination Carriers	110	9,395	6,910	200	4800
Container	3,991	28,234	20,767	280	6720
Crude tanker	1,945	19,415	14,280	300	7200
General cargo vessels	13,632	3,186	2,344	150	3600
Gas Tankers - LNG	375	36,175	26,608	220	5280
Gas Tankers - LPG	1,061	6,152	4,525	250	6000
Miscellaneous	11,902	3,199	2,354	100	2400
Offshore	4,326	5,788	4,257	250	6000
Passenger/Ferry	3,759	11,526	8,481	250	6000
Product tankers	2,926	5,455	4,012	200	4800
Reefers	2,132	5,790	4,259	200	4800
Ro.Ros	2,131	9,994	7,351	250	6000
Tankers unspecified	1,723	3,071	2,259	200	4800
Grand Total	**59,859**	**7,608**	**5,596**		
Total Main engine power kW		**452,538,704**	**332,888,947**		

Table 7

Developing the factor for fuel consumption of main engines for the total number of ships in each category, due consideration was given to alternative literature relating to this methodology[iv], the age and type of main engines within the category and the operational modes of the vessels within the category thereby supplying an average load percent indication for the engines. In addition to these criteria the Specific Fuel Consumption (SFOC) had to be assessed for the typical main engine used by the type of vessel in the category given the spread of ages of the vessels within the category.

By reference to literature[v] the suggested fleet Specific Fuel Consumption is given as 212 g/kW hr. Although the SFOC for newer engines installed on more recent new buildings is stated as having been reduced significantly to values of between 160 to 170 g/kW hr. it was considered that the value stated in the relevant paper of 212 g/kW hr. still represented a reasonable average figure for the database declared Maximum Continuous Rating fuel consumption for the individual vessel types.

Undertaking a "straw poll" of vessel operators, and contrary to the information contained in the literature[vi] (Reference: Table 1 of the above cited literature), the average percent loading of main engines in normal use was found to be approximately 85%. Given this circumstance then the actual average fuel consumption factor to be used in the calculation was derived as being:

212 g/kW hr. x 0.85 = 180.2 g/kW hr (rounded to 180 g/kW hr)

A similar type of factor was developed for the equivalent horse power consumption but this calculation was only used as a mathematical check for the calculated figures for the kilowatt values derived. **The gram per horse power value derived and used within the model is 128 g/HP hr.**

Given the foregoing assumptions and associated consumption factors as derived the main engine fuel consumption for the differing categories of vessel can be shown as:

Vessel Type	M.E. Bunker Cons (HP) per annum (Tonnes)	M.E. Bunker Cons (kW) per annum (Tonnes)
Dry Bulk	44,599,133	46,129,176
Chemical/ oil tankers	7,530,711	7,789,032
Chemical tankers	3,781,171	3,911,809
Combination Carriers	634,952	656,726
Container	96,924,458	100,252,975
Crude tanker	34,801,620	35,995,882
General cargo vessels	20,013,259	20,705,808
Gas Tankers - LNG		
Gas Tankers - LPG	5,012,945	5,185,107
Miscellaneous	11,696,486	12,103,477
Offshore	19,228,662	19,890,807
Passenger/Ferry	33,274,548	34,430,485
Product tankers	9,806,641	10,142,593
Reefers	7,584,326	7,845,282
Ro.Ros	16,356,260	16,918,179
Tanker unspecified	3,250,995	3,362,910
Grand Total - Tonnes	**314,496,167**	**325,320,249**

Table 8

It will be noted that one category of vessel; namely, "Gas Tankers – LNG" have no registered fuel consumption for their "main engines". This is due to the fact that the majority of these vessels are currently steam turbine powered and thus their fuel consumption falls under the category of "boiler consumption" that will be considered below in this document.

9.0 Auxiliary engine fuel consumption

A similar process of assessment and evaluation was undertaken for vessels' auxiliary engines (Gen sets) as undertaken for the main engine consumption methodology. Due to the vast differences in ship operation, auxiliary power (electrical power) requirements of ships throughout their voyages, the differing types of auxiliary engines (high and medium speed (rpm)) and the complications of ships either fitted with shaft generator systems or utilising diesel electric main power, reasonable generalisations were needed to approach this calculation.

To undertake this calculation information has been sought from various sources in order to gain an overview on such issues as:

- The extent of use of shaft generators
- The power of auxiliary machinery
- Whether the machinery was high speed (rpm) or medium speed.
- If the ship is equipment with shaft generators, how often the auxiliary Gen Sets are used
- The typical electrical power requirements /loads for ship operation in port, for port entry and at sea.

It would seem, as a generalisation, from the information received that shaft generators are more to be associated with smaller ship types operating with 4 stroke engines. Taking this "straw poll" type information reasonable and generalised information is compiled to reflect the general category of the vessel type. This base data is as follows:

Vessel Type	Average Aux Power requirement (kW)	Aux. Operation time (Days)	Aux. Operation time (Hours)
Dry Bulk	1000	360	8640
Chemical/ oil tankers	1000	360	8640
Chemical tankers	1300	250	6000
Combination Carriers	1000	360	8640
Container	1000	250	6000
Crude tanker	1000	360	8640
General cargo vessels	500	250	6000
Gas Tankers - LNG	1200	40	960
Gas Tankers - LPG	1000	360	8640
Miscellaneous	500	250	6000
Offshore	1000	250	6000
Passenger/Ferry	1000	360	8640
Product tankers	1000	360	8640
Reefers	1500	360	8640
Ro.Ros	1000	250	6000
Tankers unspecified	500	250	6000
Average power requirement kW	**795**		
Total Aux. power requirement kW	**47,578,063**		

Table 9

These types of engines differ with regard to their fuel consumption characteristics and the load placed upon the respective engines when in normal usage. In addition to these criteria the actual consumption relating to the use of more than one auxiliary engine during the limited periods of port entry (limited as a percentage of a year) and general vessel operations whilst in port. In the context of this work these circumstances must be considered abnormal usage.

Thus, as reflected within literature[vii] (Reference Table 1 of the cited document) and as a result of general enquiries the Specific Fuel Consumption (SFOC) of these engines varies between 230 g/kW hr and, for the higher speed engines, 260 g/kW hr.. Assuming a mean SFOC of 245 g/kW hr then by application of the load percentage the actual fuel consumption can be calculated.

Auxiliary engines generally run at lower load percentages when compared to main engines. Within the literature it is suggested that the load percent for these engines is 60% but this is considered conservative. As a generalisation therefore and taking the literature value into consideration a percent load of 65% is considered a reasonable average load for auxiliary engines (gen sets). Given this circumstance the actual fuel consumption per hour would be:

SFOC 245 g/kW hr x 0.65 = 159.25 g/kW hr (rounding to 160 g/kW hr)

Given the foregoing data and consumption factors the calculation produces the following bunker consumption for auxiliary engine usage on board the differing categories of vessel:

Vessel Type	AUX Bunker Cons (kW) per annum (Tonnes)
Dry Bulk	9,679,565
Chemical/ oil tankers	2,279,578
Chemical tankers	1,491,360
Combination Carriers	152,064
Container	3,831,360
Crude tanker	2,688,768
General cargo vessels	6,543,360
Gas Tankers - LNG	69,120
Gas Tankers - LPG	1,466,726
Miscellaneous	5,712,960
Offshore	4,152,960
Passenger/Ferry	5,196,442
Product tankers	4,044,902
Reefers	4,420,915
Ro.Ros	2,045,760
Tankers unspecified	827,040
Grand Total	**54,602,880**

Table 10

10.0 Boiler Consumption

Within the categories of ship types there are three specific ship types that have a significant boiler consumption associated with their operation. These ship types are:

- The Crude Oil Tanker where boilers are used as the power source for the operation of their cargo pumps and for a specific type of this tanker category; namely, the Aframax tanker, for maintaining heating for their cargoes
- The Gas Tanker – LNG where boilers are used for the generation of steam for their main propulsion power. Steam is also used whilst at sea for the operation of steam turbines for electrical generation. However some of the fuel for the firing of the ship's boilers is derived as boil off from their cargoes and when undertaking their boiler consumption this amount has to be taken into consideration and deducted from the total consumption.
- Product Tankers - these tankers carry "black oil" product cargoes that require heating throughout the voyage and this is achieved through steam heating with the steam from the ship's boiler.

Given the foregoing circumstances assessment had to be undertaken to quantify the use of this fuel for the foregoing uses during the operations of these vessels.

For crude oil tankers the assumptions within the calculation are therefore:

- That a crude oil tanker on average undertakes 10 loaded voyages per annum – thus 10 discharges
- For each discharge the tanker will use 150 tonnes of boiler fuel oil
- 30% of the 719 Aframax type crude oil tankers carry a heated cargo
- The voyage length for such cargo transportation is 7 days and the particular vessels undertake 24 of these voyages per annum.
- The boiler consumption per day for cargo heating is 60 tonnes.

For Gas Tanker – LNG the assumptions are:

- The total voyage time per annum is 220 days at sea.
- The boiler consumption of fuel oil as compensated for the "boil off" from its cargo is 190 tonnes per day.

For Product tankers the assumptions are:

- 40% of all product tankers carry heated cargoes
- these cargoes are carried for 150 days per annum
- The boiler consumption per day is 60 tonnes

Given the foregoing assumptions the boiler fuel calculation is:

Vessel Type	Boiler Cons. (per annum)
Dry Bulk	
Chemical/ oil tankers	
Chemical tankers	
Combination Carriers	
Container	
Crude tanker	5,091,756
General cargo vessels	
Gas Tankers - LNG	15,675,000
Gas Tankers - LPG	
Miscellaneous	
Offshore	
Passenger/Ferry	
Product tankers	10,533,600
Reefers	
Ro.Ros	
Tankers unspecified	
Grand Total	**31,300,356**

Table 11

The foregoing figure is believed to underestimate the total boiler consumption as it is likely that other ship categories may have a small boiler consumption that has been overlooked. For example, the "Tankers unspecified" category may have some boiler consumption associated with the heating during transportation of bunker fuels to ships.

11.0 Total fuel consumption and subdivision into fuel oil types – HFO and MDO

This section concludes the fuel consumption calculation for the differing categories of vessel type and then subdivides the total consumption per ship type into the two generalised fuel types of Heavy Fuel Oil (HFO) and Marine Diesel Oil (MDO).

The general HFO category defines for the purposes of this work any fuel that predominantly consists of a Residual oil component. Within the ISO 8217:2005 specification, Table 2, there are 10 differing categories of this type of oil ranging from a light residual fuel oil to the heavier boiler fuel oils. Each of these oils contains a majority residual component but also requires the addition of a "cutter" or blend stock in order to achieve the required quality specification for the finished product as defined within the specific ISO specification.

The general MDO category defines for the purposes of this work any fuel used that is predominantly a distillate product. This will include two sub categories of this type of fuel, namely, Marine Gas Oil (MGO) and Marine Diesel Oil (MDO). For convenience in undertaking this work these two sub categories are combined and termed MDO. With the ISO 8217 specification, Table 1, there are four differing quality

specifications of this fuel category of which one, DMX, should be discounted for normal use onboard any vessel and is reserved for emergency use in the appropriate emergency engines (Emergency Generator and lifeboat engines). Of the remaining three fuel qualities two are designated an MDO quality and the remaining fuel, designated as DMA, is considered an MGO.

Thus the final calculations provide the following results:

Vessel Type	M.E. Bunker Cons (kW) per annum	AUX Bunker Cons (kW) per annum	Boiler Cons (per annum)	Total Bunker Cons. per ship type	Percentage of Total per ship type
Dry Bulk	46,129,176	9,679,565		55,808,741	13.6%
Chemical/ oil tankers	7,789,032	2,279,578		10,068,609	2.4%
Chemical tankers	3,911,809	1,491,360		5,403,169	1.3%
Combination Carriers	656,726	152,064		808,790	0.2%
Container	100,252,975	3,831,360		104,084,335	25.3%
Crude tanker	35,995,882	2,688,768	5,091,756	43,776,406	10.6%
General cargo vessels	20,705,808	6,543,360		27,249,168	6.6%
Gas Tankers - LNG		69,120	15,675,000	15,744,120	3.8%
Gas Tankers - LPG	5,185,107	1,466,726		6,651,833	1.6%
Miscellaneous	12,103,477	5,712,960		17,816,437	4.3%
Offshore	19,890,807	4,152,960		24,043,767	5.8%
Passenger/Ferry	34,430,485	5,196,442		39,626,927	9.6%
Product tankers	10,142,593	4,044,902	10,533,600	24,721,095	6.0%
Reefers	7,845,282	4,420,915		12,266,198	3.0%
Ro.Ros	16,918,179	2,045,760		18,963,939	4.6%
Tankers unspecified	3,362,910	827,040		4,189,950	1.0%
Grand Total	**325,320,249**	**54,602,880**	**31,300,356**	**411,223,485**	**100.0%**

Table 12

Having established the total fuel consumption there remains the requirement to allocate proportions of this consumption into the two categories of fuel types – HFO and MDO. With this requirement in mind it was considered more easy to set assumptions as to the use of the MDO category and then deduct the final amount from the total fuel consumption figure to derive the assessed amount of the HFO category that is used by ships.

Traditionally, it would have been thought that the medium and higher rpm engines would have used MDO. This would have lead to allocating the total amount of the use of this fuel type to that consumed by auxiliary engines (gen sets). However, with more and more ships converting to "unifuel" operations, e.g. that the auxiliary engines burn the same fuel as the ship's main engine, such an assumption would be false. Earlier literature gave no real guidance as to how this had been undertaken previously and what assumptions had been used. Thus, it was necessary to set a series of assumptions for this assessment that were based upon diverse information received from vessel operators.

Thus, the series of assumptions used for this assessment are:

- 40% of all auxiliary consumption is MDO excluding the consumption for these engines on "Gas Tanker – LNG" where the total consumption is of the MDO category.
- 20% of the "General Cargo vessels" category (smaller ships) burn MDO in their main engines
- 75% of the "Miscellaneous" category burn MDO in their main engines (fishing vessels etc)
- 50% of the "Offshore" vessel category burn MDO in their main engines
- 30% of the "Passenger/Ferry" vessel category burn MDO in their main engines
- 10% of the "Ro.Ros" vessel category burn MDO in their main engines – the smaller vessels
- 50% of the "Tankers unspecified" category burn MDO in their main engines – the smaller vessels

Based upon the foregoing assumptions the sub division assessment for the use of the two differing categories of fuel would be:

Total Bunker Cons. (Tonnes)	**411,223,485**
Assessed HFO Cons. (Tonnes)	**352,474,269**
Assessed MDO Cons. (Tonnes)	**58,749,216**

Table 13

12.0 Air Emissions from bunker consumption

12.1 Carbon Dioxide emissions

The following calculations to assess the extent of carbon dioxide will differ from those calculated by use of the relevant factors stated in the MEPC Circ 471. The figures quoted in the MEPC Circ 471 are referenced to the revised 1996 IPCC Guidelines for national GHG inventories but are the "default" figures quoted in this document and are to be used only when better data is not available.

The following calculations are based upon reasonable and assessed mean molecular size of the average hydrocarbon appropriate to each fuel type although the assumption is that these fuels contain only paraffins and contain no cyclic molecules whose hydrogen/carbon ratios differ due to their unsaturated status.

For further clarity within the following calculations the following molecular weights of individual atoms are used:

Atom	Molecular weight
Carbon	12.011
Oxygen	15.9994
Hydrogen	1

Table 14

Marine Diesel and Gasoil (MDO/MGO)

(1) Non Hydrocarbon components

Component type	Percentage in fuel
Sulphur Content	0.8%
Ash and Metals	0.01%
Water	0.2%
Total	1.01%

Table 15

Total Hydrocarbon content of Fuel = 98.99%

(a) Average Molecular size of hydrocarbon in fuel = C_{18}

Thus:

C_{18} = (18 x 12.011) + (18 x 2 + 2) = 254.198 (Average Molecular weight)

Total Carbon Molecular weight = 18 x 12.011 = 216.198

Carbon % of Fuel = (216.198/254.198) x 0.9899 = 84.192% ..... (MEPC Circ 471 factor = 87.5%)

(b) Carbon content of CO_2

CO_2 = (12.011 + 2 x 15.9994) = 44.01

Carbon Content of CO_2 = 44.01 / 12.011 = 3.6641246

(c) Carbon index (g CO_2 / tonne Fuel)

Carbon index = 3.6641246 x 0.84192 = 3,085,193..... OR
3.0851929 tonnes of CO_2 per tonne of fuel combusted.....(MEPC Circ 471 factor = 3,206,000)

Heavy Fuel Oil

(1) Non Hydrocarbon components

Component type	Percentage in fuel
Sulphur Content	2.7%
Ash and Metals	0.15%
Water	0.5%
Total	3.35%

Table 16

Total Hydrocarbon content of Fuel = 96.56%

(a) Average Molecular size of hydrocarbon in fuel = C_{30}

Thus:

C_{30} = (30 x 12.011) + (30 x 2 + 2) = 422.33 (Average Molecular weight)

Total Carbon Molecular weight = 30 x 12.011 = 360.33

Carbon % of Fuel = (360.33/422.33) x 0.9665 = 82.46% ..... (MEPC Circ 471 factor = 85%)

(d) Carbon content of CO_2

CO_2 = (12.011 + 2 x 15.9994) = 44.01

Carbon Content of CO_2 = 44.01 / 12.011 = 3.6641246

(e) Carbon index (g CO_2 / tonne Fuel)

Carbon index = 3.6641246 x 0.8246 = 3,020,338..... OR
3.0203379 tonnes of CO_2 per tonne of fuel combusted.....(MEPC Circ 471 factor = 3,114,400)

From the foregoing calculations the following factors for the generation of CO_2 per tonne of fuel combusted are used:

Heavy Fuel Oil (HFO) - 3.0203379
Marine Diesel Oil (MDO) - 3.0851929

By use of the foregoing factors and the calculated amounts of the two categories of fuel oil used by ships, the following table of Carbon Dioxide emissions can be generated.

Vessel Type	Assessed Total HFO Cons. Tonnes	Assessed Total MDO Cons. Tonnes	Total CO2 emission from Bunker cons. Tonnes x 10^6	Percentage of CO2 emission per ship type (%)
Dry Bulk	51,936,915	3,871,826	168.812	13.55
Chemical/ oil tankers	9,156,778	911,831	30.470	2.45
Chemical tankers	4,806,625	596,544	16.358	1.31
Combination Carriers	747,965	60,826	2.447	0.20
Container	102,551,791	1,532,544	314.469	25.24
Crude tanker	42,700,898	1,075,507	132.289	10.62
General cargo vessels	20,490,663	6,758,506	82.740	6.64
Gas Tankers - LNG	15,675,000	69,120	47.557	3.82
Gas Tankers - LPG	6,065,143	586,691	20.129	1.62
Miscellaneous	6,453,645	11,362,792	54.549	4.38
Offshore	12,437,179	11,606,587	73.373	5.89
Passenger/Ferry	27,219,205	12,407,722	120.491	9.67
Product tankers	23,103,134	1,617,961	74.771	6.00
Reefers	10,497,832	1,768,366	37.163	2.98
Ro.Ros	16,453,818	2,510,122	57.440	4.61
Tankers unspecified	2,177,679	2,012,271	12.786	1.03
Grand Total	**352,474,269**	**58,749,216**	**1,245.844**	**100.00**

Table 17

An additional assessment can also be made given the assumption that all ships **only** consume MDO. An assumption is incorporated in this calculation that stipulates that the consumption of MDO instead of the equivalent consumption of HFO is 5% less. This assessment would create the following table of results:

Vessel Type	Total CO2 emission from Bunker cons. Tonnes x 10^6	Percentage of CO2 emission per ship type (%)	Assessed CO2 emission for only MDO cons. Tonnes x 10^6
Dry Bulk	168.812	13.55	164.169
Chemical/ oil tankers	30.470	2.45	29.651
Chemical tankers	16.358	1.31	15.928
Combination Carriers	2.447	0.20	2.380
Container	314.469	25.24	305.301
Crude tanker	132.289	10.62	128.472
General cargo vessels	82.740	6.64	80.908
Gas Tankers - LNG	47.557	3.82	46.156
Gas Tankers - LPG	20.129	1.62	19.587
Miscellaneous	54.549	4.38	53.972
Offshore	73.373	5.89	72.261
Passenger/Ferry	120.491	9.67	118.058
Product tankers	74.771	6.00	72.705
Reefers	37.163	2.98	36.224
Ro.Ros	57.440	4.61	55.969
Tankers unspecified	12.786	1.03	12.591
Grand Total	**1,245.844**	**100**	**1214.331**

Table 18

From the foregoing, it can be seen that a reduction in the emissions of Carbon Dioxide equivalent to **31.533 million tonnes** can be achieved in addition to any other abatement methodology adopted by vessels.

12.2 Sulphur Dioxide emissions

In the same manner as for Carbon Dioxide, Sulphur Dioxide can be calculated directly from bunker consumption assuming certain concentrations of sulphur in the two categories of fuel type considered in this document.

The three assumptions within the assessment are:

The sulphur content of Heavy Fuel Oil (HFO) is 2.7% - the reported average for this type of fuel.
The sulphur content of Marine Diesel Oil is 1.0%
The conversion factor for sulphur dioxide from sulphur concentration in a fuel is **1.9968847**. This factor is calculated as follows:

The molecular weight of Sulphur is 32.1; The molecular weight of Oxygen is 16.

Thus:

The molecular weight of Sulphur Dioxide = 32.1 + 2 x 16 = 64.1

The conversion factor is 64.1 divided by 32.1 = 1.9968847

Given the forgoing the results of the calculations would be:

Vessel Type	Assessed Total HFO Cons. Tonnes	Assessed Total MDO Cons. Tonnes	Total SOx emission from Bunker cons. Tonnes
Dry Bulk	51,936,915	3,871,826	2,877,541
Chemical/ oil tankers	9,156,778	911,831	511,904
Chemical tankers	4,806,625	596,544	271,066
Combination Carriers	747,965	60,826	41,542
Container	102,551,791	1,532,544	5,559,774
Crude tanker	42,700,898	1,075,507	2,323,733
General cargo vessels	20,490,663	6,758,506	1,239,732
Gas Tankers - LNG	15,675,000	69,120	846,512
Gas Tankers - LPG	6,065,143	586,691	338,723
Miscellaneous	6,453,645	11,362,792	574,856
Offshore	12,437,179	11,606,587	902,332
Passenger/Ferry	27,219,205	12,407,722	1,715,315
Product tankers	23,103,134	1,617,961	1,277,935
Reefers	10,497,832	1,768,366	601,312
Ro.Ros	16,453,818	2,510,122	937,246
Tankers unspecified	2,177,679	2,012,271	157,594
Grand Total	**352,474,269**	**58,749,216**	**20,177,117**

Table 19

The final assumption to this calculation is that all sulphur contained in the original fuel oil as received is combusted in an engine and is transformed during combustion into sulphur dioxide only. Such assumptions are not necessarily correct due to the extent of sulphur content of the fuel that is removed due to the treatment processes pre-combustion of the fuel and, further, the extent of air within the engine combustion system capable of creating sulphur trioxide during combustion of the fuel.

The fuel treatment process (purification) of the HFO prior to combustion removes an amount of the heavy hydrocarbon matter as waste or sludge and this material will contain amounts of sulphur associated particularly with this type of waste. As an approximation, roughly 0.7% of HFO is removed from the main volume of HFO during the purification of the HFO.

Given that the foregoing assessment does not take into consideration any reduction in sulphur molecule emissions due to the requirements of the Sulphur Emission Control Areas that require the combustion of fuels with a sulphur content not exceeding 1.5%, a further assessment has been made to review the reduction of sulphur emissions due to the two areas that are currently defined. In order to undertake this assessment the quantity of fuel used within these areas has to be approximated. Thus the assumptions for this further assessment are:

- The quantity of heavy fuel oil used within the two SECAs per annum is **20 million tonnes**;
- This quantity is evenly distributed between the differing ship categories according to the amount of Heavy Fuel Oil (HFO) consumed;
- That only HFO would have traditionally been used by ships within these defined areas.

Thus, the calculation using these assumptions would produce the following table of results:

Vessel Type	Assessed Total HFO Cons. Tonnes	Assessed Total MDO Cons. Tonnes	Total SOx emission from Bunker cons. Tonnes	SOx emission from Bunker cons incl SECAs. Tonnes
Dry Bulk	51,936,915	3,871,826	2,877,541	2,806,826
Chemical/ oil tankers	9,156,778	911,831	511,904	499,437
Chemical tankers	4,806,625	596,544	271,066	264,521
Combination Carriers	747,965	60,826	41,542	40,523
Container	102,551,791	1,532,544	5,559,774	5,420,144
Crude tanker	42,700,898	1,075,507	2,323,733	2,265,594
General cargo vessels	20,490,663	6,758,506	1,239,732	1,211,833
Gas Tankers - LNG	15,675,000	69,120	846,512	825,169
Gas Tankers - LPG	6,065,143	586,691	338,723	330,465
Miscellaneous	6,453,645	11,362,792	574,856	566,069
Offshore	12,437,179	11,606,587	902,332	885,398
Passenger/Ferry	27,219,205	12,407,722	1,715,315	1,678,255
Product tankers	23,103,134	1,617,961	1,277,935	1,246,479
Reefers	10,497,832	1,768,366	601,312	587,019
Ro.Ros	16,453,818	2,510,122	937,246	914,844
Tankers unspecified	2,177,679	2,012,271	157,594	154,629
Grand Total	**352,474,269**	**58,749,216**	**20,177,117**	**19,697,204**

Table 20

From the forgoing it can be seen that, based upon the assumptions used in this part of the overall model, the reduction in sulphur dioxide emissions from shipping caused by the operation of the two defined Sulphur Emission Control Areas is **479,913 tonnes** or 2.4% of the original total emission.

12.3 Nitrogen Oxide emissions

The emissions of Nitrogen Oxides (NOx) are in the main an engine related emission concentration. The slower the engine speed (rpm), the higher the production of NOx in the combustion process. This circumstance is reflected by the NOx emission boundary curve for all the diverse marine engines as found within the MARPOL Annex VI Regulation 13 and its associated NOX Technical Code, Chapter 3. However, a certain smaller proportion of the NOx emission is fuel quality related and is developed from the nitrogen concentration within the fuel being consumed by the engine. From enquiries undertaken it is reported that this form of nitrogen concentration is higher in residual type fuels most probably due to the constituent form of the fuel.

In order to estimate the extent of NOx emissions from maritime operation of ships therefore two criteria are considered for this assessment, namely;

- The engine speed of the diverse engines found onboard a ship
- The fuel quality used by these differing engines.

Given these criteria reference emission data and developed factors from empirical studies[viii] have been used in the calculation. These emission factors are:

- For the slow to medium speed engines using predominantly **HFO the factor is 76.4 kg NOx per tonne of fuel consumed**
- For the medium to high speed engines using predominantly the **MDO category of fuel the factor is 48 kg NOx per tonne of fuel consumed.**

The relevant calculation supplies the following table of results:

Vessel Type	Assessed Total HFO Cons. Tonnes	Assessed Total MDO Cons. Tonnes	Total NOx Emission from Bunker cons. Tonnes
Dry Bulk	51,936,915	3,871,826	4,153,828
Chemical/ oil tankers	9,156,778	911,831	743,346
Chemical tankers	4,806,625	596,544	395,860
Combination Carriers	747,965	60,826	60,064
Container	102,551,791	1,532,544	7,908,519
Crude tanker	42,700,898	1,075,507	3,313,973
General cargo vessels	20,490,663	6,758,506	1,889,895
Gas Tankers - LNG	15,675,000	69,120	1,200,888
Gas Tankers - LPG	6,065,143	586,691	491,538
Miscellaneous	6,453,645	11,362,792	1,038,473
Offshore	12,437,179	11,606,587	1,507,317
Passenger/Ferry	27,219,205	12,407,722	2,675,118
Product tankers	23,103,134	1,617,961	1,842,742
Reefers	10,497,832	1,768,366	886,916
Ro.Ros	16,453,818	2,510,122	1,377,558
Tankers unspecified	2,177,679	2,012,271	262,964
Grand Total	**352,474,269**	**58,749,216**	**29,748,997**

Table 21

12.4 Particulate Matter Emissions (PM 10)

As with the assessment and resulting calculations for NOx emissions above, an assessment and calculation has been undertaken to derive the extent of potential PM 10 emissions from the combustion of diverse marine fuels. The empirical data available for this is derived from papers of *V. Eyring et al.* and *Petzold et. al.,* the latter referred to in the Eyring paper. The PM 10 values do not seem to extend to all sources of particulate matter but do cover the main varieties. Thus, again the sources of PM are distinguished in this calculation by fuel type for the differing factors used for this type of emission.

The factors used are therefore;

- For HFO consumption a factor of 6.0 kg per tonne of fuel
- For the MDO Category of fuel a factor of 5.7 kg per tonne of fuel.

The relevant calculation for the assessment of this type of emission produces the following results;

Vessel Type	Assessed Total HFO Cons. Tonnes	Assessed Total MDO Cons. Tonnes	Particulate emission - PM10 Tonnes
Dry Bulk	51,936,915	3,871,826	333,691
Chemical/ oil tankers	9,156,778	911,831	60,138
Chemical tankers	4,806,625	596,544	32,240
Combination Carriers	747,965	60,826	4,834
Container	102,551,791	1,532,544	624,046
Crude tanker	42,700,898	1,075,507	262,336
General cargo vessels	20,490,663	6,758,506	161,467
Gas Tankers - LNG	15,675,000	69,120	94,444
Gas Tankers - LPG	6,065,143	586,691	39,735
Miscellaneous	6,453,645	11,362,792	103,490
Offshore	12,437,179	11,606,587	140,781
Passenger/Ferry	27,219,205	12,407,722	234,039
Product tankers	23,103,134	1,617,961	147,841
Reefers	10,497,832	1,768,366	73,067
Ro.Ros	16,453,818	2,510,122	113,031
Tankers unspecified	2,177,679	2,012,271	24,536
Grand Total	**352,474,269**	**58,749,216**	**2,449,716**

Table 22

As with the assessment with Sulphur Dioxide emissions **using the same fuel consumption criteria**, the impact within the two defined SOx Emission Control Areas (SECAs) is assessed. Given the reported efficiency of the alternative mechanisms available to control the emissions of sulphur dioxides and particulate emissions, namely seawater scrubbers, a further calculation has been undertaken to evaluate the reduction of PM10 emissions by use of such methods. **This assessment assumes a reduction of the PM 10 emission to the levels associated with the usage of Marine Diesel Oil only.**

The results of this calculation are as follows:

Vessel Type	Assessed Total HFO Cons. Tonnes	Assessed Total MDO Cons. Tonnes	Particulate emission - PM10 Tonnes	Particulate emission incl SECAs - PM10 Tonnes
Dry Bulk	51,936,915	3,871,826	333,691	332,806
Chemical/ oil tankers	9,156,778	911,831	60,138	59,982
Chemical tankers	4,806,625	596,544	32,240	32,158
Combination Carriers	747,965	60,826	4,834	4,822
Container	102,551,791	1,532,544	624,046	622,298
Crude tanker	42,700,898	1,075,507	262,336	261,608
General cargo vessels	20,490,663	6,758,506	161,467	161,118
Gas Tankers - LNG	15,675,000	69,120	94,444	94,177
Gas Tankers - LPG	6,065,143	586,691	39,735	39,632
Miscellaneous	6,453,645	11,362,792	103,490	103,380
Offshore	12,437,179	11,606,587	140,781	140,569
Passenger/Ferry	27,219,205	12,407,722	234,039	233,575
Product tankers	23,103,134	1,617,961	147,841	147,447
Reefers	10,497,832	1,768,366	73,067	72,888
Ro.Ros	16,453,818	2,510,122	113,031	112,750
Tankers unspecified	2,177,679	2,012,271	24,536	24,499
Grand Total	**352,474,269**	**58,749,216**	**2,449,716**	**2,443,708**

Table 23

From the foregoing it can be calculated that there will be a reduction of approximately 6,000 tonnes of PM 10 emissions per annum that are captured by the scrubber water and will need shore based storage for delivery in ports within the SECAs.

13.0 Summary of assessment calculations

Calculation assessment	Result Tonnes
Total Fuel Consumption by ships	411,223,485
HFO Consumption by ships	352,474,269
MDO consumption by ships	58,749,216
CO2 emissions from ships *10^6	1,245.844
Total SOx Emission from Ships	20,177,117
SOx emission reduced for SECAs	19,697,204
NOx emissions from Ships	29,748,997
PM 10 emissions from ships	2,449,716
PM 10 emissions reduced for SECAs	2,443,708

Table 24

[i] IMO, MEPC 55/INF 5 – GESAMP Reports and Studies No.75, Estimates of Oil entering the Marine Environment from Sea based Activities, page 24.
[ii] Horst W. Koehler – NOx emissions from Ocean going Ships: Calculation and Evaluation, ASME Internal Combustion Engine Division – Spring Technical Conference, May 2003.
[iii] Robert H. Perry et al; Perry's Chemical Engineers' Handbook, Sixth Edition, 1984 – ISBN 0-07-049479-7
[iv] V.Eyring et al – Emissions from International shipping: The last 50 years; Journal of Geophysical Research, Vol. 110, September 2005
[v] V.Eyring et al – Emissions from International shipping: The last 50 years; Journal of Geophysical Research, Vol. 110, September 2005
[vi] V.Eyring et al – Emissions from International shipping: The last 50 years; Journal of Geophysical Research, Vol. 110, September 2005
[vii] V.Eyring et al – Emissions from International shipping: The last 50 years; Journal of Geophysical Research, Vol. 110, September 2005
[viii] V.Eyring et al – Emissions from International shipping: The last 50 years; Journal of Geophysical Research, Vol. 110, September 2005

Type (See Note 11)	Number (Notes 1)	DWT (Notes 2)	Average DWT	Gross Tons	Average Gross Tons	Average Main Engine (HP) (Notes 3)	Average Main Engine (kW)	Average Aux Power requirement (kW)	M.E. Operation time (Days)
Bulk	7.002	366.672.852	52.367	204.015.411	29.137	10.367	7.625	1000	200
Chem oil	1.649	34.680.430	21.031	21.871.291	13.263	7.433	5.467	1000	200
Chemical tankers	1.195	9.952.079	8.328	6.190.594	5.180	4.120	3.031	1300	250
Combination Carriers	110	5.896.906	53.608	3.460.114	31.456	9.395	6.910	1000	200
Container	3.991	131.287.522	32.896	113.280.678	28.384	28.234	20.767	1000	280
Crude tanker	1.945	279.171.957	143.533	150.794.127	77.529	19.415	14.280	1000	300
Dry cargo	13.632	74.952.470	5.498	53.030.819	3.890	3.186	2.344	500	150
Gas Tankers - LNG (Notes 4)	375	27.793.870	74.117	37.135.473	99.028	36.175	26.608	1200	220
Gas Tankers - LPG	1.061	15.381.073	14.497	10.675.577	10.062	6.152	4.525	1000	250
Miscellaneous (Notes 5)	11.902	16.869.255	1.417	16.666.818	1.400	3.199	2.354	500	100
Offshore	4.326	10.698.098	2.473	10.341.820	2.391	5.788	4.257	1000	250
Passenger/Ferry	3.759	6.185.630	1.646	30.261.871	8.051	11.526	8.481	1000	250
Product tanker	2.926	49.021.104	16.754	29.559.806	10.102	5.455	4.012	1000	200
Reefers	2.132	8.901.200	4.175	9.660.901	4.531	5.790	4.259	1500	200
RoRo	2.131	19.060.654	8.944	38.258.816	17.953	9.994	7.351	1000	250
Tanker unspecified (Notes 6)	1.723	15.628.404	9.070	9.034.692	5.244	3.071	2.259	500	200
Grand Total	**59.859**	**1.072.153.505**	**17.911**	**744.238.808**	**12.433**	**7.608**	**5.596**	**795**	
Total Engine power kW							**332.888.947**	**47.578.063**	

Notes:

(1) MARPOL Annex VI applies to all ships. This list shows all ships over 399.9 gross tons to which certification for Annex VI applies

(2) The Data in this list is derived from the Fairplay database. Not all ships in this list have a recorded DWT but virtually all have a GT. DWT for the ships without DWT is calculated by using the DWT/GT ratio for the ships that have DWT for each ship type.

(3) Not all ships in this list have a recorded (HP) or (KW) but the average applies to all those that have this recorded data only.

(4) Although these ships' main engine HP and KW are recorded they have been treated as mainly having steam turbines and thus appropriate boiler cons.

(5) This category of vessel contains approx 60 differing vessel types ranging from; Anti-Pollution vessels, bucket dredgers, cable repair ships, cable ships, fisheries protection vessels, fishing vessels, hospital ships, icebreakers, oceanographic vessels, pilot vessels, sail training vessels, sludge carriers, Tugs, Whaling vessels.

(6) This category of vessel will include both small coastal tankers and bunker supply tankers

(7) This calculation takes into consideration the total energy requirement of ship types; i.e. the size of Aux. engine and its usage time. By this method the additional requirements of power for port entry and usage in port are averaged out in the calculation for bunker usage. The use of shaft generators is also taken into consideration.

(8) It is assumed that the majority of ships are unifuelled. The usage of MDO has been estimated and apportioned according to ship category.

(9) These consumptions are based upon reasonable estimates for boiler usage especially for heated crude oil and residue cargoes. The heated crude oil cargoes are assumed carried solely on 30% of the Aframax size crude oil carriers.

(10) The Carbon content and CO2 factors have been corrected and the MEPC Circ 471 Factors for GHG indexing have not been applied

(11) The assessed uncertainty of this model or methodology is approximately ± 10%

(12) The NOx factors used in this calculation are developed from a paper by Eyring et al for "Ship emissions over the last 50 years"

(13) Based upon the factors shown on Table 1 of Paper by Eyring et al for "Ships emissions over the last 50 years"

Emission assessments based upon Calculated fuel consumption

Aux. Operation time (Days) (Notes 7)	Type	M.E. Bunker Cons (HP) per annum	M.E. Bunker Cons (kW) per annum	AUX Bunker Cons (kW) per annum (Notes 8)	HFO Boiler Cons (per annum) (Notes 9)	Total Bunker Cons. per ship type	Percentage of Total per ship type
360	Bulk	44.599.133	46.129.176	9.679.565		55.808.741	13,6%
360	Chem oil	7.530.711	7.789.032	2.279.578		10.068.609	2,4%
250	Chemical tankers	3.781.171	3.911.809	1.491.360		5.403.169	1,3%
360	Combination Carriers	634.952	656.726	152.064		808.790	0,2%
250	Container	96.924.458	100.252.975	3.831.360		104.084.335	25,3%
360	Crude tanker	34.801.620	35.995.882	2.688.768	5.091.756	43.776.406	10,6%
250	Dry cargo	20.013.259	20.705.808	6.543.360		27.249.168	6,6%
40	Gas Tankers - LNG			69.120	15.675.000	15.744.120	3,8%
360	Gas Tankers - LPG	5.012.945	5.185.107	1.466.726		6.651.833	1,6%
250	Miscellaneous	11.696.486	12.103.477	5.712.960		17.816.437	4,3%
250	Offshore	19.228.662	19.890.807	4.152.960		24.043.767	5,8%
360	Passenger/Ferry	33.274.548	34.430.485	5.196.442		39.626.927	9,6%
360	Product tanker	9.806.641	10.142.593	4.044.902	10.533.600	24.721.095	6,0%
360	Reefers	7.584.326	7.845.282	4.420.915		12.266.198	3,0%
250	RoRo	16.356.260	16.918.179	2.045.760		18.963.939	4,6%
250	Tanker unspecified	3.250.995	3.362.910	827.040		4.189.950	1,0%
	Grand Total	**314.496.167**	**325.320.249**	**54.602.880**	**31.300.356**	**411.223.485**	**100,0%**

Total Bunker Cons:	**411.223.485**
Assessed HFO Cons:	**352.474.269**
Assessed MDO Cons:	**58.749.216**

Type	Assessed Total HFO Cons. Tonnes	Assessed Total MDO Cons. Tonnes	Total CO2 emission from Bunker cons. Tonnes)^6) (Notes 10)	Percentage of CO2 emission per ship type	Total SOx emission from Bunker cons. Tonnes	Total NOx Emission from Bunker cons. Tonnes (Note 12)	Particulate emission - PM10 Tonnes (Notes 13)	Assessed CO2 emission based upon sole MDO ons Tonnes (10^6)
Bulk	51.936.915	3.871.826	168,8124	13,55	2.877.541	4.153.828	333.690,90	164,1690
Chem oil	9.156.778	911.831	30,4697	2,45	511.904	743.346	60.138,11	29,6511
Chemical tankers	4.806.625	596.544	16,3581	1,31	271.066	395.860	32.240,05	15,9283
Combination Carriers	747.965	60.826	2,4468	0,20	41.542	60.064	4.834,49	2,3799
Container	102.551.791	1.532.544	314,4693	25,24	5.559.774	7.908.519	624.046,25	305,3006
Crude tanker	42.700.898	1.075.507	132,2893	10,62	2.323.733	3.313.973	262.335,78	128,4716
Dry cargo	20.490.663	6.758.506	82,7400	6,64	1.239.732	1.889.895	161.467,46	80,9081
Gas Tankers - LNG	15.675.000	69.120	47,5570	3,82	846.512	1.200.888	94.443,98	46,1556
Gas Tankers - LPG	6.065.143	586.691	20,1288	1,62	338.723	491.538	39.734,99	19,5866
Miscellaneous	6.453.645	11.362.792	54,5486	4,38	574.856	1.038.473	103.489,78	53,9716
Offshore	12.437.179	11.606.587	73,3730	5,89	902.332	1.507.317	140.780,63	72,2611
Passenger/Ferry	27.219.205	12.407.722	120,4914	9,67	1.715.315	2.675.118	234.039,24	118,0579
Product tanker	23.103.134	1.617.961	74,7710	6,00	1.277.935	1.842.742	147.841,18	72,7055
Reefers	10.497.832	1.768.366	37,1627	2,98	601.312	886.916	73.066,68	36,2242
RoRo	16.453.818	2.510.122	57,4403	4,61	937.246	1.377.558	113.030,60	55,9693
Tanker unspecified	2.177.679	2.012.271	12,7856	1,03	157.594	262.964	24.536,02	12,5909
Grand Total	**352.474.269**	**58.749.216**	**1.245,8441**	**100,00**	**20.177.117**	**29.748.997**	**2.449.716**	**1.214,3312**